

RAINFALL TABLES

FOR NORTH CENTRAL TEXAS

Methodology A-2

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Methodology

The US Geological Survey (USGS), in cooperation with the Texas Department of Transportation (TxDOT), recently conducted a study of the depth-duration frequency (DDF) of precipitation for Texas¹. In the study, the frequency of the annual maximum rainfall data was modeled using two probability distributions. The parameters from these distributions can be used to estimate the DDF for any location in Texas.

The results of the study were applied to the hydrologic models used to update the Flood Insurance Rate Maps of Harris County. The City of Austin also asked the USGS for data to update its IDF data. TxDOT will also be updating its intensity-duration frequency (IDF) data statewide.

Depth-duration frequency relationships were obtained from the USGS for each county in the North Central Texas region. The centroid of each county was used as the geographic location for the computations as shown on Figure A-1. The frequency range in the USGS study is from 2 to 500 years and precipitation duration ranges from 15-minutes to 24 hours. The main objective was to find IDF relationships for each of the counties. The results are presented in tabular form in this Appendix for each county.

The main procedure for developing the IDF relationship is shown below.

1. Convert rainfall depths to intensities for each associated duration.
2. Plot intensity vs. duration for each return period on log-log axes.
3. Follow the Dodson Method² to develop the IDF relationship shown below.

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

In the equation above, I represents the rainfall intensity in inches/hr, T represents the rainfall duration in minutes, and b , d , and e are coefficients.

4. Determine the IDF relationship for each county in the North Central Texas region, for each return period.

Since it was necessary for the IDF relationships to represent durations less than 15 minutes, the rainfall depths from Hydro-35³ were obtained for 5 and 10-minute durations. This provided for a smooth transition between the Hydro-35 data and the USGS data.

It was also necessary to develop IDF relationships for the 1-year return period. The procedure that was followed to determine the DDF relationship for each 1-year curve is listed below.

1. Plot depth vs. return period for each duration. (Each curve stops at the 2-year return period.).
2. Extrapolate each curve to the 1-year return period.
3. Convert the extrapolated depths to intensities.

In step 1, the 5 and 10-minute curves were developed using Hydro-35 data, whereas the USGS data was used to develop curves for durations greater than 10 minutes. The extrapolated intensities were then used to develop the 1-year IDF relationship for each county.

Other Comments

The process of developing IDF relationships involved the merging of DDF data from two different studies. Hydro-35 was published in 1977, but the fitting procedure used for the frequency distribution was developed in 1958. The common practice at the time was to fit the **annual series** to a distribution, then apply correction factors to convert to **partial-duration series**. These empirical factors were used to modify the statistics of the distribution to more closely represent actual precipitation data. In the USGS publication (1998), the **annual series** data was also used, but no conversion was deemed necessary, for the following reasons. First, a greater number of stations and longer periods of records were available at the time of the study. Also, two different distributions were applied for different duration ranges. These distributions were developed more recently (1986, 1990), and make use of L-moments (linear moments), which are more powerful than traditional statistics (mean, standard deviation). As a result of using more advanced statistical analyses, the selected distributions modeled the annual series without the use of conversion factors.

The values reported in the IDF tables are calculated directly from the fitted IDF equations. The fitted equations are only valid for rainfall durations between 5 minutes and 24 hours.

¹Asquith, W.H. *Depth-Duration Frequency of Precipitation for Texas*. Water-Resources Investigations Report 98-4044, US Geological Survey. Austin, TX, 1998.

²Frederick, R.H., V.A. Myers, and E.P. Auciello. NOAA *Technical Memorandum NWS Hydro-35*. Office of Hydrology. Silver Spring, MD, June 1977.

³*The Dodson Hydrology Library*. Dodson & Associates, Inc. Houston, TX, 1987.

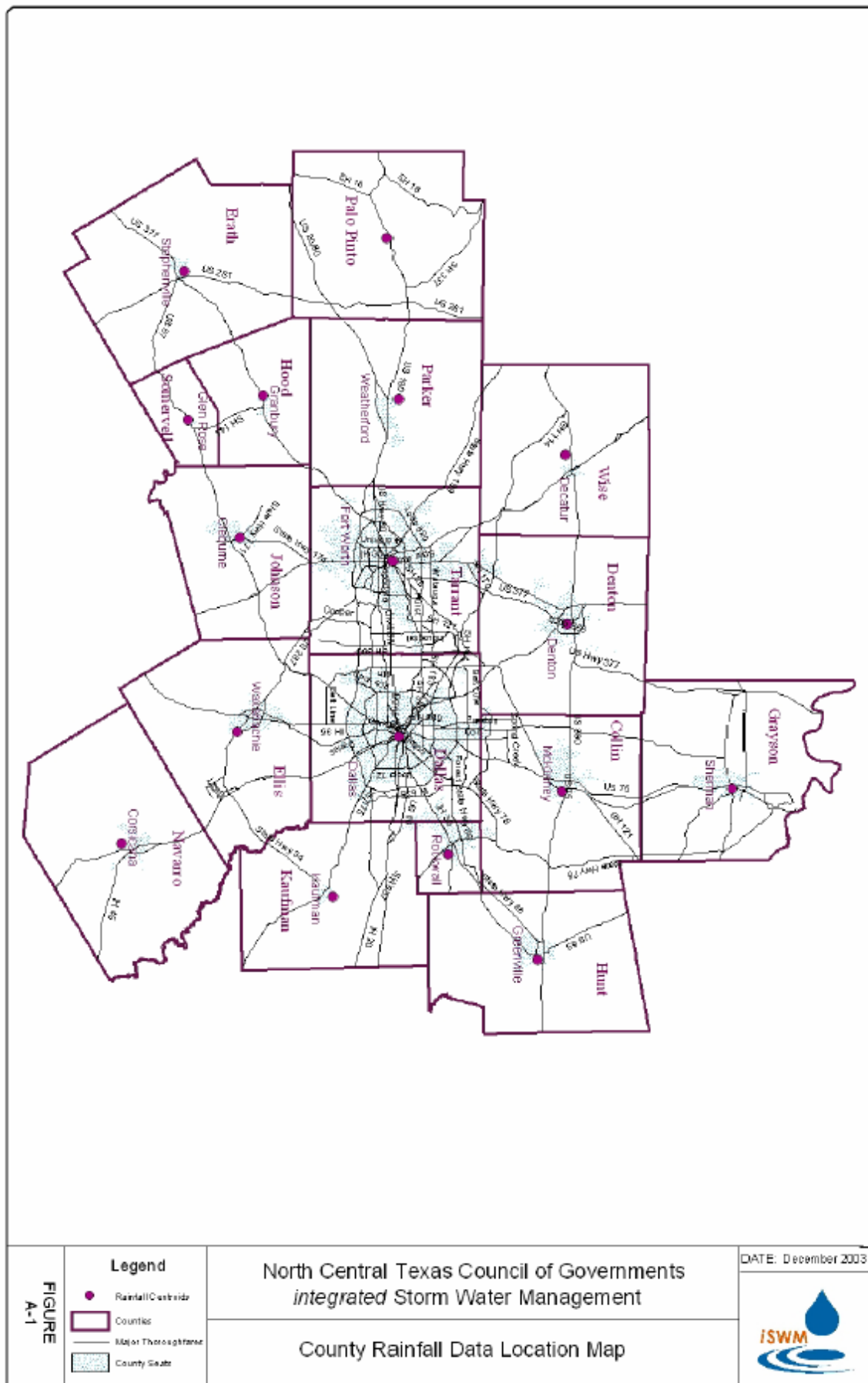


Table A-1 Collin County								
Coefficients e b d		Return Period (Years)						
		1	2	5	10	25	50	100
		0.82667 47.053 9	0.79822 50.523 9	0.78901 64.259 11	0.77386 68.951 11	0.75875 76.069 11	0.74805 81.634 11	0.73702 86.709 11
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.31	6.15	7.21	8.07	9.28	10.26	11.24
	6	5.02	5.82	6.87	7.70	8.86	9.80	10.74
	7	4.76	5.52	6.57	7.36	8.49	9.39	10.30
	8	4.52	5.26	6.29	7.06	8.15	9.02	9.90
	9	4.31	5.03	6.05	6.79	7.84	8.68	9.53
	10	4.13	4.82	5.82	6.54	7.55	8.37	9.20
	11	3.95	4.62	5.61	6.31	7.29	8.08	8.89
	12	3.80	4.45	5.41	6.09	7.05	7.82	8.60
	13	3.65	4.28	5.24	5.89	6.82	7.58	8.33
0.250	14	3.52	4.14	5.07	5.71	6.61	7.35	8.09
	15	3.40	4.00	4.91	5.54	6.42	7.14	7.86
	16	3.29	3.87	4.77	5.38	6.24	6.94	7.64
	17	3.18	3.75	4.64	5.23	6.07	6.75	7.44
	18	3.09	3.64	4.51	5.09	5.91	6.58	7.25
	19	2.99	3.53	4.39	4.96	5.76	6.41	7.07
	20	2.91	3.44	4.28	4.84	5.62	6.26	6.90
	21	2.83	3.35	4.17	4.72	5.48	6.11	6.74
	22	2.75	3.26	4.07	4.61	5.36	5.97	6.59
	23	2.68	3.18	3.98	4.50	5.24	5.84	6.45
	24	2.61	3.10	3.89	4.40	5.12	5.71	6.31
	25	2.55	3.03	3.80	4.31	5.02	5.59	6.18
	26	2.49	2.96	3.72	4.22	4.91	5.48	6.06
	27	2.43	2.89	3.64	4.13	4.81	5.37	5.94
	28	2.38	2.83	3.57	4.05	4.72	5.27	5.83
0.500	29	2.33	2.77	3.50	3.97	4.63	5.17	5.72
	30	2.28	2.71	3.43	3.89	4.54	5.07	5.62
	31	2.23	2.66	3.37	3.82	4.46	4.98	5.52
	32	2.18	2.61	3.30	3.75	4.38	4.90	5.42
	33	2.14	2.56	3.25	3.69	4.31	4.81	5.33
	34	2.10	2.51	3.19	3.62	4.23	4.73	5.24
	35	2.06	2.46	3.13	3.56	4.16	4.66	5.16
	36	2.02	2.42	3.08	3.50	4.10	4.58	5.08
	37	1.99	2.38	3.03	3.45	4.03	4.51	5.00
	38	1.95	2.34	2.98	3.39	3.97	4.44	4.92
	39	1.92	2.30	2.93	3.34	3.91	4.37	4.85
	40	1.89	2.26	2.89	3.29	3.85	4.31	4.78
	41	1.85	2.22	2.84	3.24	3.79	4.25	4.71
	42	1.82	2.19	2.80	3.19	3.74	4.19	4.65
	43	1.79	2.16	2.76	3.15	3.69	4.13	4.58
0.750	44	1.77	2.12	2.72	3.10	3.64	4.07	4.52
	45	1.74	2.09	2.68	3.06	3.59	4.02	4.46
	46	1.71	2.06	2.65	3.02	3.54	3.97	4.40
	47	1.69	2.03	2.61	2.98	3.49	3.92	4.35
	48	1.66	2.00	2.57	2.94	3.45	3.87	4.29
	49	1.64	1.98	2.54	2.90	3.40	3.82	4.24
	50	1.62	1.95	2.51	2.86	3.36	3.77	4.19
	51	1.59	1.92	2.48	2.83	3.32	3.72	4.14
	52	1.57	1.90	2.44	2.79	3.28	3.68	4.09
	53	1.55	1.87	2.41	2.76	3.24	3.64	4.04
	54	1.53	1.85	2.39	2.73	3.20	3.60	4.00
	55	1.51	1.83	2.36	2.69	3.17	3.55	3.95
	56	1.49	1.80	2.33	2.66	3.13	3.51	3.91
	57	1.47	1.78	2.30	2.63	3.10	3.48	3.87
	58	1.46	1.76	2.28	2.60	3.06	3.44	3.83
	59	1.44	1.74	2.25	2.57	3.03	3.40	3.79
1	60	1.42	1.72	2.22	2.55	3.00	3.37	3.75
2	120	0.85	1.04	1.37	1.59	1.88	2.13	2.39
3	180	0.62	0.77	1.02	1.18	1.41	1.61	1.81
6	360	0.36	0.45	0.60	0.71	0.85	0.98	1.11
12	720	0.20	0.26	0.35	0.42	0.51	0.59	0.67
24	1440	0.11	0.15	0.21	0.25	0.30	0.35	0.41

Table A-2 Dallas County								
Coefficients e b d		Return Period (Years)						
		1	2	5	10	25	50	100
		0.83258 47.679 9	0.81545 55.179 10	0.80449 70.024 12	0.79827 79.931 13	0.78187 87.970 13	0.77019 94.058 13	0.75870 100.079 13
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.30	6.06	7.17	7.96	9.18	10.15	11.17
	6	5.00	5.75	6.85	7.62	8.80	9.74	10.72
	7	4.74	5.48	6.55	7.31	8.45	9.36	10.31
	8	4.51	5.23	6.29	7.03	8.14	9.02	9.94
	9	4.30	5.00	6.05	6.78	7.85	8.70	9.59
	10	4.11	4.80	5.82	6.54	7.58	8.41	9.27
	11	3.94	4.61	5.62	6.32	7.33	8.14	8.98
	12	3.78	4.44	5.43	6.12	7.10	7.88	8.70
	13	3.64	4.28	5.26	5.93	6.89	7.65	8.45
0.250	14	3.50	4.13	5.09	5.76	6.69	7.43	8.21
	15	3.38	4.00	4.94	5.59	6.50	7.22	7.99
	16	3.27	3.87	4.80	5.44	6.32	7.03	7.78
	17	3.16	3.75	4.66	5.29	6.16	6.85	7.58
	18	3.07	3.64	4.54	5.15	6.00	6.68	7.39
	19	2.97	3.54	4.42	5.03	5.85	6.52	7.22
	20	2.89	3.45	4.31	4.90	5.72	6.37	7.05
	21	2.81	3.35	4.20	4.79	5.58	6.22	6.89
	22	2.73	3.27	4.10	4.68	5.46	6.08	6.74
	23	2.66	3.19	4.01	4.57	5.34	5.95	6.60
	24	2.59	3.11	3.92	4.48	5.23	5.83	6.46
	25	2.53	3.04	3.83	4.38	5.12	5.71	6.34
	26	2.47	2.97	3.75	4.29	5.02	5.60	6.21
	27	2.41	2.90	3.68	4.21	4.92	5.49	6.09
	28	2.36	2.84	3.60	4.12	4.82	5.39	5.98
0.500	29	2.31	2.78	3.53	4.05	4.73	5.29	5.87
	30	2.26	2.73	3.46	3.97	4.65	5.19	5.77
	31	2.21	2.67	3.40	3.90	4.56	5.10	5.67
	32	2.17	2.62	3.34	3.83	4.48	5.01	5.57
	33	2.12	2.57	3.28	3.76	4.41	4.93	5.48
	34	2.08	2.52	3.22	3.70	4.33	4.85	5.39
	35	2.04	2.48	3.16	3.64	4.26	4.77	5.31
	36	2.00	2.43	3.11	3.58	4.20	4.69	5.22
	37	1.97	2.39	3.06	3.52	4.13	4.62	5.14
	38	1.93	2.35	3.01	3.46	4.07	4.55	5.07
	39	1.90	2.31	2.96	3.41	4.01	4.48	4.99
	40	1.87	2.27	2.92	3.36	3.95	4.42	4.92
	41	1.84	2.24	2.87	3.31	3.89	4.36	4.85
	42	1.81	2.20	2.83	3.26	3.83	4.30	4.79
	43	1.78	2.17	2.79	3.22	3.78	4.24	4.72
0.750	44	1.75	2.13	2.75	3.17	3.73	4.18	4.66
	45	1.72	2.10	2.71	3.13	3.68	4.12	4.60
	46	1.70	2.07	2.67	3.08	3.63	4.07	4.54
	47	1.67	2.04	2.63	3.04	3.58	4.02	4.48
	48	1.65	2.01	2.60	3.00	3.54	3.97	4.42
	49	1.62	1.98	2.56	2.96	3.49	3.92	4.37
	50	1.60	1.96	2.53	2.93	3.45	3.87	4.32
	51	1.58	1.93	2.50	2.89	3.41	3.82	4.27
	52	1.56	1.91	2.47	2.85	3.36	3.78	4.22
	53	1.53	1.88	2.44	2.82	3.32	3.73	4.17
	54	1.51	1.86	2.41	2.79	3.29	3.69	4.12
	55	1.49	1.83	2.38	2.75	3.25	3.65	4.07
	56	1.48	1.81	2.35	2.72	3.21	3.61	4.03
	57	1.46	1.79	2.32	2.69	3.17	3.57	3.99
	58	1.44	1.77	2.30	2.66	3.14	3.53	3.94
	59	1.42	1.75	2.27	2.63	3.11	3.49	3.90
1	60	1.40	1.73	2.24	2.60	3.07	3.45	3.86
2	120	0.83	1.04	1.38	1.61	1.92	2.18	2.45
3	180	0.61	0.76	1.02	1.20	1.44	1.63	1.85
6	360	0.35	0.44	0.60	0.71	0.86	0.98	1.12
12	720	0.20	0.26	0.35	0.41	0.51	0.58	0.67
24	1440	0.11	0.15	0.20	0.24	0.30	0.35	0.40

Table A-3 Denton County								
Coefficients		Return Period (Years)						
		1	2	5	10	25	50	100
e		0.82089	0.80553	0.79891	0.78388	0.76912	0.76817	0.75660
b		43.381	50.455	65.467	70.683	78.538	89.853	95.776
d		8	9	11	11	11	12	12
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.28	6.02	7.15	8.04	9.31	10.19	11.23
	6	4.97	5.70	6.81	7.67	8.89	9.76	10.75
	7	4.70	5.41	6.50	7.33	8.50	9.36	10.32
	8	4.46	5.15	6.23	7.03	8.16	9.00	9.93
	9	4.24	4.92	5.98	6.75	7.84	8.67	9.57
	10	4.04	4.71	5.75	6.50	7.55	8.36	9.24
	11	3.87	4.52	5.54	6.27	7.29	8.08	8.93
	12	3.71	4.34	5.35	6.05	7.04	7.82	8.65
	13	3.56	4.18	5.17	5.85	6.82	7.58	8.39
0.250	14	3.43	4.04	5.00	5.67	6.61	7.36	8.14
	15	3.31	3.90	4.85	5.50	6.41	7.14	7.91
	16	3.19	3.77	4.70	5.34	6.23	6.95	7.70
	17	3.09	3.66	4.57	5.19	6.05	6.76	7.50
	18	2.99	3.55	4.44	5.05	5.89	6.59	7.31
	19	2.90	3.44	4.32	4.91	5.74	6.43	7.13
	20	2.81	3.35	4.21	4.79	5.60	6.27	6.96
	21	2.73	3.26	4.11	4.67	5.46	6.12	6.80
	22	2.66	3.17	4.01	4.56	5.34	5.99	6.65
	23	2.59	3.09	3.91	4.45	5.21	5.85	6.50
	24	2.52	3.02	3.82	4.35	5.10	5.73	6.36
	25	2.46	2.95	3.74	4.26	4.99	5.61	6.23
	26	2.40	2.88	3.66	4.17	4.89	5.50	6.11
	27	2.34	2.81	3.58	4.08	4.79	5.39	5.99
	28	2.29	2.75	3.51	4.00	4.69	5.28	5.88
0.500	29	2.24	2.69	3.44	3.92	4.60	5.18	5.77
	30	2.19	2.64	3.37	3.85	4.51	5.09	5.66
	31	2.14	2.58	3.31	3.77	4.43	5.00	5.56
	32	2.10	2.53	3.24	3.71	4.35	4.91	5.47
	33	2.06	2.49	3.18	3.64	4.28	4.83	5.38
	34	2.02	2.44	3.13	3.58	4.20	4.75	5.29
	35	1.98	2.39	3.07	3.51	4.13	4.67	5.20
	36	1.94	2.35	3.02	3.46	4.06	4.59	5.12
	37	1.91	2.31	2.97	3.40	4.00	4.52	5.04
	38	1.87	2.27	2.92	3.35	3.94	4.45	4.96
	39	1.84	2.23	2.88	3.29	3.88	4.38	4.89
	40	1.81	2.19	2.83	3.24	3.82	4.32	4.82
	41	1.78	2.16	2.79	3.19	3.76	4.26	4.75
	42	1.75	2.13	2.74	3.15	3.71	4.20	4.68
	43	1.72	2.09	2.70	3.10	3.65	4.14	4.62
0.750	44	1.69	2.06	2.66	3.06	3.60	4.08	4.56
	45	1.67	2.03	2.63	3.01	3.55	4.02	4.50
	46	1.64	2.00	2.59	2.97	3.50	3.97	4.44
	47	1.62	1.97	2.55	2.93	3.46	3.92	4.38
	48	1.59	1.94	2.52	2.89	3.41	3.87	4.32
	49	1.57	1.92	2.49	2.85	3.37	3.82	4.27
	50	1.55	1.89	2.45	2.82	3.33	3.77	4.22
	51	1.53	1.86	2.42	2.78	3.28	3.73	4.17
	52	1.51	1.84	2.39	2.75	3.24	3.68	4.12
	53	1.49	1.82	2.36	2.71	3.21	3.64	4.07
	54	1.47	1.79	2.33	2.68	3.17	3.60	4.02
	55	1.45	1.77	2.30	2.65	3.13	3.55	3.98
	56	1.43	1.75	2.28	2.62	3.09	3.51	3.93
	57	1.41	1.73	2.25	2.59	3.06	3.48	3.89
	58	1.39	1.71	2.22	2.56	3.03	3.44	3.85
	59	1.37	1.69	2.20	2.53	2.99	3.40	3.81
1	60	1.36	1.67	2.17	2.50	2.96	3.36	3.77
2	120	0.81	1.01	1.33	1.55	1.85	2.11	2.38
3	180	0.59	0.74	0.99	1.15	1.38	1.58	1.79
6	360	0.34	0.43	0.58	0.68	0.83	0.95	1.09
12	720	0.19	0.25	0.34	0.40	0.49	0.57	0.65
24	1440	0.11	0.14	0.20	0.23	0.29	0.33	0.39

Table A-4 Ellis County								
Coefficients		Return Period (Years)						
		1	2	5	10	25	50	100
e		0.84002	0.81147	0.80992	0.80183	0.78513	0.78190	0.76959
b		51.103	54.710	74.075	83.862	92.418	104.449	110.819
d		10	10	13	14	14	15	15
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.25	6.08	7.13	7.91	9.16	10.04	11.05
	6	4.98	5.77	6.82	7.59	8.80	9.66	10.64
	7	4.73	5.49	6.55	7.30	8.47	9.32	10.27
	8	4.51	5.24	6.29	7.03	8.16	9.00	9.92
	9	4.31	5.02	6.06	6.79	7.88	8.70	9.60
	10	4.13	4.81	5.84	6.56	7.62	8.43	9.31
	11	3.96	4.63	5.65	6.35	7.38	8.18	9.03
	12	3.81	4.45	5.46	6.15	7.16	7.94	8.77
	13	3.67	4.30	5.29	5.97	6.95	7.72	8.53
0.250	14	3.54	4.15	5.13	5.80	6.75	7.51	8.30
	15	3.42	4.01	4.98	5.64	6.57	7.31	8.09
	16	3.31	3.89	4.84	5.48	6.40	7.13	7.89
	17	3.21	3.77	4.71	5.34	6.24	6.95	7.70
	18	3.11	3.66	4.59	5.21	6.08	6.79	7.52
	19	3.02	3.56	4.47	5.08	5.94	6.63	7.35
	20	2.94	3.46	4.36	4.96	5.80	6.48	7.18
	21	2.86	3.37	4.26	4.85	5.67	6.34	7.03
	22	2.78	3.29	4.16	4.74	5.54	6.20	6.88
	23	2.71	3.21	4.07	4.64	5.43	6.08	6.74
	24	2.64	3.13	3.98	4.54	5.31	5.95	6.61
	25	2.58	3.06	3.89	4.44	5.21	5.84	6.48
	26	2.52	2.99	3.81	4.36	5.10	5.73	6.36
	27	2.46	2.92	3.73	4.27	5.01	5.62	6.24
	28	2.41	2.86	3.66	4.19	4.91	5.52	6.13
0.500	29	2.35	2.80	3.59	4.11	4.82	5.42	6.02
	30	2.31	2.74	3.52	4.03	4.74	5.32	5.92
	31	2.26	2.69	3.46	3.96	4.65	5.23	5.82
	32	2.21	2.64	3.39	3.89	4.57	5.15	5.73
	33	2.17	2.59	3.33	3.83	4.50	5.06	5.63
	34	2.13	2.54	3.28	3.76	4.42	4.98	5.54
	35	2.09	2.49	3.22	3.70	4.35	4.90	5.46
	36	2.05	2.45	3.17	3.64	4.28	4.83	5.38
	37	2.01	2.41	3.12	3.58	4.22	4.76	5.30
	38	1.98	2.36	3.07	3.53	4.15	4.68	5.22
	39	1.94	2.33	3.02	3.48	4.09	4.62	5.15
	40	1.91	2.29	2.97	3.42	4.03	4.55	5.07
	41	1.88	2.25	2.93	3.37	3.98	4.49	5.00
	42	1.85	2.22	2.88	3.33	3.92	4.43	4.94
	43	1.82	2.18	2.84	3.28	3.87	4.37	4.87
0.750	44	1.79	2.15	2.80	3.23	3.81	4.31	4.81
	45	1.76	2.12	2.76	3.19	3.76	4.25	4.74
	46	1.74	2.09	2.73	3.15	3.71	4.20	4.68
	47	1.71	2.06	2.69	3.10	3.66	4.14	4.63
	48	1.69	2.03	2.65	3.06	3.62	4.09	4.57
	49	1.66	2.00	2.62	3.03	3.57	4.04	4.51
	50	1.64	1.97	2.58	2.99	3.53	3.99	4.46
	51	1.62	1.95	2.55	2.95	3.49	3.95	4.41
	52	1.60	1.92	2.52	2.91	3.44	3.90	4.36
	53	1.57	1.90	2.49	2.88	3.40	3.86	4.31
	54	1.55	1.87	2.46	2.85	3.37	3.81	4.26
	55	1.53	1.85	2.43	2.81	3.33	3.77	4.21
	56	1.51	1.83	2.40	2.78	3.29	3.73	4.17
	57	1.49	1.80	2.37	2.75	3.25	3.69	4.12
	58	1.48	1.78	2.35	2.72	3.22	3.65	4.08
	59	1.46	1.76	2.32	2.69	3.18	3.61	4.04
1	60	1.44	1.74	2.29	2.66	3.15	3.57	4.00
2	120	0.86	1.05	1.41	1.65	1.98	2.26	2.54
3	180	0.62	0.77	1.04	1.23	1.48	1.69	1.92
6	360	0.36	0.45	0.61	0.73	0.88	1.01	1.16
12	720	0.20	0.26	0.35	0.42	0.52	0.60	0.69
24	1440	0.11	0.15	0.20	0.24	0.30	0.35	0.41

Table A-5 Erath County								
Coefficients e b d		Return Period (Years)						
		1	2	5	10	25	50	100
		0.80626 37.942 7	0.81545 49.894 9	0.80871 65.302 11	0.80362 75.466 12	0.79735 89.169 13	0.78645 96.255 13	0.78371 109.034 14
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.12	5.80	6.94	7.74	8.90	9.91	10.85
	6	4.80	5.48	6.60	7.40	8.52	9.50	10.42
	7	4.52	5.20	6.31	7.08	8.18	9.12	10.03
	8	4.27	4.95	6.04	6.80	7.87	8.78	9.67
	9	4.06	4.73	5.79	6.53	7.58	8.47	9.34
	10	3.86	4.52	5.57	6.29	7.32	8.18	9.03
	11	3.69	4.34	5.36	6.07	7.07	7.91	8.75
	12	3.53	4.17	5.17	5.87	6.85	7.66	8.48
	13	3.39	4.01	5.00	5.68	6.64	7.42	8.24
0.250	14	3.26	3.87	4.84	5.50	6.44	7.21	8.01
	15	3.14	3.74	4.68	5.34	6.26	7.00	7.79
	16	3.03	3.61	4.54	5.19	6.08	6.81	7.58
	17	2.93	3.50	4.41	5.04	5.92	6.63	7.39
	18	2.83	3.40	4.29	4.91	5.77	6.46	7.21
	19	2.74	3.30	4.17	4.78	5.62	6.31	7.04
	20	2.66	3.20	4.06	4.66	5.49	6.15	6.88
	21	2.58	3.12	3.96	4.54	5.36	6.01	6.72
	22	2.51	3.03	3.86	4.44	5.24	5.88	6.57
	23	2.44	2.96	3.77	4.33	5.12	5.75	6.43
	24	2.38	2.88	3.68	4.24	5.01	5.62	6.30
	25	2.32	2.81	3.60	4.14	4.90	5.51	6.17
	26	2.26	2.75	3.52	4.06	4.80	5.40	6.05
	27	2.21	2.69	3.45	3.97	4.71	5.29	5.94
	28	2.16	2.63	3.37	3.89	4.62	5.19	5.83
0.500	29	2.11	2.57	3.31	3.82	4.53	5.09	5.72
	30	2.06	2.52	3.24	3.74	4.44	5.00	5.62
	31	2.02	2.46	3.18	3.67	4.36	4.91	5.52
	32	1.98	2.41	3.12	3.61	4.29	4.82	5.43
	33	1.94	2.37	3.06	3.54	4.21	4.74	5.33
	34	1.90	2.32	3.01	3.48	4.14	4.66	5.25
	35	1.86	2.28	2.95	3.42	4.07	4.58	5.16
	36	1.83	2.24	2.90	3.36	4.00	4.51	5.08
	37	1.80	2.20	2.85	3.31	3.94	4.44	5.00
	38	1.76	2.16	2.81	3.25	3.88	4.37	4.93
	39	1.73	2.12	2.76	3.20	3.82	4.30	4.86
	40	1.70	2.09	2.72	3.15	3.76	4.24	4.78
	41	1.67	2.05	2.67	3.11	3.71	4.18	4.72
	42	1.65	2.02	2.63	3.06	3.65	4.12	4.65
	43	1.62	1.99	2.59	3.01	3.60	4.06	4.59
0.750	44	1.59	1.96	2.56	2.97	3.55	4.00	4.52
	45	1.57	1.93	2.52	2.93	3.50	3.95	4.46
	46	1.54	1.90	2.48	2.89	3.45	3.90	4.41
	47	1.52	1.87	2.45	2.85	3.41	3.85	4.35
	48	1.50	1.85	2.41	2.81	3.36	3.80	4.29
	49	1.48	1.82	2.38	2.77	3.32	3.75	4.24
	50	1.46	1.79	2.35	2.74	3.28	3.70	4.19
	51	1.44	1.77	2.32	2.70	3.24	3.66	4.14
	52	1.42	1.75	2.29	2.67	3.20	3.61	4.09
	53	1.40	1.72	2.26	2.64	3.16	3.57	4.04
	54	1.38	1.70	2.23	2.60	3.12	3.53	3.99
	55	1.36	1.68	2.21	2.57	3.08	3.49	3.95
	56	1.34	1.66	2.18	2.54	3.05	3.45	3.90
	57	1.33	1.64	2.15	2.51	3.01	3.41	3.86
	58	1.31	1.62	2.13	2.48	2.98	3.37	3.82
	59	1.29	1.60	2.10	2.45	2.95	3.33	3.78
1	60	1.28	1.58	2.08	2.43	2.91	3.30	3.74
2	120	0.76	0.95	1.27	1.49	1.81	2.06	2.35
3	180	0.56	0.69	0.93	1.10	1.34	1.53	1.76
6	360	0.32	0.40	0.55	0.65	0.79	0.91	1.05
12	720	0.19	0.23	0.32	0.38	0.46	0.54	0.62
24	1440	0.11	0.13	0.18	0.22	0.27	0.31	0.36

		Table A-6 Grayson County						
		Return Period (Years)						
Coefficients		1	2	5	10	25	50	100
e		0.81558	0.79997	0.78004	0.77400	0.75825	0.74672	0.73522
b		43.546	50.367	59.963	68.347	75.379	80.570	85.722
d		8	9	10	11	11	11	11
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.38	6.10	7.25	7.99	9.21	10.16	11.16
	6	5.06	5.77	6.90	7.63	8.80	9.71	10.68
	7	4.78	5.48	6.58	7.30	8.42	9.31	10.24
	8	4.54	5.22	6.29	7.00	8.08	8.94	9.84
	9	4.32	4.99	6.03	6.73	7.78	8.60	9.47
	10	4.12	4.78	5.79	6.48	7.49	8.30	9.14
	11	3.94	4.59	5.58	6.25	7.23	8.01	8.83
	12	3.78	4.41	5.38	6.04	6.99	7.75	8.55
	13	3.64	4.25	5.20	5.84	6.77	7.51	8.29
0.250	14	3.50	4.10	5.03	5.66	6.57	7.28	8.04
	15	3.38	3.96	4.87	5.49	6.37	7.07	7.81
	16	3.26	3.84	4.72	5.33	6.19	6.88	7.60
	17	3.15	3.72	4.59	5.18	6.02	6.69	7.40
	18	3.05	3.61	4.46	5.04	5.87	6.52	7.21
	19	2.96	3.50	4.34	4.91	5.72	6.36	7.03
	20	2.88	3.41	4.22	4.79	5.58	6.20	6.86
	21	2.79	3.32	4.12	4.67	5.44	6.06	6.71
	22	2.72	3.23	4.02	4.56	5.32	5.92	6.56
	23	2.65	3.15	3.92	4.46	5.20	5.79	6.41
	24	2.58	3.07	3.83	4.36	5.09	5.66	6.28
	25	2.51	3.00	3.75	4.27	4.98	5.55	6.15
	26	2.45	2.93	3.66	4.18	4.88	5.43	6.03
	27	2.40	2.87	3.59	4.09	4.78	5.33	5.91
	28	2.34	2.80	3.51	4.01	4.69	5.23	5.80
0.500	29	2.29	2.74	3.44	3.93	4.60	5.13	5.69
	30	2.24	2.69	3.37	3.86	4.51	5.03	5.59
	31	2.19	2.63	3.31	3.79	4.43	4.94	5.49
	32	2.15	2.58	3.25	3.72	4.35	4.86	5.40
	33	2.11	2.53	3.19	3.65	4.28	4.78	5.31
	34	2.07	2.49	3.13	3.59	4.20	4.70	5.22
	35	2.03	2.44	3.08	3.53	4.13	4.62	5.14
	36	1.99	2.40	3.03	3.47	4.07	4.55	5.06
	37	1.95	2.35	2.98	3.42	4.00	4.47	4.98
	38	1.92	2.31	2.93	3.36	3.94	4.41	4.90
	39	1.88	2.28	2.88	3.31	3.88	4.34	4.83
	40	1.85	2.24	2.84	3.26	3.82	4.28	4.76
	41	1.82	2.20	2.79	3.21	3.77	4.22	4.69
	42	1.79	2.17	2.75	3.16	3.71	4.16	4.63
	43	1.76	2.13	2.71	3.12	3.66	4.10	4.56
0.750	44	1.74	2.10	2.67	3.07	3.61	4.04	4.50
	45	1.71	2.07	2.63	3.03	3.56	3.99	4.44
	46	1.68	2.04	2.60	2.99	3.51	3.94	4.39
	47	1.66	2.01	2.56	2.95	3.47	3.89	4.33
	48	1.63	1.98	2.53	2.91	3.42	3.84	4.28
	49	1.61	1.96	2.49	2.87	3.38	3.79	4.22
	50	1.59	1.93	2.46	2.84	3.34	3.74	4.17
	51	1.57	1.90	2.43	2.80	3.30	3.70	4.12
	52	1.54	1.88	2.40	2.77	3.26	3.65	4.08
	53	1.52	1.85	2.37	2.73	3.22	3.61	4.03
	54	1.50	1.83	2.34	2.70	3.18	3.57	3.98
	55	1.48	1.81	2.31	2.67	3.14	3.53	3.94
	56	1.47	1.79	2.28	2.64	3.11	3.49	3.90
	57	1.45	1.76	2.26	2.61	3.07	3.45	3.85
	58	1.43	1.74	2.23	2.58	3.04	3.41	3.81
	59	1.41	1.72	2.21	2.55	3.01	3.38	3.77
1	60	1.39	1.70	2.18	2.52	2.98	3.34	3.73
2	120	0.83	1.03	1.35	1.57	1.87	2.11	2.38
3	180	0.61	0.76	1.00	1.17	1.40	1.60	1.80
6	360	0.35	0.45	0.60	0.70	0.85	0.97	1.11
12	720	0.20	0.26	0.35	0.42	0.51	0.59	0.67
24	1440	0.12	0.15	0.21	0.24	0.30	0.35	0.41

Table A-7 Hood County								
Coefficients e b d		Return Period (Years)						
		1	2	5	10	25	50	100
		0.81637 41.477 8	0.81319 50.451 9	0.80743 66.098 11	0.80275 76.415 12	0.79730 90.450 13	0.79586 103.535 14	0.78454 110.783 14
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.11	5.90	7.05	7.86	9.03	9.94	11.00
	6	4.81	5.58	6.71	7.51	8.65	9.54	10.56
	7	4.55	5.29	6.41	7.19	8.30	9.18	10.17
	8	4.31	5.04	6.13	6.90	7.98	8.85	9.80
	9	4.10	4.81	5.88	6.63	7.69	8.54	9.47
	10	3.92	4.60	5.66	6.39	7.43	8.25	9.15
	11	3.75	4.41	5.45	6.17	7.18	7.99	8.87
	12	3.59	4.24	5.26	5.96	6.95	7.74	8.60
	13	3.45	4.09	5.08	5.77	6.73	7.51	8.35
0.250	14	3.33	3.94	4.91	5.59	6.53	7.30	8.11
	15	3.21	3.81	4.76	5.42	6.35	7.10	7.89
	16	3.10	3.68	4.62	5.27	6.17	6.91	7.68
	17	3.00	3.57	4.48	5.12	6.01	6.73	7.49
	18	2.90	3.46	4.36	4.98	5.85	6.56	7.31
	19	2.81	3.36	4.24	4.85	5.71	6.41	7.13
	20	2.73	3.26	4.13	4.73	5.57	6.26	6.97
	21	2.65	3.17	4.03	4.62	5.44	6.11	6.81
	22	2.58	3.09	3.93	4.51	5.31	5.98	6.66
	23	2.51	3.01	3.83	4.40	5.19	5.85	6.52
	24	2.45	2.94	3.75	4.30	5.08	5.73	6.38
	25	2.39	2.87	3.66	4.21	4.98	5.61	6.25
	26	2.33	2.80	3.58	4.12	4.87	5.50	6.13
	27	2.28	2.74	3.50	4.04	4.78	5.39	6.01
	28	2.22	2.68	3.43	3.95	4.68	5.29	5.90
0.500	29	2.18	2.62	3.36	3.88	4.59	5.19	5.79
	30	2.13	2.56	3.30	3.80	4.51	5.09	5.69
	31	2.08	2.51	3.23	3.73	4.43	5.00	5.59
	32	2.04	2.46	3.17	3.66	4.35	4.92	5.50
	33	2.00	2.41	3.11	3.60	4.27	4.83	5.40
	34	1.96	2.37	3.06	3.54	4.20	4.75	5.31
	35	1.92	2.33	3.00	3.47	4.13	4.68	5.23
	36	1.89	2.28	2.95	3.42	4.06	4.60	5.15
	37	1.85	2.24	2.90	3.36	4.00	4.53	5.07
	38	1.82	2.20	2.85	3.31	3.94	4.46	4.99
	39	1.79	2.17	2.81	3.25	3.87	4.39	4.92
	40	1.76	2.13	2.76	3.20	3.82	4.33	4.85
	41	1.73	2.10	2.72	3.16	3.76	4.27	4.78
	42	1.70	2.06	2.68	3.11	3.71	4.21	4.71
	43	1.67	2.03	2.64	3.06	3.65	4.15	4.64
0.750	44	1.65	2.00	2.60	3.02	3.60	4.09	4.58
	45	1.62	1.97	2.56	2.98	3.55	4.03	4.52
	46	1.60	1.94	2.53	2.93	3.50	3.98	4.46
	47	1.57	1.91	2.49	2.89	3.46	3.93	4.40
	48	1.55	1.88	2.46	2.86	3.41	3.88	4.35
	49	1.53	1.86	2.42	2.82	3.37	3.83	4.29
	50	1.51	1.83	2.39	2.78	3.32	3.78	4.24
	51	1.49	1.81	2.36	2.75	3.28	3.73	4.19
	52	1.47	1.78	2.33	2.71	3.24	3.69	4.14
	53	1.45	1.76	2.30	2.68	3.20	3.65	4.09
	54	1.43	1.74	2.27	2.65	3.17	3.60	4.04
	55	1.41	1.71	2.24	2.61	3.13	3.56	4.00
	56	1.39	1.69	2.22	2.58	3.09	3.52	3.95
	57	1.37	1.67	2.19	2.55	3.06	3.48	3.91
	58	1.36	1.65	2.16	2.52	3.02	3.44	3.87
	59	1.34	1.63	2.14	2.50	2.99	3.41	3.82
1	60	1.32	1.61	2.12	2.47	2.96	3.37	3.78
2	120	0.79	0.97	1.29	1.52	1.83	2.10	2.38
3	180	0.58	0.71	0.95	1.12	1.36	1.56	1.78
6	360	0.33	0.41	0.56	0.66	0.81	0.93	1.06
12	720	0.19	0.24	0.32	0.38	0.47	0.54	0.63
24	1440	0.11	0.14	0.19	0.22	0.27	0.31	0.37

Table A-8 Hunt County								
Coefficients		Return Period (Years)						
		1	2	5	10	25	50	100
		e	b	d				
		0.82939	0.80293	0.78081	0.76472	0.74870	0.73779	0.72681
		50.510	53.647	62.767	66.895	73.271	78.271	83.114
		10	10	11	11	11	11	11
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.34	6.10	7.20	8.03	9.19	10.12	11.08
	6	5.07	5.79	6.87	7.66	8.78	9.68	10.60
	7	4.82	5.52	6.57	7.34	8.42	9.28	10.17
	8	4.59	5.27	6.30	7.04	8.08	8.92	9.78
	9	4.39	5.04	6.05	6.77	7.78	8.58	9.42
	10	4.21	4.84	5.83	6.52	7.50	8.28	9.09
	11	4.04	4.65	5.62	6.29	7.24	8.00	8.79
	12	3.89	4.48	5.43	6.08	7.00	7.74	8.51
	13	3.75	4.33	5.25	5.89	6.79	7.50	8.25
0.250	14	3.62	4.18	5.08	5.71	6.58	7.28	8.01
	15	3.50	4.05	4.93	5.54	6.39	7.07	7.79
	16	3.39	3.92	4.79	5.38	6.21	6.88	7.57
	17	3.28	3.80	4.65	5.23	6.05	6.70	7.38
	18	3.19	3.69	4.53	5.09	5.89	6.53	7.19
	19	3.09	3.59	4.41	4.96	5.74	6.36	7.02
	20	3.01	3.50	4.30	4.84	5.60	6.21	6.85
	21	2.93	3.40	4.19	4.72	5.47	6.07	6.69
	22	2.85	3.32	4.09	4.61	5.35	5.93	6.55
	23	2.78	3.24	4.00	4.51	5.23	5.80	6.41
	24	2.71	3.16	3.91	4.41	5.12	5.68	6.27
	25	2.65	3.09	3.82	4.32	5.01	5.56	6.15
	26	2.59	3.02	3.74	4.23	4.91	5.45	6.02
	27	2.53	2.95	3.67	4.14	4.81	5.35	5.91
	28	2.47	2.89	3.59	4.06	4.72	5.24	5.80
0.500	29	2.42	2.83	3.52	3.98	4.63	5.15	5.69
	30	2.37	2.77	3.46	3.91	4.54	5.05	5.59
	31	2.32	2.72	3.39	3.84	4.46	4.97	5.49
	32	2.28	2.67	3.33	3.77	4.38	4.88	5.40
	33	2.23	2.62	3.27	3.70	4.31	4.80	5.31
	34	2.19	2.57	3.21	3.64	4.24	4.72	5.23
	35	2.15	2.52	3.16	3.58	4.17	4.64	5.14
	36	2.11	2.48	3.11	3.52	4.10	4.57	5.06
	37	2.07	2.44	3.05	3.47	4.04	4.50	4.99
	38	2.04	2.40	3.01	3.41	3.98	4.43	4.91
	39	2.00	2.36	2.96	3.36	3.92	4.37	4.84
	40	1.97	2.32	2.91	3.31	3.86	4.30	4.77
	41	1.94	2.28	2.87	3.26	3.80	4.24	4.70
	42	1.91	2.25	2.83	3.21	3.75	4.18	4.64
	43	1.88	2.21	2.79	3.17	3.70	4.13	4.58
0.750	44	1.85	2.18	2.75	3.12	3.65	4.07	4.52
	45	1.82	2.15	2.71	3.08	3.60	4.02	4.46
	46	1.79	2.12	2.67	3.04	3.55	3.96	4.40
	47	1.77	2.09	2.64	3.00	3.50	3.91	4.35
	48	1.74	2.06	2.60	2.96	3.46	3.86	4.29
	49	1.72	2.03	2.57	2.92	3.42	3.82	4.24
	50	1.69	2.00	2.53	2.88	3.37	3.77	4.19
	51	1.67	1.98	2.50	2.85	3.33	3.73	4.14
	52	1.65	1.95	2.47	2.81	3.29	3.68	4.09
	53	1.63	1.93	2.44	2.78	3.26	3.64	4.05
	54	1.60	1.90	2.41	2.75	3.22	3.60	4.00
	55	1.58	1.88	2.38	2.72	3.18	3.56	3.96
	56	1.56	1.86	2.35	2.69	3.15	3.52	3.91
	57	1.54	1.83	2.33	2.65	3.11	3.48	3.87
	58	1.53	1.81	2.30	2.63	3.08	3.44	3.83
	59	1.51	1.79	2.28	2.60	3.04	3.41	3.79
1	60	1.49	1.77	2.25	2.57	3.01	3.37	3.75
2	120	0.89	1.08	1.39	1.61	1.90	2.15	2.40
3	180	0.65	0.79	1.04	1.21	1.44	1.62	1.83
6	360	0.37	0.47	0.62	0.73	0.87	1.00	1.13
12	720	0.21	0.27	0.36	0.43	0.53	0.60	0.69
24	1440	0.12	0.16	0.21	0.26	0.31	0.36	0.42

Table A-9 Johnson County								
Coefficients e b d		Return Period (Years)						
		1	2	5	10	25	50	100
		0.81894 42.817 8	0.80951 50.706 9	0.81158 70.148 12	0.80523 80.274 13	0.78945 89.082 13	0.78704 101.325 14	0.78336 113.822 15
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.24	5.99	7.04	7.83	9.10	9.98	10.89
	6	4.93	5.66	6.72	7.50	8.72	9.59	10.48
	7	4.66	5.37	6.43	7.19	8.37	9.23	10.11
	8	4.42	5.12	6.17	6.92	8.05	8.90	9.76
	9	4.21	4.89	5.93	6.66	7.76	8.59	9.44
	10	4.01	4.68	5.71	6.43	7.50	8.31	9.14
	11	3.84	4.49	5.51	6.21	7.25	8.04	8.87
	12	3.68	4.31	5.32	6.01	7.02	7.80	8.61
	13	3.54	4.15	5.15	5.82	6.80	7.57	8.37
0.250	14	3.41	4.01	4.98	5.65	6.60	7.36	8.14
	15	3.28	3.87	4.83	5.49	6.42	7.16	7.93
	16	3.17	3.74	4.69	5.33	6.24	6.97	7.73
	17	3.07	3.63	4.56	5.19	6.08	6.79	7.54
	18	2.97	3.52	4.44	5.05	5.92	6.62	7.36
	19	2.88	3.42	4.32	4.93	5.77	6.47	7.19
	20	2.80	3.32	4.21	4.81	5.64	6.32	7.03
	21	2.72	3.23	4.11	4.69	5.51	6.17	6.87
	22	2.64	3.15	4.01	4.58	5.38	6.04	6.73
	23	2.57	3.07	3.92	4.48	5.26	5.91	6.59
	24	2.51	2.99	3.83	4.38	5.15	5.79	6.45
	25	2.44	2.92	3.74	4.29	5.04	5.67	6.33
	26	2.38	2.85	3.66	4.20	4.94	5.56	6.21
	27	2.33	2.79	3.59	4.12	4.84	5.45	6.09
	28	2.28	2.73	3.51	4.04	4.75	5.35	5.98
0.500	29	2.23	2.67	3.44	3.96	4.66	5.25	5.87
	30	2.18	2.61	3.38	3.88	4.57	5.16	5.77
	31	2.13	2.56	3.31	3.81	4.49	5.06	5.67
	32	2.09	2.51	3.25	3.74	4.41	4.98	5.58
	33	2.05	2.46	3.19	3.68	4.34	4.89	5.49
	34	2.01	2.41	3.14	3.62	4.26	4.81	5.40
	35	1.97	2.37	3.08	3.55	4.19	4.74	5.31
	36	1.93	2.33	3.03	3.50	4.13	4.66	5.23
	37	1.90	2.29	2.98	3.44	4.06	4.59	5.15
	38	1.86	2.25	2.93	3.39	4.00	4.52	5.08
	39	1.83	2.21	2.89	3.33	3.94	4.45	5.00
	40	1.80	2.17	2.84	3.28	3.88	4.39	4.93
	41	1.77	2.14	2.80	3.23	3.82	4.32	4.86
	42	1.74	2.10	2.75	3.19	3.77	4.26	4.79
	43	1.71	2.07	2.71	3.14	3.71	4.21	4.73
0.750	44	1.68	2.04	2.67	3.10	3.66	4.15	4.67
	45	1.66	2.01	2.64	3.05	3.61	4.09	4.61
	46	1.63	1.98	2.60	3.01	3.56	4.04	4.55
	47	1.61	1.95	2.56	2.97	3.52	3.99	4.49
	48	1.58	1.92	2.53	2.93	3.47	3.94	4.43
	49	1.56	1.89	2.50	2.89	3.43	3.89	4.38
	50	1.54	1.87	2.46	2.86	3.38	3.84	4.33
	51	1.52	1.84	2.43	2.82	3.34	3.79	4.27
	52	1.50	1.82	2.40	2.78	3.30	3.75	4.22
	53	1.48	1.80	2.37	2.75	3.26	3.70	4.18
	54	1.46	1.77	2.34	2.72	3.22	3.66	4.13
	55	1.44	1.75	2.31	2.69	3.19	3.62	4.08
	56	1.42	1.73	2.28	2.65	3.15	3.58	4.04
	57	1.40	1.71	2.26	2.62	3.11	3.54	3.99
	58	1.39	1.69	2.23	2.59	3.08	3.50	3.95
	59	1.37	1.67	2.21	2.56	3.04	3.46	3.91
1	60	1.35	1.65	2.18	2.54	3.01	3.42	3.87
2	120	0.81	0.99	1.33	1.56	1.88	2.15	2.44
3	180	0.59	0.73	0.98	1.16	1.40	1.60	1.83
6	360	0.34	0.42	0.58	0.68	0.83	0.96	1.10
12	720	0.19	0.24	0.33	0.40	0.49	0.56	0.65
24	1440	0.11	0.14	0.19	0.23	0.28	0.33	0.38

Table A-10 Kaufman County								
Coefficients		Return Period (Years)						
		1	2	5	10	25	50	100
e		0.82108	0.80451	0.79370	0.78786	0.77191	0.76117	0.75823
b		47.296	54.125	68.520	78.197	86.089	92.329	103.645
d		9	10	12	13	13	13	14
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.42	6.13	7.23	8.02	9.25	10.23	11.12
	6	5.12	5.82	6.91	7.69	8.87	9.82	10.69
	7	4.85	5.54	6.62	7.38	8.52	9.44	10.30
	8	4.62	5.29	6.36	7.10	8.21	9.10	9.95
	9	4.41	5.07	6.11	6.85	7.92	8.78	9.62
	10	4.22	4.86	5.89	6.61	7.65	8.49	9.31
	11	4.04	4.67	5.69	6.39	7.41	8.22	9.03
	12	3.88	4.50	5.50	6.19	7.18	7.97	8.76
	13	3.74	4.34	5.32	6.00	6.96	7.73	8.52
0.250	14	3.60	4.20	5.16	5.83	6.76	7.51	8.28
	15	3.48	4.06	5.01	5.66	6.57	7.31	8.07
	16	3.37	3.94	4.87	5.51	6.40	7.12	7.86
	17	3.26	3.82	4.73	5.36	6.23	6.93	7.67
	18	3.16	3.71	4.61	5.23	6.08	6.76	7.49
	19	3.07	3.60	4.49	5.10	5.93	6.60	7.31
	20	2.98	3.51	4.38	4.98	5.79	6.45	7.15
	21	2.90	3.42	4.27	4.86	5.66	6.30	6.99
	22	2.82	3.33	4.17	4.75	5.53	6.17	6.85
	23	2.75	3.25	4.08	4.65	5.42	6.04	6.71
	24	2.68	3.17	3.99	4.55	5.30	5.91	6.57
	25	2.61	3.10	3.90	4.45	5.19	5.79	6.44
	26	2.55	3.03	3.82	4.36	5.09	5.68	6.32
	27	2.49	2.96	3.74	4.28	4.99	5.57	6.20
	28	2.44	2.90	3.67	4.19	4.90	5.47	6.09
0.500	29	2.39	2.84	3.60	4.11	4.81	5.37	5.98
	30	2.34	2.78	3.53	4.04	4.72	5.27	5.88
	31	2.29	2.73	3.46	3.97	4.64	5.18	5.78
	32	2.24	2.68	3.40	3.90	4.56	5.09	5.69
	33	2.20	2.63	3.34	3.83	4.48	5.01	5.59
	34	2.16	2.58	3.28	3.77	4.41	4.93	5.51
	35	2.12	2.53	3.23	3.70	4.34	4.85	5.42
	36	2.08	2.49	3.17	3.64	4.27	4.77	5.34
	37	2.04	2.44	3.12	3.59	4.20	4.70	5.26
	38	2.00	2.40	3.07	3.53	4.14	4.63	5.18
	39	1.97	2.36	3.02	3.48	4.08	4.56	5.11
	40	1.94	2.33	2.98	3.43	4.02	4.50	5.03
	41	1.90	2.29	2.93	3.38	3.96	4.43	4.97
	42	1.87	2.25	2.89	3.33	3.90	4.37	4.90
	43	1.84	2.22	2.85	3.28	3.85	4.31	4.83
0.750	44	1.82	2.19	2.81	3.23	3.80	4.25	4.77
	45	1.79	2.15	2.77	3.19	3.75	4.20	4.71
	46	1.76	2.12	2.73	3.15	3.70	4.14	4.65
	47	1.74	2.09	2.69	3.11	3.65	4.09	4.59
	48	1.71	2.06	2.66	3.07	3.60	4.04	4.53
	49	1.69	2.04	2.62	3.03	3.56	3.99	4.48
	50	1.66	2.01	2.59	2.99	3.52	3.94	4.43
	51	1.64	1.98	2.56	2.95	3.47	3.90	4.37
	52	1.62	1.96	2.52	2.92	3.43	3.85	4.32
	53	1.60	1.93	2.49	2.88	3.39	3.81	4.28
	54	1.58	1.91	2.46	2.85	3.35	3.76	4.23
	55	1.56	1.88	2.43	2.81	3.31	3.72	4.18
	56	1.54	1.86	2.41	2.78	3.28	3.68	4.14
	57	1.52	1.84	2.38	2.75	3.24	3.64	4.09
	58	1.50	1.82	2.35	2.72	3.21	3.60	4.05
	59	1.48	1.79	2.33	2.69	3.17	3.56	4.01
1	60	1.46	1.77	2.30	2.66	3.14	3.52	3.96
2	120	0.87	1.08	1.42	1.66	1.97	2.23	2.53
3	180	0.64	0.79	1.06	1.24	1.48	1.68	1.91
6	360	0.37	0.46	0.62	0.74	0.89	1.02	1.16
12	720	0.21	0.27	0.36	0.43	0.53	0.61	0.70
24	1440	0.12	0.15	0.21	0.25	0.31	0.36	0.41

		Table A-11 Navarro County						
		Return Period (Years)						
Coefficients		1	2	5	10	25	50	100
e		0.82920	0.80921	0.80665	0.79885	0.79034	0.78696	0.78204
b		49.070	55.346	74.472	84.510	98.346	111.208	124.111
d		9	10	13	14	15	16	17
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.50	6.19	7.23	8.04	9.22	10.13	11.07
	6	5.20	5.87	6.93	7.72	8.87	9.77	10.69
	7	4.92	5.59	6.65	7.42	8.55	9.43	10.34
	8	4.68	5.34	6.39	7.15	8.25	9.12	10.01
	9	4.47	5.11	6.15	6.90	7.98	8.83	9.71
	10	4.27	4.90	5.94	6.67	7.73	8.56	9.43
	11	4.09	4.71	5.74	6.46	7.49	8.31	9.16
	12	3.93	4.54	5.55	6.26	7.27	8.08	8.92
	13	3.78	4.38	5.38	6.07	7.06	7.86	8.68
0.250	14	3.64	4.23	5.22	5.90	6.87	7.65	8.46
	15	3.52	4.09	5.07	5.74	6.69	7.46	8.26
	16	3.40	3.96	4.92	5.58	6.52	7.27	8.06
	17	3.29	3.84	4.79	5.44	6.36	7.10	7.87
	18	3.19	3.73	4.67	5.30	6.20	6.93	7.70
	19	3.10	3.63	4.55	5.17	6.06	6.78	7.53
	20	3.01	3.53	4.44	5.05	5.92	6.63	7.37
	21	2.92	3.44	4.33	4.94	5.79	6.49	7.22
	22	2.85	3.35	4.23	4.83	5.67	6.35	7.07
	23	2.77	3.27	4.14	4.72	5.55	6.22	6.93
	24	2.70	3.19	4.05	4.62	5.44	6.10	6.80
	25	2.64	3.12	3.96	4.53	5.33	5.98	6.67
	26	2.57	3.05	3.88	4.44	5.23	5.87	6.55
	27	2.51	2.98	3.80	4.35	5.13	5.76	6.44
	28	2.46	2.92	3.72	4.27	5.03	5.66	6.32
0.500	29	2.40	2.85	3.65	4.19	4.94	5.56	6.22
	30	2.35	2.80	3.58	4.11	4.85	5.47	6.11
	31	2.30	2.74	3.52	4.04	4.77	5.37	6.01
	32	2.26	2.69	3.45	3.97	4.69	5.29	5.92
	33	2.21	2.64	3.39	3.90	4.61	5.20	5.82
	34	2.17	2.59	3.34	3.84	4.54	5.12	5.73
	35	2.13	2.54	3.28	3.77	4.47	5.04	5.65
	36	2.09	2.50	3.23	3.71	4.40	4.96	5.56
	37	2.05	2.45	3.17	3.65	4.33	4.89	5.48
	38	2.02	2.41	3.12	3.60	4.27	4.82	5.40
	39	1.98	2.37	3.07	3.54	4.20	4.75	5.33
	40	1.95	2.33	3.03	3.49	4.14	4.68	5.26
	41	1.91	2.30	2.98	3.44	4.08	4.62	5.18
	42	1.88	2.26	2.94	3.39	4.03	4.55	5.12
	43	1.85	2.23	2.90	3.34	3.97	4.49	5.05
0.750	44	1.82	2.19	2.86	3.30	3.92	4.43	4.98
	45	1.80	2.16	2.82	3.25	3.87	4.38	4.92
	46	1.77	2.13	2.78	3.21	3.82	4.32	4.86
	47	1.74	2.10	2.74	3.17	3.77	4.27	4.80
	48	1.72	2.07	2.70	3.13	3.72	4.21	4.74
	49	1.69	2.04	2.67	3.09	3.68	4.16	4.69
	50	1.67	2.01	2.63	3.05	3.63	4.11	4.63
	51	1.65	1.99	2.60	3.01	3.59	4.07	4.58
	52	1.62	1.96	2.57	2.97	3.54	4.02	4.53
	53	1.60	1.94	2.54	2.94	3.50	3.97	4.48
	54	1.58	1.91	2.51	2.90	3.46	3.93	4.43
	55	1.56	1.89	2.48	2.87	3.42	3.88	4.38
	56	1.54	1.87	2.45	2.84	3.39	3.84	4.33
	57	1.52	1.84	2.42	2.81	3.35	3.80	4.29
	58	1.50	1.82	2.39	2.77	3.31	3.76	4.24
	59	1.48	1.80	2.36	2.74	3.28	3.72	4.20
1	60	1.47	1.78	2.34	2.71	3.24	3.68	4.15
2	120	0.87	1.08	1.44	1.69	2.04	2.33	2.65
3	180	0.64	0.79	1.07	1.26	1.52	1.75	1.99
6	360	0.36	0.46	0.63	0.74	0.91	1.05	1.20
12	720	0.21	0.27	0.36	0.43	0.53	0.62	0.71
24	1440	0.12	0.15	0.21	0.25	0.31	0.36	0.42

		Table A-12 Palo Pinto County						
		Return Period (Years)						
Coefficients		1	2	5	10	25	50	100
e		0.82438	0.81924	0.82409	0.81899	0.81251	0.80950	0.80567
b		42.135	50.817	71.566	82.741	97.985	111.741	126.255
d		8	9	12	13	14	15	16
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.09	5.85	6.93	7.76	8.96	9.89	10.86
	6	4.78	5.53	6.61	7.42	8.59	9.50	10.46
	7	4.52	5.24	6.32	7.12	8.26	9.15	10.10
	8	4.29	4.99	6.06	6.84	7.95	8.83	9.76
	9	4.08	4.76	5.82	6.58	7.67	8.53	9.44
	10	3.89	4.55	5.60	6.35	7.41	8.25	9.15
	11	3.72	4.37	5.40	6.13	7.17	7.99	8.87
	12	3.57	4.20	5.22	5.93	6.94	7.75	8.62
	13	3.42	4.04	5.04	5.74	6.73	7.53	8.38
0.250	14	3.30	3.89	4.88	5.56	6.54	7.32	8.15
	15	3.18	3.76	4.73	5.40	6.35	7.12	7.94
	16	3.07	3.64	4.59	5.25	6.18	6.93	7.74
	17	2.97	3.52	4.46	5.10	6.02	6.76	7.55
	18	2.87	3.41	4.34	4.97	5.86	6.59	7.37
	19	2.78	3.31	4.22	4.84	5.72	6.43	7.20
	20	2.70	3.22	4.11	4.72	5.58	6.28	7.04
	21	2.62	3.13	4.01	4.61	5.45	6.14	6.88
	22	2.55	3.05	3.91	4.50	5.33	6.01	6.74
	23	2.48	2.97	3.82	4.40	5.21	5.88	6.60
	24	2.42	2.90	3.73	4.30	5.10	5.76	6.46
	25	2.36	2.83	3.65	4.21	4.99	5.64	6.34
	26	2.30	2.76	3.57	4.12	4.89	5.53	6.22
	27	2.25	2.70	3.50	4.03	4.79	5.42	6.10
	28	2.20	2.64	3.42	3.95	4.70	5.32	5.99
0.500	29	2.15	2.58	3.35	3.88	4.61	5.22	5.88
	30	2.10	2.53	3.29	3.80	4.53	5.13	5.78
	31	2.06	2.47	3.23	3.73	4.45	5.04	5.68
	32	2.01	2.43	3.16	3.66	4.37	4.95	5.58
	33	1.97	2.38	3.11	3.60	4.29	4.87	5.49
	34	1.93	2.33	3.05	3.53	4.22	4.79	5.40
	35	1.90	2.29	3.00	3.47	4.15	4.71	5.32
	36	1.86	2.25	2.95	3.42	4.08	4.63	5.23
	37	1.83	2.21	2.90	3.36	4.02	4.56	5.15
	38	1.79	2.17	2.85	3.31	3.95	4.49	5.08
	39	1.76	2.13	2.80	3.25	3.89	4.42	5.00
	40	1.73	2.10	2.76	3.20	3.83	4.36	4.93
	41	1.70	2.06	2.71	3.15	3.78	4.30	4.86
	42	1.68	2.03	2.67	3.11	3.72	4.23	4.79
	43	1.65	2.00	2.63	3.06	3.67	4.18	4.73
0.750	44	1.62	1.97	2.59	3.02	3.62	4.12	4.66
	45	1.60	1.94	2.56	2.98	3.57	4.06	4.60
	46	1.57	1.91	2.52	2.93	3.52	4.01	4.54
	47	1.55	1.88	2.49	2.89	3.47	3.96	4.48
	48	1.53	1.85	2.45	2.85	3.43	3.91	4.43
	49	1.50	1.83	2.42	2.82	3.38	3.86	4.37
	50	1.48	1.80	2.39	2.78	3.34	3.81	4.32
	51	1.46	1.78	2.35	2.74	3.30	3.76	4.27
	52	1.44	1.75	2.32	2.71	3.26	3.72	4.22
	53	1.42	1.73	2.29	2.68	3.22	3.67	4.17
	54	1.40	1.71	2.27	2.64	3.18	3.63	4.12
	55	1.38	1.68	2.24	2.61	3.14	3.59	4.07
	56	1.37	1.66	2.21	2.58	3.10	3.54	4.03
	57	1.35	1.64	2.18	2.55	3.07	3.51	3.98
	58	1.33	1.62	2.16	2.52	3.03	3.47	3.94
	59	1.32	1.60	2.13	2.49	3.00	3.43	3.90
1	60	1.30	1.58	2.11	2.46	2.97	3.39	3.85
2	120	0.77	0.95	1.28	1.51	1.83	2.11	2.41
3	180	0.56	0.69	0.94	1.11	1.36	1.56	1.80
6	360	0.32	0.40	0.54	0.65	0.80	0.92	1.06
12	720	0.18	0.23	0.31	0.37	0.46	0.53	0.62
24	1440	0.10	0.13	0.18	0.21	0.26	0.31	0.36

Table A-13 Parker County								
Coefficients e b d		Return Period (Years)						
		1	2	5	10	25	50	100
		0.81993 42.333 8	0.81528 51.064 9	0.80996 67.052 11	0.80658 77.954 12	0.80148 92.557 13	0.80055 106.196 14	0.79789 120.205 15
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.17	5.94	7.10	7.93	9.13	10.06	11.01
	6	4.86	5.61	6.76	7.57	8.74	9.65	10.59
	7	4.60	5.33	6.45	7.25	8.39	9.28	10.21
	8	4.36	5.07	6.18	6.96	8.07	8.94	9.85
	9	4.15	4.84	5.92	6.69	7.77	8.63	9.52
	10	3.96	4.63	5.69	6.44	7.50	8.34	9.22
	11	3.79	4.44	5.48	6.22	7.25	8.07	8.93
	12	3.63	4.27	5.29	6.01	7.01	7.82	8.67
	13	3.49	4.11	5.11	5.81	6.80	7.59	8.42
0.250	14	3.36	3.96	4.94	5.63	6.59	7.37	8.19
	15	3.24	3.83	4.79	5.46	6.41	7.17	7.97
	16	3.13	3.70	4.65	5.30	6.23	6.98	7.76
	17	3.02	3.59	4.51	5.16	6.06	6.80	7.57
	18	2.93	3.48	4.38	5.02	5.90	6.62	7.38
	19	2.84	3.38	4.27	4.89	5.76	6.46	7.21
	20	2.75	3.28	4.15	4.76	5.61	6.31	7.05
	21	2.68	3.19	4.05	4.65	5.48	6.17	6.89
	22	2.60	3.11	3.95	4.54	5.36	6.03	6.74
	23	2.53	3.03	3.85	4.43	5.24	5.90	6.60
	24	2.47	2.95	3.77	4.33	5.12	5.77	6.46
	25	2.41	2.88	3.68	4.24	5.01	5.65	6.33
	26	2.35	2.81	3.60	4.15	4.91	5.54	6.21
	27	2.29	2.75	3.52	4.06	4.81	5.43	6.09
	28	2.24	2.69	3.45	3.98	4.72	5.33	5.98
0.500	29	2.19	2.63	3.38	3.90	4.63	5.23	5.87
	30	2.14	2.58	3.31	3.82	4.54	5.13	5.77
	31	2.10	2.52	3.25	3.75	4.46	5.04	5.67
	32	2.06	2.47	3.19	3.68	4.38	4.95	5.57
	33	2.02	2.43	3.13	3.62	4.30	4.87	5.48
	34	1.98	2.38	3.07	3.55	4.23	4.79	5.39
	35	1.94	2.33	3.02	3.49	4.16	4.71	5.30
	36	1.90	2.29	2.97	3.43	4.09	4.63	5.22
	37	1.87	2.25	2.92	3.38	4.02	4.56	5.14
	38	1.83	2.21	2.87	3.32	3.96	4.49	5.06
	39	1.80	2.17	2.82	3.27	3.90	4.42	4.98
	40	1.77	2.14	2.78	3.22	3.84	4.36	4.91
	41	1.74	2.10	2.73	3.17	3.78	4.29	4.84
	42	1.71	2.07	2.69	3.12	3.73	4.23	4.77
	43	1.68	2.04	2.65	3.08	3.68	4.17	4.71
0.750	44	1.66	2.01	2.61	3.03	3.62	4.12	4.64
	45	1.63	1.98	2.57	2.99	3.57	4.06	4.58
	46	1.61	1.95	2.54	2.95	3.52	4.01	4.52
	47	1.58	1.92	2.50	2.91	3.48	3.95	4.46
	48	1.56	1.89	2.47	2.87	3.43	3.90	4.41
	49	1.54	1.86	2.43	2.83	3.39	3.85	4.35
	50	1.52	1.84	2.40	2.79	3.34	3.80	4.30
	51	1.50	1.81	2.37	2.76	3.30	3.76	4.25
	52	1.47	1.79	2.34	2.72	3.26	3.71	4.20
	53	1.45	1.77	2.31	2.69	3.22	3.67	4.15
	54	1.44	1.74	2.28	2.66	3.18	3.62	4.10
	55	1.42	1.72	2.25	2.62	3.15	3.58	4.05
	56	1.40	1.70	2.23	2.59	3.11	3.54	4.01
	57	1.38	1.68	2.20	2.56	3.07	3.50	3.96
	58	1.36	1.66	2.17	2.53	3.04	3.46	3.92
	59	1.35	1.64	2.15	2.50	3.00	3.42	3.88
1	60	1.33	1.62	2.12	2.48	2.97	3.39	3.84
2	120	0.79	0.97	1.29	1.52	1.84	2.10	2.40
3	180	0.58	0.71	0.95	1.12	1.36	1.57	1.79
6	360	0.33	0.41	0.56	0.66	0.80	0.93	1.06
12	720	0.19	0.24	0.32	0.38	0.47	0.54	0.62
24	1440	0.11	0.14	0.18	0.22	0.27	0.31	0.36

		Table A-14 Rockwall County						
		Return Period (Years)						
Coefficients		1	2	5	10	25	50	100
e		0.83417	0.80556	0.79987	0.79563	0.78076	0.76899	0.75652
b		50.825	53.943	69.378	79.520	87.731	93.486	98.870
d		10	10	12	13	13	13	13
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.31	6.09	7.19	7.98	9.19	10.13	11.10
	6	5.03	5.78	6.87	7.64	8.81	9.71	10.66
	7	4.78	5.50	6.58	7.33	8.46	9.34	10.25
	8	4.56	5.26	6.32	7.05	8.14	8.99	9.88
	9	4.36	5.03	6.08	6.80	7.85	8.68	9.54
	10	4.18	4.83	5.85	6.56	7.59	8.39	9.22
	11	4.01	4.64	5.65	6.34	7.34	8.12	8.93
	12	3.86	4.47	5.46	6.14	7.11	7.87	8.66
	13	3.72	4.31	5.29	5.95	6.89	7.63	8.41
0.250	14	3.59	4.17	5.12	5.78	6.69	7.41	8.17
	15	3.47	4.03	4.97	5.61	6.51	7.21	7.95
	16	3.36	3.91	4.83	5.46	6.33	7.02	7.74
	17	3.25	3.79	4.69	5.31	6.16	6.84	7.54
	18	3.15	3.68	4.57	5.17	6.01	6.67	7.36
	19	3.06	3.58	4.45	5.05	5.86	6.51	7.18
	20	2.98	3.48	4.34	4.92	5.72	6.35	7.02
	21	2.90	3.39	4.23	4.81	5.59	6.21	6.86
	22	2.82	3.31	4.13	4.70	5.47	6.07	6.71
	23	2.75	3.23	4.04	4.59	5.35	5.94	6.57
	24	2.68	3.15	3.95	4.50	5.23	5.82	6.44
	25	2.62	3.08	3.86	4.40	5.13	5.70	6.31
	26	2.56	3.01	3.78	4.31	5.02	5.59	6.19
	27	2.50	2.94	3.70	4.23	4.92	5.48	6.07
	28	2.44	2.88	3.63	4.14	4.83	5.38	5.96
0.500	29	2.39	2.82	3.56	4.06	4.74	5.28	5.85
	30	2.34	2.76	3.49	3.99	4.65	5.18	5.75
	31	2.29	2.71	3.43	3.92	4.57	5.09	5.65
	32	2.25	2.66	3.36	3.85	4.49	5.01	5.55
	33	2.21	2.61	3.30	3.78	4.42	4.92	5.46
	34	2.16	2.56	3.25	3.72	4.34	4.84	5.37
	35	2.12	2.51	3.19	3.65	4.27	4.76	5.29
	36	2.08	2.47	3.14	3.60	4.20	4.69	5.20
	37	2.05	2.43	3.09	3.54	4.14	4.62	5.13
	38	2.01	2.39	3.04	3.48	4.07	4.55	5.05
	39	1.98	2.35	2.99	3.43	4.01	4.48	4.98
	40	1.94	2.31	2.94	3.38	3.95	4.41	4.90
	41	1.91	2.27	2.90	3.33	3.90	4.35	4.84
	42	1.88	2.24	2.85	3.28	3.84	4.29	4.77
	43	1.85	2.20	2.81	3.23	3.79	4.23	4.70
0.750	44	1.82	2.17	2.77	3.19	3.73	4.17	4.64
	45	1.80	2.14	2.73	3.14	3.68	4.12	4.58
	46	1.77	2.11	2.70	3.10	3.64	4.06	4.52
	47	1.74	2.08	2.66	3.06	3.59	4.01	4.47
	48	1.72	2.05	2.62	3.02	3.54	3.96	4.41
	49	1.69	2.02	2.59	2.98	3.50	3.91	4.36
	50	1.67	1.99	2.56	2.94	3.45	3.86	4.30
	51	1.65	1.97	2.52	2.91	3.41	3.82	4.25
	52	1.63	1.94	2.49	2.87	3.37	3.77	4.20
	53	1.60	1.92	2.46	2.84	3.33	3.73	4.15
	54	1.58	1.89	2.43	2.80	3.29	3.69	4.11
	55	1.56	1.87	2.40	2.77	3.25	3.64	4.06
	56	1.54	1.85	2.37	2.74	3.22	3.60	4.02
	57	1.52	1.82	2.35	2.71	3.18	3.56	3.97
	58	1.50	1.80	2.32	2.68	3.15	3.52	3.93
	59	1.49	1.78	2.29	2.65	3.11	3.49	3.89
1	60	1.47	1.76	2.27	2.62	3.08	3.45	3.85
2	120	0.88	1.07	1.40	1.62	1.93	2.18	2.45
3	180	0.64	0.79	1.03	1.21	1.44	1.63	1.84
6	360	0.37	0.46	0.61	0.72	0.86	0.98	1.12
12	720	0.21	0.27	0.35	0.42	0.51	0.59	0.67
24	1440	0.12	0.15	0.21	0.24	0.30	0.35	0.40

Table A-15 Somervell County								
Coefficients		Return Period (Years)						
		1	2	5	10	25	50	100
e		0.81907	0.81396	0.80585	0.80055	0.79375	0.78198	0.77885
b		42.170	50.658	65.716	75.784	89.151	95.704	108.069
d		8	9	11	12	13	13	14
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.16	5.91	7.04	7.84	8.99	9.98	10.91
	6	4.86	5.59	6.70	7.49	8.61	9.57	10.48
	7	4.59	5.30	6.40	7.18	8.27	9.19	10.09
	8	4.35	5.05	6.13	6.89	7.95	8.85	9.73
	9	4.14	4.82	5.88	6.62	7.67	8.53	9.40
	10	3.95	4.61	5.65	6.38	7.40	8.24	9.09
	11	3.78	4.42	5.44	6.16	7.15	7.97	8.81
	12	3.63	4.25	5.25	5.95	6.93	7.72	8.54
	13	3.48	4.09	5.07	5.76	6.71	7.49	8.30
0.250	14	3.35	3.95	4.91	5.58	6.52	7.27	8.06
	15	3.23	3.81	4.76	5.42	6.33	7.07	7.85
	16	3.12	3.69	4.62	5.26	6.16	6.88	7.64
	17	3.02	3.57	4.48	5.12	5.99	6.70	7.45
	18	2.92	3.46	4.36	4.98	5.84	6.53	7.27
	19	2.84	3.36	4.24	4.85	5.69	6.37	7.10
	20	2.75	3.27	4.13	4.73	5.56	6.22	6.93
	21	2.67	3.18	4.02	4.61	5.43	6.07	6.78
	22	2.60	3.10	3.93	4.50	5.30	5.94	6.63
	23	2.53	3.02	3.83	4.40	5.19	5.81	6.49
	24	2.47	2.94	3.74	4.30	5.07	5.68	6.36
	25	2.41	2.87	3.66	4.21	4.97	5.57	6.23
	26	2.35	2.80	3.58	4.12	4.87	5.45	6.11
	27	2.29	2.74	3.50	4.04	4.77	5.35	5.99
	28	2.24	2.68	3.43	3.95	4.68	5.25	5.88
0.500	29	2.19	2.62	3.36	3.88	4.59	5.15	5.77
	30	2.14	2.57	3.30	3.80	4.50	5.05	5.67
	31	2.10	2.52	3.23	3.73	4.42	4.96	5.57
	32	2.05	2.47	3.17	3.66	4.34	4.88	5.48
	33	2.01	2.42	3.11	3.60	4.27	4.79	5.39
	34	1.97	2.37	3.06	3.54	4.20	4.71	5.30
	35	1.94	2.33	3.00	3.48	4.13	4.64	5.22
	36	1.90	2.29	2.95	3.42	4.06	4.56	5.13
	37	1.87	2.25	2.90	3.36	4.00	4.49	5.06
	38	1.83	2.21	2.86	3.31	3.93	4.42	4.98
	39	1.80	2.17	2.81	3.26	3.87	4.36	4.91
	40	1.77	2.13	2.76	3.20	3.81	4.29	4.84
	41	1.74	2.10	2.72	3.16	3.76	4.23	4.77
	42	1.71	2.06	2.68	3.11	3.70	4.17	4.70
	43	1.68	2.03	2.64	3.06	3.65	4.11	4.64
0.750	44	1.66	2.00	2.60	3.02	3.60	4.05	4.57
	45	1.63	1.97	2.56	2.98	3.55	4.00	4.51
	46	1.61	1.94	2.53	2.94	3.50	3.95	4.45
	47	1.58	1.91	2.49	2.90	3.46	3.89	4.40
	48	1.56	1.89	2.46	2.86	3.41	3.84	4.34
	49	1.54	1.86	2.43	2.82	3.37	3.80	4.29
	50	1.52	1.83	2.39	2.78	3.33	3.75	4.24
	51	1.49	1.81	2.36	2.75	3.28	3.70	4.19
	52	1.47	1.78	2.33	2.71	3.24	3.66	4.14
	53	1.45	1.76	2.30	2.68	3.21	3.61	4.09
	54	1.44	1.74	2.27	2.65	3.17	3.57	4.04
	55	1.42	1.72	2.25	2.62	3.13	3.53	4.00
	56	1.40	1.69	2.22	2.59	3.09	3.49	3.95
	57	1.38	1.67	2.19	2.56	3.06	3.45	3.91
	58	1.36	1.65	2.17	2.53	3.02	3.41	3.86
	59	1.35	1.63	2.14	2.50	2.99	3.38	3.82
1	60	1.33	1.61	2.12	2.47	2.96	3.34	3.78
2	120	0.79	0.97	1.29	1.52	1.84	2.09	2.38
3	180	0.58	0.71	0.95	1.13	1.37	1.56	1.79
6	360	0.33	0.41	0.56	0.66	0.81	0.93	1.07
12	720	0.19	0.24	0.32	0.39	0.47	0.55	0.63
24	1440	0.11	0.14	0.19	0.22	0.28	0.32	0.37

		Table A-16 Tarrant County						
		Return Period (Years)						
Coefficients		1	2	5	10	25	50	100
e		0.82169	0.81144	0.81423	0.79952	0.79381	0.78265	0.77982
b		43.653	51.393	71.154	77.103	90.982	97.721	110.202
d		8	9	12	12	13	13	14
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.31	6.04	7.08	8.00	9.17	10.18	11.09
	6	4.99	5.71	6.76	7.65	8.79	9.75	10.66
	7	4.72	5.42	6.47	7.32	8.44	9.37	10.26
	8	4.47	5.16	6.21	7.03	8.12	9.02	9.89
	9	4.26	4.92	5.97	6.76	7.82	8.70	9.56
	10	4.06	4.71	5.74	6.51	7.55	8.40	9.24
	11	3.88	4.52	5.54	6.29	7.30	8.12	8.95
	12	3.72	4.35	5.35	6.08	7.07	7.87	8.68
	13	3.58	4.18	5.18	5.88	6.85	7.63	8.43
0.250	14	3.44	4.04	5.01	5.70	6.65	7.41	8.20
	15	3.32	3.90	4.86	5.53	6.46	7.20	7.98
	16	3.21	3.77	4.72	5.37	6.28	7.01	7.77
	17	3.10	3.65	4.59	5.22	6.12	6.82	7.57
	18	3.00	3.54	4.46	5.08	5.96	6.65	7.39
	19	2.91	3.44	4.34	4.95	5.81	6.49	7.21
	20	2.82	3.34	4.23	4.83	5.67	6.33	7.05
	21	2.74	3.25	4.13	4.71	5.54	6.19	6.89
	22	2.67	3.17	4.03	4.60	5.41	6.05	6.74
	23	2.60	3.09	3.94	4.49	5.29	5.91	6.60
	24	2.53	3.01	3.85	4.39	5.18	5.79	6.46
	25	2.47	2.94	3.76	4.30	5.07	5.67	6.33
	26	2.41	2.87	3.68	4.21	4.97	5.56	6.21
	27	2.35	2.81	3.60	4.12	4.87	5.45	6.09
	28	2.30	2.74	3.53	4.04	4.77	5.34	5.98
0.500	29	2.25	2.69	3.46	3.96	4.68	5.24	5.87
	30	2.20	2.63	3.39	3.88	4.60	5.15	5.76
	31	2.15	2.58	3.33	3.81	4.51	5.06	5.66
	32	2.11	2.52	3.27	3.74	4.43	4.97	5.57
	33	2.06	2.48	3.21	3.68	4.36	4.88	5.47
	34	2.02	2.43	3.15	3.61	4.28	4.80	5.38
	35	1.99	2.38	3.10	3.55	4.21	4.72	5.30
	36	1.95	2.34	3.04	3.49	4.14	4.65	5.22
	37	1.91	2.30	2.99	3.43	4.08	4.57	5.14
	38	1.88	2.26	2.94	3.38	4.01	4.50	5.06
	39	1.85	2.22	2.90	3.33	3.95	4.44	4.98
	40	1.81	2.18	2.85	3.27	3.89	4.37	4.91
	41	1.78	2.15	2.81	3.22	3.84	4.31	4.84
	42	1.75	2.11	2.76	3.18	3.78	4.25	4.77
	43	1.73	2.08	2.72	3.13	3.73	4.19	4.71
0.750	44	1.70	2.05	2.68	3.09	3.67	4.13	4.65
	45	1.67	2.02	2.65	3.04	3.62	4.07	4.58
	46	1.65	1.99	2.61	3.00	3.57	4.02	4.52
	47	1.62	1.96	2.57	2.96	3.53	3.97	4.47
	48	1.60	1.93	2.54	2.92	3.48	3.91	4.41
	49	1.57	1.91	2.50	2.88	3.44	3.87	4.36
	50	1.55	1.88	2.47	2.84	3.39	3.82	4.30
	51	1.53	1.85	2.44	2.81	3.35	3.77	4.25
	52	1.51	1.83	2.41	2.77	3.31	3.72	4.20
	53	1.49	1.81	2.38	2.74	3.27	3.68	4.15
	54	1.47	1.78	2.35	2.71	3.23	3.64	4.10
	55	1.45	1.76	2.32	2.67	3.19	3.60	4.06
	56	1.43	1.74	2.29	2.64	3.16	3.55	4.01
	57	1.41	1.72	2.26	2.61	3.12	3.51	3.97
	58	1.40	1.69	2.24	2.58	3.09	3.48	3.92
	59	1.38	1.67	2.21	2.55	3.05	3.44	3.88
1	60	1.36	1.65	2.19	2.52	3.02	3.40	3.84
2	120	0.81	1.00	1.34	1.55	1.88	2.13	2.42
3	180	0.59	0.73	0.98	1.15	1.40	1.59	1.81
6	360	0.34	0.42	0.57	0.68	0.83	0.95	1.09
12	720	0.19	0.24	0.33	0.40	0.48	0.56	0.64
24	1440	0.11	0.14	0.19	0.23	0.28	0.33	0.38

Table A-17 Wise County								
Coefficients		Return Period (Years)						
		1	2	5	10	25	50	100
e		0.80578	0.79881	0.79496	0.79143	0.78680	0.78570	0.78307
b		38.593	46.352	61.396	71.487	85.260	97.989	111.129
d		7	8	10	11	12	13	14
Hours	Minutes	Rainfall Intensity (inches per hour)						
0.083	5	5.21	5.97	7.13	7.97	9.18	10.11	11.08
	6	4.89	5.63	6.78	7.59	8.77	9.69	10.64
	7	4.60	5.33	6.46	7.26	8.41	9.31	10.24
	8	4.35	5.06	6.17	6.95	8.07	8.96	9.88
	9	4.13	4.82	5.91	6.68	7.77	8.64	9.54
	10	3.94	4.61	5.67	6.42	7.49	8.34	9.23
	11	3.76	4.41	5.46	6.19	7.23	8.07	8.94
	12	3.60	4.23	5.26	5.98	7.00	7.81	8.67
	13	3.45	4.07	5.08	5.78	6.77	7.58	8.41
0.250	14	3.32	3.92	4.91	5.60	6.57	7.35	8.18
	15	3.20	3.79	4.75	5.42	6.38	7.15	7.96
	16	3.09	3.66	4.61	5.27	6.20	6.95	7.75
	17	2.98	3.54	4.47	5.12	6.03	6.77	7.55
	18	2.88	3.43	4.34	4.98	5.87	6.60	7.37
	19	2.79	3.33	4.22	4.84	5.72	6.44	7.19
	20	2.71	3.24	4.11	4.72	5.58	6.28	7.02
	21	2.63	3.15	4.00	4.60	5.44	6.14	6.87
	22	2.56	3.06	3.90	4.49	5.32	6.00	6.72
	23	2.49	2.98	3.81	4.39	5.20	5.87	6.57
	24	2.43	2.91	3.72	4.29	5.08	5.74	6.44
	25	2.36	2.84	3.64	4.19	4.98	5.62	6.31
	26	2.31	2.77	3.56	4.10	4.87	5.51	6.18
	27	2.25	2.71	3.48	4.02	4.77	5.40	6.07
	28	2.20	2.65	3.41	3.94	4.68	5.30	5.95
0.500	29	2.15	2.59	3.34	3.86	4.59	5.20	5.84
	30	2.10	2.54	3.27	3.78	4.50	5.10	5.74
	31	2.06	2.48	3.21	3.71	4.42	5.01	5.64
	32	2.02	2.43	3.15	3.64	4.34	4.92	5.54
	33	1.98	2.39	3.09	3.58	4.27	4.84	5.45
	34	1.94	2.34	3.03	3.51	4.19	4.76	5.36
	35	1.90	2.30	2.98	3.45	4.12	4.68	5.28
	36	1.86	2.26	2.93	3.40	4.05	4.60	5.19
	37	1.83	2.22	2.88	3.34	3.99	4.53	5.11
	38	1.80	2.18	2.83	3.29	3.93	4.46	5.04
	39	1.76	2.14	2.78	3.23	3.87	4.39	4.96
	40	1.73	2.10	2.74	3.18	3.81	4.33	4.89
	41	1.71	2.07	2.70	3.13	3.75	4.27	4.82
	42	1.68	2.04	2.65	3.09	3.70	4.21	4.75
	43	1.65	2.00	2.61	3.04	3.64	4.15	4.69
0.750	44	1.62	1.97	2.58	3.00	3.59	4.09	4.62
	45	1.60	1.94	2.54	2.96	3.54	4.03	4.56
	46	1.57	1.92	2.50	2.91	3.49	3.98	4.50
	47	1.55	1.89	2.47	2.87	3.45	3.93	4.44
	48	1.53	1.86	2.43	2.84	3.40	3.88	4.39
	49	1.51	1.83	2.40	2.80	3.36	3.83	4.33
	50	1.48	1.81	2.37	2.76	3.32	3.78	4.28
	51	1.46	1.78	2.34	2.73	3.27	3.73	4.23
	52	1.44	1.76	2.31	2.69	3.23	3.69	4.18
	53	1.42	1.74	2.28	2.66	3.19	3.64	4.13
	54	1.41	1.72	2.25	2.63	3.16	3.60	4.08
	55	1.39	1.69	2.22	2.60	3.12	3.56	4.04
	56	1.37	1.67	2.20	2.56	3.08	3.52	3.99
	57	1.35	1.65	2.17	2.53	3.05	3.48	3.95
	58	1.34	1.63	2.14	2.51	3.01	3.44	3.90
1	59	1.32	1.61	2.12	2.48	2.98	3.40	3.86
	60	1.30	1.59	2.10	2.45	2.95	3.37	3.82
2	120	0.78	0.96	1.28	1.51	1.83	2.10	2.40
3	180	0.57	0.71	0.95	1.12	1.36	1.57	1.80
6	360	0.33	0.41	0.56	0.66	0.81	0.93	1.07
12	720	0.19	0.24	0.33	0.39	0.48	0.55	0.63
24	1440	0.11	0.14	0.19	0.22	0.28	0.32	0.37

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Table A-18 500-year storm																		
e b d		County									County							
		Collin	Dallas	Denton	Ellis	Erath	Grayson	Hood	Hunt	Johnson	Kaufman	Navarro	Palo Pinto	Parker	Rockwall	Somervell	Tarrant	Wise
		0.6609	0.6756	0.6819	0.7082	0.7270	0.6637	0.7232	0.6538	0.7118	0.6787	0.7062	0.7520	0.7263	0.6582	0.7198	0.6985	0.7027
		70.27	78.09	79.11	99.98	102.47	72.35	100.46	68.71	96.57	82.29	102.16	122.05	101.78	70.46	100.04	87.16	89.48
		0	1	1	6	6	1	5	1	5	2	5	8	4	0	6	2	2
Hours	Minutes	Rainfall Intensity (inches per hour)									Rainfall Intensity (inches per hour)							
0.250	15	11.74	12.00	11.94	11.58	11.20	11.49	11.51	11.21	11.45	12.03	12.32	11.55	11.99	11.85	11.18	12.05	12.22
	16	11.25	11.52	11.46	11.20	10.83	11.04	11.11	10.78	11.06	11.57	11.90	11.19	11.55	11.36	10.81	11.58	11.74
	17	10.80	11.08	11.02	10.85	10.49	10.63	10.74	10.38	10.70	11.16	11.51	10.85	11.15	10.92	10.47	11.15	11.30
	18	10.40	10.68	10.62	10.53	10.17	10.25	10.40	10.02	10.36	10.77	11.16	10.53	10.78	10.51	10.16	10.75	10.90
	19	10.04	10.32	10.26	10.23	9.87	9.91	10.09	9.69	10.06	10.42	10.83	10.24	10.44	10.15	9.86	10.39	10.53
	20	9.70	9.99	9.92	9.95	9.59	9.59	9.80	9.39	9.77	10.10	10.52	9.96	10.12	9.81	9.59	10.06	10.20
	21	9.40	9.68	9.61	9.69	9.33	9.30	9.52	9.11	9.50	9.80	10.23	9.70	9.82	9.50	9.33	9.75	9.88
	22	9.11	9.39	9.32	9.44	9.09	9.03	9.27	8.85	9.25	9.52	9.96	9.46	9.55	9.21	9.09	9.47	9.59
	23	8.85	9.12	9.06	9.21	8.86	8.78	9.02	8.60	9.01	9.26	9.71	9.23	9.29	8.95	8.86	9.20	9.32
	24	8.60	8.88	8.81	8.99	8.64	8.54	8.80	8.38	8.79	9.02	9.47	9.01	9.05	8.70	8.65	8.95	9.07
	25	8.37	8.64	8.58	8.78	8.44	8.32	8.59	8.16	8.58	8.79	9.25	8.80	8.82	8.47	8.45	8.72	8.83
	26	8.16	8.43	8.36	8.59	8.25	8.12	8.38	7.96	8.38	8.57	9.04	8.61	8.60	8.25	8.26	8.50	8.61
	27	7.96	8.22	8.15	8.40	8.07	7.92	8.19	7.78	8.19	8.37	8.84	8.42	8.40	8.05	8.08	8.30	8.40
	28	7.77	8.03	7.96	8.23	7.89	7.74	8.01	7.60	8.02	8.18	8.65	8.25	8.21	7.86	7.90	8.10	8.20
0.500	29	7.59	7.85	7.78	8.06	7.73	7.57	7.84	7.43	7.85	8.00	8.47	8.08	8.03	7.68	7.74	7.92	8.01
	30	7.42	7.68	7.61	7.90	7.57	7.41	7.68	7.28	7.69	7.83	8.30	7.92	7.86	7.51	7.59	7.74	7.84
	31	7.26	7.51	7.44	7.75	7.42	7.25	7.52	7.13	7.53	7.67	8.13	7.76	7.69	7.35	7.44	7.58	7.67
	32	7.11	7.36	7.29	7.61	7.28	7.11	7.38	6.99	7.39	7.52	7.98	7.62	7.54	7.20	7.30	7.42	7.51
	33	6.97	7.21	7.14	7.47	7.14	6.97	7.24	6.85	7.25	7.37	7.83	7.48	7.39	7.06	7.16	7.28	7.36
	34	6.83	7.07	7.00	7.33	7.01	6.83	7.10	6.72	7.12	7.23	7.68	7.34	7.25	6.92	7.03	7.13	7.21
	35	6.70	6.94	6.87	7.21	6.89	6.71	6.97	6.60	6.99	7.10	7.55	7.22	7.11	6.79	6.91	7.00	7.08
	36	6.58	6.81	6.74	7.08	6.77	6.59	6.85	6.48	6.87	6.97	7.42	7.09	6.98	6.66	6.79	6.87	6.94
	37	6.46	6.69	6.62	6.97	6.65	6.47	6.73	6.37	6.75	6.85	7.29	6.97	6.86	6.54	6.68	6.75	6.82
	38	6.35	6.57	6.50	6.86	6.54	6.36	6.62	6.26	6.64	6.73	7.17	6.86	6.74	6.43	6.57	6.63	6.70
	39	6.24	6.46	6.39	6.75	6.44	6.25	6.51	6.16	6.53	6.62	7.06	6.75	6.62	6.32	6.46	6.51	6.58
	40	6.14	6.35	6.29	6.64	6.34	6.15	6.40	6.06	6.43	6.51	6.95	6.64	6.52	6.22	6.36	6.41	6.47
	41	6.04	6.25	6.18	6.54	6.24	6.05	6.30	5.97	6.33	6.41	6.84	6.54	6.41	6.12	6.26	6.30	6.37
	42	5.94	6.15	6.09	6.45	6.14	5.96	6.21	5.88	6.23	6.31	6.74	6.44	6.31	6.02	6.17	6.20	6.26
	43	5.85	6.06	5.99	6.35	6.05	5.87	6.11	5.79	6.14	6.21	6.64	6.35	6.21	5.93	6.08	6.10	6.17
0.750	44	5.76	5.97	5.90	6.26	5.96	5.78	6.02	5.70	6.05	6.12	6.54	6.25	6.12	5.84	5.99	6.01	6.07
	45	5.68	5.88	5.81	6.17	5.88	5.70	5.93	5.62	5.96	6.03	6.45	6.17	6.03	5.75	5.90	5.92	5.98
	46	5.60	5.79	5.73	6.09	5.79	5.62	5.85	5.54	5.88	5.95	6.36	6.08	5.94	5.67	5.82	5.83	5.89
	47	5.52	5.71	5.65	6.01	5.72	5.54	5.77	5.47	5.80	5.86	6.27	6.00	5.85	5.59	5.74	5.75	5.81
	48	5.44	5.63	5.57	5.93	5.64	5.47	5.69	5.39	5.72	5.78	6.19	5.92	5.77	5.51	5.67	5.67	5.73
	49	5.37	5.56	5.49	5.85	5.56	5.39	5.61	5.32	5.65	5.71	6.11	5.84	5.69	5.44	5.59	5.59	5.65
	50	5.30	5.48	5.42	5.78	5.49	5.32	5.54	5.26	5.57	5.63	6.03	5.76	5.61	5.37	5.52	5.52	5.57
	51	5.23	5.41	5.35	5.71	5.42	5.25	5.47	5.19	5.50	5.56	5.95	5.69	5.54	5.30	5.45	5.44	5.50
	52	5.16	5.34	5.28	5.64	5.35	5.19	5.40	5.12	5.43	5.49	5.88	5.62	5.47	5.23	5.38	5.37	5.42
	53	5.10	5.28	5.21	5.57	5.29	5.12	5.33	5.06	5.37	5.42	5.81	5.55	5.40	5.17	5.32	5.31	5.36
	54	5.03	5.21	5.15	5.50	5.22	5.06	5.26	5.00	5.30	5.36	5.74	5.48	5.33	5.10	5.25	5.24	5.29
	55	4.97	5.15	5.08	5.44	5.16	5.00	5.20	4.94	5.24	5.29	5.67	5.41	5.26	5.04	5.19	5.17	5.22
	56	4.91	5.09	5.02	5.38	5.10	4.94	5.14	4.89	5.18	5.23	5.60	5.35	5.20	4.98	5.13	5.11	5.16
	57	4.86	5.03	4.96	5.32	5.04	4.89	5.08	4.83	5.12	5.17	5.54	5.29	5.14	4.92	5.07	5.05	5.10
	58	4.80	4.97	4.90	5.26	4.98	4.83	5.02	4.78	5.06	5.11	5.48	5.23	5.08	4.87	5.01	4.99	5.04
	59	4.75	4.91	4.85	5.20	4.93	4.78	4.96	4.73	5.00	5.05	5.42	5.17	5.02	4.81	4.96	4.94	4.98
1	60	4.69	4.86	4.79	5.14	4.87	4.73	4.91	4.67	4.95	5.00	5.36	5.11	4.96	4.76	4.90	4.88	4.92
2	120	2.97	3.06	3.01	3.25	3.05	3.00	3.06	2.99	3.11	3.16	3.38	3.18	3.07	3.02	3.08	3.04	3.06
3	180	2.27	2.33	2.28	2.47	2.29	2.30	2.30	2.30	2.35	2.41	2.56	2.38	2.30	2.31	2.33	2.30	2.31
6	360	1.44	1.46	1.43	1.53	1.40	1.45	1.41	1.46	1.45	1.51	1.58	1.44	1.40	1.46	1.43	1.42	1.42
12	720	0.91	0.92	0.89	0.94	0.85	0.92	0.86	0.93	0.89	0.94	0.98	0.86	0.85	0.93	0.87	0.88	0.88
24	1440	0.57	0.57	0.55	0.58	0.52	0.58	0.52	0.59	0.54	0.59	0.60	0.51	0.52	0.59	0.53	0.54	0.54

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HYDROLOGIC SOILS DATA

Electronic Soil Maps

Electronic soils data in the Soil Survey Geographic (SSURGO) Database can be obtained free of charge from the National Resource Conservation Service (NRCS) at <http://soildatamart.nrcs.usda.gov>. The data is downloadable by county and includes extensive soil information, including hydrologic soil groups. The data is intended to be imported into a geographic information system (GIS) to allow for site-specific soil analysis of soil characteristics for storm design. All soil survey results can also be accessed online at <http://websoilsurvey.nrcs.usda.gov/app/>. Maps can be created and printed from this site without the use of a GIS.

B.1 Online Web Soil Survey

Following is a procedure for using the NRCS online Web Soil Survey.

1. Go to <http://websoilsurvey.nrcs.usda.gov/app/>
2. Click **Start WSS**
3. Define your Area of Interest by drawing a box around your site location.
4. Click the **Soil Map** tab
5. Click **Save or Print** in the upper right hand corner. A pdf will open in a new window that you can either print or save. It will show the area of interest along with a legend and the appropriate map units.

B.2 Downloading Soil Surveys

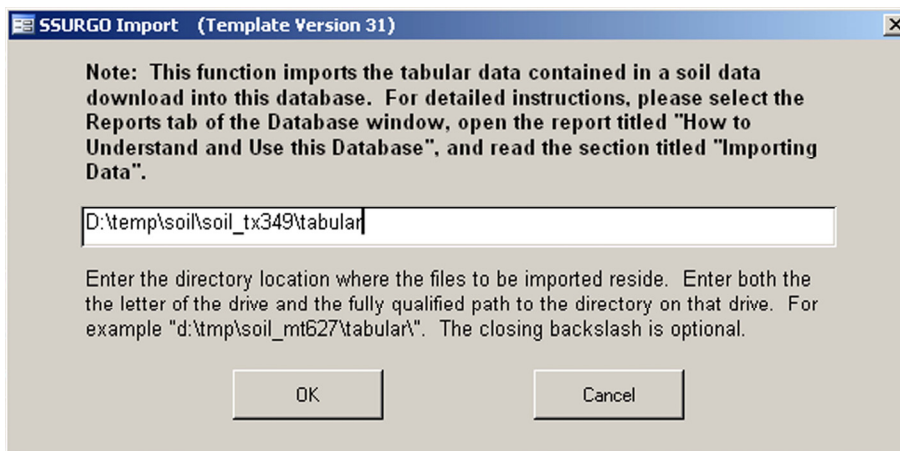
Following is a procedure for downloading data from the NRCS web site and importing it into ArcGIS.

Downloading SSURGO Soil Data into ArcInfo 9.x

1. Go to <http://soildatamart.nrcs.usda.gov>
2. Click **Select State**
3. Select State (**Texas**)
4. Select **County** of interest
5. Click **Select Survey Area**
6. Click **Download Data**
7. Enter your e-mail address in the provided form space
8. Click **Submit Request**
9. You will receive an immediate message acknowledging your request and a follow-up e-mail once your request has been processed.
10. The file(s) will be provided in compressed ZIP format, requiring the use of WinZip to extract.
11. Extract the files to a destination directory of your choice. The extracted files contain a spatial sub-folder, a tabular sub-folder, and a zip file containing the SSURGO MS Access template file.

Importing raw tabular soil data into Microsoft Access

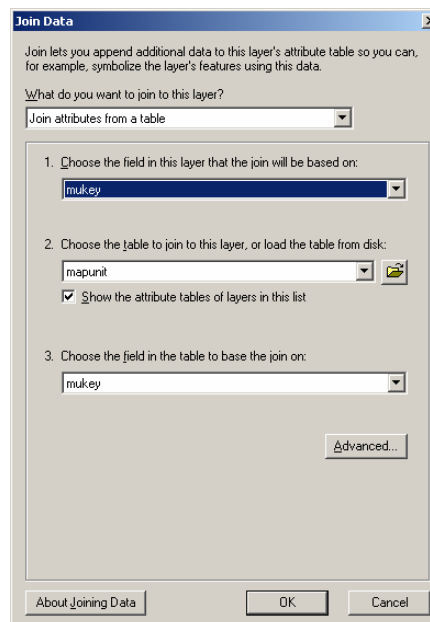
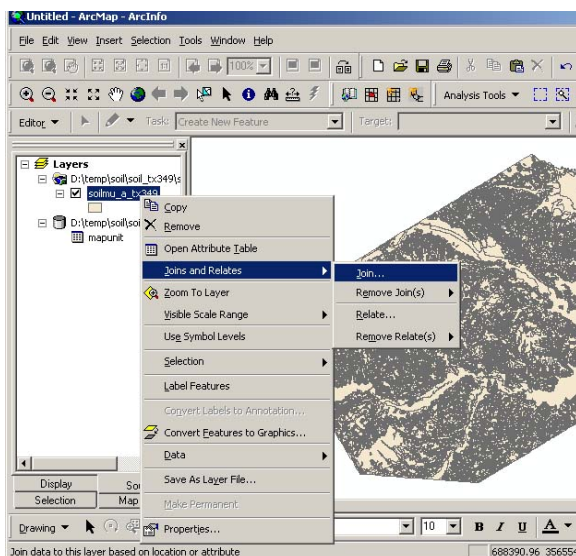
1. Extract the `soildb_US_2002.zip` file into the same destination folder by using the “extract to here” command in WinZip. This will extract the template database.
2. Open the template database and input the path name to the tabular data. This will build the SSURGO database and allow the creation of reports and queries.



3. Once the data is imported into the database, a report can be run. With the soil reports dialog box up, press the **Select All** option and generate the report. Note: Regardless of what report you wish to run, all reports are simultaneously created. The selected report is displayed on the screen.
4. All the reports are now complete, and the tables can now be added directly into ArcGIS.

Joining tables to shapefiles in ArcGIS

1. Open **ArcGIS** and add the **Soils** shapefile.
2. Add the **"mapunit"** report to ArcGIS by navigating directly to the MS Access database and opening it (via the add data dialog box). Note: mapunit is only a commonly used example, containing full soil names and prime farmland information.
3. Now that the table is added to the Table of Contents, it is ready to be joined to the existing soils shapefile.
4. Right click on the **soils** shapefile and select **join**.



5. Under the **Join Data** dialog box, select the **mukey** field in Dropdown Box 1 and select **mapunit** in Dropdown Box 2.
6. Now that your shapefile is joined with the appropriate information, the next step is to export the shapefile into a new shapefile with the joins saved permanently. Right click on the **soils** shapefile and choose **Data > Export** and **Save** your file.

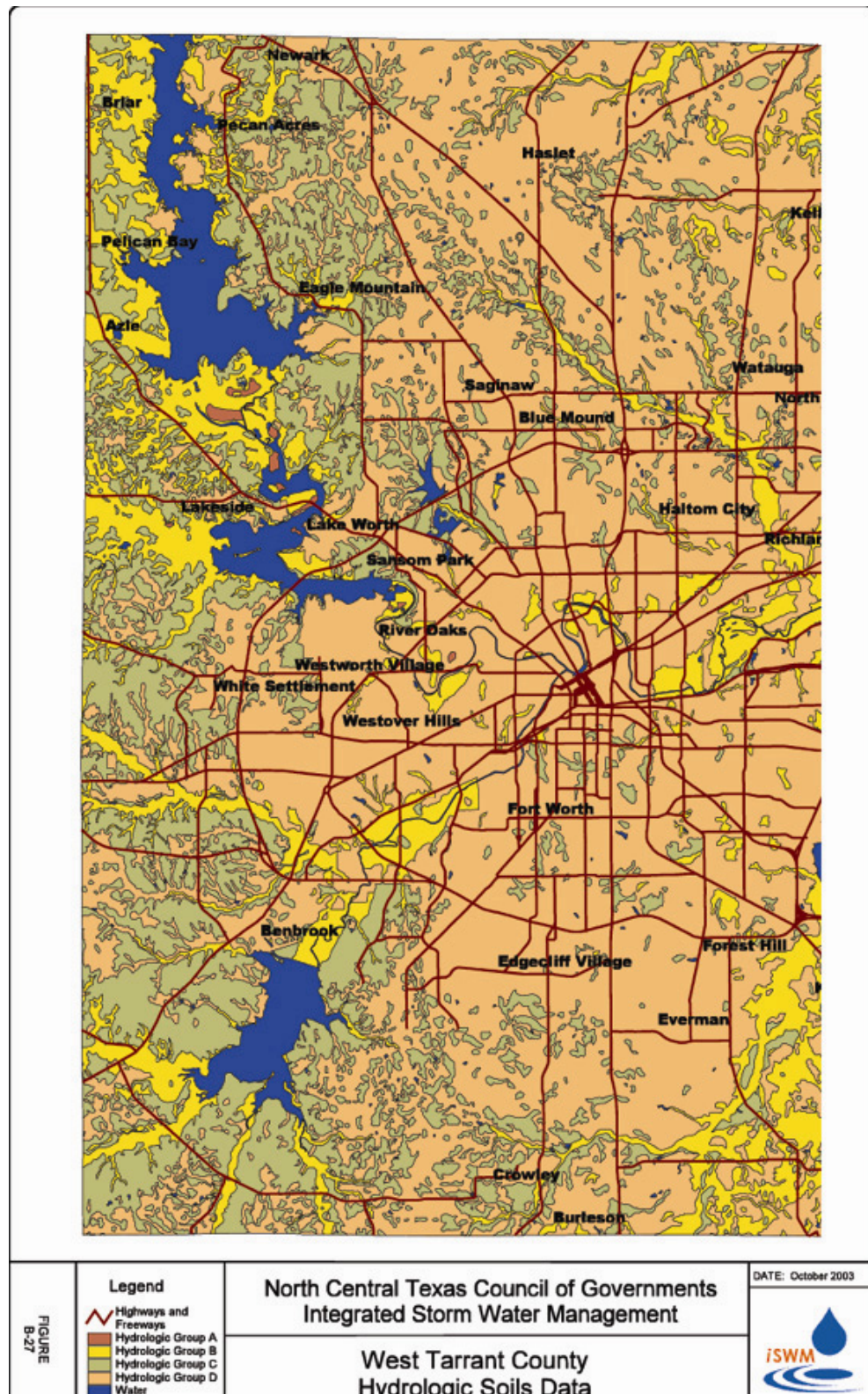


Figure B-1. Example SSURGO Soil Map – West Tarrant County

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FEDERAL, STATE & REGIONAL INITIATIVES

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C.1 Overview

As a result of the need to address the potential negative impacts of development and storm water runoff, numerous federal, state, and regional programs and regulations have been created to deal with the problems of urban runoff and nonpoint source pollution. A storm water management program is best implemented at a local level, where the local community directly influences land use and development related decisions. Federal and state legislation greatly influences and supports local governments in their efforts to manage storm water runoff in their communities.

It is the intent of iSWM to complement the federal, state, and regional initiatives in an integrated partnership approach to storm water management.

The purpose of this section is to provide a brief overview of many of the regional, state, and federal laws, regulations, and programs that are required of local government entities in the North Central Texas region that may impact local storm water management programs and activities. The initiatives are summarized in Table C.2-1 as a general guide for developers and communities indicating areas where federal, state, or regional initiatives may affect their project.

As this is not intended to be a detailed analysis of each requirement, it would be advisable to obtain a copy of the specific administrative rules for each program from the appropriate regulatory agency.

C.2 Federal Initiatives

C.2.1 National Flood Insurance Program

Established under the National Flood Insurance Act of 1968 and broadened with the passage of the Flood Disaster Protection Act of 1973, the National Flood Insurance Program (NFIP) provides federally supported flood insurance to residents in communities that voluntarily adopt and enforce regulations to reduce future flood damage. As part of the program, the Federal Emergency Management Agency (FEMA) defines minimum standards for floodplain development that the local communities must adopt to be eligible for program benefits. New construction and substantial improvements must be built at or above the base flood elevation, which is the computed elevation of the “100 year flood”. Also, new development that would result in an increase in flood heights is prohibited in the defined floodways. More information on the NFIP and floodplain management in general is available from the FEMA – Region VI office in Denton, TX.

Contact Agency	Phone	Address
Federal Emergency Management Agency (FEMA) Region VI	940-898-5399	800 N. Loop 288 Denton, TX 76209

Website: <http://www.fema.gov/regions/vi/index.shtm>

C.2.2 U.S. Army Corps of Engineers Regulatory Program

The U.S. Army Corps of Engineers (USACE) Regulatory Program implements Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899, through regulations that serve to protect the Nation’s valuable aquatic resources.

Under Section 404 of the Clean Water Act, permits are required for the discharge of dredged or fill material into waters of the United States (U.S.). Waters of the U.S. include all surface waters, such as coastal and navigable inland waters, lakes, rivers, streams, and their tributaries; interstate waters and their tributaries; wetlands adjacent to the above (e.g. swamps, marshes, bogs, or other land areas); and isolated wetlands and lakes, intermittent streams, and other waters where degradation could affect

interstate commerce. The TCEQ is responsible for conducting water quality certification reviews for 404 permits in Texas. The certification reviews are required by Section 401 of the Clean Water Act. The goal of these certification reviews is to determine whether a proposed discharge will comply with state water quality standards. The Railroad Commission of Texas is the certifying agency in Texas for projects associated with oil and gas.

Under Section 10 of the Rivers and Harbors Act of 1899, the Corps regulates all work and structures in or affecting the course, condition, or capacity of navigable waters of the U.S. Navigable waters of the U.S. are those waters that are subject to the ebb and flow of the tide shoreward to the mean high water mark and/or are presently used, have been used in the past, or may be susceptible to use in the transport of interstate or foreign commerce.

Contact Agency	Phone	Address
Texas Commission on Environmental Quality	512-239-0400	MC 174 P.O. Box 13087, Austin, TX 78711-3087
US Army Corps of Engineers, Fort Worth District (for North Area of State)	817-886-1731	CESWF-PER-R 819 Taylor St P.O. Box 17300 Fort Worth, TX 76102-0300

Website: www.tceq.state.tx.us and <http://www.swf.usace.army.mil>

C.2.3 National Environmental Policy Act, Council on Environmental Quality

Congress established the Council on Environmental Quality within the Executive Office of the President as part of the National Environmental Policy Act of 1969 (NEPA). NEPA establishes the Federal government's environmental policy to help public officials make decisions based on an understanding of the environmental consequences of their actions, and to take actions that protect, restore, and enhance the environment. To accomplish this, NEPA requires Federal agencies to either prepare or have prepared written assessments of statements that describe the:

- Affected environment and environmental consequences of a proposed project;
- Reasonable or practical alternatives to the proposed project; and
- Any mitigation measures necessary to avoid or minimize adverse environmental effects.

If a project is either directly or indirectly funded by a federal source, then the agency providing funds to the project owner is responsible for seeing that the appropriate level of environmental assessment is performed.

C.2.4 Wildlife and Habitat

The mission of the U.S. Fish and Wildlife Service (USFWS) is to conserve, protect, and enhance fish and wildlife, and their habitats for the continuing benefit of the American people. USFWS activities include, but are not limited to enforcing the federal Endangered Species Act (ESA); acquiring wetlands, fishery habitats, and other lands for restoration and preservation; insuring compliance with the National Environmental Policy Act (NEPA); managing National Wildlife Refuges and National Fish Hatcheries; and reviewing and commenting on all water resource projects.

Table C.2-1 Federal, State and Regional Initiative Indicators	
<u>Indicator Questions</u>	<u>Potentially Applicable Initiative(s)</u>
Are Federal funds to be used? Is a Federal Action Permit required?	National Environmental Policy Act, Council on Environmental Quality (Section C.2.3) Federal Agency with Action
Are structures or manmade features to be disturbed?	Texas Historical Commission (Section C.3.11)
Is this a construction project with land disturbing activity?	TPDES Storm Water Permits for Construction Activities (Section C.3.2)
Is there new landscaping and/or erosion potential ?	Local Ordinances
Will storm water discharge to an MS4 ?	TPDES MS4 Storm Water Permit Program (Phase I and II) (Section C.3.1)
Is this an industrial facility?	TPDES Industrial Storm Water Permit Program (Section C.3.3)
Is there a wastewater discharge?	TPDES Wastewater Discharge Permit Program (Section C.3.4)
Is there a nearby public water supply ?	Source Water Assessment Program (Section C.3.8)
Are there nearby groundwater usages?	Texas Groundwater Protection Committee Local Groundwater District (Section C.3.9)
Are there adjacent or nearby surface water features or wetlands that may be affected?	U.S. Army Corps of Engineers Regulatory Program (Section C.2.2)
	Texas Railroad Commission (Section C.2.2)
	Water Quality Management Plan – TCEQ (Section C.3.5)
	Surface Water Quality Standards – TCEQ (Section C.3.6)
	Total Maximum Daily Load Program – TCEQ (Section C.3.7)
Will there be dredging ?	Texas General Land Office (Section C.3.12)
	U.S. Army Corps of Engineers Regulatory Program (Section C.2.2)
	Sand, Gravel, Shell, and Marl Protection – TCEQ (Section C.3.13)
Will a dam be constructed or modified?	Texas Parks and Wildlife Department (Section C.3.14)
Is the project in a floodplain ?	U.S. Army Corps of Engineers Regulatory Program (Section C.2.2)
	Dam Safety Program – TCEQ (Section C.3.10)
Is the project in the Regulatory Zone of the Trinity River Corridor ?	National Flood Insurance Program (Section C.2.1)
	Hazard Mitigation Action Planning (Section C.4.2)
Are there potential impacts on fish, wildlife, or habitats ?	Trinity River Corridor Development Certificate (Section C.4.1) SAFE CLEAN & GREEN (Section C.4.3)
	Texas Parks and Wildlife Department (Section C.3.14) U.S. Fish and Wildlife Service (Section C.2.4)

C.3 State of Texas Initiatives

C.3.1 TPDES MS4 Storm Water Permit Program (Phase I and II)

The National Pollutant Discharge Elimination System (NPDES) permit system was originally established by the Clean Water Act of 1972 to control wastewater discharges from various industries and wastewater treatment plants known as “point” sources. Congress amended the Clean Water Act with the Water Quality Act of 1987 to expand the NPDES permit program to address “nonpoint” source pollution through schedules for permitting municipal storm water discharges. The Municipal Separate Storm Sewer System (MS4) storm water discharge permit establishes requirements for municipalities to minimize pollutants in storm water runoff to the “maximum extent practicable.”

In Texas, the Texas Commission on Environmental Quality (TCEQ) has authority to administer the NPDES program (TPDES – Texas Pollutant Discharge Elimination System). Under the TCEQ’s Municipal Separate Storm Sewer System (MS4) permit program, local governments and public entities in regulated areas are required to establish and implement a comprehensive Storm Water Management Program (SWMP) to control potential pollutants in storm water runoff discharging to Waters in the State to the maximum extent practicable and to eliminate non-storm water discharges entering the storm water system.

Contact Agency	Phone	Address
TCEQ – Storm Water and General Permits Team	512-239-4527	MC 148 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tceq.state.tx.us and www.dfwstormwater.com

This is accomplished by a municipal program which includes the implementation of structural and non-structural storm water measures to protect storm water quality. These measures are called best management practices (BMPs). BMPs include public education and public involvement activities, ordinance or other enforcement mechanisms, inspections and enforcement, employee training, and structural and non-structural controls. Storm water management ordinances, erosion and sediment control ordinances, development regulations, and other local regulations provide enforcement authority and criteria for controlling significant components of the Storm Water Management Program.

Since 1993, the Phase I permit requirements have applied in Texas to large and medium municipal separate storm sewer systems (defined by a population greater than 250,000 and population between 100,000 and 250,000, respectively, based on the 1990 census, or those areas contributing to water quality violations). In Texas, 22 entities are in the Phase I program, including the following seven local governments in North Central Texas:

- City of Dallas
- City of Fort Worth
- City of Plano
- City of Arlington
- City of Garland
- City of Irving
- City of Mesquite

Federal regulations were issued in 1999 to extend the NPDES MS4 permit program to smaller (Phase II) communities. In Texas, the TCEQ administers this permit program. The Phase II rules take a slightly different approach than Phase I rules for the implementation of local storm water management programs. Unlike Phase I communities that were required to develop detailed individual permits, each Phase II community that is the operator of a municipal storm sewer system will be required to develop a storm water management program (SWMP) to protect water quality. The SWMP will be required to either meet the conditions of a general permit or an individual permit authorized by the TCEQ.

Under the TCEQ Phase II MS4 general permit (Proposed General Permit No. TXR040000), regulated entities are required to develop and submit to the TCEQ a plan for their SWMP within 180 days from the date the permit is issued. Additional communities may be added to the Phase II program if the TCEQ determines that storm water in the community is adversely impacting the quality of receiving waters such as streams, lakes, and estuaries. Communities added to the program by the TCEQ will have 180 days from the date of notification to develop and submit a plan for their SWMP.

The U.S. EPA and TCEQ established six elements, termed “minimum control measures,” that each Phase II SWMP must address. The TCEQ has added an optional seventh minimum control measure. The control measures are listed below:

- | | |
|--|---|
| 1. Public Education and Outreach | 5. Post-Construction Runoff Control |
| 2. Public Participation / Involvement | 6. Pollution Prevention / Good Housekeeping |
| 3. Illicit Discharge Detection and Elimination | 7. Municipal Construction Activity |
| 4. Construction Site Runoff Control | |

The seventh optional minimum control measure allows regulated communities to include municipal construction activity in the MS4 general permit instead of having to obtain a permit for each construction site over five acres. The goal of this option is to reduce paperwork for regulated communities with numerous construction projects.

Each Phase II MS4 community is required to develop and submit a plan for their SWMP to the TCEQ. In the plan, the regulated community must identify its selection of BMPs for each required minimum control measure. Additionally, measurable goals to track the implementation progress and success of each BMP must be identified, and a timeline is required for the implementation of the BMPs over the five-year permit term.

For the past decade, NCTCOG on a fee-for-service basis has been providing assistance to the seven Phase I MS4 communities and TxDOT. This program was expanded in the late 1990's to all potential Phase II MS4 communities in the region as well. An overview of this program can be found in Section C.4.4.

The iSWM manual will provide tremendous assistance to the MS4 communities in the development and implementation of their SWMPs. The iSWM guidelines will specifically apply to aspects of several of the minimum control measures, thus providing the MS4 communities with the framework to accomplish these measures.

C.3.2 TPDES Storm Water Permits for Construction Activities

The TPDES storm water permit for construction activities is directed toward controlling the quality of storm water runoff from construction activities. The permit requires the development of a construction Storm Water Pollution Prevention Plan (SWPPP) that emphasizes the application of BMPs to protect storm water quality from erosion and sedimentation processes, as well as construction materials and wastes, during the construction phase of development. Guidance for practices related to storm water quality protection for construction site activities can be found in the iSWM Design Manual for Construction. In Texas, this program which became effective March 5, 2003, is managed by TCEQ.

Operators of construction sites five acres or greater are required to obtain storm water permits from the TCEQ by developing a SWPPP and filing a Notice of Intent (NOI) 48 hours prior to initiating construction activities.

Construction sites one to five acres in size require a SWPPP to be developed, but an NOI is not required to be submitted to the TCEQ. Construction sites that are part of a larger common plan of development, such as a subdivision, that is collectively greater than one or five acres, must be evaluated according to the size of the larger common plan of development when considering permit requirements. For example,

a person constructing on a ¼-acre site located within a 10-acre subdivision under construction would be required to comply with the permit requirements for sites disturbing 5 acres or more.

If storm water runoff from the construction site enters a municipal storm sewer system, the construction site operator and/or owner is also required to notify the MS4 operator about the construction activity. For large construction sites, submitting a copy of the NOI to the MS4 operator is required, and for small construction sites, a copy of the Construction Site Notice is required. Local ordinances should be checked for additional requirements. For example, in some communities the SWPPP must also be submitted to the MS4 operator.

Construction site operators on sites with an NOI are further required to submit a Notice of Termination (NOT) to TCEQ when final stabilization has been achieved on all portions of the site under their control. Refer to TPDES General Permit TXR150000 for specific permit requirements.

C.3.3 Industrial TPDES Storm Water Permit Program

The TPDES program also requires that the discharge of storm water from certain types of industrial facilities be regulated under a permit program. Industrial storm water is defined as that discharged from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing, or materials storage areas. Discharge of storm water from regulated industrial facilities in Texas is managed by the TCEQ under a single general permit issued in 2001.

Currently, the following thirty categories of industrial facilities identified in the Multi-Sector General Permit are required to have a TPDES permit for their storm water discharge:

- Timber Products
- Paper and Allied Products
- Chemical and Allied Products
- Asphalt Paving and Roofing Materials and Lubricants
- Glass, Clay, Cement, Concrete, and Gypsum Products
- Primary Metals
- Metal Mining (Ore Mining and Dressing)
- Coal Mines and Coal Mining Related Facilities
- Oil and Gas Extraction
- Mineral Mining and Dressing
- Hazardous Waste Storage Facilities
- Landfills and Land Application Sites
- Automobile Salvage Yards
- Scrap Recycling Facilities
- Steam Electric Generating Facilities
- Land Transportation and Warehousing
- Water Transportation
- Ship and Boat Building or Repairing Yards
- Air Transportation
- Treatment Works
- Food and Kindred Products
- Textile Mills, Apparel, and Other Fabric Product Manufacturing, Leather and Leather Products
- Furniture and Fixtures
- Printing and Publishing
- Rubber, Miscellaneous Plastic Products, and Miscellaneous Manufacturing Industries
- Leather Tanning and Finishing
- Fabricated Metal Products
- Transportation Equipment, Industrial or Commercial Machinery
- Electronic, Electrical, Photographic, and Optical Goods
- Miscellaneous Industrial Activities

Regulated industrial facilities are required to develop a storm water pollution prevention plan (SWPPP) and submit a Notice of Intent (NOI) for permit coverage to the TCEQ. Components of the SWPPP include

identification and elimination of potential sources of storm water contamination, storm water monitoring at each storm water outfall, employee training, and other storm water protection activities. New industrial facilities are required to submit an NOI 48 hours prior to conducting any new activity.

C.3.4 TPDES Wastewater Discharge Permit Program

Municipalities, communities, and industrial facilities are required to obtain an NPDES permit to discharge wastewater to waters of the U.S. These point source discharges have been regulated by the EPA for more than 30 years. The TCEQ administers the wastewater discharge permit program in Texas. Permit effluent limitations are developed based on the quality of the receiving water. More stringent limitations are placed on discharges to waters listed on the 303(d) list of impaired waters. As part of the permitting process, applicants are required to characterize the quality of the proposed effluent, evaluate the conditions of the receiving water, identify nearby water supply intakes, and conduct other activities to document the continued protection of water quality.

Contact Agency	Phone	Address
TCEQ – Wastewater Permitting Section	512-239-4433	MC 148 P.O. Box 13087 Austin, TX 789711-3087

Website: www.tceq.state.tx.us and www.tnrcc.state.tx.us/water/quality/tmdl/index.html

C.3.5 Water Quality Management Plan

The Water Quality Management Plan (WQMP) for Texas is developed and updated by the TCEQ as part of the requirements of the Clean Water Act. The plan provides long-range planning and technical data for water quality management activities required under the Texas Water Code and the Clean Water Act. Projected effluent limitations for dischargers are based on the recommendations in the WQMP. The Texas State Soil and Water Conservation Board (TSSWCB) is responsible for addressing water quality issues from nonpoint source pollution from agricultural and silvicultural activities. All new and amended permits are reviewed by the TCEQ for conformance with the recommendations of the WQMP. The plan is updated on a quarterly basis by the State.

For North Central Texas, NCTCOG is the designated water quality management planning agency. Under guidance of its Water Resources Council, NCTCOG annually updates the plan and submits amendments to the TCEQ for certification. The annual water quality management plan is part of the SEE Safe Clean and Green initiative outlined in Section C.4.3.

Contact Agency	Phone	Address
TCEQ – Office of Environmental Policy, Analysis, and Assessment	817-239-4900	MC 147 P.O. Box 13087, Austin, TX 789711-3087
TSSWCB – Technical Assistance	254-773-2250	Temple, TX 76501
NCTCOG – Regional Plan	817-695-9210	P.O. Box 5888 Arlington, TX 76005-5888

Website: www.tceq.state.tx.us and www.dfwstormwater.com

C.3.6 Surface Water Quality Standards

The TCEQ sets surface water quality standards in an effort to maintain the quality of water in the state consistent with public health and enjoyment, protection of aquatic life, operation of existing industries, and economic development of the state, as well as to encourage and promote development and use of regional and area-wide wastewater collection, treatment, and disposal systems. Standards are implemented primarily through effluent limits established in permits that allow discharges of wastewater into the surface waters of the state. Currently, the State of Texas has no numerical criteria for nutrients in the Texas Surface Water Quality Standards (TSWQS). The EPA is requiring states to develop nutrient

criteria. The TCEQ is currently developing and evaluating criteria to address nutrients and eutrophication.

Contact Agency	Phone	Address
TCEQ – Water Quality Assessment Section	817-239-4576	MC 150 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tceq.state.tx.us

C.3.7 Total Maximum Daily Load (TMDL) Program

Under Section 303(d) of the Clean Water Act, the State of Texas is required to develop a list of impaired waters that do not meet water quality standards. The TCEQ must then establish priority rankings for waters on the list and develop Total Maximum Daily Loads (TMDLs) for listed waters. The TMDL specifies the maximum amount of a specific pollutant of concern that a designated segment of a water body can receive and still meet water quality standards. The TMDL also allocates pollutant loadings among point and nonpoint pollutant sources, including storm water runoff. If a TMDL has been established for a water body, the impact of new point and nonpoint sources must be assessed prior to TCEQ approval of new or amended discharge or storm water permits.

For each pollutant identified, a TMDL implementation plan must be developed. The implementation plans must identify the sources of the pollutant and provide a list of actions or management measures needed to reduce the pollutant, a schedule for implementing controls or measures, milestones for implementation, and a monitoring program to measure progress. Controls and management measures need to be in place five years after the plan is developed.

The TMDL program has a broad impact on local storm water management programs because nonpoint sources of pollutants must be addressed at the local level. Currently, the TMDL requirements have been withdrawn and are under evaluation by EPA to determine whether and how the TMDL program can best be implemented to achieve the goals of the Clean Water Act. However, there are TMDLs that have already been approved for segments of the Trinity River Watershed.

Contact Agency	Phone	Address
U.S. EPA – Region 6	214- 665-6444	1445 Ross Avenue, Suite 1200 Dallas, TX 75202 (214) 665-6444
TCEQ – TMDL Section	817-239-4300	MC 150 P.O. Box 13087, Austin, TX 789711-3087

Website: <http://www.epa.gov/region6/index.htm> and <http://www.tceq.state.tx.us>

C.3.8 Source Water Assessment Program (SWAP)

The 1996 amendments to the Federal Safe Drinking Water Act brought about a new approach for ensuring clean and safe drinking water served by public water supplies known as the Source Water Assessment Program. The U.S. EPA is advocating prevention as an important tool in the protection of public drinking water sources from contamination. In order to implement source protection, an assessment of potential pollutant sources in water supply watersheds must be conducted. The goals of this assessment will be reached through implementation of a four-step method which includes watershed delineation, inventory of potential pollutant sources within the watershed, analysis of susceptibility of a water intake to the pollutant sources, and communication of this information to the public.

As many pollutants can enter waterways and reservoirs through storm water drainage systems, the SWAP efforts will provide an informational resource to local storm water pollution prevention and mitigation programs. Future water supply protection efforts to control the identified pollution sources should be coordinated with and included as part of a local storm water program.

The TCEQ's Source Water Assessment Program consists of source water protection, source water assessments, and vulnerability assessments. The Source Water Protection (SWP) program is a voluntary program that public water supply systems participate in to prevent pollution from entering surface or ground water supplies. It was created by the 1996 Amendments to the Safe Drinking Water Act and is an expansion of the Wellhead Protection (WHP) program, which protects public water supplies that use groundwater. Source water assessments and vulnerability assessments are conducted to evaluate a public water supply systems susceptibility to a wide range of contaminants.

Contact Agency	Phone	Address
TCEQ – Public Drinking Water Section	512-239-4782	MC 155 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tceq.state.tx.us

C.3.9 Texas Groundwater Protection Committee

The Texas legislature established the Texas Groundwater Protection Committee (TGPC) in 1989 with a specific charge to “. . . develop and update a comprehensive groundwater protection strategy for the state that provides guidelines for the prevention of contamination and for the conservation of groundwater and that provides for the coordination of the groundwater protection activities of the agencies represented on the committee...” (Water Code Section 26.405(2)).” The TGPC first established a groundwater protection strategy in 1988 and recently updated the strategy (February 2003). Implementation of the strategy is primarily through local groundwater districts, but may also be conducted through River Authorities and Regional Water Planning Groups, municipalities by ordinances, or county on-site treatment regulatory programs.

Contact Agency	Phone	Address
TCEQ – Texas Groundwater Protection Committee	512-239-4506	MC 197 P.O. Box 13087, Austin, TX 789711-3087

Website: www.tgpc.state.tx.us

C.3.10 Dams and Reservoirs in Texas

The Texas Commission on Environmental Quality (TCEQ) regulates the construction of dams in Texas that are six feet or more in height as per the Texas Administrative Code (Title 30, Part 1, Chapter 299 – Dams and Reservoirs). Approval from the TCEQ of plans and specifications is required for construction of a dam. The TCEQ also has the authority to inspect existing dams, and if necessary, require unsafe dams to be upgraded or removed. The Dam Safety Program is administered under the Field Operations Division of the Office of Compliance and Enforcement. More information on dams and reservoirs can be found in Appendix H and on-line at www.tnrc.state.tx.us/enforcement/dam_safety/intro2.html.

The U.S. Army Corps of Engineers Regulatory Program implements Section 9 of the Rivers and Harbors Act of 1899. Under Section 9, permits are required for the construction of dams and dikes in navigable waters of the U.S. See www.swf.usace.army.mil/pubdata/enviro/regulatory/jurisdiction/navlist.pdf for a list of navigable waters of the U.S. for the Fort Worth, Tulsa, and Albuquerque Districts within the State of Texas.

C.3.11 Texas Historical Commission

The Texas Historical Commission (THC) is the state agency for historic preservation. THC staff consults with citizens and organizations to preserve Texas' architectural, archeological, and cultural landmarks. The agency maintains the *Texas Historic Atlas*, a directory of historic site records, including data on Texas Historical Markers and National Register of Historic Places in Texas. Projects that include the

disturbance of existing features such as buildings or other manmade structures should include a search of the THC database to screen for potential historic significance. Projects that include ground disturbance, such as new construction or pipeline installation, should include an assessment of the potential for disturbance of archeological or other culturally significant sites. The contact information for the THC is below.

Contact Agency	Phone	Address
Texas Historical Commission	512-463-6100	P.O. Box 12276 Austin, TX 78711-2276

Website: <http://www.thc.state.tx.us>

C.3.12 Texas General Land Office

A General Land Office (GLO) easement may be required if the project crosses or disturbs any state-owned streambeds. The ownership of any stream is determined on a case-by-case basis by the GLO.

Contact Agency	Phone	Address
Texas General Land Office	1-800-998-4456 or 512-463-5001	1700 N. Congress Ave. Suite 840 Austin, TX 78701-1495

Website: <http://www.glo.state.tx.us>

C.3.13 Sand, Gravel, Shell, and Marl Protection

The Texas Parks and Wildlife Department (TPWD) requires a permit for a project if it "disturbs or takes" streambed materials from a streambed claimed by the State. If the stream is perennial (flows most of the time), or is more than 30 feet wide between the banks (even if it is dry most of the time), the State might claim the bed and the sand and gravel in it as State-owned.

An application must be filed with the TPWD including information on the size of the stream; the nature of the banks and the bed of the stream; the amount of material requested; the adjacent landowners; and the probable effects on the stream and its other users. The TPWD evaluates the probable impacts of the activity, and grants a permit if no significant damage is anticipated. Payment is required for any material removed, in addition to the application fee. A hearing may be required before deciding whether to issue the permit.

C.3.14 Wildlife and Habitat

The Texas Parks and Wildlife Department (TPWD) Resource Protection Division is charged with protecting the state's fish, wildlife, plant, and mineral resources from degradation or depletion. The TPWD investigates environmental contamination events that may result in impacts to fish or wildlife. The agency also provides information and recommendations to other government agencies and participates in administrative and judicial proceedings concerning pollution incidents, development projects, and other actions that may affect fish and wildlife. The Department investigates fish kills, and when responsibility for fish kills can be traced, the agency recovers from the responsible party the economic value of the fish and other lost aquatic life, which by law are state properties. As a state natural resource trustee, the TPWD assesses damages to fish and wildlife resources from oil and hazardous chemical releases and seeks restoration of these resources from the responsible party.

C.4 Regional Initiatives

The North Central Texas Council of Governments (NCTCOG) is a voluntary association of, by, and for local governments, and was established to assist local governments in planning for common needs, cooperating for mutual benefit, and coordinating for sound regional development. NCTCOG's purpose is to strengthen both the individual and collective power of local governments and to help them recognize regional opportunities, eliminate unnecessary duplication, and make joint decisions.

What is SEE? It's an acronym for Sustainable Environmental Excellence. It was first used as the title of a regional environmental conference hosted by the North Central Texas Council of Governments (NCTCOG) in August 2001. That conference helped define the most pressing issues and challenges facing the region and reemphasized a cooperative approach to solve them.

Following months of work with local governments and others, NCTCOG's Executive Board approved two plans—SEE Less Trash and SEE Safe Clean & Green Regional Environmental Corridors—as well as the mission and 10 principles of the Center of Development Excellence in June 2002. Local leaders and NCTCOG are now implementing elements of these plans and principles through numerous projects. There is also an initiative to SEE Clean Air, which is currently focused on the review of the region's "State Implementation Plan" for air quality.

NCTCOG's Department of Environment and Development supports numerous committees composed of local government officials and staff, representatives of business, industry, and nonprofit organization, as well as private citizens, to address these issues. These volunteers make possible a variety of projects and programs dealing with municipal solid waste, public works, building codes, storm water management, flooding, water quality, air quality, recycling, trails, development, and more.

The principles of SEE – moving forward in a way that benefits all North Central Texas today and into the 21st Century – now help guide the efforts of NCTCOG's Department of Environment and Development, and ultimately the region, as we collaborate to plan for this growing and changing area.

C.4.1 Trinity River Corridor Development Certificate

The Corridor Development Certificate (CDC) process aims to stabilize flood risk along the Trinity River. The CDC process does not prohibit floodplain development, but ensures that any development that does occur in the floodplain will not raise flood water levels, reduce flood storage capacity, or increase erosive water velocities.

Under the CDC process, a CDC permit is required to develop land within a specific area of the Trinity floodplain called the Regulatory Zone, which is similar to the 100-year floodplain. An application for a CDC Certificate must be filed with the appropriate local government floodplain administrator. The CDC permit application is forwarded to each of the local governments in the Trinity River Corridor for review and comment.

The US Army Corps of Engineers will also provide a Preliminary Technical Review of hydrologic and hydraulic information contained in the CDC application. Each individual local government, however, retains authority over final local development decisions.

Contact Agency	Phone	Address
Local participating governments		Local participating governments
Website: See local participating governments		
NCTCOG	817-640-3300	616 Six Flags Drive P.O. Box 5888 Arlington, TX 76005-5888

Website: http://www.dfwinfo.com/envir/trin/C_vision/safe/certificate.html

The Upper Trinity River CDC regulatory zone is comprised of the following six zones in the Metroplex:

- Upper Elm Fork
- West Fork Fort Worth
- West Fork East Fort Worth
- West Fork Mid Cities
- Confluence Area
- Lower Trinity Mainstem

Maps for each of the zones can be found at www.dfwinfo.com/envir/trin/cdc/maps/cdcmaps.html. The CDC regulatory zone and CDC review zone are represented in each map.

The **Corridor Development Certificate Manual** presents the standards for development within the Trinity River Corridor. The manual can be obtained from the North Central Texas Council of Governments or from any of the participating local governments. All local governments with development permitting authority within the river corridor are implementing the CDC process. The following governmental entities currently participate in the CDC process:

Cities

- Arlington
- Carrollton
- Coppell
- Dallas
- Farmers Branch
- Fort Worth
- Grand Prairie
- Irving
- Lewisville

Counties

- Dallas
- Denton
- Collin

Special Districts

- Tarrant Regional Water District
- Trinity River Authority

An exemption to the CDC process may be issued for specific activities outlined in the CDC Manual, including:

- Ordinary maintenance and repairs of any operational control structures,
- Outfall structures and associated intake structures where the outfall has been permitted under the Federal NPDES or State TPDES program,
- Discharge of material for backfill or bedding for utility lines, provided there is no significant change in pre-existing bottom contours and excess material is removed to an upland area, and
- Bank stabilization activities.

Under certain circumstances, the local government may issue a variance from the common permit criteria. Any development that cannot meet the established criteria detailed in the CDC Manual may request a variance. A variance shall be any modification of the literal provisions of the CDC Manual when strict enforcement of the CDC process would cause undue hardship, owing to circumstances unique to the individual property on which variance from the process is requested. Variances may also be issued for public projects deemed to be in the overall regional public interest, as determined by the jurisdiction's policy-making body.

An applicant seeking a variance must, like any other applicant, complete the CDC application form and undergo regional Review & Comment by signatories to the Interlocal Agreement. In addition, whenever a variance is requested, Preliminary Technical Review by the U.S. Army Corps of Engineers (USACE) is

required. The CDC process allows parallel review of the various federal, state, and local regulatory permits required for floodplain development to occur simultaneously. This feature of the CDC permit process ensures that no additional time is added to the local development decision-making process and that the overall federal, state, and local approval process is streamlined for quicker decision-making. Failure to comply with the provisions outlined in the CDC Manual will result in the penalties provided for under the floodplain management ordinance or regulations of the jurisdiction.

C.4.2 Hazard Mitigation Action Planning (HazMAP)

In response to a nationally identified need to reduce our vulnerability to disasters, the North Central Texas Council of Governments (NCTCOG) Department of Environment and Development, in cooperation with the Emergency Preparedness, Transportation, and Research & Information Services Departments, is coordinating multi-jurisdictional Hazard Mitigation Action Planning (HazMAP) for the 16-county region.

Hazard mitigation is the cornerstone of the Federal Emergency Management Agency's (FEMA) approach to reducing our nation's vulnerability to disasters. Hazard mitigation is defined as the actions taken to reduce or eliminate long-term risk to people and property from hazards and their effects. This definition distinguishes actions that have a long-term impact from those that are more closely associated with immediate preparedness, response, and recovery activities. Hazard mitigation is the only phase of emergency management specifically dedicated to breaking the cycle of damage, reconstruction, and repeated damage.

HazMAP is a multi-jurisdictional planning process consistent with the Disaster Mitigation Act of 2000 (DMA 2000) and the requirements of the State of Texas Division of Emergency Management (TxDEM) that is putting into place a framework for coordinated and focused hazard mitigation actions both at the local and regional levels. Important elements include:

- Guiding the effort is a HazMAP Review Team from among NCTCOG's many advisory committees, supported by an extensive outreach effort called HazMAP Partners, with government, private sector, and public representatives;
- Identifying and prioritizing the risks of a range of natural and technological hazards, from tornadoes and flooding to nuclear power plant accidents and chemical spills, as well as civil hazards;
- Considering where improved mitigation measures could help reduce hazard risks and vulnerability; and
- Working with our members to craft an initial five-year implementation strategy that will ensure continued local eligibility for federal funding.

The Stafford Act (amended by DMA 2000) requires locally-adopted and FEMA-approved mitigation action plans by November 1, 2004, in order for local governments to participate in certain federal grant programs for disaster planning and relief. Based on federal rules, the process includes annual reporting and plan updating at least every five years.

C.4.3 SAFE CLEAN & GREEN Regional Environmental Corridors

A strategic plan was adopted by NCTCOG in 2002 called SEE SAFE CLEAN & GREEN Regional Environmental Corridors, which lays a foundation for managing the region's waterways and greenways. The Vision of Success for the year 2025 is that all 2,400 miles of regional environmental corridors are SAFE CLEAN & GREEN.

The Vision of Success is further defined as:

- **SAFE** regional environmental corridors occur where the risks of loss of life and property damage from flooding are reduced, the natural function of the floodplain to safely convey storm water is preserved, and the financial integrity of the region's residents is secured.

- **CLEAN** regional environmental corridors support water quality that meets or exceeds the State's standards for public health and enjoyment, aquatic and wildlife protection, wastewater disposal needs, and sustains aesthetically attractive surface water conditions.
- **GREEN** regional environmental corridors are ribbons of greenways that tie together diverse ecological areas, open spaces, recreational and mobility opportunities throughout the region.

The strategic plan identifies opportunities for regional cooperation through a series of objectives accompanied by short-range strategic action recommendations to be undertaken in 2003 through 2007.

C.4.4 Regional Urban Storm Water Quality Management

Since 1989 the North Central Texas Council of Governments (NCTCOG) has been assisting municipalities and other entities to comply with storm water regulations issued by the Environmental Protection Agency (EPA) through a regional storm water management program. In 1990, National Pollutant Discharge Elimination System (NPDES) regulations were issued by EPA for point source discharges of storm water from municipal separate storm sewer systems (MS4s) of cities having populations of 100,000 or more. This was considered Phase I of the permitting program as outlined in Section C.3.1. In response, the seven largest cities in North Central Texas and two local districts of the Texas Department of Transportation formed a Regional Urban Storm Water Management Task Force to address many of the regulatory requirements collectively. NCTCOG served as coordinator of this regional program.

One of the application requirements was for municipalities to sample storm water from their MS4s to quantify pollutant loads and event mean concentrations. Upon approval from EPA Region 6, a network of 30 wet weather monitoring stations was set up in residential, commercial, highway, and industrial areas of Dallas, Fort Worth, Arlington, Garland, Irving, Plano, and Mesquite to sample seven storm events each for a total of 210 sample-events. These samples were analyzed for more than 190 parameters by the United States Geological Survey under contract with NCTCOG and the participating cities.

In the final analysis of the wet weather data, differences were found among the land use types. Residential outfalls had the highest levels of arsenic, diazinon, and chlordane - all of which are pesticides or major components of pesticides. Residential areas also had the highest levels of fecal bacteria indicating sewage related sources or pet waste. Not surprisingly, the nutrients phosphorus and nitrogen were also highest in storm water coming from residential areas. This is presumably indicative of excess fertilizer use. Nothing was characteristic of commercial areas probably since they tend to be a mixed assemblage of activities. From the industrial outfalls we saw an expected preponderance of metals, oil and grease, and other organics. Suspended solids were also prevalent since construction activity is considered industrial and most construction sites lacked adequate erosion control practices.

Subsequent analysis of these data yielded a list of "Constituents of Concern" (COC) based not on water quality standards (which are not directly applicable to storm water), but on frequency of detection in the storm water and on past history as a known water quality problem. The storm water COC list was split into Level 1 (highest concern) and Level 2 (lower priority). The high priority constituents of local concern in the Dallas-Fort Worth region are identified in Table C.4-1.

Table C.4-1 Storm Water Constituents of Local Concern

<u>HIGH Priority</u>	
<u>Metals</u>	<u>Others</u>
Cadmium	Chlordane
Chromium	Diazinon
Copper	Fecal coliforms
Lead	Fecal streptococcus
Zinc	TSS

In 1999, EPA issued draft regulations for Phase II of the NPDES permit program for MS4s. These

regulations impacted all remaining cities in urbanized areas along with certain designated others. The Texas Commission on Environmental Quality (TCEQ), who received delegation to administer the program in Texas, has issued a draft permit for storm water. Once the general permit is issued, regulated entities will be required to develop and implement comprehensive management programs to address urban storm water runoff over their initial five-year permit term.

Again in response to these regulations, NCTCOG expanded its storm water program in 1998 to include the smaller regulated entities and formed a Regional Storm Water Management Coordinating Council (RSWMCC) to oversee the effort. The RSWMCC first developed a Regional Strategy for Managing Storm Water Quality. This proactive policy position was intended to not only provide water quality benefits for the residents of the region, but to also comply with all applicable federal and state water quality regulations. Its stated goals for the expanded regional program are to:

- Protect the health and welfare of citizens and the environment,
- Effectively address state and federal regulations,
- Share professional knowledge and experience, and
- Provide training to governmental staff and the development community.

The Phase II regulations require regulated entities to specify what practices they will implement under six program elements. The strategy document focuses on these elements and encourages regional cooperation among participants in the program through the following series of cooperative initiatives:

- Public participation and education
- Control of construction site storm water runoff (iSWM Design Manual for Construction)
- Management of storm water impacts associated with post-construction (iSWM Design Manual for Site Development)
- Illicit discharge detection and elimination
- Municipal pollution prevention
- Regional cooperative monitoring

Through participation in the regional program and incorporation of these cooperative initiatives into their individual storm water management programs, participants can reduce their staff and administrative burdens while ensuring equity and consistency in storm water management practice across the region.

C.4.5 Center of Development Excellence

The DFW Region is expected to add around 3.5 million new residents by the year 2030, growing to over 9 million people. What effect will this growth have on transportation, open space, air quality, water quality, and water supply? How will this growth impact the quality of life for residents?

These are some of the questions being addressed by the Center of Development Excellence at the North Central Texas Council of Governments (NCTCOG). The Center of Development Excellence is a partnership of public and private interests formed to address the regional issues and infrastructure concerns of the future by fostering quality growth. Leaders in the fields of development, transportation, and government are working together to find cooperative and innovative development solutions to anticipated problems. Formed in 2002, the Center of Development Excellence is a comprehensive effort to maintain and enhance the DFW Metroplex's status as a desired location for people and businesses.

The mission of the Center of Development Excellence is to promote quality growth in North Central Texas that enhances the built environment, reduces vehicle miles of travel, uses water and energy resources effectively and efficiently, and helps advance environmental stewardship in order to ensure continued economic vitality and provide the highest attainable quality of life for all residents. Accordingly the Center

of Development Excellence recommends 10 Principles of Development Excellence as a guide to cities, counties, school districts, other public agencies, and the private sector as they plan and create future development and redevelopment in the region. The 10 Principles are:

1. **Development Options:** Provide a variety and balance of development options and land use types in communities throughout the region.
2. **Efficient Growth:** Foster redevelopment and infill of areas with existing infrastructure and promote the orderly and efficient provision of new infrastructure.
3. **Pedestrian Design:** Create more neighborhoods with pedestrian-oriented features, streetscapes, and public spaces.
4. **Housing Choice:** Sustain and facilitate a range of housing opportunities and choices for residents of multiple age groups and economic levels.
5. **Activity Centers:** Create mixed use and transit-oriented developments that serve as centers of neighborhood and community activity.
6. **Environmental Stewardship:** Protect sensitive environmental areas, preserve natural stream corridors, and create developments that minimize impact on natural features.
7. **Quality Places:** Strengthen community identity through use of compatible, quality architectural and landscape designs and preservation of significant historic structures.
8. **Transportation Efficiency:** Develop land uses, building sites, and transportation infrastructure that enhance the efficient movement of people, goods, and services.
9. **Resource Efficiency:** Provide functional, adaptable, and sustainable building and site designs that use water, energy, and material resources effectively and efficiently.
10. **Implementation:** Adopt comprehensive plans and ordinances that support Development Excellence and involve citizens and stakeholders in all aspects of the planning process.

The Center of Development Excellence is providing a forum for present-day government and business. Leaders must be just as visionary as were their predecessors if this region is to have the physical infrastructure and healthy environment needed for it to attain its full long-term potential. Regional cooperation will be crucial to maintaining that vitality. The dawning of the new century presents an opportune time to analyze our future requirements so that plans can be devised and implementation strategies can be developed which further guarantee that this region remains a leader among other regions of the nation.

STORM WATER CONTROL DESIGN EXAMPLES

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Introduction

The five storm water control examples included in Appendix D are presented to provide example computations using the most commonly used design standards. All of the possible options that might be incorporated into a storm water control structure are not covered in these examples.

For all possible design standards and options that might be incorporated into the design of a storm water control structure, refer to Chapter 1, Section 1.2 and especially to Table 1.2.1-1 on pages 1.2-1 & 1.2-2. In order to apply design standards to a given storm water control structure, additions or modifications to Chapter 1 must also be considered. These are found in the Local Criteria chapter of the Manual.

Local Criteria may determine the extent of downstream assessments; the return periods to be used for the “Streambank Protection” and “Conveyance” storms; and the acceptable design approach to be used for Water Quality Protection, Streambank Protection, and Flood Control. It is evident that there are many combinations of design options that might apply to a given storm water control structure.

Additional design examples will be developed for inclusion in Appendix D during the 2006 training efforts offered by NCTCOG.

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D.1 Storm Water Pond Design Example

The following design example is for a wet extended detention (ED) storm water pond. The design options chosen for this example are Option 1 for Water Quality Protection (WQ_v), Option 4 for Streambank Protection (SP_v), and Option 4 for Flood Control (Q_{p100}). The layout of the Rolling Meadows Subdivision is shown in Figure 1.

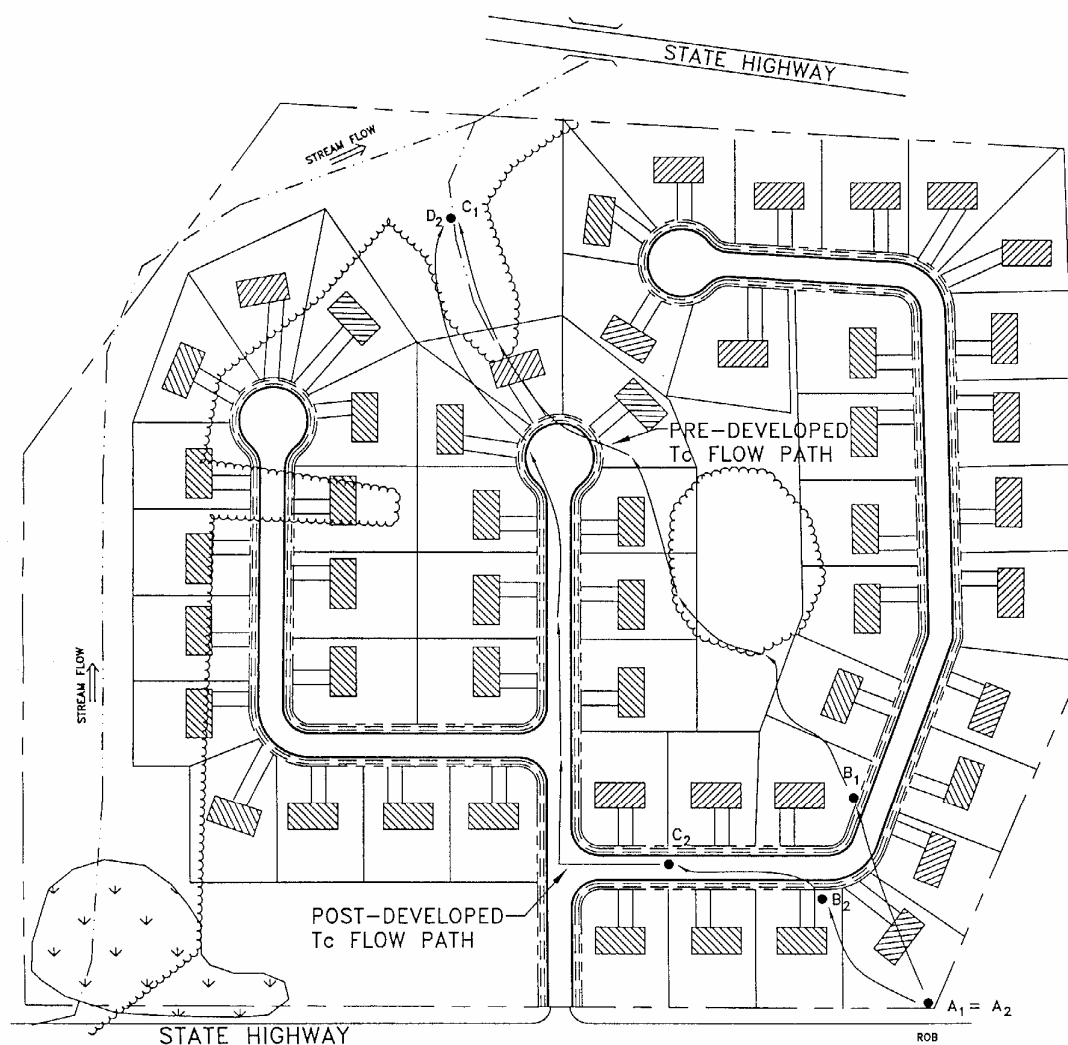


Figure 1. Rolling Meadows Site Plan

Base Data		Hydrologic Data	
Site Area = Total Drainage Area (A) = 38.0 ac		CN	Pre
Measured Impervious Area=13.8 ac; or I=13.8/38=36.3%			Post
Soils Types: 20% "C", 80% "B"		t_c	0.33 hr
Zoning: Residential ($\frac{1}{2}$ acre lots)			0.19 hr
Denton County			

Computation of Preliminary Storm Water Storage Volumes and Peak Discharges

Step 1 -- Compute runoff control volumes from the *integrated* Design Approach

More details hydrologic calculations will be required during the design step – these numbers are preliminary.

Compute Water Quality Volume, WQ_v

- Compute Runoff Coefficient, R_v

$$\begin{aligned} R_v &= 0.05 + (I) (0.009) \\ &= 0.05 + (36.3) (0.009) = 0.38 \end{aligned}$$

- Compute WQ_v

$$\begin{aligned} WQ_v &= (1.5") (R_v) (A) \\ &= (1.5") (0.38) (38.0 \text{ ac}) (1\text{ft}/12\text{in}) \\ &= \underline{1.44 \text{ ac-ft}} \end{aligned}$$

Develop Site Hydrologic and Hydrologic Input Parameters

Per Figures 2 and 3. Note that any hydrologic models using SCS procedures, such as TR-20, HEC-HMS, or HEC-1, can be used to perform preliminary hydrologic calculations

Condition	Area	CN	Tc
	Ac		hrs
pre-developed	38	76	0.33
post-developed	38	85	0.19

Perform Preliminary Hydrologic Calculations

Condition	$Q_{1\text{-yr}}$	$Q_{1\text{-yr}}$	$Q_{100\text{-yr}}$
Runoff	Inches	cfs	cfs
pre-developed	0.78	26.9	266
post-developed	1.29	61.3	402

Compute Streambank Protection Volume, (SP_v)

For stream streambank protection, provide 24 hours of extended detention for the 1-year event.

Utilize SCS approach to Compute Streambank Protection Storage Volume

See Section 2.1

- Initial abstraction (I_a) for CN of 85 is 0.353: [$I_a = (200/CN - 2)$]
- $I_a/P = (0.353)/2.64 \text{ inches} = 0.13$
- $T_c = 0.19 \text{ hours}$
- $q_u = 800 \text{ csm/in}$ (Type II Storm)

Knowing q_u and T (extended detention time), find q_o/q_i . For a Type II rainfall distribution.

- Peak outflow discharge/peak inflow discharge (q_o/q_i) = 0.022
- $V_s/V_r = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$
- Where V_s equals streambank protection storage (SP_v) and V_r equals the volume of runoff in inches.
- $V_s/V_r = 0.65$
- Therefore, $V_s = SP_v = 0.65(1.29")(1/12)(38 \text{ ac}) = 2.66 \text{ ac-ft}$ (116,077 cubic feet)

Define the average SP_v-ED Release Rate

- The above volume, 2.66 ac-ft, is to be released over 24 hours.
- $(2.66 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac}) / (24 \text{ hrs} \times 3,600 \text{ sec/hr}) = 1.34 \text{ cfs}$

Analyze Safe Passage of 100 Year Design Storm (Q_f)

At final design, provide safe passage for the 100-year event, or detain it, depending on downstream conditions and local policy. Based on field observation and review of local requirements no control of the 100-year storm is necessary. If it were storage estimates would have been made similar to the Q_p Volume in the previous sub-step.

Table 1. Summary of General Storage Requirements for Rolling Meadows			
Symbol	Control Volume	Volume Required (ac- ft)	Notes
WQ _v	Water Quality	1.44	
SP _v	Streambank Protection	2.66	Average extended detention release rate is 1.34 cfs over 24 hours
Q _f	Extreme Flood Protection	4.88	Detain to pre-developed conditions; Provide safe passage for the 100-year event in final design

The Modified Rational Method is used to estimate the storage volume.

Determine the Allowable Release Rate, Q_a

- Predevelopment Rational Coefficient, c_a= 0.45
- For t_c=0.33 hr, from Table A-3, i₁₀₀ =6.99 in/hr
- From Equation 2.1.25, Q_a= c_a i A= (0.45) (6.99) (38)=119.5 cfs

Determine the Critical Duration of the Storm T_d

- From Table 2.1.7-1, a=325.18; b=24.822
- Post-developed Rational Coefficient, c=0.61
- From Equation 2.1.26, $T_d = \sqrt{(2cAab/Q_a)} - b$

$$T_d = \sqrt{(2(0.61)(38)(325.18)(24.822)/(119.5))} - (24.822) = 31.1 \text{ min}$$
- From Table A-3, for T_d= 31.1min, i_{Td} = 5.55 in/hr

$$P_{Td} = 5.55 \text{ in/hr} (31.1 \text{ min}) (\text{hr}/ 60\text{min}) = 2.88 \text{ in}$$

Determine the Allowable Release Rate, Q_a

- Predevelopment Rational Coefficient, c_a= 0.45
- For t_c=0.33 hr, from Table A-3, i₁₀₀ =6.99 in/hr
- From Equation 2.1.25, Q_a= c_a i A= (0.45) (6.99) (38)=119.5 cfs

Compute Storage Volume

- Post-developed Time of concentration, t_c = 0.19 hr (60 min/hr) = 11.4 min
- From Equation 2.1.27a, $V_{pre} = 60 [cAa - (2cabAQ_a)^{1/2} + (Q_a/2) (b - t_c)]$

$$V_{pre} = 60 \{ [0.61(38)(325.18) - 2 (0.61)(24.822)(38)(119.5)]^{1/2} + (119.5/2) (24.822 - 11.4) \}$$

$$= 99154 \text{ ft}^3$$
- From Equation 2.1.27a, $V_{max} = V_{pre} * P_{180}/P_{Td}$

$$P_{180} = 1.79 \text{ in/hr (3 hr) in Table A-3}$$

$$V_{\max} = 99154 (5.37 / 2.88) = 184881 \text{ ft}^3 = 4.24 \text{ ac-ft}$$

Experience has shown that additional 10-15% storage is required when multiple levels of extended detention are provided. So, for preliminary sizing purposes added 15% to the required volume for downstream flood control. $O_f = 1.15 (4.24) = 4.88 \text{ ac-ft}$

PEAK DISCHARGE SUMMARY				
JOB:	P'TREE MEADOWS			EWB
DRAINAGE AREA NAME:	PRE-DEVELOPED CONDITIONS			3-Jan-00
COVER DESCRIPTION	SOIL GROUP A, B, C, D?	C from TABLE 2.1.4-2	CN from TABLE 2.1.5-1	AREA (in acres)
meadow (good cond.)	D	0.5	78	30.40
meadow (good cond.)	C	0.5	71	2.60
woods (good cond.)	C	0.15	70	5.00
		AREA SUBTOTALS:		38.00
Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.36"	Cross Section	Wetted Per	Avg Velocity	Tt (hrs)
Sheet Flow	dense grass	'n'= 0.24	150ft	2.50%
				0.29 hrs
Shallow Flow	unpaved		500 ft	4.00%
			3.23 fps	0.04 hrs
Channel Flow				
Total Area in Acres = Weighted CN = Time of Concentration = Pond Factor =	38.00	Total Sheet Flow = 0.29 hrs.	Total Shallow Flow = 0.04 hrs.	Total Channel Flow = 0.00 hrs.
	76			
	0.33 hrs			
	1			
		RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE (cfs)	
1 Year	2.64	0.78	26.9	
2 Year	3.36	1.26	45.1	
5 Year	4.8	2.37	88	
10 Year	5.52	2.97	113	
25 Year	6.96	4.22	165	
50 Year	7.92	5.09	205	
100 Year	9.36	6.41	266	

Figure 2. Rolling Meadows Pre-Development Conditions

PEAK DISCHARGE SUMMARY				
JOB:	P'TREE MEADOWS			EWB
DRAINAGE AREA NAME:	POST-DEVELOPED CONDITIONS			3-Jan-00
COVER DESCRIPTION	SOIL GROUP A, B, C, D?	C from TABLE 2.1.4-2	CN from TABLE 2.1.5-1	AREA (in acres)
open space (good cond.)	D	0.5	80	20.00
woods (good cond.)	C	0.15	70	5.0
impervious area	D	.95	98	10.4
Impervious area	C	.95	98	2.6
AREA SUBTOTALS:				38.00
Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.36"	Cross Section	Wetted Per	Avg Velocity	Tt (hrs)
Sheet Flow	short grass	'n' = 0.15	100 ft	2.50%
				0.15 hrs
Shallow Flow	paved		300 ft	2.00%
			2.87 fps	0.03 hrs
Channel Flow Hydraulic Radius		'n' = 0.013	600 ft	2.00%
	X-S estimated	WP estimated	16.21 fps	0.01 hrs
Total Area in Acres =	38.00	Total Sheet	Total Shallow	Total Channel
Weighted CN =	85	Flow =	Flow =	Flow =
Time of Concentration =	0.19 hrs	0.15 hrs.	0.03 hrs.	0.01 hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE (cfs)	
1 Year	2.64	1.29	61.3	
2 Year	3.36	1.89	92.3	
5 Year	4.8	3.18	159	
10 Year	5.52	3.85	196	
25 Year	6.96	5.21	269	
50 Year	7.92	6.14	322	
100 Year	9.36	7.53	402	

Figure 3. Rolling Meadows Post-Development Conditions

Step 2 -- Determine if the development site and conditions are appropriate for the use of a storm water pondSite Specific Data:

The site area and drainage area to the pond is 38.0 acres. Existing ground at the pond outlet is 919 MSL. Soil boring observations reveal that the seasonally high water table is at elevation 918. The underlying soils are predominantly clay and are suitable for earthen embankments and to support a wet pond without a liner. The stream invert at the adjacent stream is at elevation 916.

Other site screening aspects listed in Section 3.1 and 3.2.1 were assessed and a pond was found to be suitable.

Step 3 -- Confirm local design criteria and applicability

There are no additional requirements for this site.

Step 4 -- Determine pretreatment volume

Size wet forebay to treat 0.1"/impervious acre. $(13.8 \text{ ac})(0.1") (1'/12") = 0.12 \text{ ac-ft}$
(forebay volume is included in WQ_v as part of permanent pool volume)

Step 5 -- Determine permanent pool volume (and water quality extended detention volume)

Size permanent pool volume to contain 50% of WQ_v :
 $0.5 \times (1.44 \text{ ac-ft}) = 0.72 \text{ ac-ft}$. (includes 0.12 ac-ft of forebay volume)

Size extended detention volume to contain 50% of WQ_v : $0.5 \times (1.44 \text{ ac-ft}) = 0.72 \text{ ac-ft}$

Note: This design approach assumes that all of the extended detention volume will be in the pond at once. While this will not be the case, since there is a discharge during the early stages of storms, this conservative approach allows for extended detention control over a wider range of storms, not just the target rainfall.

Step 6 -- Determine pond location and preliminary geometry. Conduct pond grading and determine storage available for permanent pool and water quality extended detention

This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond. Storage must be provided for the permanent pool (including sediment forebays), extended detention (WQ_v -ED), SP_v -ED, downstream flood protection, plus sufficient additional storage to pass the 100-year storm with minimum freeboard. An elevation-storage table and curve is prepared using the average area method for computing volumes. See Figure 4 for pond location on site, Figure 5 grading and Figure 6 for Elevation-Storage Data.

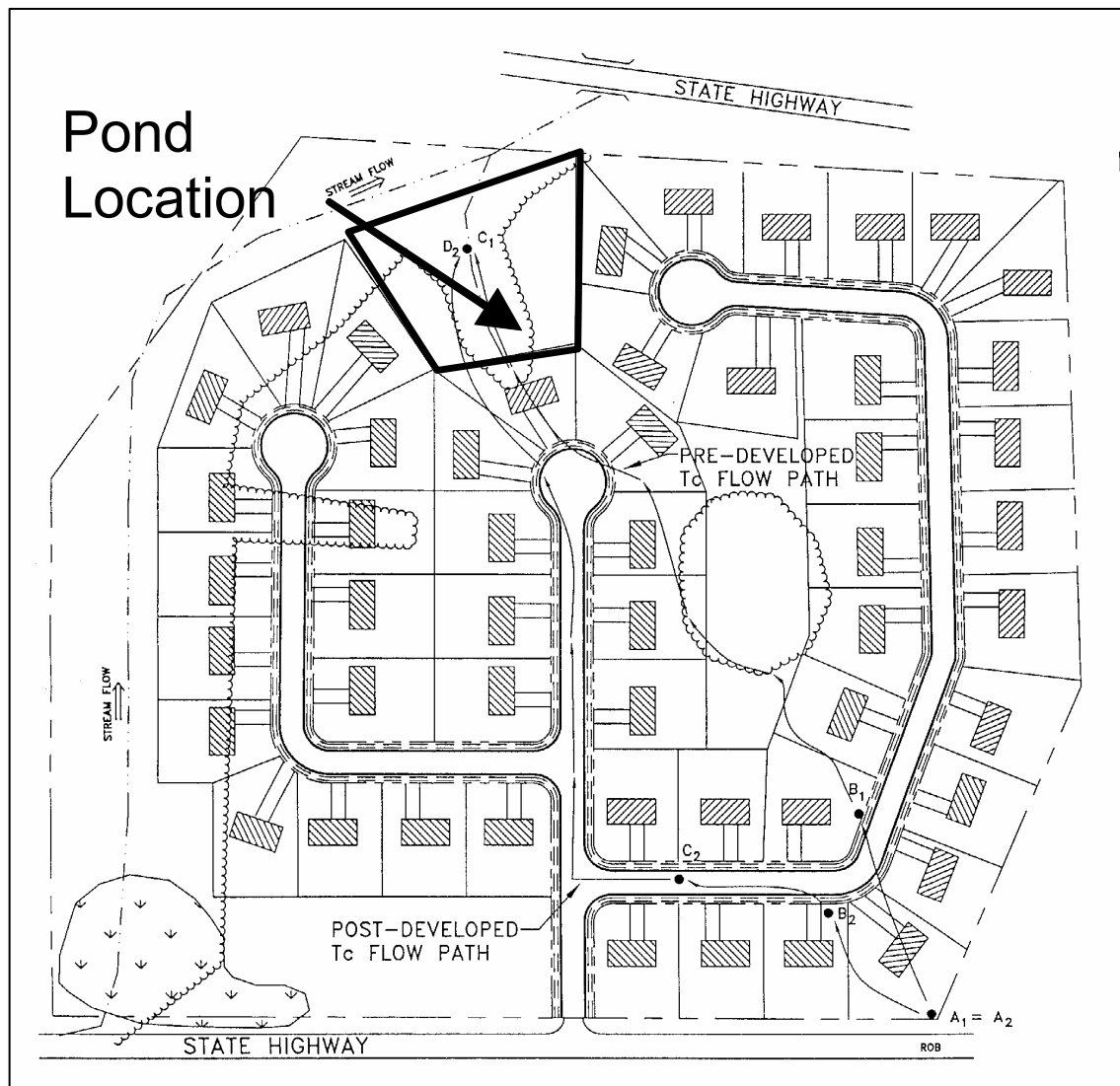


Figure 4. Pond Location on Site

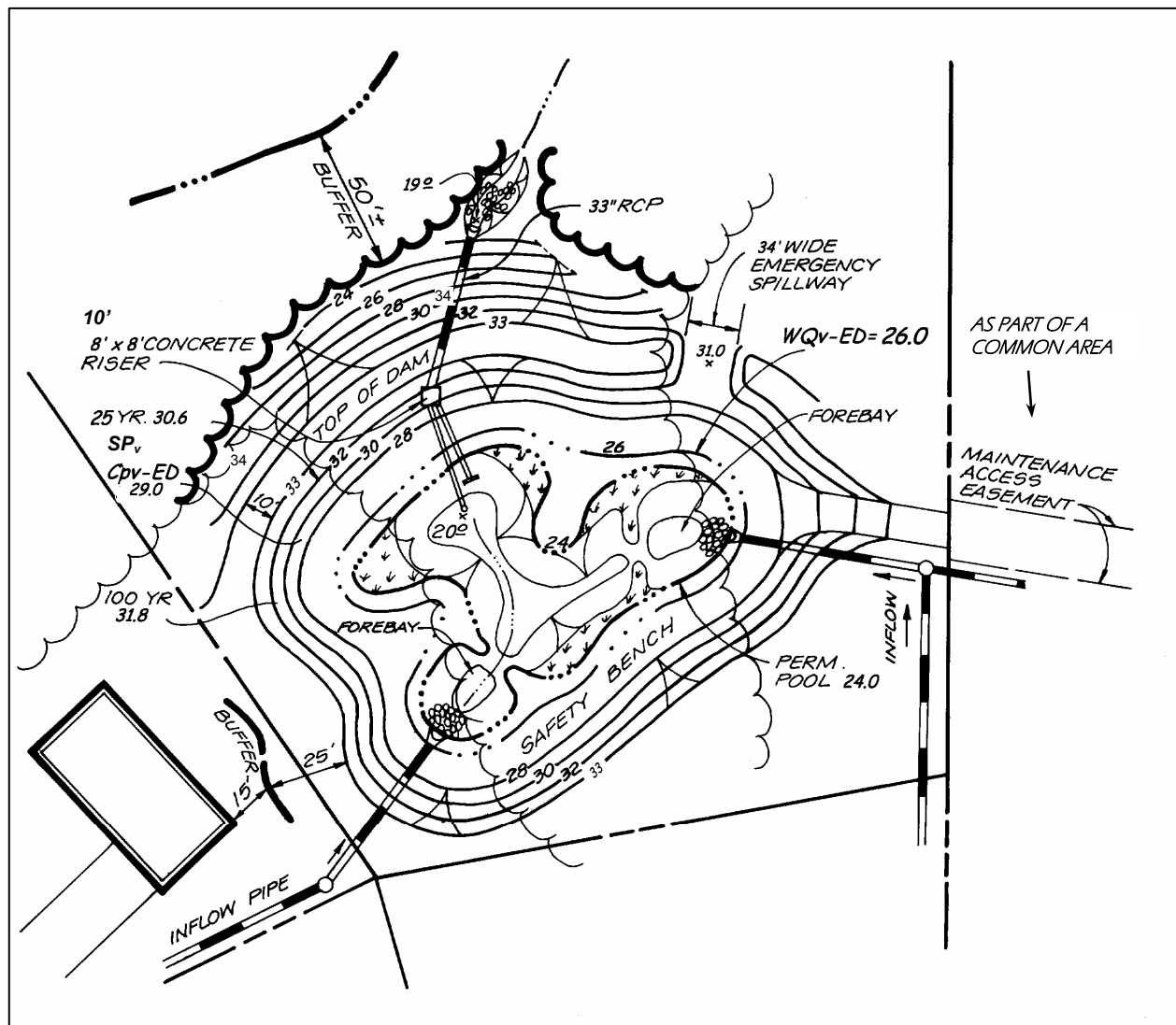


Figure 5. Plan View of Pond Grading (Not to Scale)

Elevation MSL	Average Area ft ²	Depth ft	Volume ft ³	Cumulative Volume ft ³	Cumulative Volume ac-ft	Volume Above Permanent Pool ac-ft
920.0						
921.0	7838	1	7838	7838	0.18	
923.0	11450	2	22900	30738	0.71	
924.0	14538	1	14538	45275	1.04	0
925.0	15075	1	15075	60350	1.39	0.35
925.5	16655	0.5	8328	68678	1.58	0.54
926.0	17118	0.5	8559	77236	1.77	0.73
926.5	21000	0.5	10500	87736	2.01	0.97
927.0	25000	0.5	12500	100236	2.30	1.26
927.5	30000	0.5	15000	115236	2.65	1.61
928.0	36000	0.5	18000	133236	3.06	2.02
928.5	38000	0.5	19000	152236	3.49	2.46
929.0	41000	0.5	20500	172736	3.97	2.93
929.5	43000	0.5	21500	194236	4.46	3.42
930.0	45000	0.5	22500	216736	4.98	3.94
930.5	47000	0.5	23500	240236	5.52	4.48
931.0	49000	0.5	24500	264736	6.08	5.04
931.5	52000	0.5	26000	290736	6.67	5.64
932.0	55000	0.5	27500	318236	7.31	6.27
932.5	58000	0.5	29000	347236	7.97	6.93
933.0	61000	0.5	30500	377736	8.67	7.63
933.5	65000	0.5	32500	410236	9.42	8.38
934.0	69000	0.5	34500	444736	10.21	9.17
935.0	74000	1	74000	518736	11.91	10.87

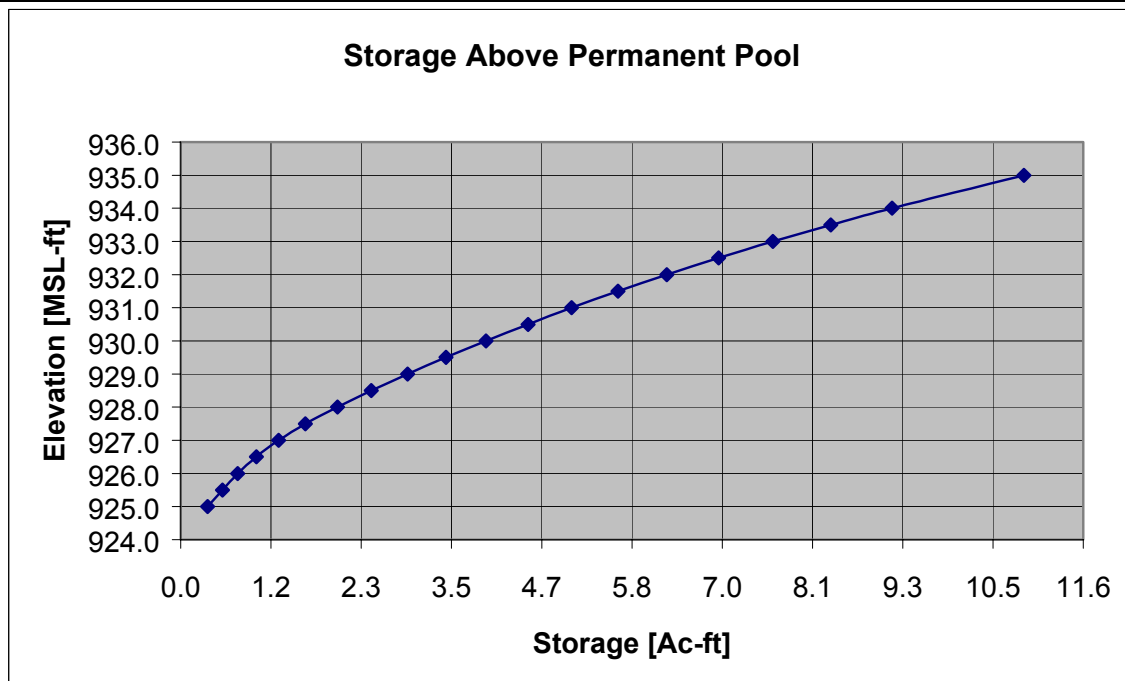


Figure 6. Storage-Elevation Table and Curve

Set basic elevations for pond structures

- The pond bottom is set at elevation 920.0.
- Provide gravity flow to allow for pond drain, set riser invert at 919.5.
- Set barrel outlet elevation at 919.0.

Set water surface and other elevations

- Required permanent pool volume = 50% of $WQ_v = 0.72$ ac-ft. From the elevation-storage table, read elevation 924.0 (1.04 ac-ft > 0.72 ac-ft). The site can accommodate it and it allows a small safety factor for fine sediment accumulation - OK
- Forebay volume provided in two pools with avg. vol. = 0.08 ac-ft each (0.16 ac-ft > 0.12 ac-ft) OK
- Required extended detention volume (WQ_v -ED) = 0.72 ac-ft. From the elevation-storage table (volume above permanent pool), read elevation 926.0 (0.73 ac-ft > 0.72 ac-ft) OK. Set extended detention wsel = 926.0

Note: Total storage at elevation 926.0 = 1.77 ac-ft (greater than required WQ_v of 1.44 ac-ft)

Compute the required WQ_v -ED orifice diameter to release 0.72 ac-ft over 24 hours

- Avg. extended detention release rate = $(0.72 \text{ ac-ft}) / (43,560 \text{ ft}^2/\text{ac}) / (24 \text{ hr}) / (3600 \text{ sec/hr}) = 0.36 \text{ cfs}$
- Average head = $(926.0 - 924.0) / 2 = 1.0'$
- Use orifice equation to compute cross-sectional area and diameter
 - $Q = CA(2gh)^{0.5}$, for $Q = 0.36 \text{ cfs}$, $h = 1.0 \text{ ft}$, $C = 0.6$ = discharge coefficient) solve for A
 - $A = 0.36 \text{ cfs} / [(0.6)((2)(32.2 \text{ ft/s}^2)(1.0 \text{ ft}))^{0.5}]$ $A = 0.075 \text{ ft}^2$, $A = \pi d^2 / 4$; dia. = 0.31 ft = 3.7"
 - Use 4" pipe with 4" gate valve to achieve equivalent diameter

Compute the stage-discharge equation for the 3.7" dia. WQ_v orifice

- $Q_{WQ_v\text{-ED}} = CA(2gh)^{0.5} = (0.6)(0.075 \text{ ft}^2) [((2)(32.2 \text{ ft/s}^2))^{0.5}] (h^{0.5})$,
- $Q_{WQ_v\text{-ED}} = (0.36) h^{0.5}$, where: $h = \text{wsel} - 924.16$

(Note: account for one half of orifice diameter when calculating head)

Step 7 -- Compute extended detention orifice release rate(s) and size(s), and establish SP_v elevation

Set the SP_v pool elevation

- Required SP_v storage = 2.66 ac-ft (see Table 1).
- From the elevation-storage table, read elevation 929 (this includes the WQ_v).
- Set SP_v wsel = 929

Size SP_v orifice

- Size to release average of 1.34 cfs.
 - Average WQ_v -ED orifice release rate is 0.66 cfs, based on average head of 3.34' $(926 - 924.16 + (929 - 926)/2)$
 - SP_v -ED orifice release = $1.34 - 0.66 = 0.66 \text{ cfs}$
- Head = $(929 - 926.0)/2 = 1.5'$

Use orifice equation to compute cross-sectional area and diameter

- $Q = CA(2gh)^{0.5}$, for $h = 1.5'$
 - $A = 0.68 \text{ cfs} / [(0.6)((2)(32.2'/s^2)(1.5'))^{0.5}]$
 - $A = 0.12 \text{ ft}^2$, $A = \pi d^2 / 4$;
 - $\text{dia.} = 0.38 \text{ ft} = 4.6''$
 - Use PVC pipe to the nearest 1" (in this case 5" PVC pipe)

Compute the stage-discharge equation for the 4.6" dia. SP_v orifice

- $Q_{\text{SPv-ED}} = CA(2gh)^{0.5} = (0.6)(0.12 \text{ ft}^2) [((2)(32.2'/s^2))^{0.5}](h^{0.5})$,
- $Q_{\text{SPv-ED}} = (0.55)(h^{0.5})$, where: $h = \text{wsel} - 926.19$

(Note: Use the distance from the water surface to the center of the orifice when calculating head)

Step 8 -- Calculate Q_f (100-year storm) release rate and water surface elevation

In order to calculate the release rate and water surface elevation, the designer must set up a stage-storage-discharge relationship for the control structure for each of the low flow release pipes (WQ_v-ED and SP_v-ED) plus the 100 year storm.

Develop basic data and information

- The 100 year pre-developed peak discharge = 266 cfs,
- The post developed inflow = 402 cfs, from Table 1,
- From previous estimate $Q_f = 4.88 \text{ ac-ft}$.
- From elevation-storage table (Figure 6), read elevation 930.9.

Size 100-year slot to release 266 cfs at elevation 930.9.

- @ wsel 930.9:
 - WQ_v-ED orifice releases 0.93 cfs,
 - SP_v-ED orifice releases 1.19 cfs, therefore;
 - Allowable $Q_p = 266 \text{ cfs} - (.93 + 1.19) = 263.9 \text{ cfs}$, say 264 cfs.
- Max head = $(930.9 - 929) = 1.9'$
- Use weir equation to compute slot length
 - $Q = CLH^{3/2}$
 - $L = 264 \text{ cfs} / (3.1)(1.9^{3/2}) = 32.5 \text{ ft}$
- Use four 8.5 ft x 2 ft slots for 100-year release (opening should be slightly larger than needed so as to have the barrel control before slot goes from weir flow to orifice flow).

Check orifice equation using cross-sectional area of opening

- $Q = CA(2gh)^{0.5}$, for $h = 1.0'$ (For orifice equation, h is from midpoint of slot)
- $A = 4(8.5')(2') = 68.0 \text{ ft}^2$
- $Q = 0.6(68.0 \text{ ft}^2) [(64.4)(1.0)]^{0.5} = 327 \text{ cfs} > 266 \text{ cfs}$, so use weir equation

$$Q_{100} = (3.1)(34')H^{3/2}, \quad Q_{100} = (105.8)H^{3/2}, \quad \text{where } H = \text{wsel} - 929.0$$

Size barrel to release approximately 266 cfs at elevation 930.9

- Check inlet condition: (use Section 4.2 culvert charts)
 - $H_w = 930.9 - 919.5 = 11.4$ ft
 - Try 60" diameter RCP, Using Figure 4.2-2(a) with entrance condition 1
 - $H_w / D = 11.4 / 5 = 2.28$, Discharge = 280 cfs
- Check outlet condition:
 - $Q = a [(2gH)/(1+k_m+k_pL)]^{0.5}$
 where:
 - Q = discharge in cfs
 - a = pipe cross sectional area in ft^2
 - g = acceleration of gravity in ft/sec^2
 - H = head differential (wsel - downstream centerline of pipe or tailwater elev.)
 - k_m = coefficient of minor losses (use 1.0)
 - k_p = pipe friction loss coef. ($= 5087n^2/d^{4/3}$, d in ", n is Manning's n)
 - L = pipe length in ft
 - $H = 930.9 - (919.0 + 2.5) = 9.4'$
 - for 60" RCP, 70 feet long:
 - $Q = 19.63 [(64.4) (9.4) / 1 + 1 + (.003) (70)]^{0.5} = 324.9$ cfs
 - 280 cfs < 325 cfs, so barrel is inlet controlled.

Note: Pipe will control flow before high stage inlet reaches max head.

Complete stage-storage-discharge summary (Figure 7) up to preliminary 100-year wsel (930.9) and route 100 year post-developed condition inflow using computer software.

Elevation MSL	Storage ac-ft	Flow Flow WQV-ED 3.7" eq dia		Riser						Barrel				Emergency Spillway		Total Discharge
				SPv-ED 4.7" eq dia		High Stage Slot										
						Orifice		Weir								
		H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	H ft	Q cfs	Q cfs
924.0	0.00	0	0													0
925.0	0.35	0.8	0.33													0.33
925.5	0.54	1.3	0.42													0.42
926.0	0.73	1.8	0.49	0	0											0.49
926.5	0.97	2.3	0.55	0.3	0.31											0.86
927.0	1.26	2.8	0.61	0.8	0.50											1.11
927.5	1.61	3.3	0.66	1.3	0.63											1.29
928.0	2.02	3.8	0.71	1.8	0.74											1.45
928.5	2.46	4.3	0.75	2.3	0.84											1.59
929.0	2.93	4.8	0.79	2.8	0.92	N/A		0.0	0.0							1.71
929.5	3.42	5.3	0.83	3.3	1.00			0.5	37.4							39.2
930.0	3.94	5.8	0.87	3.8	1.07			1.0	105.8							107.7
930.5	4.48	6.3	0.91	4.3	1.14			1.5	194.4							196.5
930.9	4.93	6.7	0.93	4.7	1.19			1.9	277.1	11.4	280.0	9.4	324.9			279.2
931.0	5.04	-	-	-	-	1.0	327.0	2.0	299.2	11.5	280.0	9.5	326.6	0.0	0.0	280.0
931.5	5.64	-	-	-	-					12.0	285.0	10.0	335.1	0.5	24.0	309.0
932.0	6.27	-	-	-	-					13.0	290.0	10.5	343.4	1.0	79.0	369.0
932.5	6.93	-	-	-	-					13.5	300.0	11.0	351.4	1.5	154.0	454.0

Figure 7 Stage-Storage-Discharge Summary

Note: Adequate outfall protection must be provided in the form of a riprap channel, plunge pool, or combination to ensure non-erosive velocities. Plans must indicate pipe class, joint type, and bedding.

Step 9 -- Design embankment(s) and spillway(s)

Set the emergency spillway at elevation 931.0 and use design information and criteria Earth Spillways (not included in this manual)

- Q_{100} inflow = 402 cfs.
- Try 34' wide vegetated emergency spillway with 3:1 side slopes.
 - @ elevation 932.6, $H = 1.5'$, Emergency spillway, $Q_{ES} = 154$ cfs. Primary spillway, $Q_{PS} = 300$ cfs
 - $Q_{ES} + Q_{PS} = 454$ cfs, will be able to safely convey $Q_f = 402$. (use computer routing for exact elevations and discharges).
 - 100 year wsel = 932.2, say 932.5, so set top of embankment with 1 foot of freeboard at elevation 933.5.

Step 10 -- Investigate potential pond hazard classification

Refer to Texas Commission on Environmental Quality (TCEQ) Dam Safety Program to establish preliminary classification of embankment and whether special design criteria need to be met. Their regulations apply for the construction of dams that are six feet or more in height.

Check pond classification: Height = $931 - 919 = 12'$, equals assumed embankment height, Pond will remain Category II or lower.

As reported in Table 1, the preliminary maximum storage volume required is about 4.24 acre-feet. Therefore, for initial design considerations, no additional dam safety requirements will apply. Once final design elevations and storage volumes have been determined, a final check for dam rules exemption should be made by the designer.

Step 11. -- Design inlets, sediment forebay(s), outlet structures, maintenance access, and safety features.

Table 2 Summary of Controls Provided					
Control Element	Type/Size of Control	Storage Provided	Elevation	Discharge	Remarks
<i>Units</i>		<i>Acre-feet</i>	<i>MSL</i>	<i>cfs</i>	
Permanent Pool		0.86	924.0	0	part of WQ_v
Forebay	submerged berm	0.12	924.0	0	included in permanent pool volume
Water Quality Extended Detention (WQ_v -ED)	4" pipe, sized to 3.7" equivalent diameter	0.72	926.0	0.36	part of WQ_v , above perm. pool, discharge is average release rate over 24 hours
Streambank Protection (SP_v -ED)	6" pipe sized to 5.0" equivalent diameter	2.66	929.0	1.34	volume above perm. pool, discharge is average release rate over 24 hours
Downstream Flood Protection (Q_p)	Four 8.5' x 2' slots on a 10' x 8' riser, 60" barrel.	4.88	931.0	280	volume above perm. pool
Extreme Flood Protection (Q_{f-100})	34' wide earth spillway	6.53	932.2	207	volume above perm. pool

See Figure 8 for profile through principal spillway of the facility.
See Figure 9 for a schematic of the riser.

Step 12 -- Prepare Vegetation and Landscaping Plan

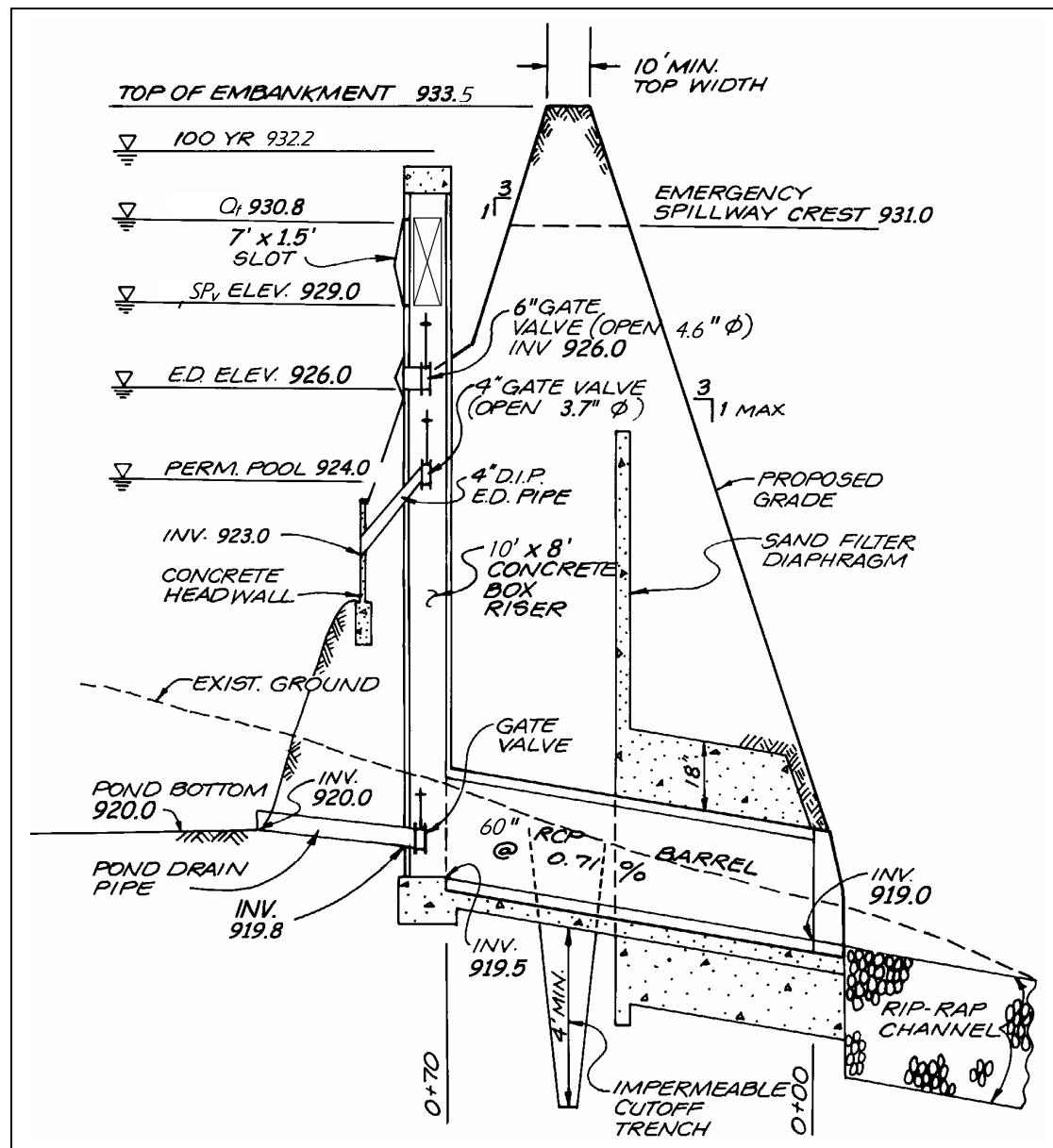


Figure 8. Profile of Principal Spillway

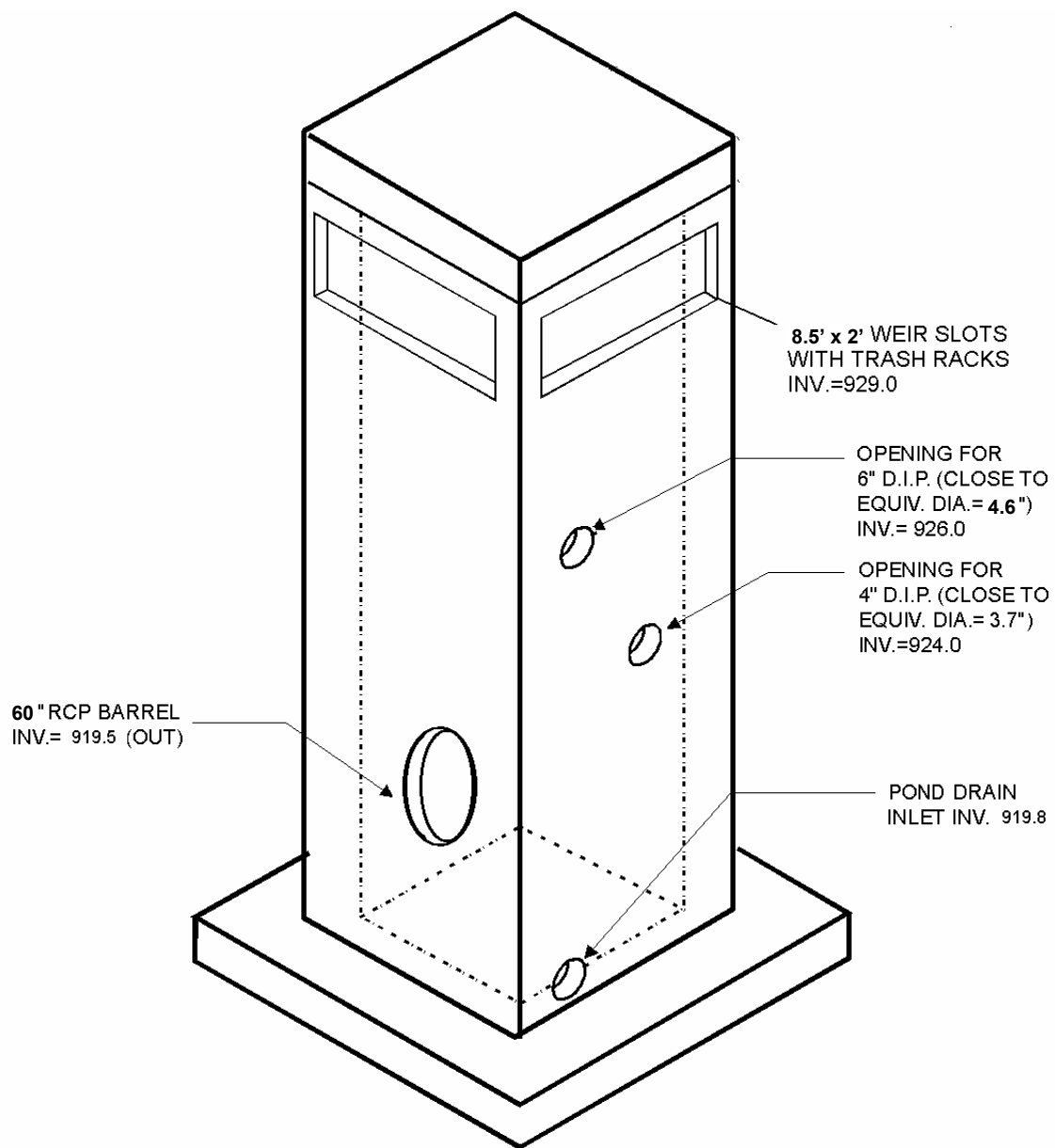


Figure 9. Schematic of Riser Detail

D.2 Bioretention Area Design Example

This example focuses on the design of a bioretention facility to meet the water quality treatment requirements of the Wellington Recreation Center. The design options chosen for this example are Option 1 for Water Quality Protection (WQ_v), Option 4 for Streambank Protection (SP_v), and Option 4 for Flood Control (Q_{p100}). Streambank Protection and Flood Control are not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of bioretention is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility or pass through the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). Under some conditions, Streambank Protection storage can be provided by bioretention facilities. The layout of the Wellington Recreation Center is shown in Figure 1.

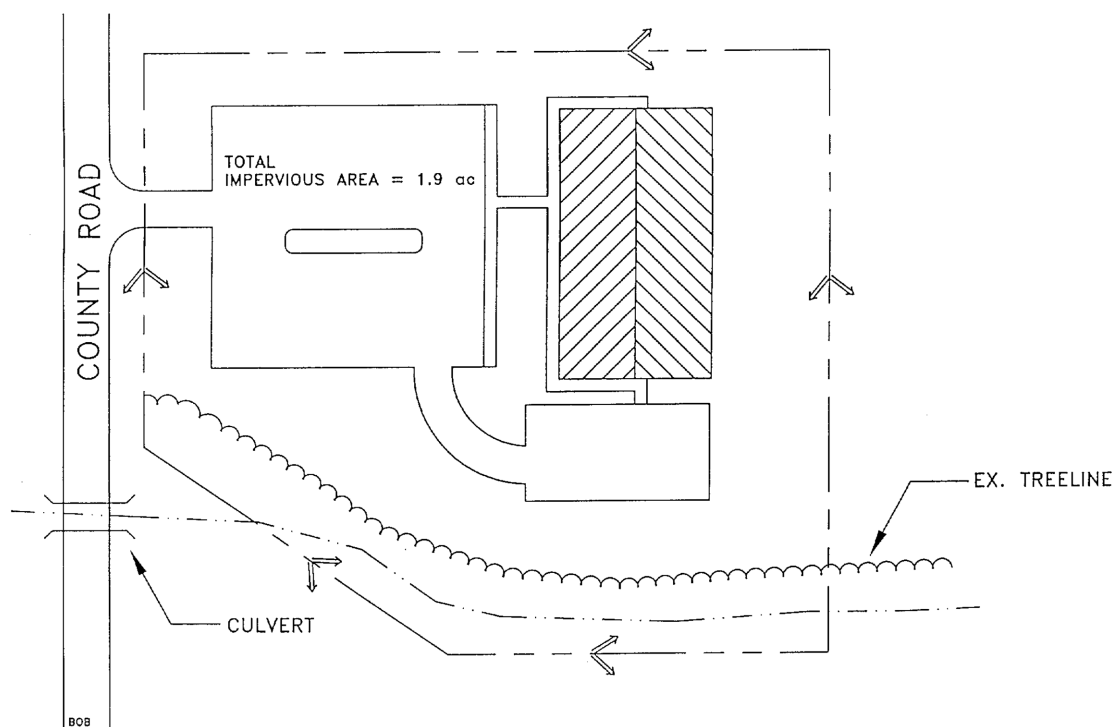


Figure 1. Wellington Recreation Center Site Plan

Base Data		Hydrologic Data	
Site Area = Total Drainage Area (A) = 3.0 ac		Pre	Post
Measured Impervious Area = 1.9 ac; or I =1.9/3.0 = 63.3%		CN	77
Soils Type "D" Collin County		t _c	91
		0.41 hr	0.20 hr

Computation of Preliminary Storm Water Storage Volumes and Peak Discharges

Step 1 -- Compute runoff control volumes from the *integrated* Design Approach

Compute Water Quality Volume (WQ_v):

- Compute Runoff Coefficient, R_v

$$R_v = 0.05 + (63.3) (0.009) = 0.62$$

- Compute WQ_v

$$\begin{aligned} \text{WQ}_v &= (1.5") (R_v) (A) / 12 \\ &= (1.5") (0.62) (3.0\text{ac}) (43,560\text{ft}^2/\text{ac}) (1\text{ft}/12\text{in}) \\ &= \underline{8,102 \text{ ft}^3} \end{aligned}$$

Compute Stream Streambank Protection Volume (SP_v):

For stream streambank protection, provide 24 hours of extended detention for the 1-year event.

In order to determine a preliminary estimate of storage volume for streambank protection and flood control, it will be necessary to perform hydrologic calculations using approved methodologies. This example uses the NRCS TR-55 methodology presented in Section 2.1 to determine pre- and post-development peak discharges for the 1-yr, and 100-yr 24-hour return frequency storms.

- Per attached TR-55 calculations (Figures 2 and 3)

Condition	CN	Q _{1-year} <i>Inches</i>	Q _{1-year} <i>cfs</i>	Q _{100 year} <i>cfs</i>
Pre-developed	77	0.83	2.1	21
Post-Developed	91	1.79	6.7	37

- Utilize modified TR-55 approach to compute streambank protection storage volume

Initial abstraction (I_a) for CN of 91 is 0.27: [$I_a = (200/\text{CN} - 2)$]

$$I_a/P = (0.198) / 2.64 \text{ inches} = 0.075$$

$$T_c = 0.20 \text{ hours}$$

$$q_u = 820 \text{ csm/in}$$

Knowing q_u and T (extended detention time), find q_o/q_i for a Type II rainfall distribution.

$$\text{Peak outflow discharge/peak inflow discharge } (q_o/q_i) = 0.022$$

For a Type II rainfall distribution,

$$V_s/V_r = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$$

Where V_s equals streambank protection storage (SP_v) and V_r equals the volume of runoff in inches.

$$V_s/V_r = 0.65$$

$$\text{Therefore, } V_s = \text{SP}_v = 0.65(1.74")(1/12)(3 \text{ ac}) = 0.28 \text{ ac-ft} = 12,317 \text{ ft}^3$$

Analyze for Safe Passage of 100 Year Design Storm (Q_f):

At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure, typically the same one used for the 25 year storm flood protection control.

Table 1. Summary of General Design Information for Wellington Recreation Center			
Symbol	Control Volume	Volume Required (cubic feet)	Notes
WQ_v	Water Quality	8,102	
SP_v	Streambank Protection	12,317	
Q_f	Extreme Flood Protection	NA	Provide safe passage for the 100-year event in final design

Figure 2. Wellington Recreation Center Pre-Developed Conditions

PEAK DISCHARGE SUMMARY				
JOB:	Wellington Recreation Center			EWB
DRAINAGE AREA NAME:	Post-Development Conditions			3-Jan-00
COVER DESCRIPTION	SOIL GROUP A, B, C, D?	C from TABLE 2.1.4-2	CN from TABLE 2.1.5-1	AREA (in acres)
open space (good cond.)	D		80	0.50
woods (good cond.)	D		70	0.60
impervious area	D		98	1.90
AREA SUBTOTALS:				38.00
Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.6"	Cross Section	Wetted Per	Avg Velocity	Tt (hrs)
Sheet Flow	dense grass	'n' = 0.24	50 ft	1.50%
				0.14 hrs
Shallow Flow	paved		600 ft	2.00%
			2.87 fps	0.06 hrs
Channel Flow Hydraulic Radius		'n' = 0.024	50 ft	2.00%
	X-S estimated	WP estimated	7.25 fps	0.00 hrs
Total Area in Acres =	3.00	Total Sheet	Total Shallow	Total Channel
Weighted CN =	91	Flow =	Flow =	Flow =
Time of Concentration =	0.20 hrs	0.14 hrs.	0.06 hrs.	0.00 hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE (cfs)	
1 Year	2.64	1.74	6.7	
2 Year	3.60	2.64	10.4	
5 Year	5.04	4.02	16.0	
10 Year	6.00	4.96	20.0	
25 Year	7.20	6.14	25.0	
50 Year	8.40	7.32	31.0	
100 Year	9.84	8.75	37.0	

Figure 3. Wellington Recreation Center Post-Developed Conditions

Step 2 -- Determine if the development site and conditions are appropriate for the use of a bioretention area.

Site Specific Data:

Existing ground elevation at the facility location is 922.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 913.0 feet and underlying soil is predominately clay. Adjacent creek invert is at 912.0 feet.

Step 3 -- Confirm local design criteria and applicability

There are no additional local criteria that must be met for this design.

Step 4 -- Compute WQ_v peak discharge (Q_{wq})

Step 5 -- Size flow diversion structure, if needed

Bioretention areas can be either on or off-line. On-line facilities are generally sized to receive, but not necessarily treat, the 25-year event. Off-line facilities are designed to receive a more or less exact flow rate through a weir, channel, manhole, "flow splitter", etc. This facility is situated to receive direct runoff from grass areas and parking lot curb openings and piping for the 25-year event (25.0 cfs), and *no special flow diversion structure is incorporated.*

Step 6 -- Determine size of bioretention ponding / filter area

$$A_f = (WQ_v) (d_f) / [(k) (h_f + d_f) (t_f)]$$

where:

A_f = surface area of filter bed (ft²)

d_f = filter bed depth (ft)

k = coefficient of permeability of filter media (ft/day)

h_f = average height of water above filter bed (ft)

t_f = design filter bed drain time (days) (48 hours is recommended)

$$A_f = (8,102 \text{ ft}^3)(5') / [(0.5'/\text{day}) (0.25' + 5') (2 \text{ days})] \text{ (With } k = 0.5'/\text{day, } h_f = 0.25', t_f = 2 \text{ days)}$$

$$A_f = \underline{7,716 \text{ sq ft}}$$

Step 7 -- Set design elevations and dimensions of facility

Assume a roughly 2 to 1 rectangular shape. Given a filter area requirement of 7,716 sq ft, say facility is roughly 65' by 120'. See Figure 5. Set top of facility at 921.0 feet, with the berm at 922.0 feet. The facility is 5' deep, which will allow 3' of freeboard over the seasonally high water table. See Figure 6 for a typical section of the facility.

Step 8 -- Design conveyance to facility (off-line systems)

This facility is not designed as an off-line system.

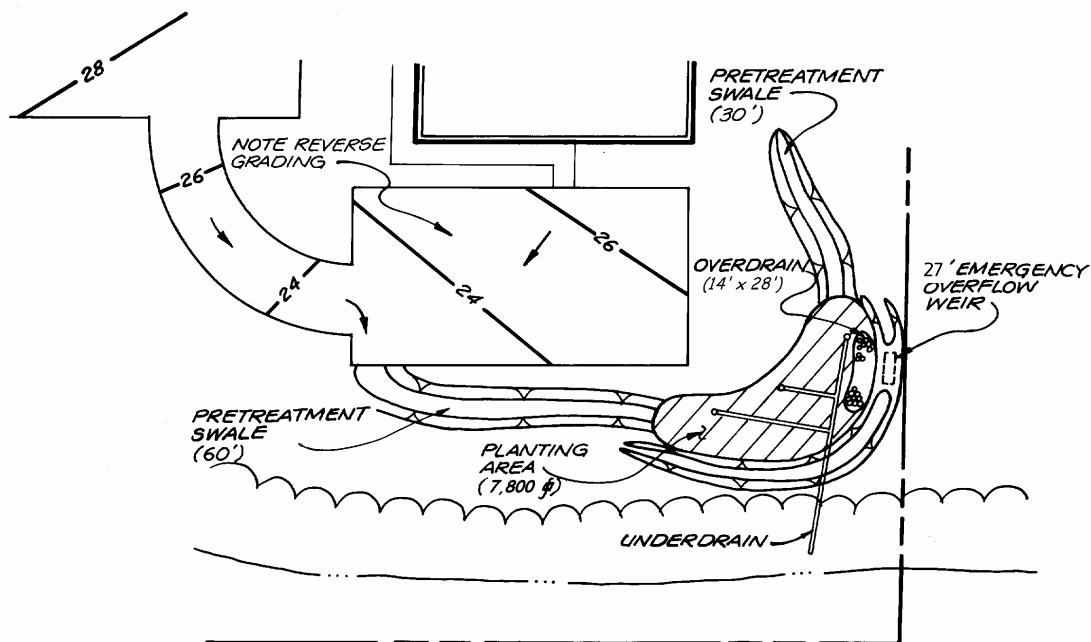


Figure 5. Plan View of Bioretention Facility

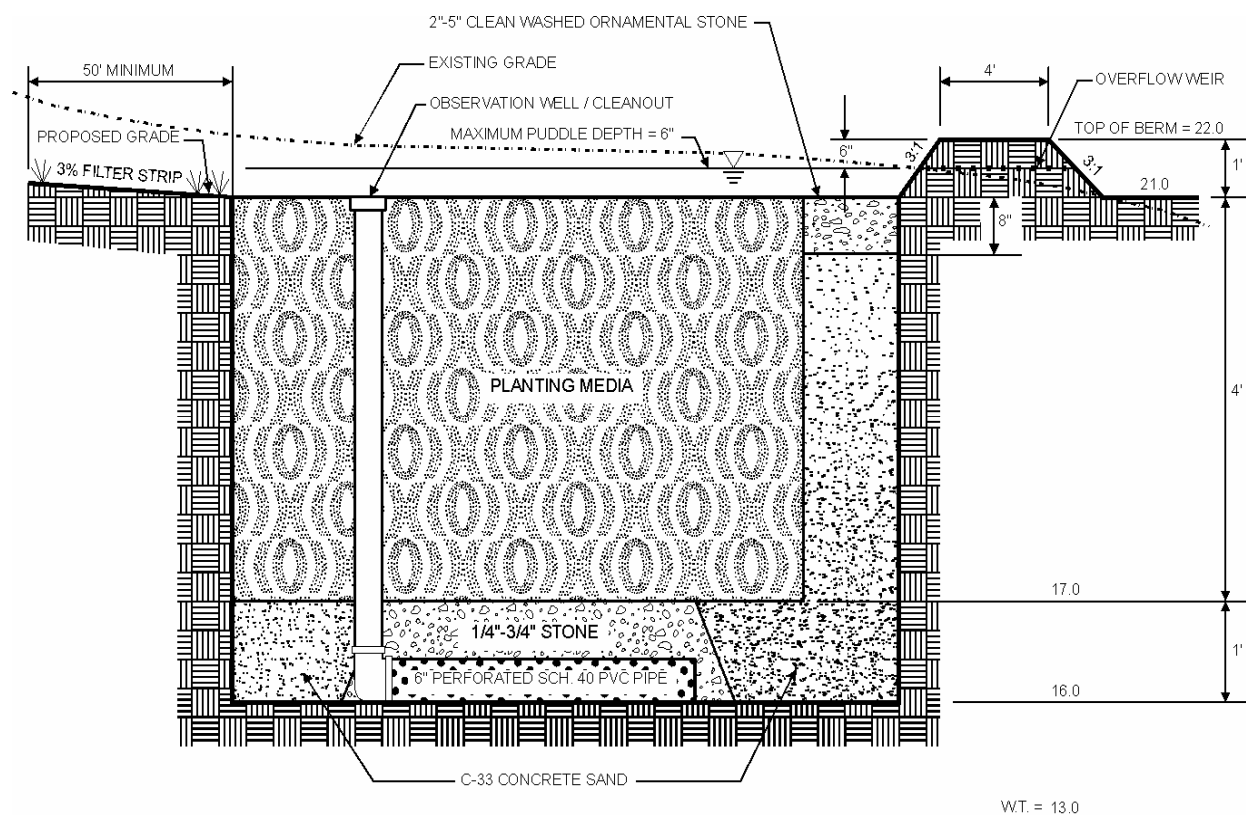


Figure 6. Typical Section of Bioretention Facility

Step 9 -- Design pretreatment

Pretreat with a grass channel, based on guidance provided in Table 5.2.3-1, below. For a 3.0 acre drainage area, 63% imperviousness, and slope less than 2.0%, provide a 90' grass channel at 1.5% slope. The value from Table 5.2.3-1 is 30' for a one acre drainage area.

Table 5.2.3-1 Pretreatment Grass Channel Guidance for 1.0 Acre Drainage Area (Adapted from Claytor and Schueler, 1996)							
Parameter	≤ 33% Impervious		Between 34% & 66% Impervious		≥ 67% Impervious		Notes
Slope	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	Max slope = 4%
Grassed channel min. length (feet)	25	40	30	45	35	50	Assumes a 2' wide bottom width

Step 10 -- Size underdrain area

Base underdrain design on 10% of the A_f or 772 sq ft. Using 6" perforated plastic pipes surrounded by a three-foot-wide gravel bed, 10' on center (o.c.). See Figures 5 and 6.

(772 sq ft)/3' per foot of underdrain = 257', say 260' of perforated underdrain

Step 11 -- Design emergency overflow

To ensure against the planting media clogging, design a small ornamental stone window of 2" to 5" stone connected directly to the sand filter layer. This area is based on 5% of the A_f or 386 sq ft. Say 14' by 28'. See Figures 5 and 6.

The parking area, curb and gutter are sized to convey the 25-year event to the facility. Should filtering rates become reduced due to facility age or poor maintenance, an overflow weir is provided to pass the 25-year event. Size this weir with 6" of head, using the weir equation.

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

Where C = 2.65 (smooth crested grass weir)

$$Q = 25.0 \text{ cfs}$$

$$H = 6"$$

$$\text{Solve for L: } L = Q / [(C) (H^{3/2})] \text{ or } (25.0 \text{ cfs}) / [(2.65) (.5)^{1.5}] = 26.7' \text{ (say 27')}$$

Outlet protection in the form of riprap or a plunge pool/stilling basin should be provided to ensure non-erosive velocities. See Figures 5 and 6.

Step 12 -- Prepare Vegetation and Landscaping Plan

Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Select species locations (i.e., on center planting distances) so species will not "shade out" one another. Do not plant trees and shrubs with extensive root systems near pipe work. A potential plant list is presented in Appendix F.

D.3 Sand Filter Design Example

This example focuses on the design of a surface sand filter to meet the water quality treatment requirements of the Falcon Creek Community Center. The design options chosen for this example are Option 1 for Water Quality Protection (WQ_v), Option 4 for Streambank Protection (SP_v), and Option 4 for Flood Control (Q_{p100}). Streambank Protection and Flood Control are not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of sand filters is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). The layout of the Falcon Creek Community Center is shown in Figure 1.

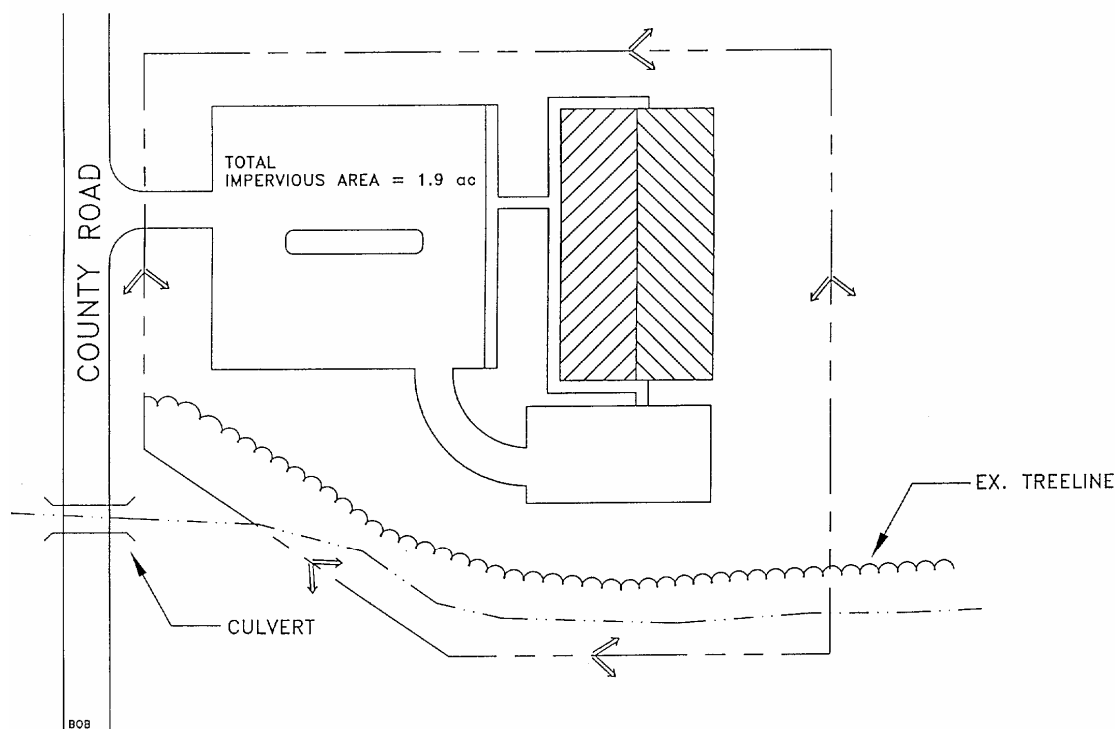


Figure 1. Falcon Creek Community Center Site Plan

Base Data		Hydrologic Data	
Site Area = Total Drainage Area (A) = 3.0 ac		CN	Pre 78 Post 91
Impervious Area = 1.9 ac; or $I = 1.9/3.0 = 63.3\%$		t_c	0.41hr 0.16 hr
Soils Type "D" Dallas County			

Computation of Preliminary Storm Water Storage Volumes and Peak Discharges

Step 1 -- Compute runoff control volumes from the *integrated* Design Approach

Compute Water Quality Volume (WQ_v):

- Compute Runoff Coefficient, R_v

$$R_v = 0.05 + (63.3) (0.009) = 0.62$$

- Compute WQ_v

$$\begin{aligned} WQ_v &= (1.5") (R_v) (A) / 12 \\ &= (1.5") (0.62) (3.0 \text{ ac}) (43,560 \text{ ft}^2/\text{ac}) (1\text{ft}/12\text{in}) \\ &= 8,102 \text{ ft}^3 = 0.186 \text{ ac-ft} \end{aligned}$$

Compute Stream Streambank Protection Volume, (SP_v):

For stream streambank protection, provide 24 hours of extended detention for the 1-year event.

- Develop Site Hydrologic and Hydrologic Input Parameters and Perform Preliminary Hydrologic Calculations

Per Figures 2 and 3. Note that any hydrologic models using SCS procedures, such as TR-20, HEC-HMS, or HEC-1, can be used to perform preliminary hydrologic calculations

Condition	CN	Q _{1-year}	Q _{1-year}	Q _{100 year}
		<i>Inches</i>	<i>cfs</i>	<i>cfs</i>
Pre-developed	78	0.88	2.2	20.0
Post-Developed	91	1.74	7.3	39.0

- Utilize modified TR-55 approach to compute streambank protection storage volume

Initial abstraction (I_a) for CN of 91 is 0.198: (TR-55) [I_a = (200/CN - 2)]

$$I_a/P = (0.198) / 2.64 \text{ inches} = 0.075$$

$$T_c = 0.16 \text{ hours}$$

$$q_u = 900 \text{ csm/in}$$

Knowing q_u and T (extended detention time), find q_o/q_i for a Type II rainfall distribution.

$$\text{Peak outflow discharge/peak inflow discharge } (q_o/q_i) = 0.02$$

$$V_s/V_r = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$$

Where V_s equals streambank protection storage (SP_v) and V_r equals the volume of runoff in inches.

$$V_s/V_r = 0.655$$

$$\text{Therefore, } V_s = SP_v = 0.655(1.74")(1/12)(3 \text{ ac}) = 0.285 \text{ ac-ft} = 12,415 \text{ ft}^3$$

- Define the average extended detention Release Rate

The above volume, 0.30 ac-ft, is to be released over 24 hours.

$$(0.30 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac}) / (24 \text{ hrs} \times 3,600 \text{ sec/hr}) = 0.15 \text{ cfs}$$

Analyze for Safe Passage of 100 Year Design Storm (Q_f):

At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure, typically the same one used for the 25-year storm flood protection control.

Table 1. Summary of General Design Information for Falcon Creek Community Center			
Symbol	Control Volume	Volume Required (cubic feet)	Notes
WQ_v	Water Quality	8,102	
SP_v	Streambank Protection	12,415	
Q_f	Extreme Flood Protection	NA	Provide safe passage for the 100-year event in final design

PEAK DISCHARGE SUMMARY				
JOB:	Falcon Creek Center			EWB
DRAINAGE AREA NAME:	Pre-Developed Conditions			3-Jan-00
COVER DESCRIPTION	SOIL GROUP A, B, C, D?	C from TABLE 2.1.4-2	CN from TABLE 2.1.5-1	AREA (in acres)
meadows (good cond.)	D		78	2.40
woods (good cond.)	D		77	0.60
AREA SUBTOTALS:				3.00
Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.6"	Cross Section	Wetted Per	Avg Velocity	Tt (hrs)
Sheet Flow	Dense grass	'n' = 0.24	150 ft	2.50%
				0.35 hrs
Shallow Flow	unpaved		500 ft	2.00%
			2.28 fps	0.06 hrs
Channel Flow Hydraulic Radius				
Total Area in Acres =	3.00	Total Sheet	Total Shallow	Total Channel
Weighted CN =	78	Flow =	Flow =	Flow =
Time of Concentration =	0.41 hrs	0.35 hrs.	0.06 hrs.	0.00 hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE (cfs)	
1 Year	2.64	0.88	2.2	
2 Year	3.60	1.57	4.2	
5 Year	4.8	2.54	6.9	
10 Year	5.76	3.37	9.3	
25 Year	7.20	4.66	13.0	
50 Year	8.40	5.76	17.0	
100 Year	9.6	6.98	20.0	

Figure 2. Falcon Creek Community Center Pre-Developed Conditions

PEAK DISCHARGE SUMMARY				
JOB:	Falcon Creek Center			EWB
DRAINAGE AREA NAME:	Post-Developed Conditions			3-Jan-00
COVER DESCRIPTION	SOIL GROUP A, B, C, D?	C from TABLE 2.1.4-2	CN from TABLE 2.1.5-1	AREA (in acres)
open space (good cond.)	D		78	0.50
woods (good cond.)	D		77	0.60
impervious	D		98	1.90
AREA SUBTOTALS:				3.00
Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.6"	Cross Section	Wetted Per	Avg Velocity	Tt (hrs)
Sheet Flow	short grass	'n' = 0.15	50 ft	1.50%
				0.10 hrs
Shallow Flow	paved		600 ft	2.00%
			2.87 fps	0.06 hrs
Channel Flow Hydraulic Radius= 0.75		'n' = 0.024	50 ft	2.00%
	X-S estimated	WP estimated	7.25 fps	0.00hrs
Total Area in Acres =	3.00	Total Sheet	Total Shallow	Total Channel
Weighted CN =	91	Flow =	Flow =	Flow =
Time of Concentration =	0.16 hrs	0.10 hrs.	0.06 hrs.	0.00 hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE (cfs)	
1 Year	2.64	1.74	7.3	
2 Year	3.60	2.64	11.0	
5 Year	4.8	3.79	17.0	
10 Year	5.76	4.72	21.0	
25 Year	7.20	6.14	27.0	
50 Year	8.40	7.32	33.0	
100 Year	9.6	8.51	39.0	

Figure 3. Falcon Creek Community Center Post-Developed Conditions

Step 2 -- Determine if the development site and conditions are appropriate for the use of a surface sand filter.

Site Specific Data:

Existing ground elevation at the facility location is 22.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 13.0 feet. Adjacent creek invert is at 12.0.

Step 3 -- Confirm local design criteria and applicability.

There are no additional requirements for this site.

Step 4 -- Compute WQ_v , peak discharge (Q_{wq}) & Head

- Water Quality Volume:

WQ_v previously determined to be 8,102 cubic feet.

- Determine available head (See Figure 5)

Low point at parking lot is 23.5. Subtract 2' to pass Q_{100} discharge (39) and a half foot for channel to facility (21.0). Low point at stream invert is 12.0. Set outfall underdrain pipe 2' above stream invert and add 0.5' to this value for drain (14.5). Add to this value 8" for the gravel blanket over the underdrains, and 18" for the sand bed (16.67). The total available head is 21.0 - 16.67 or 4.33 feet. Therefore, the average depth, h_f , is $(h_f) = 4.33' / 2$, and $h_f = 2.17'$.

The peak rate of discharge for the water quality design storm is needed for the sizing of off-line diversion structures, such as sand filters and grass channels. Conventional SCS methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2". This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff bypasses the filtering treatment practice due to an inadequately sized diversion structure and leads to the design of undersized bypass channels.

The following procedure can be used to estimate peak discharges for small storm events. It relies on the volume of runoff computed using the Small Storm Hydrology Method (Pitt, 1994) and utilizes the NRCS, TR-55 Graphical Peak Discharge Method (USDA, 1986). A brief description of the calculation procedure is presented below.

- Using the water quality volume (WQ_v), a corresponding Curve Number (CN) is computed utilizing the following equation:

$$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25QP)^{1/2}]$$

where P = rainfall, in inches (use 1.5" for the Water Quality Storm)
and Q = runoff volume, in inches (equal to $WQ_v \div \text{area}$)

- Once a CN is computed, the time of concentration (t_c) is computed
- Using the computed CN, t_c and drainage area (A), in acres; the peak discharge (Q_{wq}) for the Water Quality Storm is computed (based on the procedures identified in Section 2.1 (typically Type II in the North Central Texas region).
 - Read initial abstraction (I_a), compute I_a/P
 - Read the unit peak discharge (q_u) for appropriate t_c

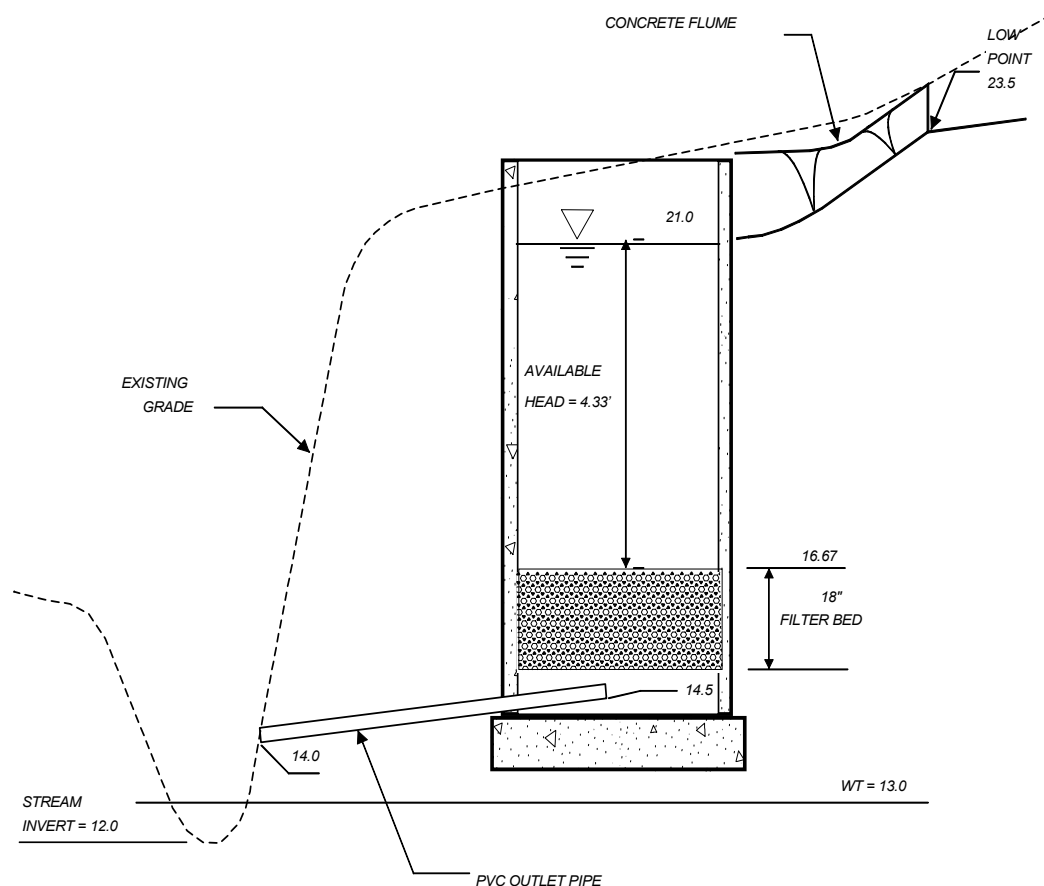


Figure 5. Available Head Diagram

- Using the water quality volume (WQ_v), compute the water quality peak discharge (Q_{wq})

$$Q_{wq} = q_u \cdot A \cdot WQ_v$$

where

Q_{wq} = the peak discharge, in cfs

q_u = the unit peak discharge, in cfs/mi²/inch

A = drainage area, in square miles

WQ_v = Water Quality Volume, in watershed inches

For this example, the steps are as follows:

Compute modified CN for 1.5" rainfall

$P = 1.5"$

$Q = WQ_v \div \text{area} = (8,102 \text{ ft}^3 \div 3 \text{ ac} \div 43,560 \text{ ft}^2/\text{ac} \times 12 \text{ in/ft}) = 0.74"$

$CN = \frac{1000}{[10+5P+10Q-10(Q^2+1.25*Q*P)^{1/2}]}$
 $= \frac{1000}{[10+5*1.5+10*0.74-10(0.74^2+1.25*0.74*1.5)^{1/2}]}$
 $= 95.01$

Use $CN = 95$

For $CN = 95$ and the $T_c = 0.16$ hours, compute the Q_p for a 1.5" storm. With the $CN = 95$, a 1.5" storm will produce 0.74" of runoff. $I_a = 0.105$, therefore $I_a/P = 0.105/1.5 = 0.088$. From Section 2.1, $q_u = 625$ csm/in, and therefore $Q_{wq} = (900 \text{ csm/in}) (3.0 \text{ ac}/640 \text{ ac/sq mi.}) (0.74") = \underline{3.1 \text{ cfs}}$.

Step 5 -- Size flow diversion structure (see Figure 6):

Size a low flow orifice to pass 3.1 cfs with 1.5' of head using the Orifice equation.

$$Q = CA(2gh)^{1/2}; 3.1 \text{ cfs} = (0.6) (A) [(2) (32.2 \text{ ft/s}^2) (1.5')]^{1/2}$$

$$A = 0.53 \text{ sq ft} = \pi d^2/4; d = 0.8' \text{ or } 9.8"; \underline{\text{use 10 inches}}$$

Size the 100-year overflow as follows: the 100-year wsel is set at 23.0. Use a concrete weir to pass the 100-year flow (39.0 cfs) into a grassed overflow channel using the Weir equation. Assume 2' of head to pass this event. Overflow channel should be designed to provide sufficient energy dissipation (e.g., riprap, plunge pool, etc.) so that there will be non-erosive velocities.

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

$$39 = 3.1 (L) (2')^{1.5}$$

$$L = 4.45'; \underline{\text{use } L = 4'-5''} \text{ which sets flow diversion chamber dimension.}$$

$$\text{Weir wall elev.} = 21.0. \text{ Set low flow invert at } 21.0 - [1.5' + (0.5 \times 10'' \times 1 \text{ ft}/12'')] = 19.08.$$

Step 6 -- Size filtration bed chamber (see Figure 7):

From Darcy's Law: $A_f = WQ_v (d_f) / [k (h_f + d_f) (t_f)]$

where $d_f = 18''$

$$k = 3.5 \text{ ft/day}$$

$$h_f = 2.17'$$

$$t_f = 40 \text{ hours}$$

$$A_f = (8,102 \text{ cubic feet}) (1.5') / [3.5 (2.17' + 1.5') (40 \text{ hr}/(24 \text{ hr/day}))]$$

$$A_f = \underline{567.7 \text{ sq ft}}; \text{ using a 2:1 ratio, say filter is } \underline{17' \text{ by } 34'} (= 578 \text{ sq ft})$$

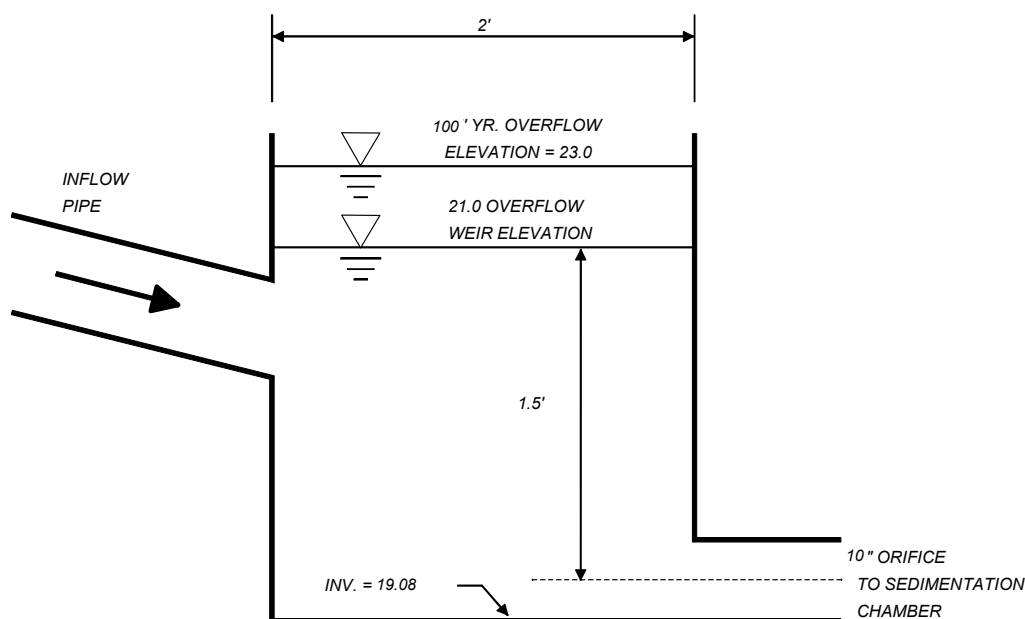


Figure 6. Flow Diversion Structure

Step 7-- Size sedimentation chamber

From Camp-Hazen equation, for $I < 75\%$: $A_s = 0.066 (WQ_v)$

$A_s = 0.066 (8,102 \text{ cubic ft})$ or 535 sq ft

given a width of 17 feet, the length will be $535'/17'$ or 31.5 feet (use 17' x 32')

Step 8 -- Compute V_{\min}

$V_{\min} = \frac{3}{4}(WQ_v)$ or $0.75 (8,102 \text{ cubic feet}) = \underline{6,077 \text{ cubic feet}}$

Step 9 -- Compute storage volumes within entire facility and sedimentation chamber orifice size:

Volume within filter bed (V_f): $V_f = A_f (d_f) (n)$; $n = 0.4$ for sand
 $V_f = (578 \text{ sq ft}) (1.5') (0.4) = \underline{347 \text{ cubic feet}}$

Temporary storage above filter bed ($V_{f\text{-temp}}$): $V_{f\text{-temp}} = 2 h_f A_f$
 $V_{f\text{-temp}} = 2 (2.17') (578 \text{ sq ft}) = \underline{2,509 \text{ cubic feet}}$

Compute remaining volume for sedimentation chamber (V_s):
 $V_s = V_{\min} - [V_f + V_{f\text{-temp}}]$ or $6,077 - [347 + 2,509] = \underline{3,221 \text{ cubic feet}}$

Compute height in sedimentation chamber (h_s): $h_s = V_s/A_s$

$(3,221 \text{ cubic ft}) / (17' \times 32') = 5.9'$ which is larger than the head available (4.33'); increase the size of the settling chamber, using 4.33' as the design height;

$(3,221 \text{ cubic ft}) / 4.33' = 744 \text{ sq ft}$; $744' / 17'$ yields a length of 43.8 feet (say 44')

New sedimentation chamber dimensions are 17' by 44'

With adequate preparation of the bottom of the settling chamber (rototil earth, place gravel, then surge stone), the bottom can infiltrate water into the substrate. The runoff will enter the groundwater directly without treatment. The stone will eventually clog without protection from settling solids, so use a removable geotextile to facilitate maintenance. Note that there is 2.17' of freeboard between bottom of recharge filter and water table.

Provide perforated standpipe with orifice sized to release volume (within sedimentation basin) over a 24 hr period (see Figure 8). Average release rate equals $3,221 \text{ ft}^3 / 24 \text{ hr} = 0.04 \text{ cfs}$

Equivalent orifice size can be calculated using orifice equation:

$Q = CA(2gh)^{1/2}$, where h is average head, or $4.33' / 2 = 2.17'$.

$0.04 \text{ cfs} = 0.6 * A * (2 * 32.2 \text{ ft/s}^2 * 2.17 \text{ ft})^{1/2}$

$A = 0.005 \text{ ft}^2 = \pi D^2 / 4$: therefore equivalent orifice diameter equals 1".

Recommended design is to cap stand pipe with low flow orifice sized for 24 hr detention. Over-perforate pipe by a safety factor of 10 to account for clogging. Note that the size and number of perforations will depend on the release rate needed to achieve 24 hr detention. A multiple orifice stage-discharge relation needs to be developed for the proposed perforation configuration. Stand pipe should discharge into a flow distribution chamber prior to filter bed. Distribution chamber should be between 2 and 4 feet in length and same width as filter bed. Flow distribution to the filter bed can be achieved either with a weir or multiple orifices at constant elevation. See Figure 9 for stand pipe details.

Step 10 -- Design inlets, pretreatment facilities, underdrain system, and outlet structures

Step 11. Compute overflow weir sizes

Assume overflow that needs to be handled is equivalent to the 10" orifice discharge under a head of 3.5 ft (i.e., the head in the diversion chamber associated with the 100-year peak discharge).

$Q = CA(2gh)^{1/2}$

$Q = 0.6(0.55 \text{ ft}^2)[(2)(32.2 \text{ ft/s}^2)(3.5 \text{ ft})]^{1/2}$

$Q = 4.91 \text{ cfs}$, say 5.0 cfs

For the overflow from the sediment chamber to the filter bed, size to pass 5 cfs.

Weir equation: $Q = CLh^{3/2}$, assume a maximum allowable head of 0.5'

$5.0 = 3.1 * L * (0.5 \text{ ft})^{3/2}$

$L = 4.56 \text{ ft}$, Use $L = 4.75 \text{ ft}$.

Similarly, for the overflow from the filtration chamber to the outlet of the facility, size to pass 5.0 cfs.

Weir equation: $Q = CLh^{3/2}$, assume a maximum allowable head of 0.5'

$5.0 = 3.1 * L * (0.5 \text{ ft})^{3/2}$

$L = 4.56 \text{ ft}$, Use $L = 4.75 \text{ ft}$.

Adequate outlet protection and energy dissipation (e.g., riprap, plunge pool, etc.) should be provided for the downstream overflow channel.

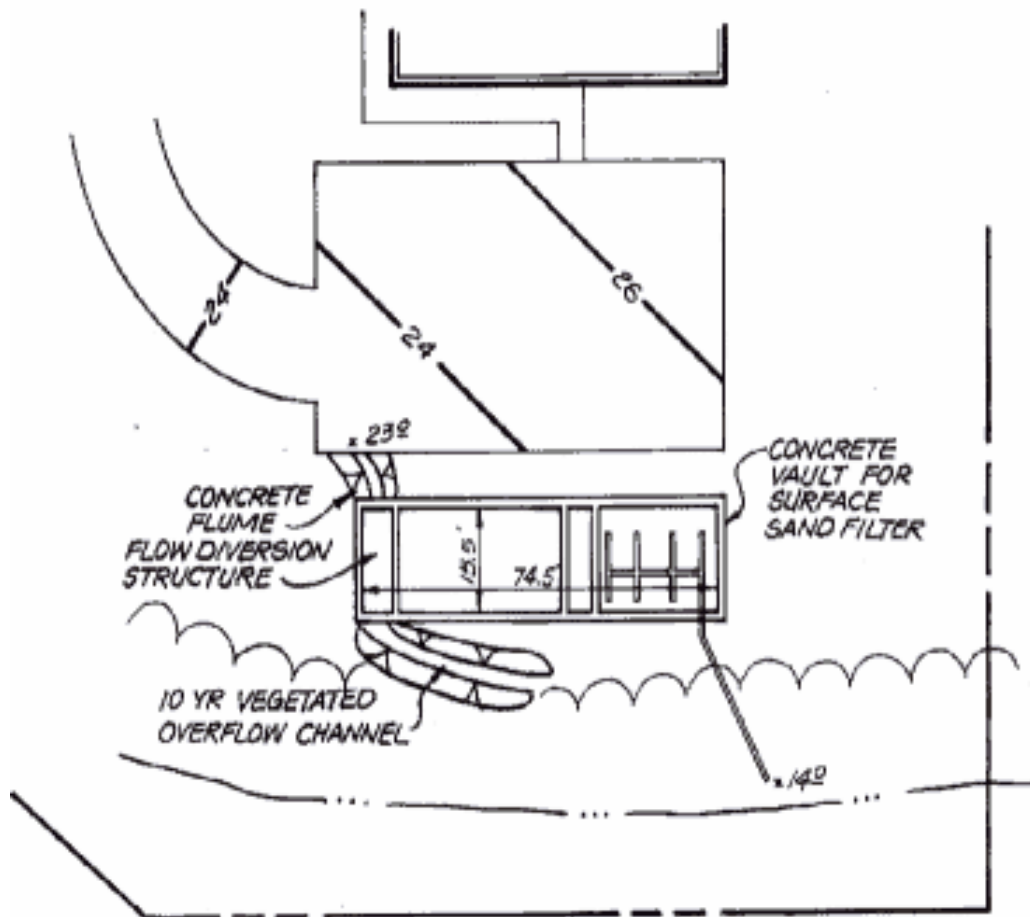


Figure 7. Surface Sand Filter Site Plan

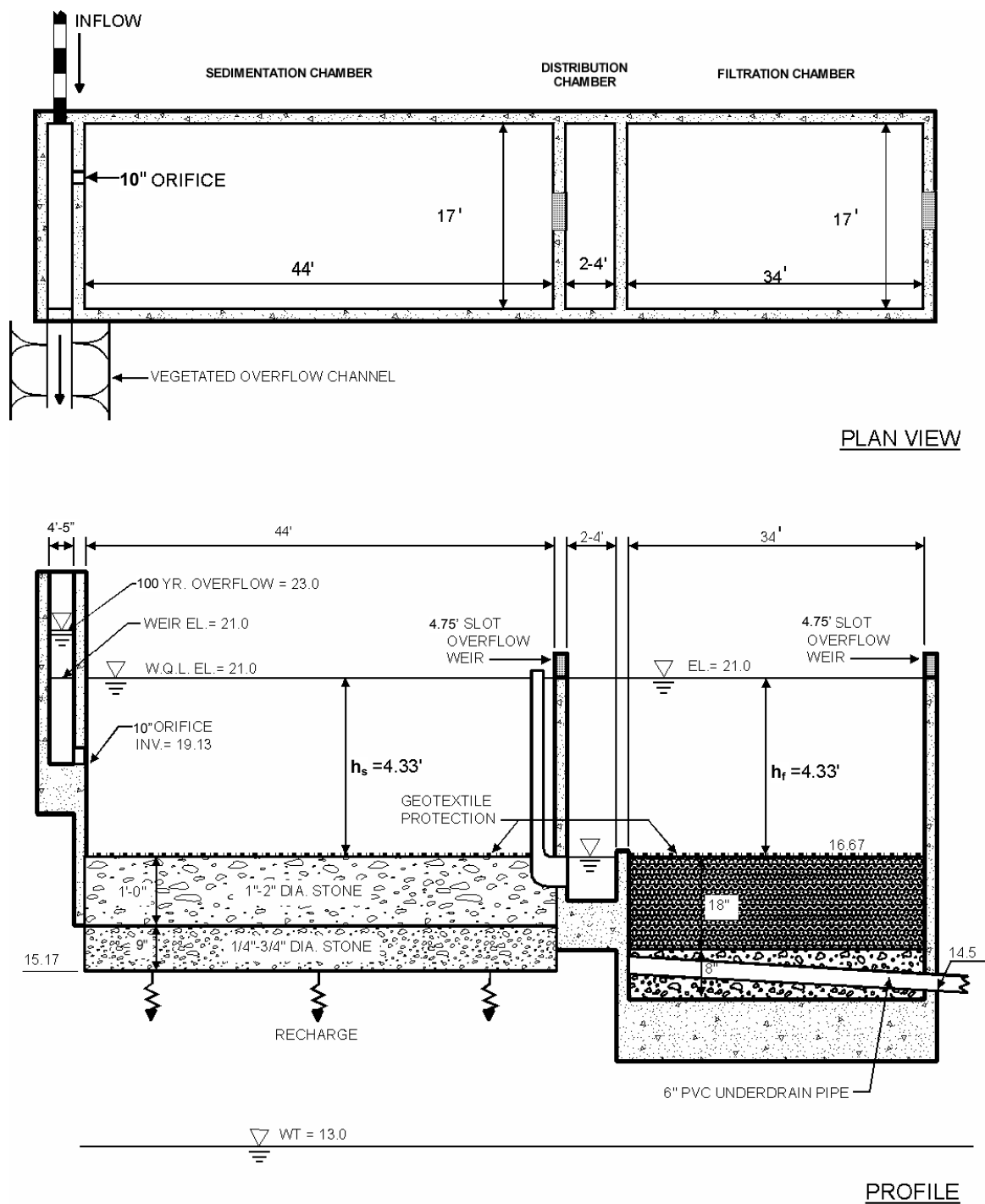


Figure 8. Plan and Profile of Surface Sand Filter

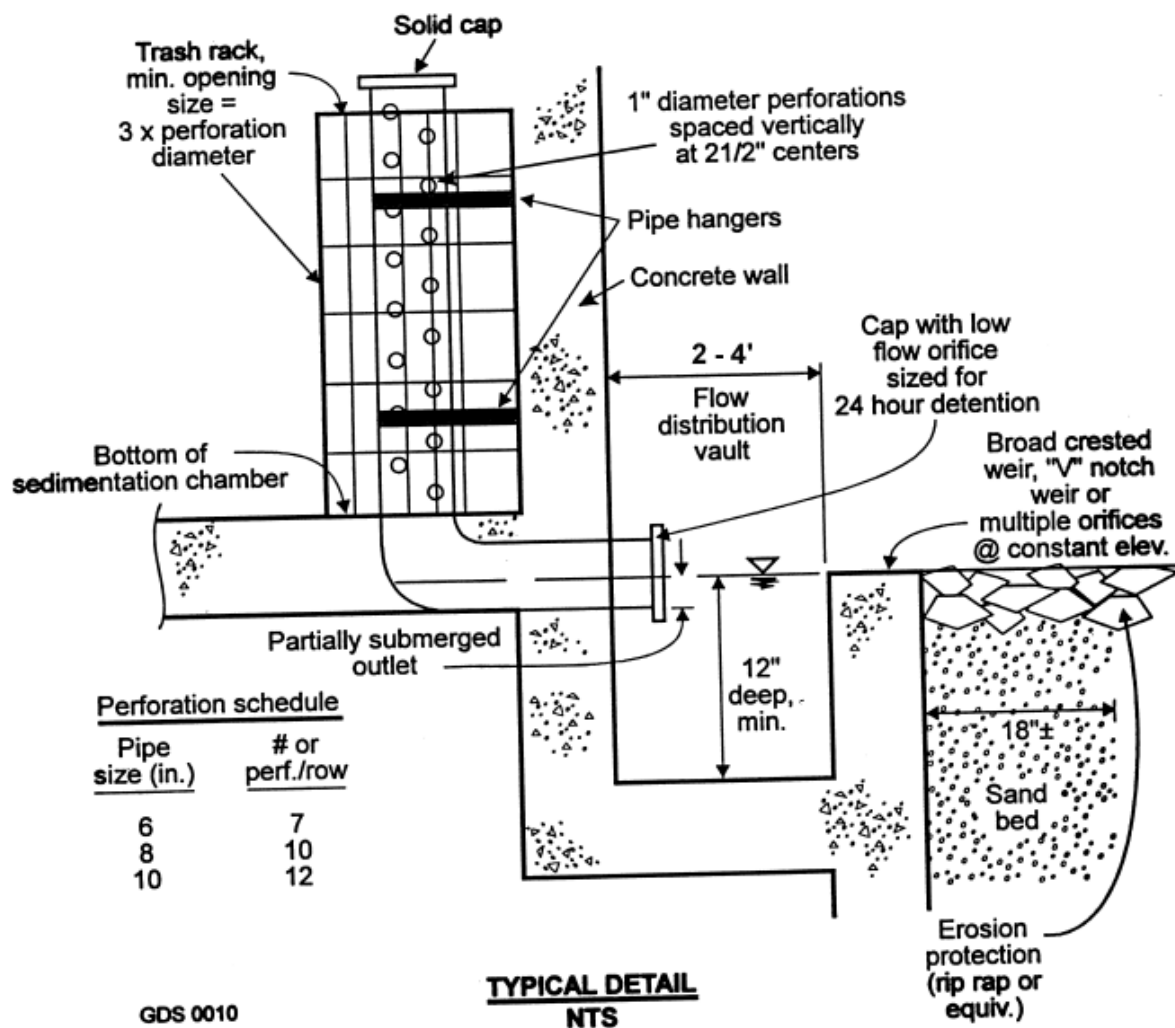


Figure 9. Perforated Stand Pipe Detail

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D.4 Infiltration Trench Design Example

This example focuses on the design of an infiltration trench to meet the water quality treatment requirements of the site. The design options chosen for this example are Option 1 for Water Quality Protection (WQ_v), Option 4 for Streambank Protection (SP_v), and Option 4 for Flood Control (Q_{p100}). Streambank Protection and Flood Control are not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of infiltration trenches is to provide water quality treatment and groundwater recharge and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). The layout of the Cottonwood Creek Community Center is shown in Figure 1.

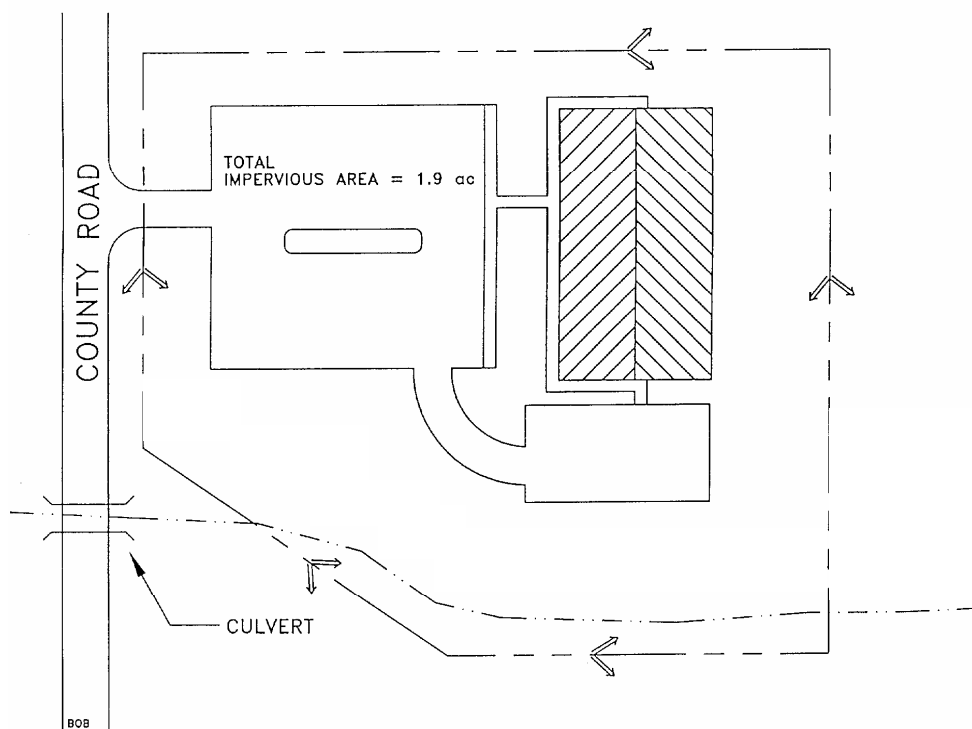


Figure 1. Cottonwood Creek Community Center Site Plan

Base Data		Hydrologic Data	
Site Area = Total Drainage Area (A) = 3.0 ac		CN	Pre 55
Impervious Area = 1.9 ac; or $I = 1.9/3.0 = 63.3\%$			Post 82
Soils Type "B" Wise County		t_c	0.42 hr
			0.16 hr

Step 1 -- Compute runoff control volumes from the *integrated* Design Approach**Compute Water Quality Volume (WQ_v):**

- Compute Runoff Coefficient, R_v

$$R_v = 0.05 + (63.3) (0.009) = 0.62$$

- Compute WQ_v

$$\begin{aligned} WQ_v &= (1.5") (R_v) (A) / 12 \\ &= (1.5") (0.62) (3.0 \text{ ac}) (43,560 \text{ ft}^2/\text{ac}) (1\text{ft}/12\text{in}) \\ &= 8,102 \text{ ft}^3 = 0.186 \text{ ac-ft} \end{aligned}$$

Compute Stream Streambank Protection Volume, (SP_v):

For stream streambank protection, provide 24 hours of extended detention for the 1-year event.

- Develop Site Hydrologic and Hydrologic Input Parameters and Perform Preliminary Hydrologic Calculations

Per Figures 2 and 3. Note that any hydrologic models using SCS procedures, such as TR-20, HEC-HMS, or HEC-1, can be used to perform preliminary hydrologic calculations

Condition	CN	Q _{1-year}	Q _{1-year}	Q _{100 year}
		<i>Inches</i>	<i>cfs</i>	<i>cfs</i>
Pre-developed	55	0.11	0.1	8.9
Post-Developed	82	1.1	4.4	29.0

- Utilize modified TR-55 approach to compute streambank protection storage volume

Initial abstraction (I_a) for CN of 82 is 0.44: (TR-55) [I_a = (200/CN - 2)]

$$I_a/P = (0.44)/2.64 \text{ inches} = 0.17$$

$$T_c = 0.17 \text{ hours}$$

$$q_u = 850 \text{ csm/in}$$

Knowing q_u and T (extended detention time), find q_o/q_i for a Type II rainfall distribution.

$$\text{Peak outflow discharge/peak inflow discharge } (q_o/q_i) = 0.02$$

$$V_s/V_r = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$$

Where V_s equals streambank protection storage (SP_v) and V_r equals the volume of runoff in inches.

$$V_s/V_r = 0.655$$

$$\text{Therefore, } V_s = SP_v = 0.655(1.10")(1/12)(3 \text{ ac}) = 0.18 \text{ ac-ft} = 7,841 \text{ ft}^3$$

- Define the average extended detention Release Rate

The above volume, 0.18 ac-ft, is to be released over 24 hours.

$$(0.18 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac}) / (24 \text{ hrs} \times 3,600 \text{ sec/hr}) = 0.09 \text{ cfs}$$

Analyze for Safe Passage of 100 Year Design Storm (Q_f):

At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure.

Table 1 Summary of General Design Information for Falcon Creek Community Center			
Symbol	Control Volume	Volume Required (cubic feet)	Notes
WQ_v	Water Quality	8,102	
SP_v	Streambank Protection	7,841	
Q_f	Flood Protection	NA	Provide safe passage for the 100-year event in final design

Figure 2. Cottonwood Creek Community Center Pre-Developed Conditions

Figure 3. Cottonwood Creek Community Center Post-Developed Conditions

Step 2 -- Determine if the development site and conditions are appropriate for the use of an infiltration trench

Site Specific Data:

Table 2 presents site-specific data, such as soil type, percolation rate, and slope, for consideration in the design of the infiltration trench.

Table 2 Site Specific Data	
Criteria	Value
Soil	Sandy Loam
Percolation Rate	1"/hour
Ground Elevation at BMP	20'
Seasonally High Water Table	13'
Stream Invert	12'
Soil slopes	<1%

Step 3 -- Confirm local design criteria and applicability

Table 3, below, summarizes the requirements that need to be met to successfully implement infiltration practices. On this site, infiltration is feasible, with restrictions on the depth and width of the trench.

Table 3 Infiltration Feasibility	
Criteria	Status
Infiltration rate (f_c) greater than or equal to 0.5 inches/hour.	Infiltration rate is 1.0 inches/hour. OK.
Soils have a clay content of less than 20% and a silt/clay content of less than 40%.	Sandy Loam meets both criteria.
Infiltration cannot be located on slopes greater than 6% or in fill soils.	Slope is <1%; not fill soils. OK.
Hotspot runoff should not be infiltrated.	Not a hotspot land use. OK.
Infiltration is prohibited in karst topography.	Not in karst. OK.
The bottom of the infiltration facility must be separated by at least two feet vertically from the seasonally high water table.	Elevation of seasonally high water table: 13' Elevation of BMP location: 20'. The difference is 7'. Thus, the trench can be up to 5' deep. OK.
Infiltration facilities must be located 100 feet horizontally from any water supply well.	No water supply wells nearby. OK.
Maximum contributing area generally less than 5 acres. (Optional)	3 acres. OK.
Setback 25 feet down-gradient from structures.	Fifty feet straight-line distance between the parking lot and the tree line. OK if the trench is 25' wide or narrower.

Step 4 -- Compute WQ_v peak discharge (Q_{wq})

- Compute Water Quality Volume:

WQ_v previously determined to be 8,102 cubic feet.

The peak rate of discharge for the water quality design storm is needed for the sizing of off-line diversion structures, such as sand filters and grass channels. Conventional SCS methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2". This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the filtering treatment practice due to an inadequately sized diversion structure or leads to the design of undersized grass channels.

The following procedure can be used to estimate peak discharges for small storm events. It relies on the volume of runoff computed using the Small Storm Hydrology Method (Pitt, 1994) and utilizes the NRCS, TR-55 Graphical Peak Discharge Method (USDA, 1986). A brief description of the calculation procedure is presented below.

$$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25 QP)^{1/2}]$$

where P = rainfall, in inches (use 1.5" for the Water Quality Storm)

and Q = runoff volume, in inches (equal to $WQ_v \div \text{area}$)

- Once a CN is computed, the time of concentration (t_c) is computed (based on the methods identified in TR-55, Chapter 3: "Time of concentration and travel time").
- Using the computed CN, t_c and drainage area (A), in acres; the peak discharge (Q_{wq}) for the Water Quality Storm is computed (based on the procedures identified in TR-55, Chapter 4: "Graphical Peak Discharge Method"). Use appropriate rainfall distribution type (typically Type II in the North Central Texas region).
 - Read initial abstraction (I_a), compute I_a/P
 - Read the unit peak discharge (q_u) for appropriate t_c
 - Using the water quality volume (WQ_v), compute the peak discharge (Q_{wq})

$$Q_{wq} = q_u * A * WQ_v$$

where

Q_{wq} = the peak discharge, in cfs

q_u = the unit peak discharge, in cfs/mi²/inch

A = drainage area, in square miles

WQ_v = Water Quality Volume, in watershed inches

For this example, the steps are as follows:

Compute modified CN for 1.5" rainfall

$P = 1.5"$

$Q = WQ_v \div \text{area} = (8,102 \text{ ft}^3 \div 3 \text{ ac} \div 43,560 \text{ ft}^2/\text{ac} \times 12 \text{ in/ft}) = 0.74"$

$$\begin{aligned} CN &= 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25*Q*P)^{1/2}] \\ &= 1000/[10 + 5*1.5 + 10*0.74 - 10(0.74^2 + 1.25*0.74*1.5)^{1/2}] \\ &= 91.1 \end{aligned}$$

Use CN = 91

For CN = 91 and the $T_c = 0.16$ hours, compute the Q_{wq} for a 1.5" storm. With the CN = 91, a 1.5" storm will produce 0.74" of runoff. $I_a = 0.198$, therefore $I_a/P = 0.198/1.5 = 0.132$. $q_u = 825 \text{ csm/in}$, and

therefore:

$$Q_{wq} = (825 \text{ csm/in}) (3.0 \text{ ac}/640 \text{ ac/sq mi.}) (0.74") = \underline{2.86 \text{ cfs.}}$$

Step 5 -- Size the infiltration trench

The area of the trench can be determined by the following equation:

$$A = \frac{WQ_v}{(nd + kT / 12)}$$

Where:

A = Surface Area

n = porosity

d = trench depth (feet)

k = percolation (inches/hour)

T = Fill Time (time for the practice to fill with water), in hours

Assume that:

n = 0.32

d = 5 feet (see above; feasibility criteria)

k = 1 inch/hour (see above; site data)

T = 2 hours

Therefore:

$$A = 8,102 \text{ ft}^3 / (0.32 \times 5 + 1 \times 2/12) \text{ ft}$$

$$A = 4,586 \text{ ft}^2$$

Since the width can be no greater than 25' (see above; feasibility), determine the length:

$$L = 4,586 \text{ ft}^2 / 25 \text{ ft}$$

$$L = 183 \text{ feet}$$

Assume that 1/3 of the runoff from the site drains to Point A and 2/3 drains to Point B. Use an L-shaped trench in the corner of the site (see Figure 4 for a site plan view). The surface area of the trench is proportional to the amount of runoff it drains (e.g., the portion draining from Point A is half as large as the portion draining Point B).

Step 6 -- Size the flow diversion structures

Since two entrances are used, two flow diversions are needed.

For the entire site:

$Q_{100\text{-year}} = 29 \text{ cfs}$ (See Figure 3)

Peak flow for $WQ_v = 2.86 \text{ cfs.}$ (Step 3).

For the first diversion (Point A)

Assume peak flow equals 1/3 of the value for the entire site.

Thus, $Q_{100\text{-year}} = 29/3 = 9.7 \text{ cfs}$

Peak flow for $WQ_v = 2.86/3 = 0.95 \text{ cfs}$

Size the low flow orifice to pass 0.95 cfs with 1.5' of head using the Orifice equation.

$$Q = CA(2gh)^{1/2}; 0.95 \text{ cfs} = 0.6A(2 \times 32.2 \text{ ft/s}^2 \times 1.5')^{1/2}$$

$$A = 0.16 \text{ sq. ft.} = \pi d^2/4; d = 0.45'; \text{ use 6" pipe with 6" gate valve}$$

Size the 100-year overflow weir crest at 22.5'. Use a concrete weir to pass the 100-year flow ($9.7 - 0.95 = 8.75$ cfs). Assume 1 foot of head to pass this event. Size using the weir equation.

$$Q = CLH^{1.5}; L = Q/(CH^{1.5})$$

$$L = 8.75 \text{ cfs} / (3.1)(1)^{1.5} = 2.8'; \text{ use } 2.8' \text{ (see Figure 5)}$$

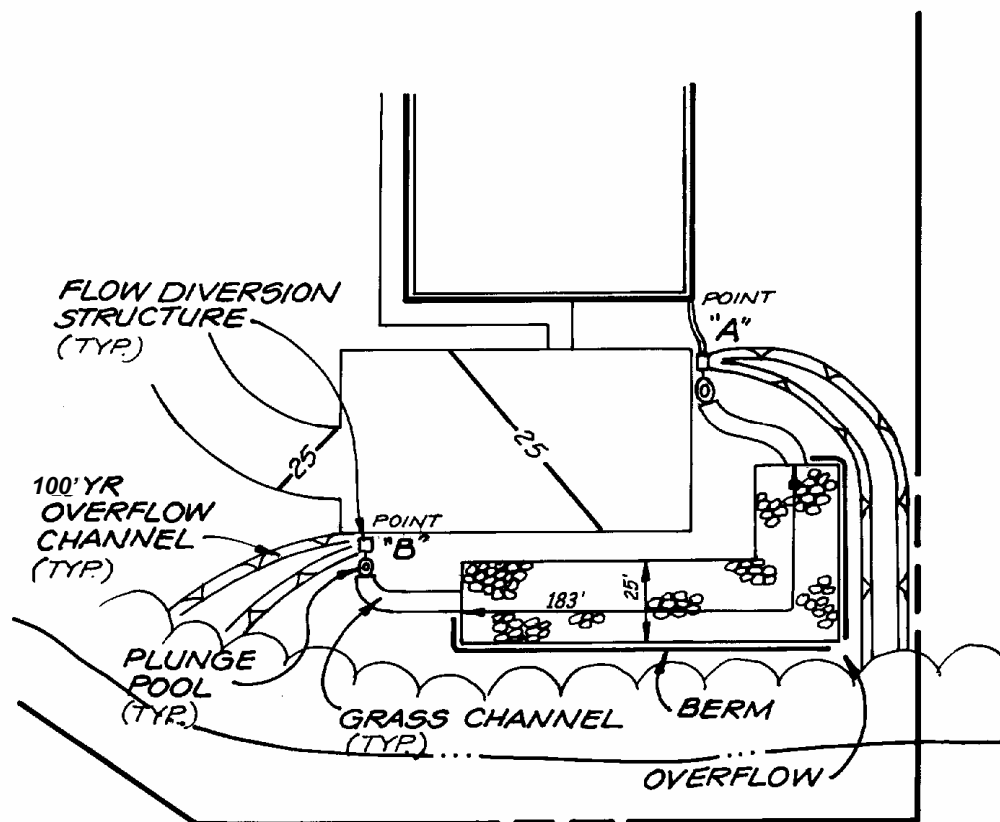


Figure 4. Infiltration Trench Site Plan

Size the second diversion (Point B) using the same techniques.

Peak flow equal 2/3 of the value for the entire site. Thus:

$$Q_{100\text{-year}} = 29 \times 0.67 = 19.3 \text{ cfs}$$

$$\text{Peak flow for } WQ_v = 2.86 \times 0.67 = 1.47 \text{ cfs}$$

Size the low flow orifice to pass 1.47 cfs with 1.5' of head using the Orifice equation.

$$Q = CA(2gh)^{1/2}; 1.91 \text{ cfs} = 0.6A(2 \times 32.2 \text{ ft/s}^2 \times 1.5')^{1/2}$$

$$A = 0.32 \text{ sq. ft.} = \pi d^2/4; d = 0.64'; \text{ use } 8" \text{ pipe with } 8" \text{ gate valve}$$

Size the 100-year overflow weir crest at 22.0'. Use a concrete weir to pass the 100-year flow ($19.3 - 1.91 = 17.39$ cfs). Assume 1 foot of head to pass this event. Size using the weir equation.

$$Q = CLH^{1.5}; L = Q/(CH^{1.5})$$

$$L = 17.39 \text{ cfs} / (3.1)(1)^{1.5} = 5.6'; \text{ use } 5.6' \text{ (see Figure 5)}$$

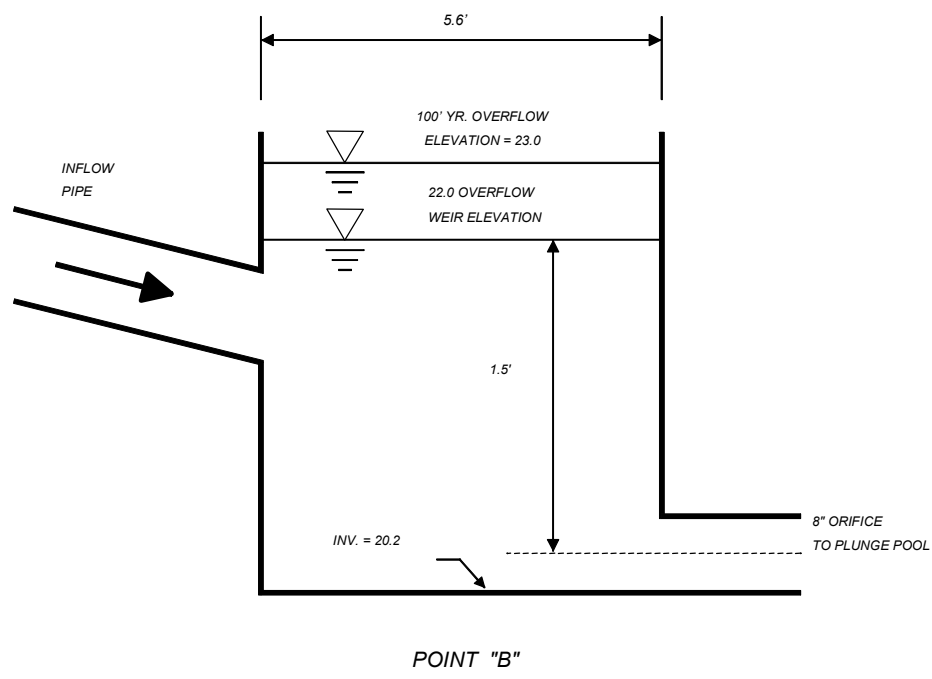
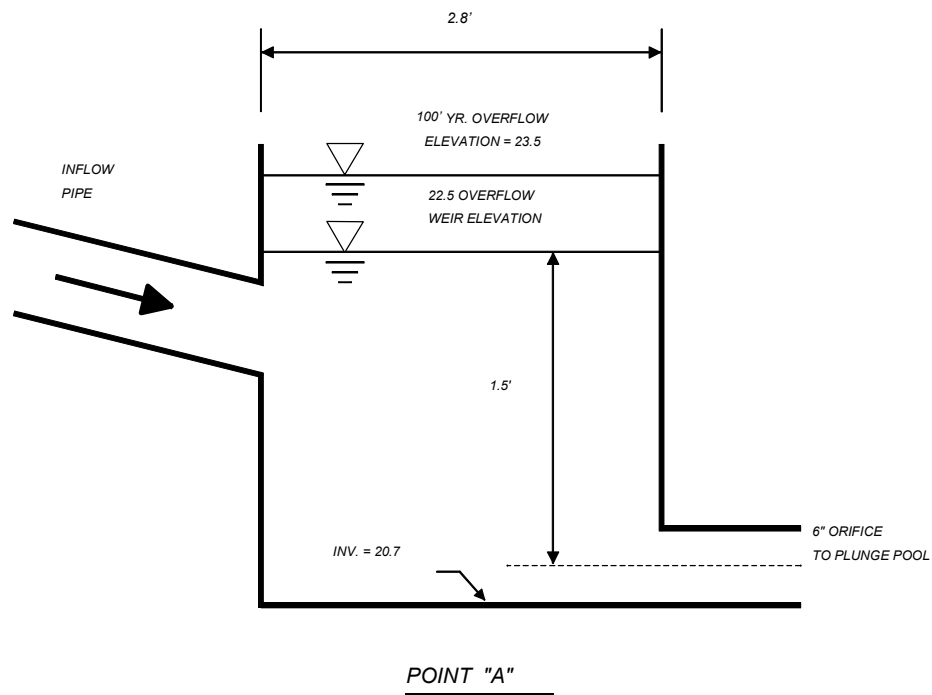


Figure 5. Flow Diversion Structures

Step 7. Size pretreatment volume and design pretreatment measures

As rule of thumb, size pretreatment to treat 25% of the WQ_v . Therefore, treat $8,102 \times 0.25 = 2,026 \text{ ft}^3$.

For pretreatment, use a pea gravel filter layer with filter fabric, a plunge pool, and a grass channel.

Pea Gravel Filter

The pea gravel filter layer covers the entire trench with 2" (see Figure 6). Assuming a porosity of 0.32, the water quality treatment in the pea gravel filter layer is:

$$WQ_{\text{filter}} = (0.32)(2'')(1 \text{ ft}/12 \text{ inches})(4,586 \text{ ft}^2) = 245 \text{ ft}^3$$

Plunge Pools

Use a 5'X10' plunge pool at Point A and a 10'X10' plunge pool at Point B with average depths of 2'.

$$\text{Total } WQ_{\text{pool}} = (10 \text{ ft})(10+5 \text{ ft})(2 \text{ ft}) = 300 \text{ ft}^3$$

Grass Channel

Thus, the grass channel needs to treat at least $(2,026 - 245 - 300)\text{ft}^3 = 1,481 \text{ ft}^3$

Use a Manning's equation nomograph or software to size the swale.

The channel at point A should treat one third of $1,481 \text{ ft}^3$ or 494 ft^3

- Assume a trapezoidal channel with 4' channel bottom, 3H:1V side slopes, and a Manning's n value of 0.15. Use a nomograph to size the swale; assume a 1% slope.
- Use a peak discharge of 0.95 cfs (Peak flow for one third of WQ_v , or $2,700 \text{ ft}^3$)
- Compute velocity: $V=0.47 \text{ ft/s}$
- To retain the 1/3 of the WQ_v ($2,700 \text{ ft}^3$) for 10 minutes, the length would be 282 feet.
- Since the swale only needs to treat 25% of the water quality volume minus the treatment provided by the plunge pool and the gravel layer, or 494 ft^3 , the length should be pro-rated to reflect this reduction.

Therefore, adjust length:

$$L = (282 \text{ ft})(494 \text{ ft}^3/2,700 \text{ ft}^3) = 52 \text{ feet. Use 55 feet.}$$

The channel at point B should treat two thirds of $1,481 \text{ ft}^3$, or 988 ft^3

- Assume a trapezoidal channel with 5' channel bottom, 3H:1V side slopes, and a Manning's n value of 0.12. Use a nomograph to size the swale; assume a 0.5% slope.
- Use a peak discharge of 1.91 cfs (Peak flow for two thirds of WQ_v , or $5,401 \text{ ft}^3$)
- Compute velocity: $V=0.51 \text{ ft/s}$
- To retain the 2/3 of the WQ_v ($5,401 \text{ ft}^3$) for 10 minutes, the length would be 306 feet.
- Since the swale only needs to treat 25% of the water quality volume minus the treatment provided by the plunge pool and the gravel layer, or 988 ft^3 , the length should be pro-rated to reflect this reduction.

Therefore, adjust length:

$$L = (306 \text{ ft})(988 \text{ ft}^3/5,401 \text{ ft}^3) = 55 \text{ feet. Use 55 feet.}$$

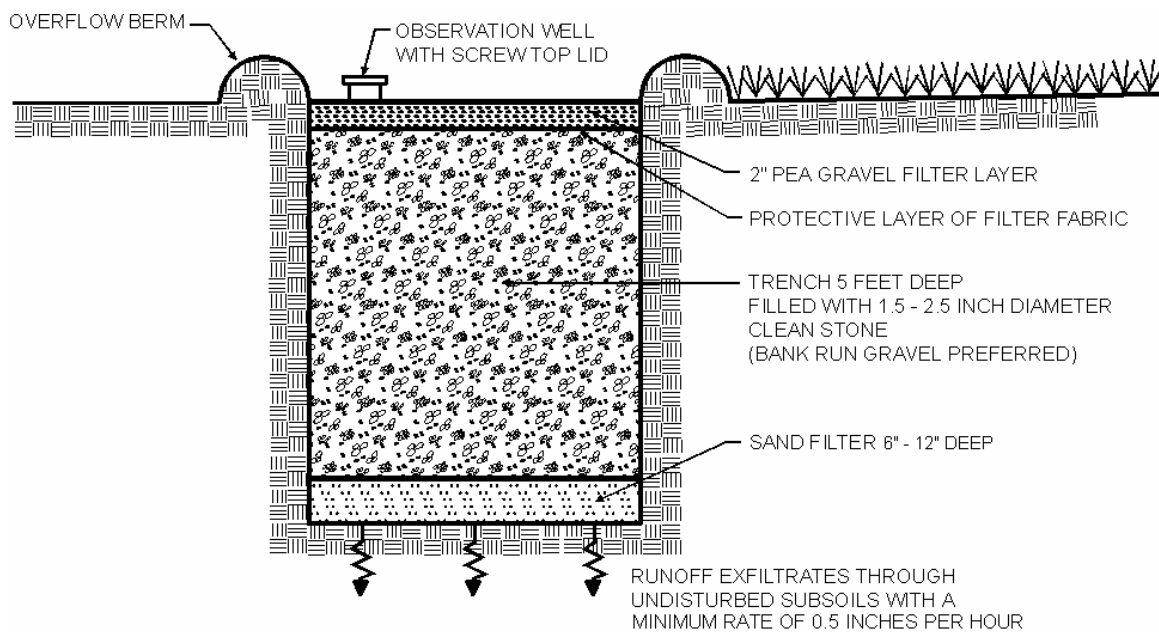


Figure 6. Infiltration Trench Cross Section

Step 8 -- Design Spillway(s)

Adequate storm water outfalls should be provided for the overflow associated with the 100-year and larger design storm events, ensuring non-erosive velocities on the down slope.

D.5 Enhanced Swale Design Example

This example focuses on the design of a dry swale to meet the water quality treatment requirements of the site. The design options chosen for this example are Option 1 for Water Quality Protection (WQ_v), Option 4 for Streambank Protection (SP_v), and Option 4 for Flood Control (Q_{p100}). It is assumed that the Local Criteria requires enhanced swales to adequately convey the 25-year peak flow. Streambank Protection and Flood Control are not addressed in this example other than quantification of preliminary storage volume and peak discharge requirements. It is assumed that the designer can refer to the previous pond example in order to extrapolate the necessary information to determine and design the required storage and outlet structures to meet these criteria. In general, the primary function of dry swales is to provide water quality treatment and groundwater recharge and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. Where quantity control is required, the bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults). The layout of the Wellington Recreation Center is shown in Figure 1.

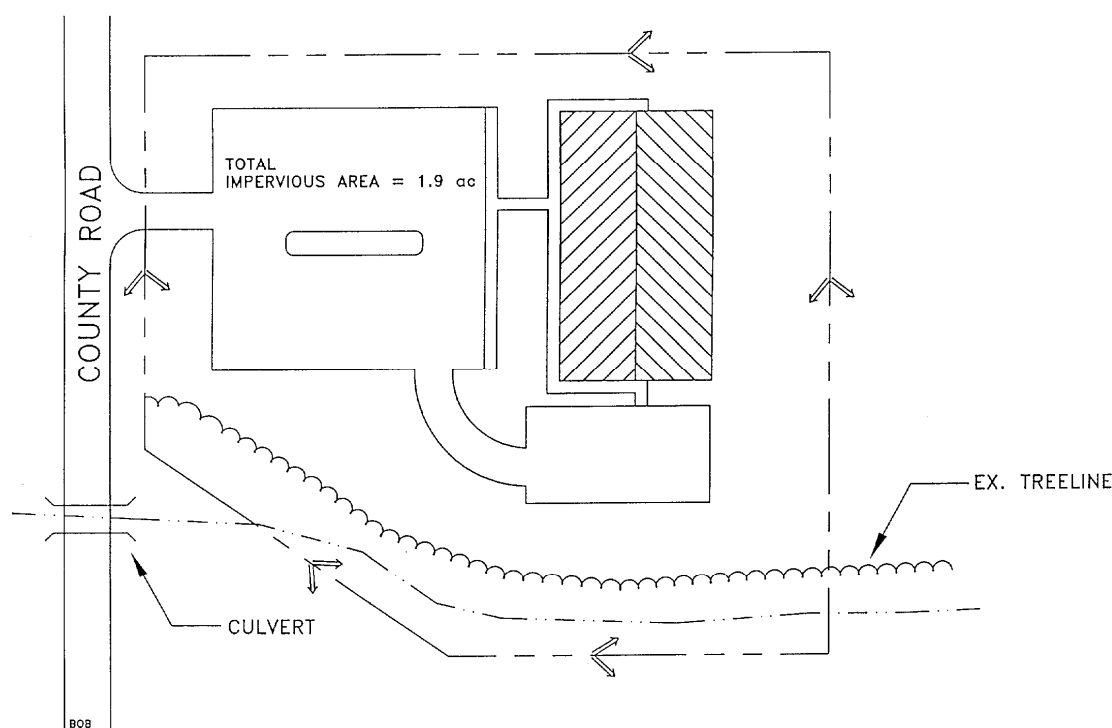


Figure 1. Wellington Recreation Center Site Plan

Base Data		Hydrologic Data	
Site Area = Total Drainage Area (A) = 3.0 ac			
Impervious Area = 1.9 ac; or $I = 1.9/3.0 = 63.3\%$		CN	77
Soils Type 50% "C", 50% "D" Tarrant County		t_c	.41
			91
			.20

Computation of Preliminary Storm Water Storage Volumes and Peak Discharges

Two swales will be designed to carry flow to the existing stream, one around each side of the development.

Step 1 -- Compute runoff control volumes from the *integrated* Design Approach

Compute Water Quality Volume (WQ_v):

- Compute Runoff Coefficient, R_v

$$R_v = 0.05 + (63.3) (0.009) = 0.62$$

- Compute WQ_v

$$\begin{aligned} WQ_v &= (1.5") (R_v) (A) / 12 \\ &= (1.5") (0.62) (3.0\text{ac}) (43,560\text{ft}^2/\text{ac}) (1\text{ft}/12\text{in}) \\ &= \underline{8,102 \text{ ft}^3} = 0.19 \text{ ac-ft} \end{aligned}$$

Compute Stream Streambank Protection Volume (SP_v):

For stream streambank protection, provide 24 hours of extended detention for the 1-year event.

In order to determine a preliminary estimate of storage volume for streambank protection and flood control, it will be necessary to perform hydrologic calculations using approved methodologies. This example uses the NRCS TR-55 methodology presented in Section 2.1 to determine pre- and post-development peak discharges for the 1-yr, 25-yr, and 100-yr 24-hour return frequency storms.

- Per attached TR-55 calculations (Figures 2 and 3)

Condition	CN	Q _{1-year} Inches	Q _{1-year} cfs	Q _{100 year} cfs
Pre-developed	74	0.69	1.7	17.0
Post-Developed	90	1.66	6.5	33.0

- Utilize modified TR-55 approach to compute streambank protection storage volume

Initial abstraction (I_a) for CN of 90 is 0.222: [I_a = (200/CN - 2)]

$$I_a/P = (0.222)/ 2.64 \text{ inches} = 0.08$$

$$T_c = 0.21 \text{ hours}$$

$$q_u = 840 \text{ csm/in}$$

Knowing q_u and T (extended detention time), find q_o/q_i for a Type II rainfall distribution.

$$\text{Peak outflow discharge/peak inflow discharge } (q_o/q_i) = 0.022$$

For a Type II rainfall distribution,

$$V_s/V_r = 0.683 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3$$

Where V_s equals streambank protection storage (SP_v) and V_r equals the volume of runoff in inches.

$$V_s/V_r = 0.65$$

$$\text{Therefore, } V_s = SP_v = 0.65(1.66")(1/12)(3 \text{ ac}) = 0.27 \text{ ac-ft} = 11,761 \text{ ft}^3$$

Analyze for Safe Passage of 100 Year Design Storm (Q_f):

At final design, prove that discharge conveyance channel is adequate to convey the 100-year event and discharge to receiving waters, or handle it with a peak flow control structure.

Table 1 Summary of General Design Information for Wellington Recreation Center			
Symbol	Control Volume	Volume Required (cubic feet)	Notes
WQ_v	Water Quality	8,102	
SP_v	Streambank Protection	11,761	
Q_f	Flood Protection	NA	Provide safe passage for the 100-year event in final design

PEAK DISCHARGE SUMMARY				
JOB:	Wellington of Recreation Center			EWB
DRAINAGE AREA NAME:	Pre-Developed Conditions			
COVER DESCRIPTION	SOIL GROUP A, B, C, D?	C from TABLE 2.1.4-2	CN from TABLE 2.1.5-1	AREA (in acres)
woods (good cond.)	C		70	1.5
woods (good cond.)	D		78	1.5
AREA SUBTOTALS:				3.00
Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.36"	Cross Section	Wetted Per	Avg Velocity	Tt (hrs)
Sheet Flow	dense grass	'n' = 0.24	150 ft	1.50%
				0.36 hrs
Shallow Flow	unpaved		500 ft	2.00%
			2.28 fps	0.06 hrs
Channel Flow				
Total Area in Acres =	3.00	Total Sheet	Total Shallow	Total Channel
Weighted CN =	74	Flow =	Flow =	Flow =
Time of Concentration =	0.42 hrs	0.36 hrs.	0.06 hrs.	0.00 hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE (cfs)	
1 Year	2.64	0.69	1.7	
2 Year	3.36	1.14	3.0	
5 Year	4.56	2.02	5.4	
10 Year	5.52	2.79	7.6	
25 Year	6.72	3.80	11.0	
50 Year	7.92	4.85	14.0	
100 Year	9.12	5.94	17.0	

Figure 2. Wellington Recreation Center Pre-Developed Conditions

PEAK DISCHARGE SUMMARY				
JOB:	Wellington on Recreation Center			EWB
DRAINAGE AREA NAME:	Post-Developed Conditions			3-Jan-00
COVER DESCRIPTION	SOIL GROUP A, B, C, D?	C from TABLE 2.1.4-2	CN from TABLE 2.1.5-1	AREA (in acres)
open space (good cond.)	C		74	0.25
woods (good cond.)	C		70	0.30
impervious	C		98	1.90
open space (good cond.)	D		80	0.25
woods (good cond.)	D		77	0.30
AREA SUBTOTALS:				3.00
Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.36"	Cross Section	Wetted Per	Avg Velocity	Tt (hrs)
Sheet Flow	dense grass	'n' = 0.24	50 ft	1.50%
				0.15 hrs
Shallow Flow	paved		600 ft	2.00%
			2.87 fps	0.06 hrs
Channel Flow Hydraulic Radius= 0.75		'n' = 0.024	50 ft	2.00%
	X-S estimated	WP estimated	7.25 fps	0.00hrs
Total Area in Acres =	3.00	Total Sheet	Total Shallow	Total Channel
Weighted CN =	90	Flow =	Flow =	Flow =
Time of Concentration =	0.21 hrs	0.15 hrs.	0.06 hrs.	0.00 hrs.
Pond Factor =	1	RAINFALL TYPE II		
STORM	Precipitation (P) inches	Runoff (Q)	Qp, PEAK DISCHARGE (cfs)	
1 Year	2.64	1.66	6.5	
2 Year	3.36	2.32	9.3	
5 Year	4.56	3.45	14.0	
10 Year	5.52	4.38	18.0	
25 Year	6.72	5.55	23.0	
50 Year	7.92	6.73	28.0	
100 Year	9.12	7.91	33.0	

Figure 3. Wellington Recreation Center Post-Developed Conditions

Step 2 -- Determine if the development site and conditions are appropriate for the use of an enhanced dry swale system

Existing ground elevation at the facility location is 922.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 913.0 feet and underlying soils are predominately clay. Adjacent creek invert is at 912.0 feet.

Step 3 -- Confirm local design criteria and applicability

There is a local requirement that the 25-year storm is contained within the top of banks of all channels, including these enhanced swale controls.

No additional local criteria are applicable.

Step 4 -- Determine pretreatment volume

Size two shallow forebays at the head of the swales equal to 0.05" per impervious acre of drainage (each) (Note, total recommended pretreatment requirement is 0.1"/imp acre). (1.9 ac) (0.05") (1ft/12") (43,560 sq ft/ac) = 344.9 ft³

Use a 2' deep pea gravel drain at the head of the swale to provide erosion protection and to assist in the distribution of the inflow. There will be no side inflow nor need for pea gravel diaphragm along the sides.

Step 5 -- Determine swale dimensions

Required: bottom width, depth, length, and slope necessary to store WQ_v with less than 18" of ponding (see Figure 5 for representative site plan).

Unit Peak Discharge (q_u), csm/in

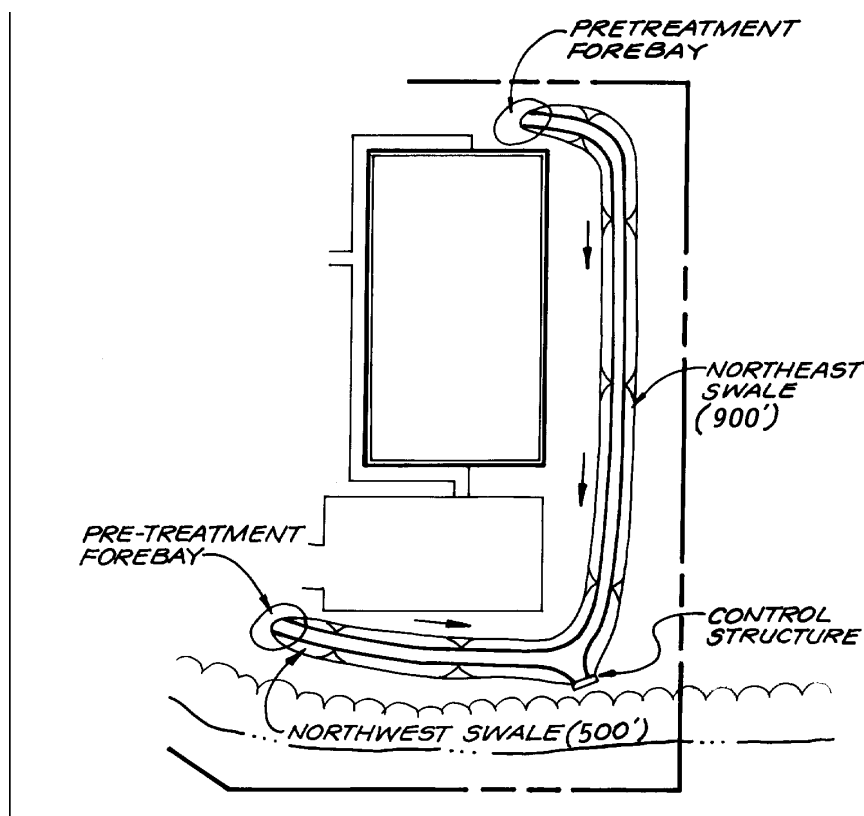


Figure 5. Enhanced Dry Swale Site Plan

Assume a trapezoidal channel with a maximum WQ_v depth of 18". Control for this swale will be a shallow concrete wall with a low flow orifice, trash rack located per Figures 5 and 6. Per the site plan, we have about 1,400' of swale available, if the swale is put in with two tails. The outlet control will be set at the existing invert minus three feet ($922.0 - 3.0 = 919.0$). The existing uphill invert for the northwest fork is 924.0 (length of 500'), the invert for the northeast fork is 928.0 (at a length of 900').

Slope of northwest fork is $(924 - 919)/500' = 0.01$ or 1.0%

Slope of northeast fork is $(928 - 919)/900' = 0.01$ or 1.0%

Minimum slope is 1.0 % [okay]

For a trapezoidal section with a bottom width of 6', a WQ_v average depth of 9", 3:1 side slopes, compute a cross sectional area of $(6') (0.75') + (0.75') (2.25') = 6.2 \text{ ft}^2$ (see Figure 7).

$(6.2 \text{ sq ft}) (1,400 \text{ ft}) = 8,680 \text{ cubic feet} [> WQ_v \text{ of } 8,102 \text{ ft}^3; \text{OK}]$

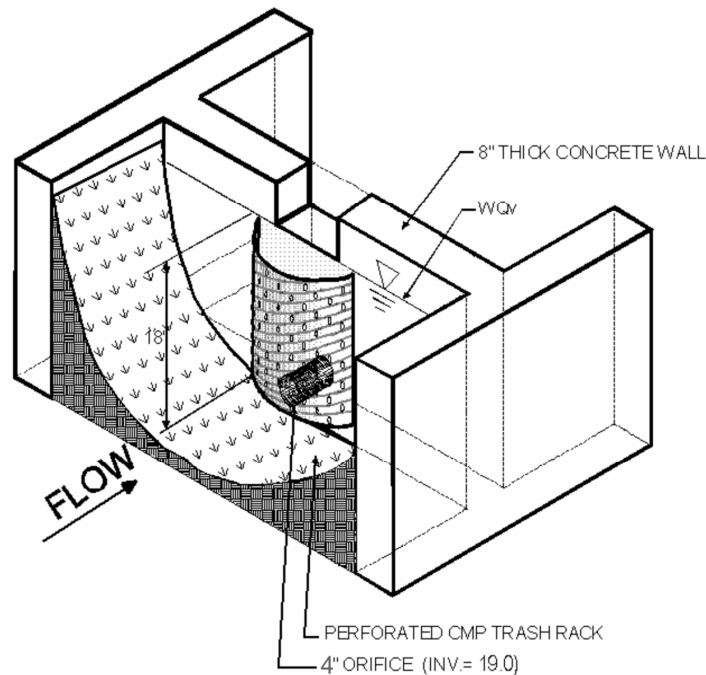


Figure 6 Control Structure at End of Swale

Step 6 -- Compute number of check dams (or similar structure) required to detain WQ_v (see Figure 7)

For the northwest fork, 500 ft @ 1.0% slope, and maximum depth at 18", place checkdams at:

$$1.5' / 0.01 = 150' \quad \text{place at 150', 4 required}$$

For the northeast fork, 900 ft @ 1.0% slope, and maximum 18" depth, place checkdams at:

$$1.5' / 0.01 = 150' \quad \text{place at 150', 6 required}$$

Step 7 -- Calculate draw-down time

In order to ensure that the swale will draw down within 24 hours, the planting soil will need to pass a maximum rate of 1.5' in 24 hours ($k = 1.5'$ per day). Provide 6" perforated underdrain pipe and gravel system below soil bed (see Figure 7).

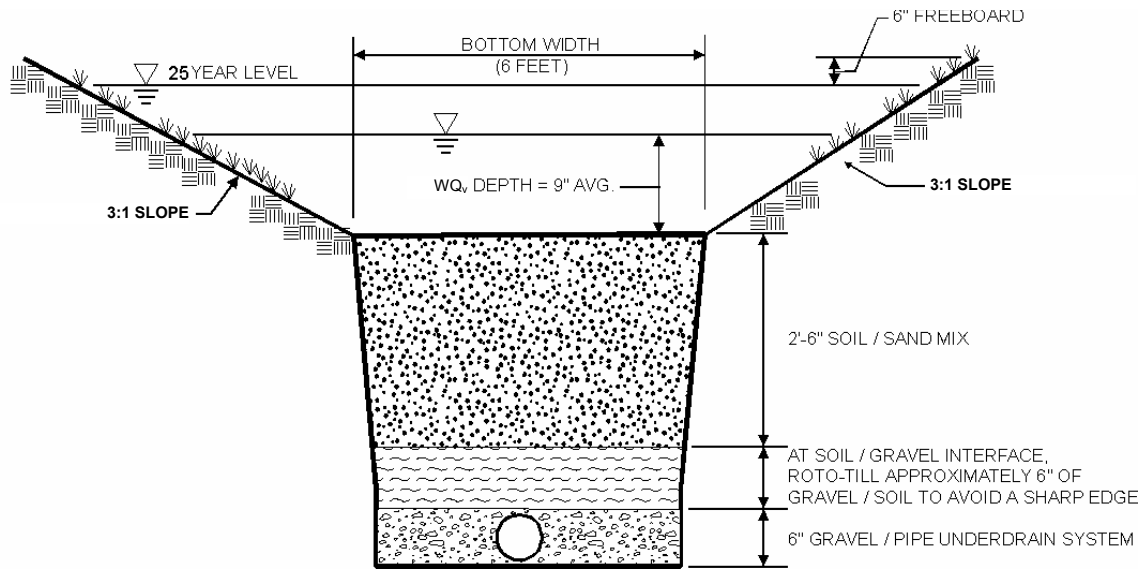


Figure 7 Trapezoidal Dry Swale Section

Step 8 -- Check 25-year flows for velocity erosion potential and freeboard

Given the local requirements to contain the 25-year flow within banks with freeboard. In this example only the 25-year flow will be checked assuming that lower flows will be handled. The 25-year flow is 23.0 cfs, assume that 30% goes through northwestern swale (6.9 cfs) and 70% goes through the northeastern swale (9.3 cfs). Design for the larger amount (13.3 cfs). From separate computer analysis, with a slope of 1.0%, the 25-year velocity will be 2.7 feet-per-second at a depth of .63 feet, provide an additional .5' of freeboard above top of checkdams or about 1.2' (total channel depth = 2.7').

Find 25-year overflow weir length required: (weir eq. $Q = CLH^{3/2}$), where $C = 3.1$, $Q_{25} = 23$ cfs, $H = 1.2$; Rearranging the equation yields:

$$L = 23 \text{ cfs} / (3.1 \cdot 1.2^{1.5}) = 5.6' \quad \text{Use } 5 \text{ ft}$$

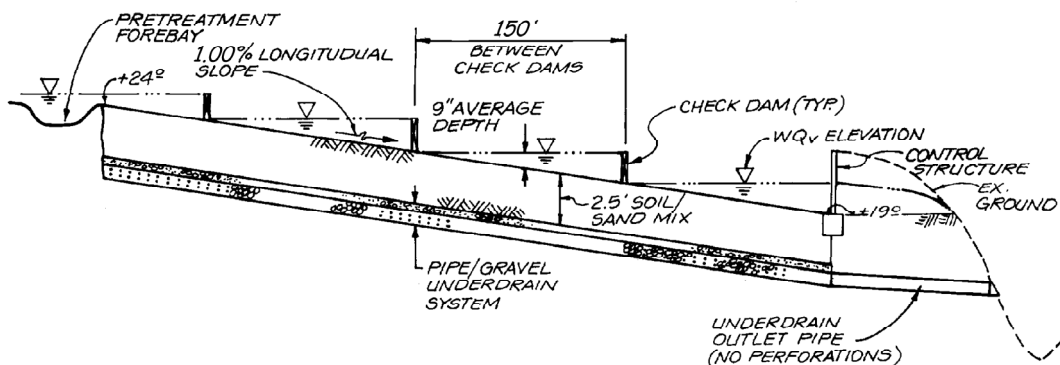


Figure 8 Profile of Northwest Fork Dry Swale

Step 9 -- Design low flow orifice at downstream headwall and checkdams (See Figure 6)

Design orifice to pass 8,102 cubic feet in 6 hours.

8,102 cubic feet / [(6 hours) (3600 sec/hour)] = 0.4 cfs

Use Orifice equation: $Q = CA(2gh)^{1/2}$

Assume $h = 1.5'$

$A = (0.4 \text{ cfs}) / [(0.6) ((2) (32.2 \text{ ft/s}^2) (1.5'))^{1/2}]$

$A = 0.068 \text{ sq ft}$, dia = 0.29 feet or 3.6" Use 4" orifice.

Provide 3" v-notch slot in each check dam.

Step 10 – Design inlets, sediment forebay(s), and underdrain system

See Figure 8

Step 11 – Prepare Vegetation and Landscaping Plan

iSWM™ WORKSHEETS AND CHECKLISTS

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Filtration Facility Maintenance Checklist

Infiltration Trench Maintenance Checklist

Enhanced Swale/Grass Channel/Filter Strip Maintenance Checklist

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Worksheet for Conceptual iSWM Site Plan

		Included?		
		Yes	No	Comments
I. Review of <u>integrated</u> Site Design Practices				
A. Conservation of Natural Features and Resources				
Are there opportunities to:				
1.	conserve undisturbed vegetation?			
2.	conserve floodplains?			
3.	conserve steep slopes?			
4.	conserve natural drainageways?			
5.	conserve streams?			
6.	conserve wetlands?			
7.	conserve other natural features?			
8.	conserve critical areas?			
B. Lower Impact Site Design Techniques				
Are there opportunities to:				
1.	reduce clearing and grading?			
2.	locate development in less sensitive areas?			
3.	utilize open space development?			
4.	utilize other techniques?			
C. Reduction of Impervious Cover				
Are there opportunities to:				
1.	reduce roadway lengths?			
2.	reduce roadway widths?			
3.	reduce building footprints?			
4.	reduce parking lots?			
5.	utilize fewer or alternative cul-de-sacs?			
6.	utilize pervious pavement?			
7.	utilize other reduction measures?			
D. Utilization of Natural Features for Storm Water Management				
Are there opportunities to:				
1.	utilize buffers?			
2.	utilize undisturbed areas?			
3.	utilize natural drainageways vs storm drain systems?			
4.	utilize vegetated swales vs curb and gutter?			
5.	drain runoff to pervious areas?			
6.	utilize other measures or features?			
E. Can Credits be obtained for use of <u>integrated</u> Site Design Practices?				

Worksheet for Conceptual iSWM Site Plan (Continued)

	Comments
2. Review <u>integrated Design Approach</u>	
A. How will the <i>integrated</i> Design Approach be addressed for Water Quality Protection ?	
B. How will the <i>integrated</i> Design Approach be addressed for Streambank Protection ?	
C. How will the <i>integrated</i> Design Approach be addressed for On-Site Flood Control ?	
D. How will the <i>integrated</i> Design Approach be addressed for Downstream Flood Control ?	

	Yes	No	Comments
3. Review of <u>Water Quality Volume Reduction Methods</u>			
Can the Water Quality Volume be reduced by:			
A. conservation and/or restoration of natural areas ?			
B. use of stream buffers ?			
C. use of vegetated channels ?			
D. use of overland flow filtration/groundwater recharge ? ..			
E. use of low imperviousness development ?			

	Yes	No	Comments
4. Review of potential <u>hot spots</u>			
Are any of the following located or to be located on the site which may require special treatment and design consideration?			
A. Gas/fueling stations?			
B. Vehicle maintenance areas?			
C. Vehicle washing/steam cleaning areas?			
D. Auto recycling facilities?			
E. Illegal dumpsites?			
F. Outdoor material storage areas?			
G. Loading and transfer areas?			
H. Landfills?			
I. Industrial facilities?			
J. Other areas that may be a potential pollution source?			

Worksheet for Conceptual iSWM Site Plan (Continued)

	Included?		
	Yes	No	Comments
5. Review of <u>integrated Storm Water Controls</u>			
Which of the following controls will potentially be used on the site?			
A. Alum Treatment System?.....	_____	_____	_____
B. Bioretention System?	_____	_____	_____
C. Culverts?	_____	_____	_____
D. Dry Detention?	_____	_____	_____
E. Energy Dissipation?	_____	_____	_____
F. Enhanced Swales?	_____	_____	_____
G. Extended Dry Detention?	_____	_____	_____
H. Filter Strips?	_____	_____	_____
I. Grass Channels?	_____	_____	_____
J. Gravity (Oil-Grit) Separator?	_____	_____	_____
K. Infiltration Trenches?.....	_____	_____	_____
L. Modular Porous Paver Systems?	_____	_____	_____
M. Multi-Purpose Detention Areas?	_____	_____	_____
N. Open Channels?	_____	_____	_____
O. Organic Filters?	_____	_____	_____
P. Porous Concrete?	_____	_____	_____
Q. Proprietary Systems?	_____	_____	_____
R. Sand Filters (Surface/Perimeter)?	_____	_____	_____
S. Storm Water Ponds?	_____	_____	_____
T. Storm Water Wetlands?	_____	_____	_____
U. Street Gutters/Inlets/Pipe Systems?	_____	_____	_____
V. Submerged Gravel Wetland?.....	_____	_____	_____
W. Underground Detention?	_____	_____	_____
X. Underground Sand Filters?	_____	_____	_____
Y. Other controls?	_____	_____	_____

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Checklist for Conceptual iSWM Site Plan Preparation and Review

		Included?		
		Yes	No	Comments
Mapping and plans which illustrate at a minimum: (recommended scale of 1" = 50' or greater)				
1. Project Description				
A.	Name, legal address, & telephone number of applicant...			
B.	Name, legal address & telephone number of preparer.....			
C.	Common address and legal description of site			
D.	Vicinity map			
E.	Proposed land use with Standard Industrial Code No.			
		Yes	No	Comments
2. Existing Conditions				
A.	Copy of applicable digital orthophoto showing proposed project boundaries.....			
B.	Best available existing topography (no greater than 2-foot contours recommended)			
C.	Total Site Area and Total Impervious Area (acres).....			
D.	Benchmarks used for site control if available			
E.	Perennial and intermittent streams			
F.	Predominant soils from USDA soil surveys and/or on site soil borings			
G.	Boundaries of existing predominant vegetation			
H.	Location and boundaries of natural feature protection and conservation areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks, etc.)			
I.	Location of existing roads, buildings, parking lots and other impervious areas			
J.	Location of existing utilities (e.g., water, sewer, gas, electric) and easements			
K.	Location of existing conveyance systems such as storm drains, inlets, catch basins, channels, swales, and areas of overland flow			
L.	Flow paths			
M.	Location of floodplain/floodway limits and relationship of site to upstream/downstream properties and drainages...			
N.	Location and dimensions of existing channels, bridges or culvert crossings			

Checklist for Conceptual iSWM Site Plan Preparation and Review (Continued)

	<u>Yes</u>	<u>No</u>	<u>Comments</u>
3. Conceptual Site Layout			
A. Complete the iSWM Conceptual Plan Worksheet	_____	_____	_____
B. Hydrologic analysis to determine conceptual runoff rates, volumes and velocities to support selection of Storm Water Controls.....	_____	_____	_____
C. Conceptual site design identifying <i>integrated</i> site design practices used	_____	_____	_____
D. Identification and calculation of storm water site design credits	_____	_____	_____
E. Conceptual estimates of <i>integrated</i> Design Approach requirements.....	_____	_____	_____
F. Conceptual selection, location and size of proposed structural storm water controls	_____	_____	_____
G. Conceptual limits of proposed clearing and grading.....	_____	_____	_____

Checklist for Preliminary iSWM Site Plan Preparation and Review

	Included?		
	Yes	No	Comments
Mapping and plans which illustrate at a minimum: (recommended scale of 1" = 50' or greater)			
1. Existing Conditions Hydrologic Analysis			
A. Existing and proposed topography (no greater than 2-foot contours recommended)	_____	_____	_____
B. Total Site Area and Total Impervious Area (acres).....	_____	_____	_____
C. Perennial and intermittent streams	_____	_____	_____
D. Predominant soils from USDA soil surveys or soil borings	_____	_____	_____
E. Boundaries of existing predominant vegetation and proposed limits of clearing and grading	_____	_____	_____
F. Location and boundaries of natural feature protection and conservation areas such as wetlands, lakes, ponds, and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks, etc.)	_____	_____	_____
G. Location of existing and proposed roads, buildings, parking lots and other impervious areas	_____	_____	_____
H. Location of existing and proposed utilities (e.g., water, sewer, gas, electric) and easements	_____	_____	_____
I. Preliminary selection and location of storm water controls	_____	_____	_____
J. Location of existing and proposed conveyance systems such as storm drains, inlets, catch basins, channels, swales, and areas of overland flow	_____	_____	_____
K. Flow paths	_____	_____	_____
L. Location of floodplain/floodway limits and relationship of site to upstream/downstream properties and drainages...	_____	_____	_____
M. Preliminary location and dimensions of proposed channel modifications, such as bridge or culvert crossings	_____	_____	_____
N. Existing conditions hydrologic analysis for runoff rates, volumes and velocities showing methodologies used and supporting calculations.....	_____	_____	_____

Checklist for Preliminary iSWM Site Plan Preparation and Review (Continued)

	Included?		
	Yes	No	Comments
2. Project Description and Design Considerations (updated information from Conceptual Plan)			
A. Name, legal address and telephone number of applicant _____	_____	_____	_____
B. Name, legal address and telephone number of preparer . _____	_____	_____	_____
C. Common address and legal description of site _____	_____	_____	_____
D. Vicinity map _____	_____	_____	_____
E. Discussion of <i>integrated</i> Site Design Practices _____	_____	_____	_____
F. Discussion of Credits for <i>integrated</i> Site Design _____	_____	_____	_____
G. Discussion of storm water controls _____	_____	_____	_____
H. Discussion of groundwater recharge considerations _____	_____	_____	_____
I. Discussion of hotspot land uses and runoff treatment.....	_____	_____	_____
	Yes	No	Comments
3. Post-Development Hydrologic Analysis			
A. Proposed (post-development) conditions hydrologic analysis for runoff rates, volumes, and velocities showing the methodologies used and supporting calculations _____	_____	_____	_____
B. Preliminary estimates of <i>integrated</i> Design Approach requirements _____	_____	_____	_____
C. Preliminary identification and calculation of credits for <i>integrated</i> site designs _____	_____	_____	_____
D. Location and boundary of proposed natural feature protection areas _____	_____	_____	_____
	Yes	No	Comments
4. Downstream Assessments			
A. Preliminary analysis of potential downstream impact/effects of project, where necessary.....	_____	_____	_____
	Yes	No	Comments
5. Storm Water Management System Design			
A. Hydrologic and hydraulic analysis of the storm water management system for all applicable design storms.....	_____	_____	_____
B. Preliminary sizing calculations for storm water controls including contributing drainage area, storage, and outlet configuration.....	_____	_____	_____
C. Narrative describing the selected storm water controls	_____	_____	_____

Checklist for Final iSWM Site Plan Preparation and Review

		Included?		
		Yes	No	Comments
1. Existing Conditions Hydrologic Analysis				
A.	Updated checklist from Preliminary iSWM Site Plan	_____	_____	_____
2. Project Description and Design Considerations				
A.	Updated checklist from Preliminary iSWM Site Plan	_____	_____	_____
3. Post-Development Hydrologic Analysis				
A.	Updated checklist from Preliminary iSWM Site Plan	_____	_____	_____
B.	Final sizing calculations for storm water controls including contributing drainage area, storage, and outlet configuration.....	_____	_____	_____
C.	Stage-discharge or outlet rating curves and inflow and outflow hydrographs for storage facilities.....	_____	_____	_____
D.	Final analysis of potential downstream impact/effects of project, where necessary	_____	_____	_____
E.	Dam safety and breach analysis, where necessary	_____	_____	_____
4. Downstream Assessments				
A.	Update checklist from Preliminary iSWM Site Plan	_____	_____	_____
		Yes	No	Comments
5. Storm Water Management System Design				
A.	Update checklist from Preliminary iSWM Site Plan	_____	_____	_____
B.	Existing and proposed structural elevations (e.g., invert of pipes, manholes, etc.)	_____	_____	_____
C.	Design water surface elevations	_____	_____	_____
D.	Structural details and specifications of structural control designs, outlet structures, embankments, spillways, grade control structures, conveyance channels, etc.....	_____	_____	_____
E.	Professional Engineer seal, signature and date	_____	_____	_____
6. Construction Storm Water Pollution Prevention Plan				
A.	Required elements specified in iSWM Design Manual for Construction and/or local ordinances.....	_____	_____	_____
B.	Sequence/phasing of construction and temporary stabilization measures.....	_____	_____	_____
C.	Temporary structures that will be converted into permanent storm water controls	_____	_____	_____

Checklist for Final iSWM Site Plan (Continued)

		Included?		
		Yes	No	Comments
7. Landscaping Plan				
A.	Arrangement of planted areas, natural areas, and other landscaped features.....	_____	_____	_____
B.	Information required to construct landscaping elements ..	_____	_____	_____
C.	Descriptions and standards for the methods, materials and vegetation that are to be used	_____	_____	_____
		Yes	No	Comments
8. Operations and Maintenance Plan				
A.	Name, legal address and phone number of responsible parties for maintenance activities.....	_____	_____	_____
B.	Description and schedule of maintenance tasks	_____	_____	_____
C.	Description of applicable easements	_____	_____	_____
D.	Description of funding source	_____	_____	_____
E.	Access and safety issues.....	_____	_____	_____
F.	Procedures for testing and disposal of sediments, if required	_____	_____	_____
G.	Expected service life of structures and estimated cost to replace	_____	_____	_____
H.	Executed Maintenance Agreement(s), as required	_____	_____	_____
		Yes	No	Comments
9. Evidence of Acquisition of Applicable Federal, State, and Local Permits				
A.	USACE Regulatory Program permits.....	_____	_____	_____
B.	401 water quality certification.....	_____	_____	_____
C.	TPDES Construction permit.....	_____	_____	_____
D.	Other	_____	_____	_____
E.	Other	_____	_____	_____
		Yes	No	Comments
10. Waiver requests				
A.	Evidence of acquisition of all necessary legal agreements (e.g., easements, covenants, land trusts, etc.)	_____	_____	_____

Operation and Maintenance Inspection Report for Storm Water Management Ponds

(Adapted from Watershed Management Institute, Inc.)

Inspector Name _____ Project Location _____
 Inspection Date _____
 Storm Water Pond _____
 Normal Pool _____
 Normally Dry _____
 Embankment Type: Earthen ☐ Concrete ☐ Watershed _____

Inspection Items	Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
Pond Components				
1. Embankment and/or Emergency spillway				
a. Adequate vegetation and ground cover			A	
b. Embankment erosion			A	
c. Animal burrows			A	
d. Unauthorized plantings			A	
e. Cracking, bulging, or sliding of dam				
i. Upstream face			A	
ii. Downstream face			A	
iii. At or beyond toe Upstream			A	
Downstream			A	
iv. Emergency spillway			A	
f. Pond, toe & chimney drains clear and functioning			A	
g. Leaks on downstream face			A	
h. Abutment protection or riprap failures			A	
i. Visual settlement or horizontal misalignment of top of dam			A	
j. Emergency spillway clear of debris			A	
k. Other (specify)			A	
2. Riser and principal spillway				
Type: Reinforced concrete _____				
Corrugated pipe _____				
Masonry _____				
a. Low flow orifice obstructed			A	
b. Low flow trash rack			A	
i. Debris removal necessary				
ii. Corrosion control			A	

Inspection Items		Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
c.	Weir trash rack			A	
	i. Debris removal necessary				
	ii. Corrosion control			A	
d.	Excessive sediment accumulation inside riser			A	
e.	Concrete/Masonry condition			A	
	Riser and barrels				
	i. Cracks or displacement				
	ii. Minor spalling (<1")			A	
	iii. Major spalling (rebars exposed)			A	
	iv. Joint failures			A	
	v. Water tightness			A	
f.	Metal pipe condition			A	
g.	Control valve			A	
	i. Operational/exercised				
	ii. Chained and locked			A	
h.	Pond drain valve			A	
	i. Operational/exercised			A	
	ii. Chained and locked			A	
i.	Outfall channels flowing			A	
j.	Other (specify)			A	
3.	Permanent pool (wet ponds)				
a.	Undesirable vegetative growth			M	
b.	Floating or floatable debris removal required			M	
c.	Visible pollution			M	
d.	High Water Marks			M	
e.	Shoreline problems			M	
f.	Sediment build-up			M	
g.	Other (specify)			M	
4.	Sediment forebays				
a.	Sedimentation Noted			M	
b.	Sediment removal when depth > 50% design depth			M	
5.	Dry pond areas				
a.	Vegetation adequate			M	
b.	Undesirable vegetative growth			M	
c.	Undesirable woody vegetation			M	
d.	Low flow channels clear of obstructions			M	
e.	Standing water or wet spots			M	
f.	Sediment and/or trash accumulation			M	
g.	Other (specify)			M	
6.	Condition of outfalls into pond				
a.	Riprap failures			A,S	

Inspection Items		Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
b.	Slope erosion			A,S	
c.	Storm drain pipes			A,S	
d.	Endwalls/headwalls			A,S	
e.	Other (specify)			A,S	
7.	Other				
a.	Encroachments on ponds or easement area			M	
b.	Complaints from residents (describe on back)			M	
c.	Aesthetics			M	
	i. Grass height				
	ii. Graffiti removal necessary			M	
	iii. Other (specify)			M	
d.	Any public hazards (specify)			M	
e.	Maintenance access			M	
8.	Constructed wetland areas				
a.	Vegetation healthy and growing			A	
b.	Evidence of invasive species			A	
c.	Excessive sedimentation in wetland area			A	

Inspection Frequency Key A=Annual, M=Monthly, S=After major storm

Summary

1. Inspectors Remarks:

2. Overall condition of Facility (Check one)

☐ Acceptable
☐ Unacceptable

3. Dates any maintenance must be completed by:

Inspectors Signature

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Operation and Maintenance Inspection Report for Filtration Facility

(Adapted from Watershed Management Institute, Inc.)

Inspector Name _____ Project Location _____
 Inspection Date _____
 Watershed _____
 As-built Plans available? _____

Inspection Items	Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
1. Debris removal				
Adjacent area clear of debris			M	
Inlets and outlets clear of debris			M	
Filtration facility free of debris			M	
Illegal dumping			M	
Vandalism			M	
2. Vegetation				
Adjacent area stabilized			M	
Grass mowed			M	
Any evidence of erosion			M	
3. Oil and grease				
Any evidence of filter clogging			M	
4. Water retention where required				
Water holding chambers at normal pool			M	
No evidence of leakage			M	
5. Sediment deposition				
Filtration chamber clean of sediments			A	
Water chambers not more than ½ full of sediments			A	
6. Structural components				
Any evidence of structural deterioration			A	
Grates in good condition			A	
Any evidence of spalling or cracking of structural parts			A	
7. Outlets/overflow spillway				
Good condition (no need for repair)			A	
Any evidence of erosion			A	
8. Overall function of facility				
Any evidence of flow bypassing facility			A	
Any noticeable odors outside of facility			A	

Inspection Items	Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
9. Pump (Where applicable)				
Catalog cuts and wiring diagram for pump available			A	
Waterproof conduits for wiring appear to be intact			A	
Panel box is well marked			A	
Any evidence of pump failure (excess water in pump well, etc.)			A	

Inspection Frequency Key A=Annual, M=Monthly, S=After major storm

Necessary Action:

If any of the items above were answered Yes for "Maintenance Needed", a time frame needs to be established for repair or correction.

No action necessary. Continue routine inspections.

Correct noted facility deficiencies by (date) _____

Facility repairs were previously indicated and completed. Site reinspection is necessary to verify corrections or improvements.

Site reinspection completed on (date) _____

Site reinspection was satisfactory.

Next routine inspection is scheduled for approximately (date): _____

Inspectors Signature

Operation and Maintenance Inspection Report for Infiltration Trenches

(Adapted from Watershed Management Institute, Inc.)

Inspector Name _____ Project Location _____
 Inspection Date _____
 Watershed _____
 As-built Plans available? _____

Inspection Items	Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
1. Debris removal				
Trench surface clear of debris			M	
Inlets clear of debris			M	
Inflow pipes clear of debris			M	
Overflow spillway clear of debris			M	
2. Sediment traps, forebays, or pretreatment swales				
Obviously trapping sediment			A	
Greater than 50% of original storage volume remaining			A	
3. Vegetation				
Mowing done when necessary			M	
Fertilized per specification			M	
Any evidence of erosion			M	
Contributing drainage area stabilized			M	
4. Dewatering				
Trench dewaterers between storms			M	
5. Sediment removal of trench				
Any evidence of sedimentation in trench			A	
Does sediment accumulation currently require removal			A	
6. Inlets				
Good condition			A	
Any evidence of erosion			A	
7. Outlets/overflow spillway				
Good condition (no need for repair)			A	
Any evidence of erosion			A	
8. Aggregate repairs				
Surface of aggregate clean			A	
Top layer of stone in need of replacement			A	
Trench in need of rehabilitation			A	

Inspection Items	Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
9. Vegetated surface				
Evidence of erosion present			M	
Perforated inlet functioning adequately			M	
Does water stand on vegetated surface			M	
Does good vegetative cover exist			M	
10. Overall function of facility				
Any evidence of flow bypassing facility			S	
Water level in monitoring well			S	
Damage to cap or well			S	

Inspection Frequency Key A=Annual, M=Monthly, S=After major storm

Necessary Action:

If any of the items above were answered Yes for "Maintenance Needed", a time frame needs to be established for repair or correction.

No action necessary. Continue routine inspections.

Correct noted facility deficiencies by (date) _____

Facility repairs were previously indicated and completed. Site reinspection is necessary to verify corrections or improvements.

Site reinspection completed on (date) _____

Site reinspection was satisfactory.

Next routine inspection is scheduled for approximately (date): _____

Inspectors Signature

Operation and Maintenance Inspection Report for Enhanced Swales / Grass Channels / Filter Strips

(Adapted from Watershed Management Institute, Inc.)

Inspector Name _____ Project Location _____
 Inspection Date _____
 Watershed _____
 As-built Plans available? _____

Inspection Items	Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
1. Debris removal				
Facility and adjacent area clear of debris			M	
Inlets and outlets clear of debris			M	
Any dumping of yard wastes into facility			M	
Has litter (branches, etc.) been removed			M	
2. Vegetation				
Adjacent area stabilized			M	
Grass mowed			M	
Plant height not less than design water depth			M	
Fertilized per specifications			M	
Any evidence of erosion			M	
Is plant composition according to approved plans			M	
Any unauthorized or inappropriate plantings			M	
Any dead or diseased plants			M	
Any evidence of plant stress from inadequate watering			M	
Any evidence of deficient stakes or wires			M	
3. Oil and grease				
Any evidence of filter clogging			M	
4. Dewatering				
Facility dewaterers between storms			M	
5. Check dams/energy dissipators/sumps				
Any evidence of sedimentation buildup			A,S	
Are sumps greater than 50% full of sediment			A,S	
Any evidence of erosion at downstream toe of drop structures			A,S	

Inspection Items	Checked? Yes / No	Maintenance Needed? Yes / No	Inspection Frequency	Comments
6. Sediment deposition				
Swale clean of sediments			A	
Sediments should not be > than 20% of swale design depth			A	
7. Outlets/overflow spillway				
Good condition (no need for repair)			A,S	
Any evidence of erosion			A,S	
Any evidence of blockages			A,S	
8. Integrity of facility				
Has facility been blocked or filled inappropriately			A	
9. Bioretention Planting Soil				
Any evidence of planting soil erosion			A	
10. Organic Layer				
Mulch covers entire area (NO voids) and to specified thickness			A	
Mulch is in good condition			A	

Inspection Frequency Key A=Annual, M=Monthly, S=After major storm

Necessary Action:

If any of the items above were answered Yes for "Maintenance Needed", a time frame needs to be established for repair or correction.

No action necessary. Continue routine inspections.

Correct noted facility deficiencies by (date) _____

Facility repairs were previously indicated and completed. Site reinspection is necessary to verify corrections or improvements.

Site reinspection completed on (date) _____

Site reinspection was satisfactory.

Next routine inspection is scheduled for approximately (date): _____

Inspectors Signature

LANDSCAPING AND AESTHETICS GUIDANCE

Introduction

Landscaping is a critical element in the design of storm water facilities for water quantity and quality management, serving both functional and aesthetic purposes. Plants and vegetation perform a number of functions in storm water controls and conveyance facilities, including:

- Slowing and retarding flow by increasing hydraulic roughness
- Preventing the erosion of bare soil
- Enhancing infiltration of runoff into the soil
- Providing pollutant removal through vegetative uptake
- Preventing access to deep open water areas
- Contributing to wildlife and fish habitat
- Improving the overall appearance of storm water facilities

The purpose of this Appendix is to provide guidance on landscaping and plant selection for storm water facilities and structural controls, as well as provide an overview on developing aesthetically-pleasing storm water facilities. This appendix is divided into the following sections:

- Subsection F.1 covers general landscaping guidance that should be considered when landscaping any storm water facility.
- Subsection F.2 discusses the physical site factors and considerations involved in selecting plant material for storm water facility landscaping.
- Subsection F.3 includes key factors to consider in selecting plant material for storm water landscaping are reviewed, including hardiness, physiographic regions, inundation tolerance, and other factors.
- Subsection F.4 outlines more specific guidance on landscaping criteria and plant selection for individual structural storm water control designs, including:
 - Storm Water Ponds and Wetlands
 - Bioretention Areas
 - Infiltration Trench and Surface Sand Filter Facilities
 - Enhanced Swales and Grass Channels
 - Filter Strips and Stream Buffers
 - Green Roofs
- Subsection F.5 contains a detailed plant list of trees and shrubs that may be used when preparing a vegetation and landscaping planting plan for a storm water facility.
- Subsection F.6 provides examples of aesthetics and good landscaping in structural control design.

For information on native and adapted plants and trees to create landscapes that need less water, pesticides, and fertilizer to thrive in the North Central Texas climate, visit www.txsmartscape.com. Excessive fertilizer in runoff can lead to “overgrowth” of submerged plants.

F.1 General Landscaping Guidance

Below are general guidelines that should be followed in the landscaping of any storm water control or conveyance facility.

DO NOT:

- ❑ Plant trees, scrubs or any type of woody vegetation on an embankment
- ❑ Plant trees and shrubs within 15 feet of the toe of slope of a dam.
- ❑ Plant trees or shrubs known to have long tap roots within the vicinity of the earthen dam or embankment, or subsurface drainage facilities.
- ❑ Plant trees and shrubs within 25 feet of a principal spillway structure (e.g., riser)
- ❑ Plant trees and shrubs within 25 feet of perforated pipes.
- ❑ Block maintenance access to structures with trees or shrubs.
- ❑ Plant trees and shrubs within 25 feet of a structural concrete dam.

DO:

- ❑ Take into account site characteristics and plant selection guidelines (see subsections F.2 and F.3, respectively) when selecting plants for storm water facilities.
- ❑ Consider how plant characteristics will affect the landscape and the performance of a structural storm water control or conveyance.
- ❑ Carefully consider the long-term vegetation management strategy for the structural control, keeping in mind the maintenance legacy for the future owners.
- ❑ Preserve existing natural vegetation when possible.
- ❑ Avoid the overuse of any plant materials.
- ❑ Have soils tested to determine if there is a need for amendments.
- ❑ Select plants that can thrive in on-site soils with no additional amendments or a minimum of amendments.
- ❑ Consider water availability, particularly for wetland and water-intensive plantings.
- ❑ Decrease the areas where turf is used. Use low maintenance ground cover to absorb run-off.
- ❑ Plant stream and edge of water buffers with trees, shrubs, ornamental grasses, and herbaceous materials where possible, to stabilize banks and provide shade.
- ❑ Provide slope stabilization methods for slopes steeper than 2:1, such as planted erosion control mats. Also, use seed mixes with quick germination rates in this area. Augment temporary seeding measures with container crowns or root mats of more permanent plant material.
- ❑ Utilize erosion control mats and fabrics to protect inverts of channels that are subject to frequent wash outs.
- ❑ Stabilize all water overflows with plant material that can withstand strong current flows. Root material should be fibrous and substantial but lacking a tap root.
- ❑ Sod area channels that are not stabilized using erosion control mats.
- ❑ Divert flows temporarily from seeded areas until stabilized.
- ❑ Check water tolerances of existing plant materials prior to inundation of area.
- ❑ Stabilize aquatic and safety benches with emergent wetland plants and wet seed mixes.
- ❑ Provide a 15-foot clearance from a non-clogging, low flow orifice.

- ❑ Limit herbaceous embankment plantings to 10 inches in height, to allow visibility for the inspector who is looking for burrowing rodents that may compromise the integrity of the embankment.
- ❑ Shade inflow and outflow channels, as well as the southern exposures of pond, to reduce thermal warming
- ❑ Avoid plantings that will require routine or intensive chemical applications (i.e. turf area).
- ❑ Maintain and frame desirable views. Be careful not to block views at entrances, exits, or difficult road curves. Screen or buffer unattractive views into the site.
- ❑ Use plants to prohibit pedestrian access to pools or slopes that may be unsafe.
- ❑ Keep maintenance area open to allow future access for pond maintenance.
- ❑ Provide a planting surface that can withstand the compaction of vehicles using maintenance access roads.
- ❑ Make sure the facility maintenance agreement includes a maintenance requirement of designated plant material.
- ❑ Provide signage for:
 - Storm water management facilities to help educate the public
 - Wildflower areas to designate limits of mowing
 - Preserving existing natural vegetation

F.2 Site Considerations

A development site's characteristics often will help to determine which plant materials and planting methods the site designer should select and will help improve plant establishment. Primary site considerations include:

- (1) Soil Characteristics
- (2) Drainage
- (3) Slope
- (4) Orientation

Soil Characteristics

Plant establishment and growth can be limited by a number of different soil characteristics including:

- Soil texture
- PH -- whether acid, neutral, or alkali
- Nutrient levels -- nitrogen, phosphorus, potassium
- Minerals -- such as chelated iron, lime
- Salinity
- Toxicity

Soils are made up of four basic ingredients: mineral elements, pore space, organic matter and other items consisting mainly of living organisms including fungi, bacteria, and nematodes. One classification of soils is based upon the mineral part of soil and consists of four sizes of particles. Clay particles are the smallest, followed by silt, sand, and gravel. The USDA has devised another system of classifying soil particles. In this system soil is divided into seven categories: clay, silt, and five sizes of sand.

Soil texture is determined by the percentage of sand, silt, and clay in the soil. The structure of a soil is influenced by soil texture and also by the aggregation of small soil particles into larger particles. The amount of aggregation in a soil is strongly influenced by the amount of organic matter present.

Soil samples should be analyzed by experienced and qualified individuals who can explain the results and provide information on any soil amendments that are required. Soil fertility can often be corrected by applying fertilizer or by increasing the level of organic matter in the soil. Soil pH can be corrected with applications of lime. Where poor soils can't be amended, seed mixes and plant material must be selected to establish ground cover as quickly as possible.

Areas that have recently been involved in construction can become compacted so that plant roots cannot penetrate the soil. Seeds lying on the surface of compacted soils can be washed away or be eaten by birds. Soils should be loosened to a minimum depth of two inches, preferably to a four-inch depth. Hard soils may require disking to a deeper depth. Loosening soils will improve seed contact with the soil, provide greater germination rates, and allow the roots to penetrate into the soil. If the area is to be sodded, disking will allow the roots to penetrate into the soil.

Whenever possible, topsoil should be spread to a depth of four inches (two inch minimum) over the entire area to be planted. This provides organic matter and important nutrients for the plant material. This also allows the stabilizing materials to become established faster, while the roots are able to penetrate deeper and stabilize the soil, making it less likely that the plants will wash out during a heavy storm. If topsoil has been stockpiled in deep mounds for a long period of time, it is desirable to test the soil for pH as well as microbial activity. If the microbial activity has been destroyed, it may be necessary to inoculate the soil after application.

Drainage

Soil moisture and drainage have a direct bearing on the plant species and communities that can be supported on a site. Factors such as soil texture, topography, groundwater levels and climatic patterns all influence soil drainage and the amount of water in the soil. Identifying the topography and drainage of the site will help determine potential moisture gradients. The following categories can be used to describe the drainage properties of soils on a site:

Flooded - Areas where standing water is present most of the growing season.

Wet - Areas where standing water is present most of the growing season, except during times of drought. Wet areas are found at the edges of ponds, rivers, streams, ditches, and low spots. Wet conditions exist on poorly drained soils, often with a high clay content.

Moist - Areas where the soil is damp. Occasionally, the soil is saturated and drains slowly. These areas usually are at slightly higher elevations than wet sites. Moist conditions may exist in sheltered areas protected from sun and wind.

Well-drained - Areas where rain water drains readily and puddles do not last long. Moisture is available to plants most of the growing season. Soils usually are medium textures with enough sand and silt particles to allow water to drain through the soil.

Dry - Areas where water drains rapidly through the soil. Soils are usually coarse, sandy, rocky or shallow. Slopes are often steep and exposed to sun and wind. Water runs off quickly and does not remain in the soil.

Slope

The degree of slope can also limit its suitability for certain types of plants. Plant establishment and growth requires stable substrates for anchoring root systems and preserving propagules such as seeds and plant fragments, and slope is a primary factor in determining substrate stability. Establishing plants directly on or below eroding slopes is not possible for most species. In such instances, plant species capable of rapid spread and anchoring soils should be selected or bioengineering techniques should be used to aid the establishment of a plant cover.

In addition, soils on steep slopes generally drain more rapidly than those on gradual slopes. This means that the soils may remain saturated longer on gradual slopes. If soils on gradual slopes are classified as poorly drained, care should be taken that plant species are selected that are tolerant of saturation.

Site topography also affects maintenance of plant species diversity. Small irregularities in the ground surface (e.g., depressions, etc.) are common in natural systems. More species are found in areas with many micro-topographic features than in areas without such features. Raised sites are particularly important in wetlands because they allow plants that would otherwise die while flooded to escape inundation.

In wetland plant establishment, ground surface slope interacts with the site hydrology to determine water depths for specific areas within the site. Depth and duration of inundation are principal factors in the zonation of wetland plant species. A given change in water levels will expose a relatively small area on a steep slope in comparison with a much larger area exposed on a gradual or flat slope. Narrow planting zones will be delineated on steep slopes for species tolerant of specific hydrologic conditions, whereas gradual slopes enable the use of wider planting zones.

Orientation

Slope exposure should be considered for its effect on plants. A southern-facing slope receives more sun and is warmer and drier, while the opposite is true of a northern slope. Eastern- and western-facing slopes are intermediate, receiving morning and afternoon sun, respectively. Western-facing slopes tending to receive more wind.

F.3 Plant Selection for Storm Water Facilities

F.3.1 Hardiness Zones

Hardiness zones are based on historical annual minimum temperatures recorded in an area. A site's location in relation to plant hardiness zones is important to consider first because plants differ in their ability to withstand very cold winters. This does not imply that plants are not affected by summer temperatures. Given that Texas summers can be very hot, heat tolerance is also a characteristic that should be considered in plant selection.

It is best to recommend plants known to thrive in specific hardiness zones. The plant list included at the end of this appendix identifies the hardiness zones for each species listed as a general planting guide. It should be noted, however, that certain site factors can create microclimates or environmental conditions which permit the growth of plants not listed as hardy for that zone. By investigating numerous references and based on personal experience, a designer should be able to confidently recommend plants that will survive in microclimates.

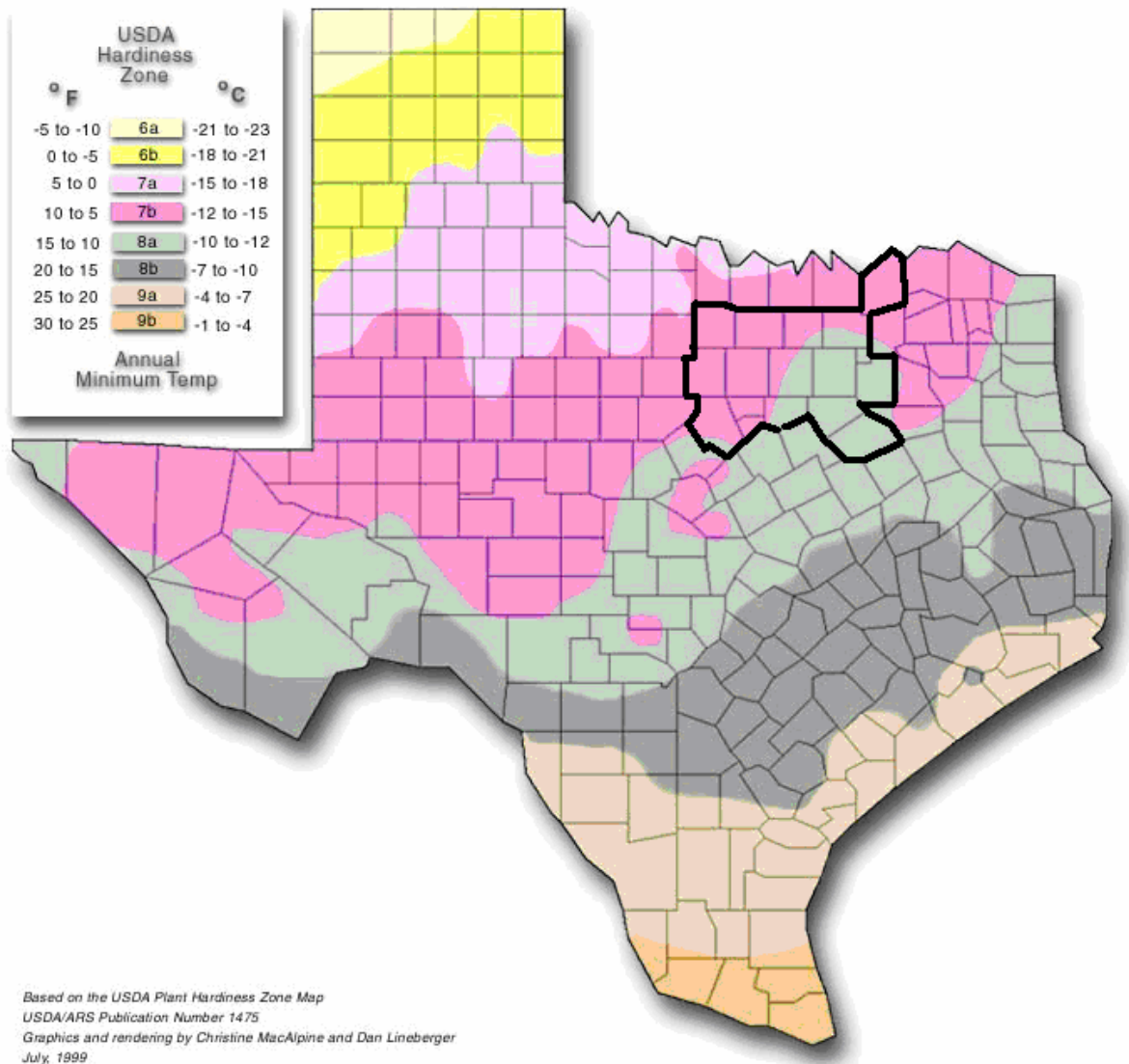


Figure F-1 USDA Plant Hardiness Zones in Texas

F.3.2 Physiographic Provinces

There are three physiographic provinces in Texas that describe distinct geographic regions in the state with similar physical and environmental conditions (Figure F-2). These physiographic provinces include, from northwest to southeast, High Plains, Edwards Plateau, and Gulf Coastal Plains (subdivided into multiple subregions). Each physiographic region is defined by unique geological strata, soil type, drainage patterns, moisture content, temperature and degree of slope which often dictate the predominant vegetation. Because the predominant vegetation has evolved to live in these specific conditions, a successful storm water management facility planting design can be achieved through mimicking these natural associations. The three physiographic regions are described below with associated vegetation listed as general planting guidance.

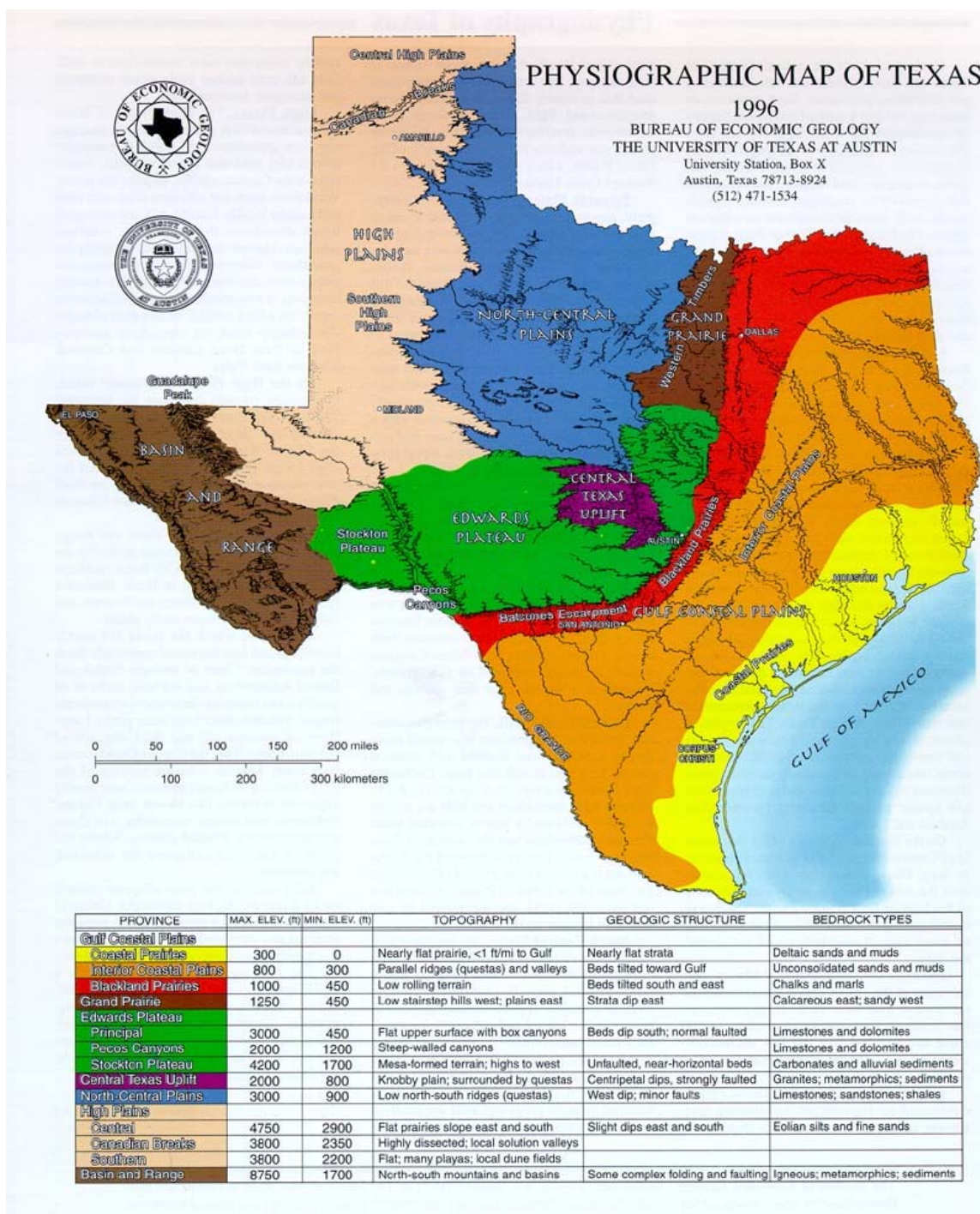


Figure F-2 Physiographic map of Texas

Gulf Coastal Plains. The Gulf Coastal Plains include three subprovinces named the Coastal Prairies, the Interior Coastal Plains, and the Blackland Prairies. The Coastal Prairies begin at the Gulf of Mexico shoreline. Young deltaic sands, silts, and clays erode to nearly flat grasslands that form almost imperceptible slopes to the southeast. Trees are uncommon except locally along streams and in Oak mottes, growing on coarser underlying sediments of ancient streams. Minor steeper slopes, from 1 foot to as much as 9 feet high, result from subsidence of deltaic sediments along faults. Between Corpus Christi

and Brownsville, broad sand sheets pocked by low dunes and blowouts forming ponds dominate the landscape.

The Interior Coastal Plains comprise alternating belts of resistant uncemented sands among weaker shales that erode into long, sandy ridges. At least two major down-to-the coast fault systems trend nearly parallel to the coastline. Clusters of faults also concentrate over salt domes in East Texas. That region is characterized by pine and hardwood forests and numerous permanent streams. West and south, tree density continuously declines, pines disappear in Central Texas, and chaparral brush and sparse grasses dominate between San Antonio and Laredo.

On the Blackland Prairies of the innermost Gulf Coastal Plains, chalks and marls weather to deep, black, fertile clay soils, in contrast with the thin red and tan sandy and clay soils of the Interior Gulf Coastal Plains. The blacklands have a gentle undulating surface, cleared of most natural vegetation and cultivated for crops.

From sea level at the Gulf of Mexico, the elevation of the Gulf Coastal Plains increases northward and westward. In the Austin San Antonio area, the average elevation is about 800 feet. South of Del Rio, the western end of the Gulf Coastal Plains has an elevation of about 1,000 feet.

Grand Prairie. The eastern Grand Prairie developed on limestones; weathering and erosion have left thin rocky soils. North and west of Fort Worth, the plateau like surface is well exposed, and numerous streams dissect land that is mostly flat or that gently slopes southeastward. There, silver bluestem-Texas wintergrass grassland is the flora. Primarily sandstones underlie the western margin of the Grand Prairie, where post oak woods form the Western Cross Timbers.

Edwards Plateau. The Balcones Escarpment, superposed on a curved band of major normal faults, bounds the eastern and southern Edwards Plateau. Its principal area includes the Hill Country and a broad plateau. Stream erosion of the fault escarpment sculpts the Hill Country from Waco to Del Rio. The Edwards Plateau is capped by hard Cretaceous limestones. Local streams entrench the plateau as much as 1,800 feet in 15 miles. The upper drainages of streams are waterless draws that open into box canyons where springs provide permanently flowing water. Sinkholes commonly dot the limestone terrain and connect with a network of caverns. Alternating hard and soft marly limestones form a stair-step topography in the central interior of the province.

The Edwards Plateau includes the Stockton Plateau, mesa like land that is the highest part of this subdivision. With westward decreasing rainfall, the vegetation grades from mesquite juniper brush westward into creosote bush tarbush shrubs.

The Pecos River erodes a canyon as deep as 1,000 feet between the Edwards and Stockton Plateaus. Its side streams become draws forming narrow blind canyons with nearly vertical walls. The Pecos Canyons include the major river and its side streams. Vegetation is sparse, even near springs and streams.

Central Texas Uplift. The most characteristic feature of this province is a central basin having a rolling floor studded with rounded granite hills 400 to 600 feet high. Enchanted Rock State Park is typical of this terrain. Rocks forming both basin floor and hills are among the oldest in Texas. A rim of resistant lower Paleozoic formations surrounds the basin. Beyond the Paleozoic rim is a second ridge formed of limestones like those of the Edwards Plateau. Central live oak mesquite parks are surrounded by live oak ash juniper parks.

North-Central Plains. An erosional surface that developed on upper Paleozoic formations forms the North-Central Plains. Where shale bedrock prevails, meandering rivers traverse stretches of local prairie. In areas of harder bedrock, hills and rolling plains dominate. Local areas of hard sandstones and limestones cap steep slopes severely dissected near rivers. Lengthy dip slopes of strongly fractured limestones display extensive rectangular patterns. Western rocks and soils are oxidized red or gray where gypsum dominates, whereas eastern rocks and soils weather tan to buff. Live oak ash juniper parks grade westward into mesquite lotebush brush.

High Plains. The High Plains of Texas form a nearly flat plateau with an average elevation approximating 3,000 feet. Extensive stream-laid sand and gravel deposits, which contain the Ogallala aquifer, underlie the plains. Windblown sands and silts form thick, rich soils and caliche locally. Havard shin oak mesquite brush dominates the silty soils, whereas sandsage Havard shin oak brush occupies the sand sheets. Numerous playa lakes scatter randomly over the treeless plains. The eastern boundary is a westward-retreating escarpment capped by a hard caliche. Headwaters of major rivers deeply notch the caprock, as exemplified by Palo Duro Canyon and Caprock Canyons State Parks.

On the High Plains, widespread small, intermittent streams dominate the drainage. The Canadian River cuts across the province, creating the Canadian Breaks and separating the Central High Plains from the Southern High Plains. Pecos River drainage erodes the west-facing escarpment of the Southern High Plains, which terminates against the Edwards Plateau on the south.

Basin and Range. The Basin and Range province contains eight mountain peaks that are higher than 8,000 feet. At 8,749 feet, Guadalupe Peak is the highest point in Texas. Mountain ranges generally trend nearly north-south and rise abruptly from barren rocky plains.

Plateaus in which the rocks are nearly horizontal and less deformed commonly flank the mountains. Cores of strongly folded and faulted sedimentary and volcanic rocks or of granite rocks compose the interiors of mountain ranges. Volcanic rocks form many peaks. Large flows of volcanic ash and thick deposits of volcanic debris flank the slopes of most former volcanoes. Ancient volcanic activity of the Texas Basin and Range province was mostly explosive in nature, like Mount Saint Helens. Volcanoes that poured successive lava flows are uncommon. Eroded craters, where the cores of volcanoes collapsed and subsided, are abundant.

Gray oak, pinyon pine, and alligator juniper parks drape the highest elevations. Creosote bush and lechuguilla shrubs sparsely populate plateaus and intermediate elevations. Tobosa black grama grassland occupies the low basins.

Floodplain Plant Communities – Floodplain areas are a microclimatic area that results in a characteristic plant community that is similar in all three physiographic provinces. Floodplain plant communities are an important reference community since many storm water practices are located with this area. Floodplains occur along streams in both steep and level areas. The most noteworthy plants found along floodplains are River Birch, Willows, Poplars, Maple, Sweet Gum, Sycamore, Box Elder, Green Ash, American Elm, Swamp White Oak, Bur Oak, Honeylocust and Hackberry. Shrubs commonly found in floodplains include Shrub Willows, Yaupon, Buttonbush, Blackberry, and Elderberry.

F.3.3 Other Considerations in Plant Selection

Use or Function

In selecting plants, consideration must be given to their desired function in the storm water management facility. Is the plant needed as ground cover, soil stabilizer, biofilter or source of shade? Will the plant be placed for functional or aesthetic purposes? Does the adjacent use provide conflicts or potential problems and require a barrier, screen, or buffer? Nearly every plant and plant location should be provided to serve some function in addition to any aesthetic appeal.

Plant Characteristics

Certain plant characteristics are so obvious, they may actually be overlooked in the plant selection. These are:

- ☐ Size
- ☐ Shape

For example, tree limbs, after several years, can grow into power lines. A wide growing shrub may block maintenance access to a storm water facility. Consider how these characteristics can work for you or against you, today and in the future.

Other plant characteristics must be considered to determine how the plant grows and functions seasonally, and whether the plant will meet the needs of the facility today and in the future. Some of these characteristics are:

- ☐ Growth Rate
- ☐ Regeneration Capacity
- ☐ Maintenance Requirements (e.g. mowing, harvesting, leaf collection, etc.)
- ☐ Aesthetics

In urban or suburban settings, a plant's aesthetic interest may be of greater importance. Residents living next to a storm water system may desire that the facility be appealing or interesting to look at throughout the year. Aesthetics is an important factor to consider in the design of these systems. Failure to consider the aesthetic appeal of a facility to the surrounding residents may result in reduced value to nearby lots. Careful attention to the design and planting of a facility can result in maintained or increased values of a property.

Availability and Cost

Often overlooked in plant selection is the availability from wholesalers and the cost of the plant material. There are many plants listed in landscape books that are not readily available from the nurseries. Without knowledge of what is available, time spent researching and finding the one plant that meets all the needs will be wasted, if it is not available from the growers. It may require shipping, therefore, making it more costly than the budget may allow. Some planting requirements, however, may require a special effort to find the specific plant that fulfills the needs of the site and the function of the plant in the landscape.

Native versus Nonnative Species

This Manual encourages the use of native plants in storm water management facilities, since they are best suited to thrive under the physiographic and hardiness conditions encountered at a site. Unfortunately, not all native plants provide the desired landscape or appearance, and may not always be available in quantity from local nurseries. Therefore, naturalized plants that are not native species, but can thrive and reproduce in the new area may be a useful alternative.

Because all landscaping needs may not be met by native or naturalized plants, some ornamental and exotic species are provided in this guide that can survive under difficult conditions encountered in a storm water management facility. Since many storm water facilities are adjacent to residential areas, the objectives of the storm water planting plan may shift to resemble the more controlled appearance of nearby yards, or to provide a pleasing view. Great care should be taken; however, when introducing plant species so as not to create a situation where they may become invasive and take over adjacent natural plant communities.

Moisture Status

In landscaping storm water management facilities, hydrology plays a large role in determining which species will survive in a given location.

For areas that are to be planted within a storm water management facility it is necessary to determine what type of hydrologic zones will be created within the facility.

The six zones shown in Table F-1 in the next section describe the different conditions encountered in storm water management facilities. Every facility does not necessarily reflect all of these zones. The hydrologic zones designate the degree of tolerance the plant exhibits to differing degrees of inundation by

water. Each zone has its own set of plant selection criteria based on the hydrology of the zone, the storm water functions required of the plant and the desired landscape effect.

F.4 Specific Landscaping Criteria for Structural Storm Water Controls

F.4.1 Storm Water Ponds and Wetlands

Storm water ponds and wetlands are engineered basins and wetland areas designed to control and treat storm water runoff. Aquatic vegetation plays an important role in pollutant removal in both storm water ponds and wetlands. In addition, vegetation can enhance the appearance of a pond or wetland, stabilize side slopes, serve as wildlife habitat, and can temporarily conceal unsightly trash and debris.

Within a storm water pond or wetland, there are various hydrologic zones as shown in Table F-1 that must be considered in plant selection. These hydrologic zones designate the degree of tolerance a plant must have to differing degrees of inundation by water. Hydrologic conditions in an area may fluctuate in unpredictable ways; thus the use of plants capable of tolerating wide varieties of hydrologic conditions greatly increases the successful establishment of a planting. Plants suited for specific hydrologic conditions may perish when those conditions change, exposing the soil, and therefore, increasing the chance for erosion. Each of the hydrologic zones is described in more detail below along with examples of appropriate plant species.

Table F-1 Hydrologic Zones

<u>Zone #</u>	<u>Zone Description</u>	<u>Hydrologic Conditions</u>
Zone 1	Deep Water Pool	1-6 feet depth (permanent pool)
Zone 2	Shallow Water Bench	Normal pool elevation to 1 foot depth
Zone 3	Shoreline Fringe	Regularly inundated
Zone 4	Riparian Fringe	Periodically inundated
Zone 5	Floodplain Terrace	Infrequently inundated
Zone 6	Upland Slopes	Seldom or never inundated

Zone 1: Deep Water Area (1- 6 Feet)

Ponds and wetlands both have deep pool areas that comprise Zone 1. These pools range from one to six feet in depth, and are best colonized by submergent plants, if at all.

This pondscaping zone is *not* routinely planted for several reasons. First, the availability of plant materials that can survive and grow in this zone is limited, and it is also feared that plants could clog the storm water facility outlet structure. In many cases, these plants will gradually become established through natural recolonization (e.g., transport of plant fragments from other ponds via the feet and legs of waterfowl). If submerged plant material is commercially available and clogging concerns are addressed, this area can be planted. The function of the planting is to reduce resedimentation and improve oxidation while creating a greater aquatic habitat.

- ❑ Plant material must be able to withstand constant inundation of water of one foot or greater in depth.

- ❑ Plants may be submerged partially or entirely.
- ❑ Plants should be able to enhance pollutant uptake.
- ❑ Plants may provide food and cover for waterfowl, desirable insects, and other aquatic life.

Some suggested emergent or submergent species include, but are not limited to: Water Lily, Deepwater Duck Potato, Spatterdock, Wild Celery and Redhead Grass.

Zone 2: Shallow Water Bench (*Normal Pool To 1 Foot*)

Zone 2 includes all areas that are inundated below the normal pool to a depth of one foot, and is the primary area where emergent plants will grow in storm water wetlands. Zone 2 also coincides with the aquatic bench found in storm water ponds. This zone offers ideal conditions for the growth of many emergent wetland species. These areas may be located at the edge of the pond or on low mounds of earth located below the surface of the water within the pond. When planted, Zone 2 can be an important habitat for many aquatic and nonaquatic animals, creating a diverse food chain. This food chain includes predators, allowing a natural regulation of mosquito populations, thereby reducing the need for insecticidal applications.

- ❑ Plant material must be able to withstand constant inundation of water to depths between six inches and one foot deep.
- ❑ Plants will be partially submerged.
- ❑ Plants should be able to enhance pollutant uptake.
- ❑ Plants may provide food and cover for waterfowl, desirable insects and other aquatic life.

Common emergent wetland plant species used for storm water wetlands and on the aquatic benches of storm water ponds include, but are not limited to: Arrowhead/Duck Potato, Soft Rush, various Sedges, Softstem Bulrush, Switchgrass, Pickerelweed, Pond Cypress and various Asters.

Zone 3: Shoreline Fringe (*Regularly Inundated*)

Zone 3 encompasses the shoreline of a pond or wetland, and extends vertically about one foot in elevation from the normal pool. This zone includes the safety bench of a pond, and may also be periodically inundated if storm events are subject to extended detention. This zone occurs in a wet pond or shallow marsh and can be the most difficult to establish since plants must be able to withstand inundation of water during storms, when wind might blow water into the area, or the occasional drought during the summer. In order to stabilize the soil in this zone, Zone 3 must have a vigorous cover.

- ❑ Plants should stabilize the shoreline to minimize erosion caused by wave and wind action or water fluctuation.
- ❑ Plant material must be able to withstand occasional inundation of water. Plants will be partially submerged partially at this time.
- ❑ Plant material should, whenever possible, shade the shoreline, especially the southern exposure. This will help to reduce the water temperature.
- ❑ Plants should be able to enhance pollutant uptake.
- ❑ Plants may provide food and cover for waterfowl, songbirds, and wildlife. Plants could also be selected and located to control overpopulation of waterfowl.
- ❑ Plants should be located to reduce human access, where there are potential hazards, but should not block the maintenance access.
- ❑ Plants should have very low maintenance requirements, since they may be difficult or impossible to reach.

- ❑ Plants should be resistant to disease and other problems which require chemical applications (since chemical application is not advised in storm water ponds).

Many of the emergent wetland plants that perform well in Zone 2 also thrive in Zone 3. Some other species that do well include Broom Grass, Upland Sea-Oats, Dwarf Tickseed, various Ferns, Hawthorns. If shading is needed along the shoreline, the following tree species are suggested: Boxelder, Ash, Willow, Red Maples and Willow Oak.

Zone 4: Riparian Fringe (*Periodically Inundated*)

Zone 4 extends from one to four feet in elevation above the normal pool. Plants in this zone are subject to periodic inundation after storms, and may experience saturated or partly saturated soil inundation. Nearly all of the temporary extended detention (ED) storage area is included within this zone.

- ❑ Plants must be able to withstand periodic inundation of water after storms, as well as occasional drought during the warm summer months.
- ❑ Plants should stabilize the ground from erosion caused by run-off.
- ❑ Plants should shade the low flow channel to reduce the pool warming whenever possible.
- ❑ Plants should be able to enhance pollutant uptake.
- ❑ Plant material should have very low maintenance, since they may be difficult or impossible to access.
- ❑ Plants may provide food and cover for waterfowl, songbirds and wildlife. Plants may also be selected and located to control overpopulation of waterfowl.
- ❑ Plants should be located to reduce pedestrian access to the deeper pools.

Some frequently used plant species in Zone 4 include Broom Grass, Yellow Indian Grass, Joe Pye Weed, Lilies, Flatsedge, Hollies, Forsythia, Lovegrass, Hawthorn and Sugar Maples.

Zone 5: Floodplain Terrace (*Infrequently Inundated*)

Zone 5 is periodically inundated by flood waters that quickly recede in a day or less. Operationally, Zone 5 extends from the maximum two year or SP_v water surface elevation up to the 25 or 100 year maximum water surface elevation. Key landscaping objectives for Zone 5 are to stabilize the steep slopes characteristic of this zone, and establish a low maintenance, natural vegetation.

- ❑ Plant material should be able to withstand occasional but brief inundation during storms, although typical moisture conditions may be moist, slightly wet, or even swing entirely to drought conditions during the dry weather periods.
- ❑ Plants should stabilize the basin slopes from erosion.
- ❑ Ground cover should be very low maintenance, since they may be difficult to access on steep slopes or if the frequency of mowing is limited. A dense tree cover may help reduce maintenance and discourage resident geese.
- ❑ Plants may provide food and cover for waterfowl, songbirds, and wildlife.
- ❑ Placement of plant material in Zone 5 is often critical, as it often creates a visual focal point and provides structure and shade for a greater variety of plants.

Some commonly planted species in Zone 5 include many wildflowers or native grasses, many Fescues, many Viburnums, Witch Hazel, Blueberry, American Holly, American Elderberry and Red Oak.

Zone 6: Upland Slopes (*Seldom or Never Inundated*)

The last zone extends above the maximum 100 year water surface elevation, and often includes the outer buffer of a pond or wetland. Unlike other zones, this upland area may have sidewalks, bike paths, retaining walls, and maintenance access roads. Care should be taken to locate plants so they will not overgrow these routes or create hiding places that might make the area unsafe.

- ❑ Plant material is capable of surviving the particular conditions of the site. Thus, it is not necessary to select plant material that will tolerate any inundation. Rather, plant selections should be made based on soil condition, light, and function within the landscape.
- ❑ Ground covers should emphasize infrequent mowing to reduce the cost of maintaining this landscape.

Placement of plants in Zone 6 is important since they are often used to create a visual focal point, frame a desirable view, screen undesirable views, or serve as a buffer.

Some frequently used plant species in Zone 6 include most ornamentals (as long as soils drain well, many wildflowers or native grasses, Linden, False Cypress, Magnolia, most Spruce, Mountain Ash and most Pine.

- ❑ Table F-2 provides a list of selected wetland plants for storm water ponds and wetlands. For hydrologic zones 1-4, provide shade to allow a greater variety of plant materials. Particular attention should be paid to seasonal color and texture of these plantings.

Table F-2 Wetland Plants (Herbaceous Species) for Storm Water Facilities

<u>Scientific Name</u>	<u>Common Name</u>	<u>Hydrologic Zone</u>
<i>Acorus calamus</i>	Sweetflag	2
<i>Andropogon gerardii</i>	Big Bluestem	6
<i>Andropogon glomeratus</i>	Bushy Broom Grass	3
<i>Andropogon virginicus</i>	Broom Grass	4
<i>Asclepias tuberosa</i>	Butterfly-weed	6
<i>Bouteloua certipendula</i>	Sideoats Grama	6
<i>Buchloe dactyloides</i>	Buffalograss	6
<i>Carex spp.</i>	Caric Sedges	2
<i>Chasmanthium latifolium</i>	Upland Sea-Oats	3
<i>Coreopsis tinctoria</i>	Dwarf Tickseed	3
<i>Cynodon dactylon</i>	Bermuda Grass	5,6
<i>Echinacea purpurea</i>	Purple Coneflower	6
<i>Elocharis quadrangulata</i>	Square Stem Spikerush	2
<i>Elymus Canadensis</i>	Canada Wildrye	4,5
<i>Elymus virginicus</i>	Virginia Wildrye	4,5
<i>Eupatorium fistulosum</i>	Joe Pye Weed	4
<i>Eupatorium serotinum</i>	Late Boneset	3,4

<u>Scientific Name</u>	<u>Common Name</u>	<u>Hydrologic Zone</u>
<i>Eustoma grandiflora</i>	Texas Bluebells	4
<i>Helianthus angustifolius</i>	Swamp Sunflower	2
<i>Helianthus maximiliani</i>	Maximilian Sunflower	3,4,5,6
<i>Hibiscus laevis</i>	Halberdleaf Hibiscus	2,3
<i>Juncus effuses</i>	Soft Rush	2
<i>Leersia oryzoides</i>	Rice Cut Grass	2
<i>Leptochola dubia</i>	Green Spangletop	6
<i>Liatris mucronata</i>	Gayfeather	6
<i>Liatris punctata</i>	Gayfeather	6
<i>Liatris pycnostachya</i>	Gayfeather	5,6
<i>Liatris spicata</i>	Spiked Gayfeather	3
<i>Lobelia cardinalis</i>	Cardinal Flower	3
<i>Malvaviscus drummondii</i>	Turk's Cap	4,5,6
<i>Nuphar luteum</i>	Spatterdock	1
<i>Nymphaea mexicana</i>	Yellow Water Lily	1
<i>Nymphaea odorata</i>	Fragrant Water Lily	1
<i>Osmunda cinnamomea</i>	Cinnamon Fern	3
<i>Osmunda regalis</i>	Royal Fern	3
<i>Panicum capillare</i>	Witchgrass	3,4,5,6
<i>Panicum virgatum</i>	Switchgrass	2
<i>Peltandra virginica</i>	Green Arum	2
<i>Pennisetum alopecuroides</i>	Fountaingrass	6
<i>Poa arachnifera</i>	Texas Bluegrass	6
<i>Polygonum hydropiperoides</i>	Smartweed	2
<i>Pontederia cordata</i>	Pickernelweed	2,3
<i>Pontederia lanceolata</i>	Pickernelweed	2
<i>Rudbeckia hirta</i>	Black-eyed Susan	4
<i>Sagittaria lancifolia</i>	Lance-leaf Arrowhead	2
<i>Sagittaria latifolia</i>	Duck Potato	2
<i>Salvia farinacea</i>	Mealy Blue Sage	6
<i>Salvia greggii</i>	Autumn Sage	6
<i>Saururus cernuus</i>	Lizard's Tail	2
<i>Schizachyrium scoparium</i>	Little Bluestem	6

<u>Scientific Name</u>	<u>Common Name</u>	<u>Hydrologic Zone</u>
<i>Scirpus americanus</i>	Three-square	2
<i>Scirpus californicus</i>	Giant Bulrush	2
<i>Scirpus validus</i>	Softstem Bulrush	2,3
<i>Sorgham nutans</i>	Yellow Indian Grass	4
<i>Tripsacum dactyloides</i>	Eastern Gammagrass	3,4,5,6
<i>Valpia octoflora</i>	Common Sixweeksgrass	6
<i>Woodwardia virginica</i>	Virginia Chain Fern	2

Source: Aquascape, Inc.
Texas Parks and Wildlife Department

**Zone 1: 12 to 36 inch depth below normal pool elevation**

Water Lily, Deep Water Duck Potato, Spatterdock, Wild Celery, Redhead Grass

**Zone 2: 0 to 12 inch depth below normal pool elevation**

Arrowhead/Duck Potato, Soft Rush, various Sedges, Softstem Bulrush, Switchgrass, Southern Blue Flag Iris, Swamp Hibiscus, Swamp Lily, Pickerelweed, Pond Cypress, various Asters

**Zone 3: 0 to 12 inch elevation above normal pool elevation**

Various species from above, Broom Grass, Upland Sea-Oats, Dwarf Tickseed, various Ferns, Hawthorns, Boxelder, Ash, Willow, Red Maple, Willow Oak

**Zone 4: 1 to 4 foot elevation above normal pool elevation**

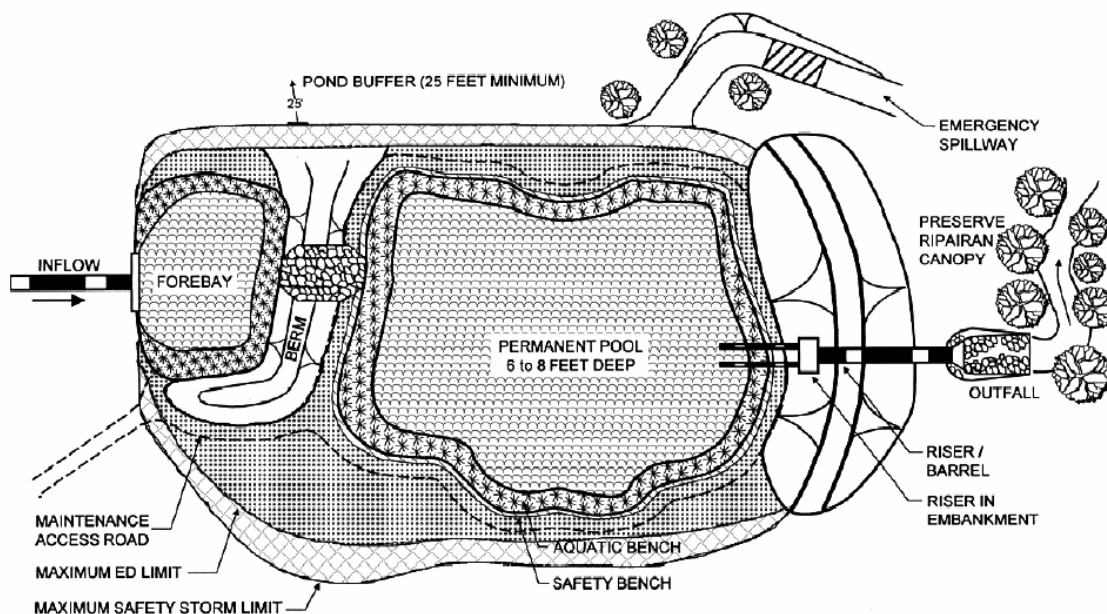
Broom Grass, Yellow Indian Grass, Ironweed, Joe Pye Weed, various Lilies, Flatsedge, Hollies, Lovegrass, Hawthorn, Sugar Maple

**Zone 5: SP_v to Q_p or Q_f water surface elevation**

Many wildflowers or native grasses, many Fescues, many Viburnums, Witch Hazel, Blueberry, American Holly, American Elderberry, Red Oak

**Zone 6: Q_f water surface elevation and above**

Many ornamentals as long as soils drain well, many wildflowers or native grasses, Linden, False Cypress, Magnolia, most Spruce, Mountain Ash, most Pine

Figure F-3 Legend of Hydrologic Zones Around Storm Water Facilities**Figure F-4 Plan View of Hydrologic Zones around Storm Water Wet ED Pond**

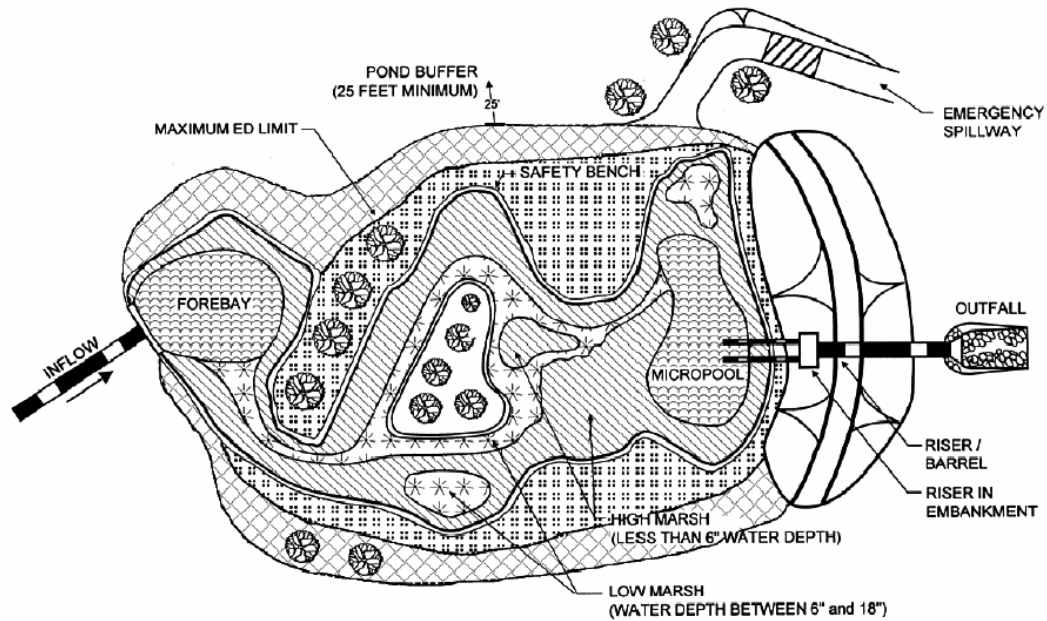


Figure F-5 Plan View of Hydrologic Zones around Storm Water ED Shallow Wetland

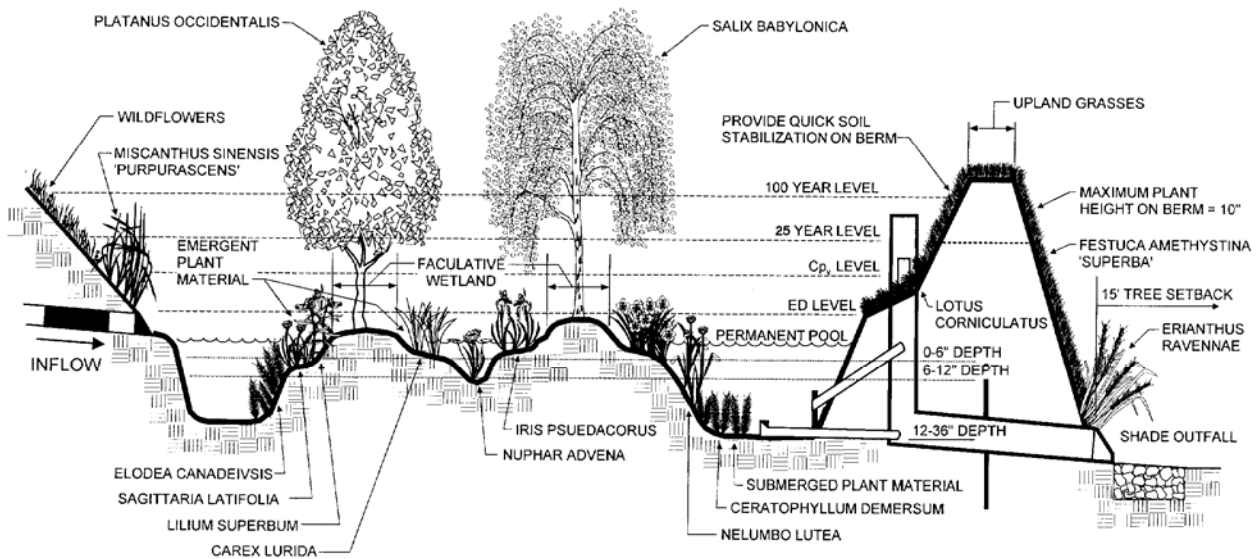


Figure F-6 Section of Typical Shallow ED Wetland

F.4.2 Bioretention Areas

Bioretention areas are structural storm water controls that capture and treat runoff using soils and vegetation in shallow basins or landscaped areas. Landscaping is therefore critical to the performance and function of these facilities. Below are guidelines for soil characteristics, mulching, and plant selection for bioretention areas.

Planting Soil Bed Characteristics

The characteristics of the soil for the bioretention facility are perhaps as important as the facility location and size. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through adsorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground.

The planting soil should be a sandy loam, loamy sand, loam, or a loam/sand mix (should contain a minimum of 35 to 60% sand, by volume). The clay content for these soils should be less than 25% by volume. Soils should fall within the SM, ML, SC classifications of the Unified Soil Classification System (USCS). A permeability of at least 1.0 feet per day (0.5"/hr) is required (a conservative value of 0.5 feet per day should be used for design). The soil should be free of stones, stumps, roots, or other woody material over 1" in diameter. Brush or seeds from noxious weeds, such as Johnson Grass, Mugwort, Nutsedge, and Canadian Thistle should not be present in the soils. Placement of the planting soil should be in lifts of 12 to 18", loosely compacted (tamped lightly with a dozer or backhoe bucket). The specific characteristics are presented in Table F-3.

Table F-3 Planting Soil Characteristics

Parameter	Value
pH range	5.2 to 7.00
Organic matter	1.5 to 4.0%
Magnesium	35 lbs. per acre, minimum (0.0072 lbs/Sq yd)
Phosphorus (P_2O_5)	75 lbs. per acre, minimum (0.0154 lbs/Sq yd)
Potassium (K_2O)	85lbs. per acre, minimum (0.0175 lbs/Sq yd)
Soluble salts	500 ppm
Clay	10 to 25%
Silt	30 to 55%
Sand	35 to 60%

(Adapted from EQR, 1996; ETAB, 1993)

Mulch Layer

The mulch layer plays an important role in the performance of the bioretention system. The mulch layer helps maintain soil moisture and avoids surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the mulch/soil interface. It also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment. The mulch layer should be standard landscape style, single or double, shredded hardwood mulch or chips. The mulch layer should be well aged (stockpiled or stored for at least 12 months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of three inches. Grass clippings should not be used as a mulch material.

Planting Plan Guidance

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat storm water runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility (Figure F-7). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. A sample of appropriate plant materials for bioretention facilities are included in Table F-4. More potential bioretention species can be found in the wetland plant list in subsection F.5.

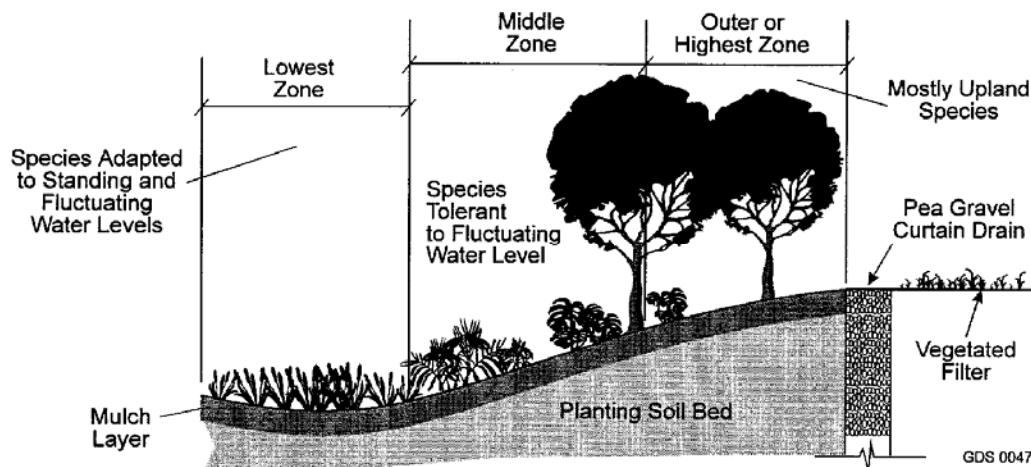


Figure F-7 Planting Zones for Bioretention Facilities

The layout of plant material should be flexible, but should follow the general principals described below. The objective is to have a system that resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth.

- ☐ Native plant species should be specified over exotic or foreign species.
- ☐ Appropriate vegetation should be selected based on the zone of hydric tolerance
- ☐ Species layout should generally be random and natural.

The tree-to-shrub ratio should be 2:1 to 3:1. On average, the trees should be spaced 8 feet apart. Plants should be placed at irregular intervals to replicate a natural forest. Woody vegetation should not be specified at inflow locations.

A canopy should be established with an understory of shrubs and herbaceous materials.

- ☐ Woody vegetation should not be specified in the vicinity of inflow locations.
- ☐ Trees should be planted primarily along the perimeter of the bioretention area.
- ☐ Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, drought) should be

considered when laying out the planting plan.

- ❑ Noxious weeds should not be specified.
- ❑ Aesthetics and visual characteristics should be a prime consideration.
- ❑ Traffic and safety issues must be considered.
- ❑ Existing and proposed utilities must be identified and considered.

Plant materials should conform to the American Standard Nursery Stock, published by the American Association of Nurserymen, and should be selected from certified, reputable nurseries. Planting specifications should be prepared by the designer and should include a sequence of construction, a description of the contractor's responsibilities, a planting schedule and installation specifications, initial maintenance, and a warranty period and expectations of plant survival. Table F-5 presents some typical issues for planting specifications. Figure F-8 shows an example of a sample planting plan for a bioretention area.

Table F-4 Commonly Used Species for Bioretention Areas

<u>Trees</u>	<u>Shrubs</u>	<u>Herbaceous Species</u>
<i>Acer rubrum</i> Red Maple (Zones 2, 3, 4)	<i>Amorpha fruticosa</i> False Indigo (Zones 3, 4)	<i>Andropogon virginicus</i> Broom Sedge/ Grass (Zone 4)
<i>Betula nigra</i> River Birch (Zones 4, 5)	<i>Aronia arbutifolia</i> Red Chokeberry (Zones 2, 3)	<i>Eupatorium fistulosum</i> Joe Pye Weed (Zone 4)
<i>Cercis canadensis</i> Eastern Redbud (Zones 4, 5)	<i>Callicarpa Americana</i> American Beautyberry (Zones 4, 5)	<i>Iris pseudacorus</i> Yellow Iris
<i>Crataegus reverchonii</i> Reverchon's Hawthorn (Zone 6)	<i>Hamamelis virginiana</i> Witch Hazel (Zone 5)	<i>Lobelia cardinalis</i> Cardinal Flower (Zone 3)
<i>Juglans nigra</i> Black Walnut (Zone 6)	<i>Lindera benzoin</i> Spicebush	<i>Malvaviscus drummondii</i> Turk's Cap (Zones 4, 5, 6)
<i>Juniperus virginiana</i> Eastern Red Cedar (Zones 5, 6)	<i>Myrica pennsylvanica</i> Bayberry	<i>Panicum capillare</i> Witchgrass (Zones 3, 4, 5, 6)
<i>Platanus occidentalis</i> Sycamore	<i>Prunus mexicana</i> Mexican Plum (Zones 5, 6)	<i>Panicum virgatum</i> Switchgrass (Zone 2)
<i>Quercus phellos</i> Willow Oak (Zones 3, 4, 5)	<i>Rhamnus caroliniana</i> Carolina Buckthorn (Zones 4, 5, 6)	<i>Pennisetum alopecuroides</i> Fountaingrass (Zone 6)
<i>Quercus macrocarpa</i> Bur Oak (Zones 5, 6)	<i>Viburnum rufidum</i> Rusty Blackhaw (Zones 4, 5, 6)	<i>Rudbeckia hirta</i> Black Eyed Susan (Zone 4)

Table F-5 Planting Plan Specification Issues for Bioretention Areas

Specification Element	Elements
Sequence of Construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation.
Contractor's Responsibilities	Specify the contractors responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting Schedule and Specifications	Specify the materials to be installed, the type of materials (e.g., B&B, bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency; removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering schedule after initial installation (once per day for 14 days is common); repair and replacement of staking and wires.
Warranty	Specify warranty period, the required survival rate, and expected condition of plant species at the end of the warranty.

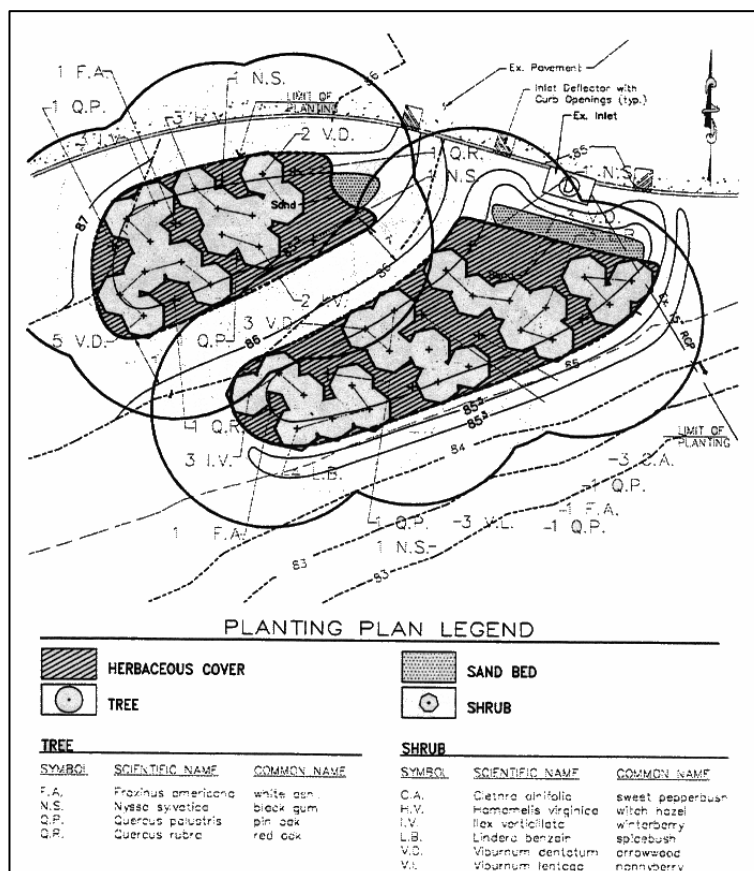


Figure F-8 Sample Bioretention Area Planting Plan
(Source: VDCR, 1999)

F.4.3 Surface Sand Filters and Infiltration Trenches

Both surface sand filters and infiltration trenches can be designed with a grass cover to aid in pollutant removal and prevent clogging. The sand filter or trench is covered with permeable topsoil and planted with grass in a landscaped area. Properly planted, these facilities can be designed to blend into natural surroundings.

Grass should be capable of withstanding frequent periods of inundation and drought. Vegetated filter strips and buffers should fit into and blend with surrounding area. Native grasses are preferable, if compatible.

Design Constraints:

- ☐ Check with your local review authority to see if the planning of a grass cover or turf over a sand filter or infiltration trench is allowed.
- ☐ Do not plant trees or provide shade within 15 feet of infiltration or filtering area or where leaf litter will collect and clog infiltration area.
- ☐ Do not locate plants to block maintenance access to the facility.
- ☐ Sod areas with heavy flows that are not stabilized with erosion control mats.
- ☐ Divert flows temporarily from seeded areas until stabilized.
- ☐ Planting on any area requiring a filter fabric should include material selected with care to insure that no tap roots will penetrate the filter fabric.

F.4.4 Enhanced Swales, Grass Channels and Filter Strips

Table F-6 provides a number of grass species that perform well in the stressful environment of an open channel structural control such as an enhanced swale or grass channel, or for grass filter strips. In addition, wet swales may include other wetland species (see F.4.1). Select plant material capable of salt tolerance in areas that may include high salt levels.

Table F.6 Common Grass Species for Dry and Wet Swales and Grass Channels

<u>Common Name</u>	<u>Scientific Name</u>	<u>Notes</u>
Bermuda grass	<i>Cynodon dactylon</i>	1,2
Big Bluestem	<i>Andropogon gerardii</i>	2, 3, Not for wet swales
Witchgrass	<i>Panicum capillare</i>	2,3, Not for wet swales
Switchgrass	<i>Panicum virgatum</i>	3
Buffalograss	<i>Buchloe dactyloides</i>	1, 2, 3
Bushy Bluestem	<i>Andropogon glomeratus</i>	2,3
Virginia Wildrye	<i>Elymus virginicus</i>	2,3,4 Not for wet swales
Texas Bluegrass	<i>Poa arachnifera</i>	2,3, Not for wet swales
Common Sixweekgrass	<i>Vulpia octoflora</i>	2,3
Green Sprangletop	<i>Leptochloa dubia</i>	2,3
Canada Wildrye	<i>Elymus canadensis</i>	2,3,4, Wet swales

<u>Common Name</u>	<u>Scientific Name</u>	<u>Notes</u>
Longleaf Chasmanthium / Upland Sea Oats	<i>Chasmanthium latifolium</i>	2,3,4
Eastern Gammagrass	<i>Tripsacum dactyloides</i>	2,3
<p>Note 1: These grasses are sod-forming and can withstand frequent inundation, and are thus ideal for the swale or grass channel environment. Most are salt-tolerant, as well.</p> <p>Note 2: Where possible, one or more of these grasses should be in the seed mixes</p> <p>Note 3: Native Texas grasses</p> <p>Note 4: Shade tolerant</p>		

F.4.5 Green Roofs

- The growth medium is generally 2 to 6 inches thick and made of a material that drains relatively quickly. Commercial mixtures containing coir (coconut fiber), pumice, or expanded clay are available. Sand, gravel, crushed brick, and peat are also commonly used. Suppliers recommend limiting organic material to less than 33% to reduce fire hazards. The City of Portland, Oregon has found a mix of 1/3 topsoil, 1/3 compost, and 1/3 perlite may be sufficient for many applications. Growth media can weigh from 16 to 35 psf when saturated depending on the type (intensive/extensive), with the most typical range being from 10-25 psf.
- When dry, all of the growth media are light-weight and prone to wind erosion. It is important to keep media covered before planting and ensure good coverage after vegetation is established.
- Selecting the right vegetation is critical to minimize maintenance requirements. Due to the shallowness of the growing medium and the extreme desert-like microclimate on many roofs, plants are typically alpine, dryland, or indigenous. Ideally, the vegetation should be:
 - Drought-tolerant, requiring little or no irrigation after establishment
 - Self-sustaining, without fertilizers, pesticides, or herbicides
 - Able to withstand heat, cold, and high winds
 - Shallow root structure
 - Low growing, needing little or no mowing or trimming
 - Fire resistant
 - Perennial or self propagating, able to spread and cover blank spots by itself

Visit www.txsmartscape.com to look up plants meeting the above criteria.

- A mix of sedum/succulent plant communities is recommended because they possess many of these attributes. Certain wildflowers, herbs, forbs, grasses, mosses, and other low groundcovers can also be used to provide additional habitat benefits or aesthetics; however, these plants need more watering and maintenance to survive and keep their appearance.
- Green roof vegetation is usually established by one or more of the following methods: seeding, cuttings, vegetation mats, and plugs/potted plants.
 - Seeds can be either hand sown or broadcast in a slurry (hydraseeded). Seeding takes longer to establish and requires more weeding, erosion control, and watering than the other methods.
 - Cuttings or sprigs are small plant sections. They are hand sown and require more weeding, erosion control, and watering than mats.
 - Vegetation mats are sod-like mats that achieve full plant coverage very quickly. They provide immediate erosion control, do not need mulch, and minimize weed intrusion. They generally require less ongoing maintenance than the other methods.
 - Plugs or potted plants may provide more design flexibility than mats. However, they take longer to achieve full coverage, are more prone to erosion, need more watering during establishment,

require mulching, and more weeding.

- Green roof vegetation is most easily established during the spring or fall.

F.5 Trees and Shrubs for Storm Water Facilities

The following pages present a detailed list of wetland trees and shrubs that may be used for storm water management facilities such as storm water ponds, storm water wetlands and bioretention areas. (Source: Garber and Moorhead, 1999)

Table F-7 Wetland indicator status, growth form, flood tolerance and seed dispersal and treatment for selected native wetland trees and shrubs.

<u>Species</u>	<u>Indicator*</u>	<u>Form</u>	<u>Flood Tolerance**</u>	<u>Seed Dispersal***</u>	<u>Seed Treatments****</u>	<u>Comments</u>
Boxelder <i>Acer negundo</i>	FACW-	Tree	T	Sept.-Mar.	Cold Strat. 30-40 Days (Mech. Rup. Peri-carp)	Can propagate by softwood cuttings
Red Maple <i>Acer rubrum</i>	FAC	Tree	T	Apr.-July	Strat. not required	Can propagate by softwood cuttings, tissue culture
Hazel Alder <i>Alnus serrulata</i>	OBL	Tree	NE	Sept.-Oct.	Cold Strat. 30-60 Days	Can propagate by cuttings, tissue culture
Common Pawpaw <i>Asimina triloba</i>	FAC-	Tree	I	Sept.-Oct.	Scarification Required Cold Strat. 60-90 Days	
River Birch <i>Betula nigra</i>	FACW	Tree	IT	May-June	Cold Strat. 60-90 Days	Can propagate by softwood cuttings
American Hornbeam <i>Carpinus caroliniana</i>	FAC	Tree	WT	Oct.-Spring	Cold Strat. 60 Days	
Water Hickory <i>Carya aquatica</i>	OBL	Tree	IT	Oct.-Dec.	Cold Strat. 30-90 Days Warm Strat. 60 Days	
Bitternut Hickory <i>Carya cordiformis</i>	FAC	Tree	NE	Sept.-Dec.	Cold Strat. 90 Days	
Pecan <i>Carya illinoensis</i>	FAC +	Tree	IT	Sept.-Dec.	Cold Strat. 30-90 Days	
Sugarberry <i>Celtis laevigata</i>	FAC	Tree	IT	Oct.-Dec.	Cold Strat. 60-90 Days	
Common Buttonbush <i>Cephalanthus occidentalis</i>	OBL	Shrub	VT	Sept.-Oct.	Strat. not req.	
American Sycamore <i>Platanus occidentalis</i>	FAC +	Tree	T	Feb.-Apr.	Cold Strat. 60-90 Days	
Eastern Cottonwood <i>Populus deltoides</i>	FAC	Tree	VT	May-Aug.	Strat. not req.	Can propagate by cuttings
Wafer Ash <i>Ptelea trifoliata</i>	FAC	Shrub	NE	Sept.	Cold Strat. 90-120 Days	

			<u>Flood</u>	<u>Seed</u>	<u>Seed</u>	
<u>Species</u>	<u>Indicator*</u>	<u>Form</u>	<u>Tolerance**</u>	<u>Dispersal***</u>	<u>Treatments****</u>	<u>Comments</u>
Cherrybark Oak <i>Quercus pagoda</i>	FAC +	Tree	I	Aug.-Dec. Cold Strat.	30-90 Days	Red Oak group
Laurel Oak <i>Quercus laurifolia</i>	FACW	Tree	IT	Aug.-Dec.	Cold Strat. 30-90 Days	Red Oak group
Overcup Oak <i>Quercus lyrata</i>	OBL	Tree	T	Aug.-Dec.	Strat. not req.	White Oak group
Water Oak <i>Quercus nigra</i>	FAC+	Tree	T	Aug.-Dec.	Cold Strat. 30-90 Days	Red Oak group
Willow Oak <i>Quercus phellos</i>	FACW	Tree	T	Aug.-Dec.	Cold Strat. 30-90 Days	Red Oak group
Shumard Oak <i>Quercus shumardii</i>	FAC	Tree	IT	Aug.-Dec.	Cold Strat. 30-90 Days	Red Oak group
Black Willow <i>Salix nigra</i>	FACW+	Tree	VT	June-July	Not required.	Seed will not remain viable in storage. Plant within 10 days after collection. Can propagate by cuttings
Baldcypress <i>Taxodium distichum</i> var. <i>distichum</i>	OBL	Tree	VT	Oct.-Nov.	Cold Strat. 90 Days.	Soak seed for 5 min. in ethyl alcohol before placing in cold stratification.
Pondcypress <i>Taxodium distichum</i> var. <i>nutans</i>	OBL	Tree	VT	Oct.-Nov.	Cold Strat. 60-90 Days.	Soak seed for 24 to 48 hrs. in 0.0196 citric acid before placing in cold stratification.
American Elm <i>Ulmus Americana</i>	FAC	Tree	T	Mar.-June	Cold Strat. 60-90 Days	Can propagate by cuttings
Cedar Elm <i>Ulmus crassifolia</i>	FAC	Tree	I	Apr.-June	Cold Strat. 60-90 Days	Can propagate by cuttings
Slippery Elm <i>Ulmus rubra</i>	FAC	Tree	I	Apr.-June	Cold Strat. 60-90 Days	Can propagate by cuttings
Rough-Leaf Dogwood <i>Cornus drummondii</i>	FAC	Tree	T	Aug.-Jan.	Warm Strat. 70°-80° 1 Day Cold Strat. 30 Days	
Hawthornes <i>Crataegus reverchonii</i> <i>Crataegus viridis</i>	FAC	Shrub	IT	Fall-Winter	May Req. Scarification Warm Strat. 70°-80° 30-90 Days Cold Strat. 90-180 Days	
Common Persimmon <i>Diospyros virginiana</i>	FAC	Tree	T	Oct.-Nov.	Cold Strat. 60-90 Days	

Species	Indicator*	Form	Flood Tolerance**	Seed Dispersal***	Seed Treatments****	Comments
Green Ash <i>Fraxinus pennsylvanica</i>	FACW-	Tree	VT	Oct.-Feb.	Cold Strat. 60-90 Days	
Waterlocust <i>Gleditsia aquatica</i>	OBL	Tree	T	Sept.-Dec.	Req. Scarification	
Decidious Holly <i>Illex deciduas</i>	FACW	Shrub	VT	Sept.-Mar.	Warm Strat. 68°-Day, 86°-Night 60 Days Cold Strat.-60	
Spicebush <i>Lindera benzoin</i>	FACW	Shrub	NE	Sept.-Oct.	Cold Strat. 120 Days	
Sweetgum <i>Liquidambar styraciflua</i>	FAC	Tree	T	Sept.-Nov.	Cold Strat. 30 Days	
Sweetbay <i>Magnolia virginiana</i>	OBL	Tree	IT	Sept.-Nov.	Cold Strat. 90-180 Days	Can propagate by cuttings
Red Mulberry <i>Morus rubra</i>	FACU	Tree	IT	June-Aug.	Cold Strat. 30-90 Days	
Southern Bayberry <i>Myrica cerifera</i>	FAC	Shrub	NE	Aug.-Oct.	Cold Strat. 60-90 Days	
Redbay <i>Persea borbonia</i>	FACW	Tree	MT	Fall	Not established	

* **Indicator:** OBL-obligate; FACW-facultative wetland; FAC-facultative; FACU-facultative upland.

Indicators may be modified by (+) or (-) suffix; (+) indicates a species more frequently found in wetlands; (-) indicates species less frequently found in wetlands.

** **Flood Tolerance Mature Plants:**

VT-Very Tolerant: Survives flooding for periods of two or more growing seasons.

T-Tolerant: Survives flooding for one growing season.

I-Intermediately Tolerant: Survives one to three months of flooding during growing season

WT-Weakly Tolerant: Survives several days to several weeks of growing-season flooding.

IT-Intolerant: Cannot survive even short periods of a few days or weeks of growing-season flooding.

NE-Not established.

*** **Seed Dispersal:** Approximate dates across natural range of a given species.

**** **Seed Treatments:**

Cold stratification: Place moist seeds in polyethylene plastic bags and place in refrigerated storage at 33°-41° F for specified time.

Warm stratification: Place moist seeds in polyethylene plastic bags at 68°-86° F for specified time. Scarification-mechanical or chemical treatment to increase permeability of seed coat.

Table F-8 Seedling response of selected species to flooding conditions

Species	Water Level	Seedling Survival*	Comments
Boxelder <i>Acer negundo</i>	Total submersion Growing Season	100% at 2 weeks 70% at 3 weeks 36% at 4 weeks 0% at 32 days	Chlorotic leaves after 4 days. Slow recovery.
Red Maple <i>Acer rubrum</i>	Partial submersion Growing season	100% at 5 days 90% at 10 days 0% at 20 days	Adventitious roots developed after 15 days Height growth decreased in saturated soil
	Soil saturation Growing season	Growing season 100% at 32 days	Soil saturation
River Birch <i>Betula nigra</i>	Soil saturation Growing season	100% at 32 days	Growth severely stunted
Pecan <i>Carya illinoensis</i>	Total submersion Growing season	75% at 4 weeks	
Sugarberry <i>Celtis laevigata</i>	Soil saturation Growing season	100% at 60 days	
Common Buttonbush <i>Cephalanthus occidentalis</i>	Total submersion Growing season	100% at 30 days	
Green Ash <i>Fraxinus pennsylvanica</i>	Total submersion Growing season	100% at 5 days 90% at 10 days 73% at 20 days 20% at 30 days	Lower leaves chlorotic after 8 days
	Partial submersion Growing season	100% at 14 days	Better growth in saturated soil than soil at field capacity
	Soil saturation Growing season	100% at 60 days	
Sweetgum <i>Liquidambar styraciflua</i>	Total submersion Growing season	0% at 32 days	
	Partial submersion Growing season	0% at 3 months	
American Sycamore <i>Platanus occidentalis</i>	Total submersion Growing season Soil saturation Growing season	100% at 10 days 0% at 30 days 95% at 32 days	Growth decreased by satu- rated soil
Eastern Cottonwood <i>Populus deltoids</i>	Total submersion Growing season	0% at 16 days	Best growth when water ta- ble is 2 feet below surface
	Partial submersion Growing season	90% at 10 days 70% at 20 days 47% at 30 days	High mortality when deep- ly flooded
Cherrybark Oak <i>Quercus pagoda</i>	Total submersion Growing season	87% at 5 days 6% at 10 days	Height growth decreased by soil saturation
	Partial submersion Growing season	0% at 20 days 89% at 15 days 47% at 30 days 13% at 60 days	
Water Oak <i>Quercus nigra</i>	Partial submersion Growing season	Survived 2 months	
Willow Oak <i>Quercus phellos</i>	Soil saturation Growing season	100% at 50 days	Poorer growth in saturated soil than soil at field capac- ity
Shumard Oak <i>Quercus shumardii</i>	Total submersion Growing season	100% at 5 days 90% at 10 days 6% at 20 days	Height growth poorer in saturated soil than soil at field capacity
	Soil saturation Growing season	100% at 30 days 66% at 60 days	

Adapted from Teskey & Hinkley, 1977

* Seeding survival in relation to length of flooding

Table F-8 continued

<u>Species</u>	<u>Water Level</u>	<u>Seedling Survival</u> *	<u>Comments</u>
Black Willow <i>Salix nigra</i>	Total submersion Growing season	100% at 30 days	Better height growth in saturated soil than soil at field capacity
	Soil saturation Growing season	100% at 60 days	
Baldcypress <i>Taxodium distichum</i> var. <i>distichum</i>	Total submersion Growing season	100% at 4 weeks	
American Elm <i>Ulmus Americana</i>	Total submersion Growing season	100% at 10 days 27% at 20 days 0% at 30 days	Height growth decreased in saturated soil
	Soil saturation Growing season	100% at 15 days 94% at 60 days	

* Seeding survival in relation to length of flooding

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Storm Water Computer Models and Information Tools

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G.1 Introduction

Storm water management is becoming increasingly complex. The simple notion of collecting runoff and sending it efficiently to the nearest stream is being replaced with considerations of storm water quantity and quality control, infrastructure management, master planning and modeling, financing, complaint tracking, and more. Information needs are critical to a successful local program. North Central Texas communities need to both invest in and be aware of new and emerging technologies that can provide the ability to collect, organize, maintain and effectively use vast amounts of data and information for their community's storm water management activities.

There is a great deal of computer software that has been developed based on the intensive research effort in urban hydrology, hydraulics, and storm water quality. Computer models use the computational power of computers to automate the tedious and time-consuming manual calculations. Most models also include extensive routines for data management, including input and output procedures, and possibly including graphics and statistical capabilities.

Computer modeling became an integral part of storm drainage planning and design in the mid-1970s. Several agencies undertook major software developments and these were soon supplemented by a plethora of proprietary models, many of which were simply variants on the originals. The proliferation of personal computers in the 1990s has made it possible for virtually every engineer to use state-of-the-art analytical technology for purposes ranging from analysis of individual pipes to comprehensive storm water management plans for entire cities.

In addition to the simulation of hydrologic and hydraulic processes, computer models can have other uses. They can provide a quantitative means to test alternatives and controls before implementation of expensive measures in the field. If a model has been calibrated and verified at a minimum of one site, it may be used to simulate non-monitored conditions and to extrapolate results to similar ungauged sites. Models may be used to extend time series of flows, stages and quality parameters beyond the duration of measurements, from which statistical performance measures then may be derived. They may also be used for design optimization and real-time control.

A local staff or design engineer will typically use one or more of these pieces of software in storm water facility design and review, according to the design objectives and available resources. However, it should be kept in mind that proper use of computer modeling packages requires a good knowledge of the operations of the software model and any assumptions that the model makes. The engineer should have knowledge of the hydrological, hydraulic and water quality processes simulated and knowledge of the algorithms employed by the model to perform the simulation.

G.2 Types of Models

In urban storm water management there are typically three types of computer models that are commonly used: *hydrologic*, *hydraulic* and *water quality* models. There are also a number of other specialty models to simulate ancillary issues (some of which are sub-sets of the three main categories) such as sediment transport, channel stability, lake quality, dissolved oxygen, evapotranspiration, etc.

G.2.1 Hydrologic Models

Hydrologic models attempt to simulate the rainfall-runoff process to tell us "how much water, how often." They use rainfall information and watershed characteristics to provide runoff data including peak flow, flood hydrograph, and flow frequencies. Hydrologic models can be either:

- *Deterministic* – giving one answer for a specific input set, or
- *Stochastic* – involving random inputs giving any number of responses for a given set of parameters;

- *Continuous* – simulating many storm events over a period of time, or
- *Single Event* – simulating one storm event;
- *Lumped* – representing a large area of land use by a single set of parameters, or
- *Distributed* – land areas are broken into many small homogeneous areas each of which has a complete hydrologic calculation made on it.

G.2.2 Hydraulic Models

Hydraulic models take a known flow amount (typically the output of a hydrologic model) and provide information about flow height, location, velocity, direction, and pressure. Hydraulic models share some of the differing characteristics of hydrologic models (continuous vs. single event) and add the following:

- *One-dimensional* – calculating flow information in one direction (e.g. downstream) only, or
- *Multi-dimensional* – calculating flow information in several dimensions (e.g. in and out of the channel and downstream);
- *Steady* – having a single unchanging flow velocity value at a point in the system, or
- *Unsteady* – having changing flow velocities with time;
- *Uniform* – assuming the channel slope and energy slope are equal, or
- *Non-uniform* – solving a more complex formulation of the energy and momentum equations to account for the dynamic nature of flows.

For most problems encountered in hydraulics, a simple one-dimensional, steady model will work well. But if the volume and time distribution of flow are important (for example, in a steeper stream with storage behind a series of high culvert embankments) an unsteady model is needed. If there is a need to predict with accuracy the ebb and flow of floodwater out of a channel (for example in a wide, flat floodplain where there are relief openings under a road) then a 2-dimensional model becomes necessary. If pressure flow and the accurate computation of a hydraulic grade line are important an unsteady, non-uniform model with pressure flow calculating capabilities is needed.

G.2.3 Water Quality Models

The goal in water quality modeling is to adequately simulate the various processes and interactions of storm water pollution. Water quality models have been developed with an ability to predict loadings of various types of storm water pollutants.

Water quality models can become very complex if the complete cycle of buildup, wash-off, and impact are determined. These models share the various features of hydrologic and hydraulic models in that it is the runoff flow that carries the pollutants. Therefore, a continuous hydrologic model with estimated pollution concentrations becomes a continuous water quality pollution model. Water quality models can reflect pollution from both point and nonpoint sources.

Water quality models tend to have applications that are targeted toward specific pollutants, source types, or receiving waters. Some models involve biological processes as well as physical and chemical processes. Often great simplifications or gross assumptions are necessary to be able to model pollutant accumulations, transformations, and eventual impacts.

Detailed short time increment predictions of “pollutographs” are seldom needed for the assessment of receiving water quality. Hence, the total storm event loads or mean concentrations are normally adequate. Simple spreadsheet-based loading models involve an estimate of the runoff volume which, when multiplied by an event mean concentration, provide an estimate of pollution loading. Because of the lack of ability to calibrate such models for variable physical parameters, such simple models tend to be more accurate the longer the time period over which the pollution load is averaged. An annual pollutant load prediction may tend toward a central estimate, while any specific storm prediction may be

grossly in error when compared to actual loadings because antecedent conditions vary widely from week to week. Simulation models have the ability to adjust a number of loading parameters for calibration purposes and can simulate pollution accumulation over a long period. They can then more reliably predict loadings for any specific storm event.

While calibration data is not always needed in hydrologic or hydraulic models for an acceptably accurate answer, in water quality models the non-calibrated prediction is often off by orders of magnitude. Water quality predictions are not credible without adequate site-specific data for calibration and verification. However, even without specifically accurate loading values, relative effects of pollution abatement controls can be tested using uncalibrated models.

G.2.4 Computer Model Applications

Storm water computer models can also be categorized by their use or application:

Screening-level models are typically equations or spreadsheet models that give a first estimate of the magnitude of urban runoff quality or quantity. At times this is the only level that is necessary to provide answers. This is true either because the answer needs to be only approximate or because there is no data to justify a more refined procedure.

Planning-level models are used to perform “what if” analysis comparing, in a general way, design alternatives or control options. They are used to establish flow frequencies, floodplain boundaries, and general pollution loading values.

Design-level models are oriented toward the detailed simulation of a single storm event for the purposes of urban storm water design. They provide a more complete description of flow or pollution values anywhere in the system of concern and allow for adjustment of various input and output variables in some detail. They can be more exact in the impact of control options, and tend to have a better ability to be calibrated to fit observed data.

Operational models are used to produce actual control decisions during a storm event. They are often linked with SCADA systems. They are often developed from modified or strongly calibrated design models, or can be developed on a site-specific basis to appropriately link with the system of concern and accurately model the important physical phenomena.

G.3 The Modeling Process

G.3.1 Basic Computer Modeling Principles

The following basic principles apply to all forms of computer modeling:

1. All computer models require site-specific information to be supplied by the user. Inputs are the measured or estimated parameters the model needs to make calculations. For example, basic hydrologic models might include: area, slope, land use, channel forms and roughness, connectivity, and rainfall. A basic hydraulic model would include: channel slope, discharge, roughness, shape, obstructions or constrictions, and connectivity. Water quality models may add pollution loading or build-up-washoff factors, and fate and transport information. All models, for planning and design, allow the modeler to try different combinations of variables to see what happens (called a “what if” analysis).
2. While modeling generally yields more information, simpler methods may provide sufficient information for design or solving management issues. In general, the simplest method that provides the desired analysis should be used. The risk of using a more complex (and presumably “better”) model is that it requires more expertise, data, support, and resources to use and understand. There is also a consequent higher probability of misapplication.

3. If water quality problems are being considered, it still may not be necessary to simulate quality processes since most control strategies are based on hydrologic or hydraulic considerations. Quality processes are very difficult to simulate accurately. If abatement strategies can be developed without the simulation of water quality parameters, the overall modeling program will be greatly simplified.

Models sometimes may be used to extrapolate beyond the record of measured data record. It is important to recognize, however, that models do not extend data, but rather generate simulated numbers that should never be assumed to be the same as data collected in the field. Careful consideration should be given when using models to provide input to receiving water quality analyses. The quality response of most receiving waters is relatively insensitive to such short-term variations. In many instances, the total storm load will suffice to determine the receiving water response. Simulation of short time increment changes in concentrations and loads is generally necessary only for analysis of control options, such as storage or high-rate treatment, whose efficiency may depend on the transient behavior of the quality constituents.

The overall modeling process involves: (1) development of study or model objectives, (2) identification of resources and constraints, and finally, (3) the selection and implementation of the model itself.

G.3.2 Model Objectives

It is important to know specifically to what accuracy and in what format the answers are needed. Requiring a simple peak flow is far different from needing to know the timing of peaks from several different intersecting watersheds. Estimating future floodplain elevations along a reach is a fundamentally different problem than finding the probability of roadway overtopping.

A review of the problem begins the process of determining the model objectives. These objectives also establish a performance or design criteria for the model. Must the system handle the 25-year storm? Are future conditions important? Which ones? Are annual loadings of pollution adequate? Which pollutants?

Those aspects of the system to be modeled will dictate what models are appropriate for use. For example, if storm sewers are present, then an open channel model can be ruled out as an appropriate model for the entire system. If a specific type of hydraulic structure is present that a standard model cannot handle, an alternate way to simulate that structure will be necessary.

Model objectives also explain how the numbers generated from the model will relate to the needs of the study. For example, if a cost-benefit analysis is required, the model results must be interpreted in terms of overall life-cycle cost and not simply in terms of discharge rate.

G.3.3 Model Constraints

Availability of data, funds, time, and user ability can potentially constrain modeling solutions. The goal of any modeling effort is to develop an approach that stays within the constraints dictated while addressing the needs of the study identified in the previous step. Data collection/availability and cost are usually the chief constraints.

Sources of existing available data should be researched. Look for data that tends to “ground truth” model outputs. Even partial data can be useful if it helps to validate the model or modeling results. After existing data sources have been identified, the need to gather additional data is assessed. Automated processes and systems such as GIS and GPS can reduce both cost and human error. A consideration of the long-term use of data and its maintenance is necessary. For example, if the model is to eventually become an operational model, the ability to maintain the data in a cost effective way becomes of paramount importance.

Accuracy and the corresponding necessary level of detail are of overriding importance. Accuracy depends on both the accuracy of the input data and the degree to which the model adequately represents the hydrologic, hydraulic, or water quality processes being modeled. For example, if lumped hydrologic

parameters are adequate, then the cost of the modeling effort can be reduced. However, the ability to determine information within the sub-basin represented by a single parameter is lost. Changing model needs from an average 500-acre sub-basin size to a 50-acre size can increase the cost of a model almost ten fold. Is the information derived worth the cost?

Both risk and uncertainty affect the modeler's ability to predict results accurately. Risk is an estimated chance of an occurrence, such as flooding. Uncertainty is the error associated with measuring or estimating key parameters or functions. Uncertainty arises due to errors in sampling, measurement, estimation and forecasting, and modeling. For hydrologic and hydraulic analysis, stage and discharge are of prime importance. Uncertainty in discharge is due to short or nonexistent flood records, inaccurate rainfall-runoff modeling, and inaccuracy in known flood flow regulation where it exists. Stage uncertainty comes from errors and unknowns in roughness, geometry, debris accumulation, sediment effects, and other factors.

Accuracy developed in one area can be impacted by rough estimates in another, and the technological gains lost. For example, the gains in accuracy from very precise field surveys of cross sections can be lost if the estimates of roughness coefficients or discharge rates are very approximate.

Sensitivity analysis involves holding all parameters constant except one and assessing the change in the output variable of concern with a certain percent change in the input variable. Those variables that are amplified in the output should be estimated with higher accuracy and with a more detailed consideration of the potential range of values and the need for conservative design. The modeler must try to assess how accurate estimates are and to account for risk and uncertainty through estimating the range of potential error and choosing values that balance conservative engineering with cost consciousness. The designer typically develops a "most likely" estimate of a certain design parameter (for example, 10-year storm rainfall or Manning's roughness coefficient) and then uses sensitivity analysis to test the impact of variability in the parameter estimate on the final solution

G.3.4 Selection and Implementation

Once the model objectives and constraints have been evaluated, the model (or models) is selected and the study or design is implemented. Typical steps in model implementation include *validation*, *calibration*, *verification*, and *production*.

Validation involves a determination that the model is structured and coded as intended for the range of variables to be encountered in the study. Validation tests key algorithms for accuracy. For example, if a hydrologic model cannot handle short time steps or long time periods, it cannot be used without modification. If a certain model begins to lose accuracy at high or low imperviousness or cannot accurately handle backwater situations, and these will be encountered in practice the model cannot be used. Often validation is a one-time effort, after which the modeler is comfortable with the model's "quirks" and knows how to deal with them. Validation often involves pushing parameters to the limit of reasonable extent to test an algorithm. For example, in a hydrologic model infiltration can be reduced to zero to test if the input and output hydrographs are equal. Or the model can be run with small rainfalls using porous soils to determine if no runoff is generated, or only runoff from directly connected impervious areas.

Calibration is the comparison of a model to field measurements, other known estimates of output (e.g. regression equations), or another model known to be accurate, and the subsequent adjustment of the model to best fit those measurements.

Verification then tests the calibrated model against another set of data not used in the calibration. This step is not always possible due to the general shortage of other data. Goodness of prediction is done through a simple comparison of the difference in observed and predicted peaks, pollution loads, flood elevations or volumes divided by the observed values and expressed as a percentage, or as simple ratio. Assessing the goodness of fit of a hydrograph is done by calculating the sum of the squares of the difference between observed and predicted values at discreet time steps.

Once the model is prepared for use, attention shifts to efficient *production* methods that minimize the potential for errors while maximizing efficiency. Often “production line” efforts are used for large modeling projects. However, constant attention must be paid to ensure the execution of correct procedures, detailed documentation of efforts and input/output data sets, and recognition of anomalies that would invalidate a particular model run.

While there is much to be gained from simple user interfaces and black box approaches that simplify the input and output processes, there is an inherent danger that the modeler will not be aware of errors or problems in the modeling process. For example, in hydraulic modeling, shifts from super- to sub-critical flow happen at sharp break points and are reflected in a jump in water surface. If not caught, a model will under predict flow elevation. Numeric instability in mathematical algorithms may give oscillating answers that have nothing to do with reality. A structured review process must be established to insure reasonableness of output and accuracy of input values has been used. Labeling of data sets should be systematic and exact.

G.4 Summary of Commonly-Used Models

Computer models can be simple, representing only a very few measured or estimated input parameters or can be very complex involving twenty times the number of input parameters. The “right” model is the one that: (1) the user thoroughly understands, (2) gives adequately accurate and clearly displayed answers to the key questions, (3) minimizes time and cost, and (4) uses readily available or collected information. Complex models used to answer simple questions are not an advantage. However, simple models that do not model key necessary physical processes are useless.

There is no one engineering model or software that addresses all hydrologic, hydraulic, and water quality situations. Design needs and troubleshooting for watershed and storm water management occur on several different scales and can be either system-wide (i.e., watershed) or localized. System-wide issues can occur on both large and small drainage systems, but generally require detailed, and often expensive, watershed models and/or design tools. The program(s) chosen to address these issues should handle both major and minor drainage systems. Localized issues also exist on both major and minor drainage systems, but unlike system-wide problems, flood and water quality solution alternatives can usually be developed quickly and cheaply using simpler engineering methods and design tools.

Table G.4-1 lists several widely used computer programs and modeling packages. The programs were examined for their applicability to both system-wide and localized issues, the methodologies used for computations, and ease-of-use.

For the purposes of this table, major drainage systems are defined as those receiving flow from larger watersheds. These are typically FEMA-regulated streams, lakes, or reservoirs. Minor drainage systems are smaller natural and man-made systems that drain to the more major streams. Minor drainage systems can have both closed and open-channel components and can include, but are not limited to, neighborhood storm sewers, culverts, ditches, and tributaries.

A brief description of program capabilities and methodologies are presented in a short discussion of each program.

Table G.4-1 Storm Water Modeling Programs and Design Tools					
	Major System Modeling	Minor System Modeling	Hydrologic Features	Hydraulic Features	Water Quality Features
Hydrology Software					
HEC-HMS (HEC-1)	X		X		
TR-55			X		
PondPack		X	X	X	
WMS	X		X		
Watershed Modeling	X		X		
Hydraulics Software					
HEC-RAS (HEC-2)	X			X	
WSPRO	X			X	
EPA SWMM	X	X	X	X	X
CulvertMaster		X		X	
FlowMaster		X		X	
Water Quality Software					
HSPF	X		X		X
BASINS	X		X	X	X
QUAL2E	X			X	X
WASP5	X			X	X
SLAMM	X		X		X

G.4.1 Hydrology Programs

HEC-HMS (HEC-1) - Flood Hydrograph Package

HEC-1 was developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers to simulate the surface runoff response of a watershed to rainfall events. Although it is a DOS-based program, it is still considered by many in the engineering and regulatory communities to be the leading model for major drainage system applications such as Flood Insurance Studies and watershed master planning. The Federal Emergency Management Agency (FEMA) accepts both HEC-1 and HEC-HMS.

In a HEC-HMS model, the watershed is represented in the model as an interconnected system of hydrologic (e.g., sub-basins, reservoirs, ponds) and hydraulic (e.g., channels, closed conduits, pumps) components. The model computes a runoff hydrograph at each component, combining two or more hydrographs as it moves downstream in the watershed. The model has a variety of rainfall-runoff simulation methods, including the popular SCS Curve Number methodology. The user can define rainfall events using gage or historical data, or HEC-HMS can generate synthetic storms. Hydrograph generation is performed using the unit hydrograph technique. Clark, SCS Dimensionless, and Snyder Unit Hydrographs are the available methodologies. Several common channel and storage routing techniques are available as well.

HEC-HMS is not considered a "design tool." The program has limited hydraulic capabilities. It does not account for tailwater effects and cannot adequately simulate many urban hydraulic structures such as pipe networks, culverts, and multi-stage detention pond outlet structures. However, there are other hydrologic applications developed within HEC-HMS that have been utilized with much success. Multiplan-multiflood analyses allow the user to simulate a number of flood events for different watershed situations (or plans). The dam safety option enables the user to analyze the impact dam overtopping or structural failure on downstream areas. Flood damage analyses assess the economic impact of flood damage.

Because it is not a Windows-based program, HEC-1 does not have easy-to-use input and output report generation and graphical capabilities, and therefore is generally not considered a user-friendly program. Because of its wide acceptance, several software development companies have incorporated the source code into enhanced "shells" to provide a user-friendly interface and graphical input and output capabilities. Examples of these programs include Graphical HEC-1 developed by Haested Methods and WMS developed by the Environmental Modeling Research Laboratory.

The Corps of Engineers developed a user-friendly, Windows-based Hydrologic Modeling System (HEC-HMS) intended to replace the DOS-based HEC-1 model. HEC-HMS has all the components of HEC-1, with more user-friendly input and output processors and graphical capabilities. HEC-1 files can be imported into HEC-HMS.

TR-55 - Technical Release 55

The TR-55 model is a DOS-based software package used for estimating runoff hydrographs and peak discharges for small urban watersheds. The model was developed by the NRCS (formally SCS), and therefore uses SCS hydrograph methodology to estimate runoff. No other methodology is available in the program. Four 24-hour regional rainfall distributions are available for use. Rainfall durations less than 24-hours cannot be simulated. Using detailed input data entered by the user, the TR-55 model can calculate the area-weighted CN, time of concentration and travel time. Detention pond (i.e., storage) analysis is also available in the TR-55 model, and is intended for initial pond sizing. Final design requires a more detailed analysis.

A Windows-based version (Win TR-55) has been developed by the NRCS. Haestad Methods, Inc., included most of the TR-55 capabilities in its PondPack program described below. Both Win TR-55 and Pond Pack are models acceptable to FEMA.

PONDPACK

PondPack, by Haestad Methods, Inc., is Windows-based software developed for modeling general hydrology and runoff from site development. The program analyzes pre- and post-developed watershed conditions and sizes detention ponds. It also computes outlet rating-curves with consideration of tailwater effects, accounts for pond infiltration, calculates detention times and analyzes channels.

Rainfall options are unlimited. The user can model any duration or distribution, for synthetic or real storm events. Several peak discharge and hydrograph computation methods are available, including SCS, the Rational Method and the Santa Barbara Unit Hydrograph procedure. Infiltration can be considered, and pond and channel routing options are available as well. Like TR-55, PondPack allows the user to calculate hydrologic parameters, such as the time of concentration, within the program.

PondPack has limited, but useful hydraulic features, using Manning's equation to model natural and man-made channels and pipes. A wide variety of detention pond outlet structure configurations can be modeled, including low flow culverts, weirs, riser pipes, and even user-defined structures.

WMS - Watershed Modeling System

WMS was developed by the Engineer Computer Graphics Laboratory of Brigham Young University. WMS is a Windows-based user interface that provides a link between terrain models and GIS software, with industry standard lumped parameter hydrologic models, including HEC-1, TR-55, TR-20 and others. The hydrologic models can be run from the WMS interface. The link between the spatial terrain data and the hydrologic model(s) gives the user the ability to develop hydrologic data that is typically gathered using manual methods from within the program. For example, when using SCS methodologies, the user can delineate watersheds and sub-basins, determine areas and curve numbers, and calculate the time of concentration at the computer. Typically, these computations are done manually, and are laborious and time-consuming. WMS attempts to utilize digital spatial data to make these tasks more efficient.

Watershed Modeling

The Watershed Modeling program was developed to compute runoff and design flood control structures. The program can run inside the MicroStation CAD system. Like WMS, this feature enables the program

to delineate and analyze the drainage area of interest. Area, curve number, land use and other hydrologic parameters can be computed and/or catalogued for the user, removing much of the manual calculation typically performed by the hydrologic modeler.

Watershed Modeling contains a variety of methods to calculate flood hydrographs, including SCS, Snyder and Rational methods. Rainfall can be synthetic or user-defined, with any duration and return period. Rainfall maps for the entire U.S. are provided to help the user calculate IDF relationships. Several techniques are available for channel and storage routing. The user also has a wide variety of outlet structure options for detention pond analysis and design.

G.4.2 Hydraulics Programs

HEC-RAS - River Analysis System

HEC-RAS is a Windows-based hydraulic model developed by the Corps of Engineers to replace the popular, DOS-based HEC-2 model. RAS has the ability to import and convert HEC-2 input files and expands upon the capabilities of HEC-2. Since its introduction several years ago, the user-friendly HEC-RAS has become known as an excellent model for simulation of major systems (i.e., open channel flow) and has become the chief model for calculating floodplain elevations and determining floodway encroachments for Flood Insurance Studies. Like HEC-2, HEC-RAS has been accepted for FIS analysis by the FEMA. However, RAS is a much easier model to use than HEC-2 as it has an extremely useful interface that provides the immediate capability to view model input and output data in graphical, tabular, and report formats.

HEC-RAS performs one-dimensional analysis for steady flow water surface profiles, using the energy equation. Energy losses are calculated using Manning's equation and contraction and expansion changes. Rapidly varied flow (e.g., hydraulic jumps) is modeled using the momentum equation. The effects of in-stream structures, such as bridges, culverts, weirs, floodplain obstructions, and in-stream changes such as levees and channel improvements can be simulated. The model allows the user to define the geometry of the channel or structure to the level of detail required by the application. One popular and useful feature of the HEC-RAS model is the capability to easily facilitate floodway encroachment analysis. Five encroachment methods are available to the user.

The HEC-RAS model has components for unsteady flow and has sediment transport simulations under development. HEC-GeoRAS provides an interface with GIS platforms which allows the preparation of input data for import into HEC-RAS. Several software developers have released other enhanced versions of RAS that provide the capability to import GIS data for channel geometry and export RAS output for floodplain and floodway delineation. Examples of such software include BOSS RMS, developed by BOSS International and SMS (Surface Water Modeling System), distributed by the Scientific Software Group.

WSPRO

WSPRO was developed by the USGS to compute water surface profiles for one-dimensional, gradually varied, steady flow. Like HEC-RAS, WSPRO can develop profiles in subcritical, critical, and supercritical flow regimes. WSPRO is designated HY-7 in the Federal Highway Administration ICPR (Interconnected Pond Routing) Model, and its original objective was analysis and design of bridge openings and embankment configurations. Since then, the model has been expanded to model open channels and culverts.

Open channel computations use standard step-backwater techniques. Flow through bridges is simulated using an energy-balancing technique that uses a coefficient of discharge and estimates an effective flow length. Pressure flow under bridges is simulated using orifice-type flow equations developed by the FHWA. Culvert flow is simulated using FHWA techniques for inlet control and energy balance for outlet control.

WSPRO is considered a fairly easy-to-use DOS-based model, applicable to water surface profile analysis for highway design, flood insurance studies, and establishing stage-discharge relationships. However,

the model in its original form is not Windows based and therefore does not have the useful editing and graphical features found in HEC-RAS. Like HEC-RAS, a third party software developer has designed SMS (Surface Water Modeling Software) to support both pre- and post-processing of WSPRO data.

EPA SWMM - Storm Water Management Model

EPA SWMM was developed by the Environmental Protection Agency (EPA) to analyze storm water quantity and quality problems associated with runoff from urban areas. EPA SWMM has become the model of choice for simulation of minor drainage systems primarily composed of closed conduits. The model can simulate both single-event and continuous events and has the capability to model both wet and dry weather flow. The basic output from SWMM consists of runoff hydrographs, pollutographs, storage volumes, and flow stages and depths.

SWMM's hydraulic computations are link-node based and are performed in separate modules, called blocks. The EXTRAN computational block solves complete dynamic flow routing equations to simulate backwater, looped pipe connections, manhole surcharging, and pressure flow. It is the most comprehensive model in its capabilities to simulate urban storm flow and many cities have used it successfully for storm water, sanitary, or combined sewer system modeling. Open channel flow can be simulated using the TRANSPORT block, which solves the kinematic wave equations for natural channel cross-sections.

Although evaluated for this study as a hydraulic model, SWMM has both hydrologic and water quality components. Hydrologic processes are simulated using the RUNOFF block, which computes the quantity and quality of runoff from drainage areas and routes the flow to the major sewer system lines. Pollutant transport is simulated in tandem with hydrologic and hydraulic computations and consists of calculation of pollutant buildup and washoff from land surfaces and pollutant routing, scour, and in-conduit suspension in flow conduits and channels.

EPA SWMM is a public domain, DOS-based model. For large watersheds with extensive pipe networks, input and output processing can be tedious and confusing. Because of the popularity of the model commercial, third-party enhancements to SWMM have become more common, making the model a strong choice for minor system drainage modeling. Examples of commercially enhanced versions of EPA SWMM include MIKE SWMM, distributed by BOSS International, XPSWMM by XP-Software, and PCSWMM by Computational Hydraulics Inc (CHI). CHI also developed PCSWMM GIS, which ties the SWMM model to a GIS platform.

CULVERTMASTER

CulvertMaster, developed by Haestad Methods, Inc., is an easy-to-use, Windows-based culvert simulation and design program. The program can analyze pressure or free surface flow conditions. CulvertMaster can handle drawdown and backwater conditions, including composite profiles and hydraulic jumps. A variety of common culvert shapes and section types are available. Tailwater effects are considered and user can enter a constant tailwater elevation, a rating curve, or specify an outlet channel section. Culvert hydraulics are solved using FHWA methodology for inlet and outlet control computations. Roadway and weir overtopping are checked in the solution of the culvert.

CulvertMaster does have a hydrologic analysis component to determine peak flow using the Rational Method, SCS Graphical Peak Methods. The user also has the option of entering a known peak flow rate. The user must enter all rainfall and runoff information (e.g., IDF data, rainfall depths, curve numbers, C coefficients, etc).

FLOWMASTER

FlowMaster, also developed by Haestad Methods, Inc., is a Windows-based hydraulic pipe and channel design program. The user enters known information on the channel section or pipe, and allows the program to solve for the unknown parameter(s), such as diameter, depth, slope, roughness, capacity, velocity, etc. Solution methods include Manning's equation, the Darcy-Weisbach formula, Hazen-Williams formula, and Kutter's Formula. The program also features calculations for weirs, orifices, gutter flow, ditch, and median flow and discharge into curb, grated, and slot inlets.

Other Hydraulics Programs

In addition to the Hydraulics Software listed in Table G.4-1, appropriately applied versions of the following computer models are also available for use.

- *CULVERT* – by TxDOT for hydraulic analysis and design of culverts.
- *WINSTORM* – by TxDOT for analysis and design of storm sewer.
- *HY8* – by the Federal Highway Association (FHWA) for hydraulic analysis and design of culverts.
- *HY8Energy* – by FHWA for the selection and analysis of energy dissipation structures.
- *CHANLPRO* – by U.S. Army Corps of Engineers for analysis and design of streambank protection.

G.4.3 Water Quality Programs

HSPF - Hydrologic Simulation Program FORTTRAN

The HSPF model was developed by the EPA for the continuous or single-event simulation of runoff quantity and quality from a watershed. The original model was developed from the Stanford Watershed Model, which simulated runoff quantity only. It was expanded to include quality components, and has since become a popular model for continuous nonpoint source water quality simulations. Nonpoint source conventional and toxic organic pollutants from urban and agricultural land uses can be simulated on pervious and impervious land surfaces and in streams and well-mixed impoundments. The various hydrologic processes are represented mathematically as flows and storages. The watershed is divided into land segments, channel reaches, and reservoirs. Water, sediment, and pollutants leaving a land segment move laterally to a downstream land segment, a stream or river reach, or reservoir. Infiltration is considered for pervious land segments.

HSPF model output includes time series information for water quality and quantity, flow rates, sediment loads, and nutrient and pesticide concentrations. To manage the large amounts of data associated with the model, HSPF includes a database management system. To date, HSPF is still a DOS-based model and therefore does not have the useful graphical and editing options of a Windows-based program. Input data requirements for the model are extensive and the model takes some time to learn. However the EPA continues to expand and develop HSPF, and still recommends it for the continuous simulation of hydrology and water quality in watersheds.

BASINS - Better Assessment Science Integrating Point and NonPoint Sources

The BASINS watershed analysis system was developed by the EPA for use by regional, state, and local pollution control agencies to analyze water quality on a watershed-wide basis. BASINS integrates the ArcView GIS environment, national databases containing watershed data, modeling programs, and water quality assessment tools into one stand-alone program. The program will analyze both point and nonpoint sources and supports the development of the total maximum daily loads (TMDLs). The assessment tools and models utilized in BASINS include TARGET, ASSESS, Data Mining, HSPF, TOXIRoute, and QUAL2E. The databases, assessment tools and models are directly tied to the ArcView GIS environment.

QUAL2EU - Enhanced Stream Water Quality Model

QUAL2EU was developed by the EPA and intended for use as a water quality planning tool. The model actually consists of four modules: QUAL2E - the original water quality model, QUAL2EU - the water quality model with uncertainty analysis, and pre- and post-processing modules. QUAL2EU simulates steady state or dynamic conditions in branching streams and well-mixed lakes, and can evaluate the impact of waste loads on water quality. It also can enhance a field sampling program by helping to identify the magnitude and quality characteristics of nonpoint waste loads. Up to 15 water quality constituents can be modeled. Dynamic simulation allows the user to study the effects of diurnal variations in water quality (primarily DO and temperature). The steady state option allows the user to perform uncertainty analyses.

QUAL2EU is a DOS-based program, and the user will require some length of time to develop a QUAL2EU model, mainly due to the complexity of the model and data requirements for a simulation.

However, to ease user interaction with the model an interactive preprocessor (AQUAL2) has been developed to help the user build input data files. A postprocessor (Q2PLOT) also exists that displays model output in textual or graphical formats.

WASP5 - Water Quality Analysis Simulation Program

The WASP5 model was developed by the EPA to simulate contaminant fate in surface waters. Both chemical and toxic pollution can be simulated in one, two, or three dimensions. Problems studied using WASP5 include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination. WASP5 has an associated stand alone hydrodynamic model called DYNHYD5 that simulates variable tidal cycles, wind, and unsteady flows. DYNHYD4 supplies flows and volumes to the water quality model. The model is DOS-based; however WASP packages can be obtained from outside vendors that include interactive tabular and graphical pre- and post-processors.

SLAMM - Source Loading and Management Model

The SLAMM model was originally developed as a planning tool to model runoff water quality changes resulting from urban runoff pollutants. The model has been expanded to include simulation of common water quality best management practices such as infiltration BMPs, wet detention ponds, porous pavement, street cleaning, catchbasin cleaning, and grass swales. Unlike other water quality models, SLAMM focuses on small storm hydrology and pollutant washoff which is large contributor to urban stream water quality problems. SLAMM computations are based on field observations, as opposed to theoretical processes. SLAMM can be used in conjunction with more commonly used hydrologic models to predict pollutant sources and flows.

G.5 Information Tools

G.5.1 Geographic Information Systems (GIS)

A Geographic Information System (GIS) is a computer-based database system designed to spatially analyze and display data. A GIS stores information about a given area as a collection of thematic layers that can be linked together by geo-referencing. This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world storm water problems from tracking complaints to master planning applications and infrastructure management.

GIS Components

A functional GIS integrates four key components: hardware, software, data, and trained users:

- **Hardware** – Desktop computers and digitizing equipment are the primary hardware components of a typical local GIS system.
- **Software** – GIS software provides the functionality and tools needed to capture or input, store, analyze, display, and output geographic information.
- **Data** – Generally, the most costly part of a GIS is data development. Some geographic data and related tabular data can be collected in-house or purchased from commercial data providers. A GIS can also integrate tabular data or electronic drafting (CAD) data to build information into the GIS database.
- **Users** – GIS technology is of limited value without trained operators who understand the data, system, organization and how to apply the resources to achieve the desired results.

GIS Functions

General purpose geographic information systems essentially perform four processes or tasks:

1. Data Input – Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology can sometimes automate this process fully for projects using scanning technology. Some jobs may require some manual digitizing using a digitizing table. Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from a number of different sources including the North Central Texas GIS Data Clearinghouse at <http://gis.dfwinfo.com/geodata/>.

2. Data Conversion – It is likely that some needed data may not be in the correct format or proper map projection to use with your system. Most GIS software has the ability to do this conversion, but in some cases this is better done by a contractor who specializes in data conversion. Be careful with third party data. It is imperative that you understand the source, quality, age, accuracy, and limitations of a dataset. This and other information about a dataset is often provided in (FGDG) metadata that accompanies the dataset.

3. Query and Analysis – Once there is a functioning GIS database containing geographic information, it can be queried to answer questions such as:

- Who owns the land parcel being flooded?
- What is the distance between two stream locations?
- Which homes are located in the updated floodplain?
- How will the new development impact downstream properties?
- What types of infrastructure give us the most complaints and where are they located?

GIS provides both simple point-and-click query capabilities and sophisticated spatial analysis tools to provide timely information to storm water managers and analysts alike. GIS technology can also be used to analyze geographic data to look for patterns and trends and to undertake "what if" scenarios. Most modern GIS's have many powerful analytical tools including:

- *Size Analysis* – Provides specific information about a feature. (e.g. What is the area and perimeter of a parcel?)
- *Proximity Analysis* – Determines relationships between objects and areas. (e.g. Who is located within 100 feet of the streambank?)
- *Overlay Analysis* – Performs integration of different data layers. (e.g. What is the SCS curve number for this sub-watershed considering soils and land use?) Figure G.3-1 illustrates the overlay concept.
- *Network Analysis* – Analyzes the connectivity of linear features and establishes routes or direction of flow. (e.g. Which pipes feed into this junction box?)
- *Raster Analysis* – Utilizes a raster model to address a number of hydrologic issues. (e.g. What does the 3-D model of this watershed look like? Where does the water flow?)

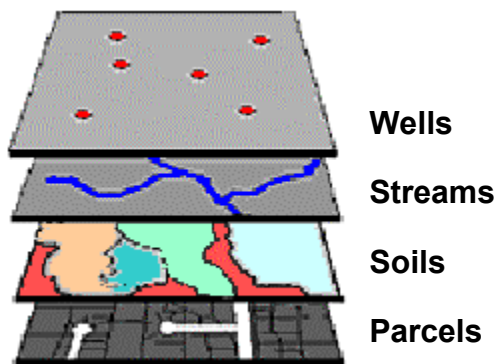


Figure G.5-1 Example of Overlay Analysis

Source: ESRI

4. Data Display, Output, and Visualization – Geographic information systems excel at being able to create rich and detailed maps, graphs, and other types of output which allow local staff, elected officials, and the general public to be able to visualize and understand complex problems and large amounts of information. These maps and charts can be integrated with reports, three-dimensional views, photographic images, and multimedia presentations.

Use of GIS in Storm Water Management

GIS can be useful to a community in a wide variety of storm water-related applications:

- GIS can be used for the mapping of surface features, land uses, soils, rainfall amounts, watershed boundaries, slopes, land cover, etc.
- A GIS can manage a storm water system inventory and information about facility conditions, storm sewer networks, maintenance scheduling, and problem areas.
- GIS can be used to automate certain tasks such as measuring the areas of subwatersheds, plotting floodplain boundaries, or assessing storm water utility fees. Figure G.5-2 shows an example of automated hydrologic mapping.
- A GIS can be used to evaluate water quality impacts and answer cause and effect questions, such as the relationship between various land uses and in-stream pollution monitoring results.
- “What if” analyses can be undertaken with GIS. For example, various land use scenarios and their impacts on pollution or flooding can be tried in various combinations to determine the best management solutions or to determine the outcome of current decisions. When tied to hydrology, hydraulics, and/or water quality models, this type of analysis becomes a powerful tool to assess the impacts of new development on downstream properties. For example, Figure G.5-3 shows the flooding impacts on a small tributary for a proposed new development approved during a rezoning.
- GIS databases can provide staff, elected officials, and citizens with immediate answers and ready information. For example, inventory, complaints, and other information about storm water infrastructure (including pictures) can be placed in a database tied to geographic location.
- Complex problems or changes over time, such as water quality improvements, can be easily visualized in maps and graphs generated by GIS systems. GIS maps can be used to educate or convince citizens and political leadership concerning a course of action or a project's viability.
- GIS maps can be used to educate or convince citizens and political leadership concerning a course of action or a project's viability.

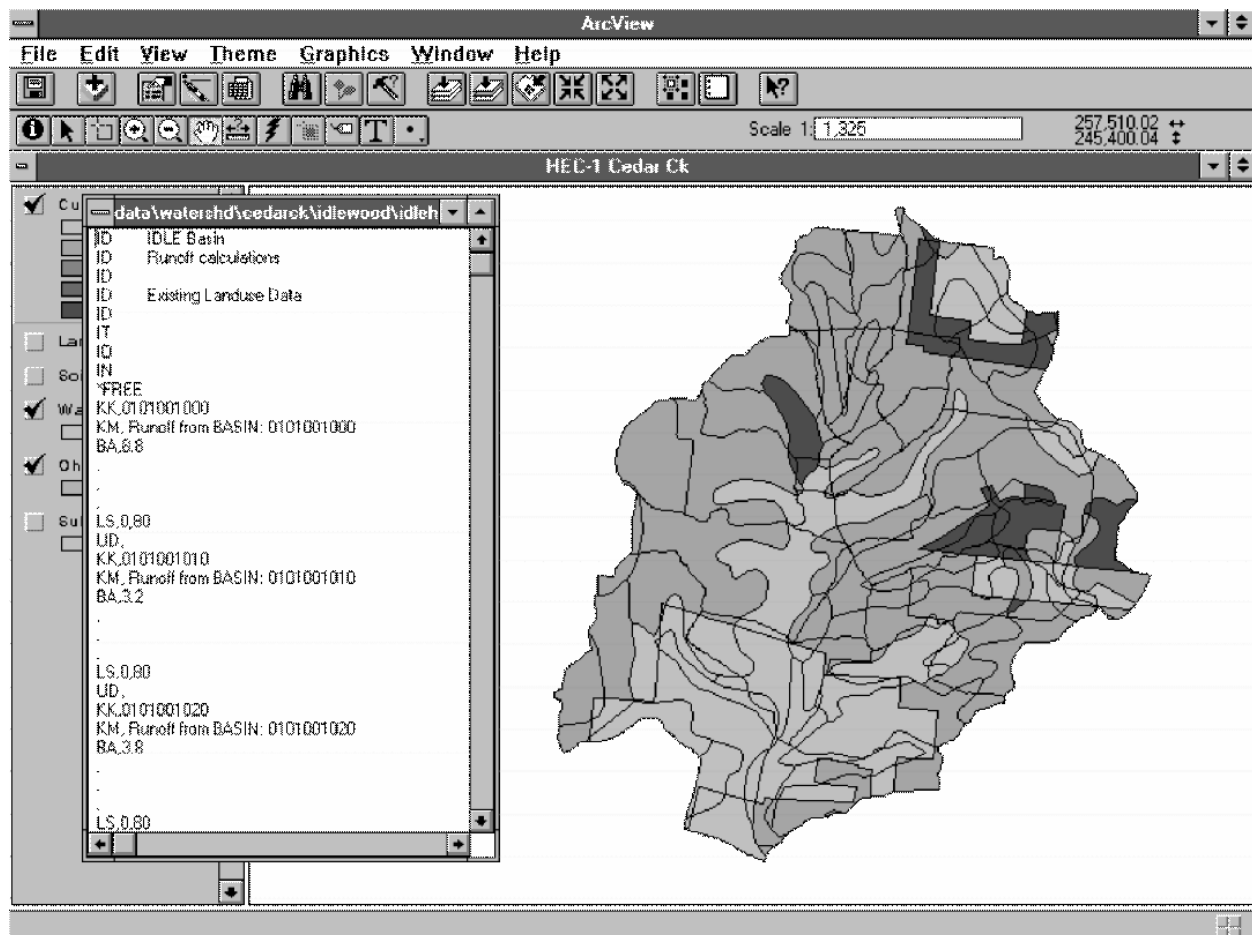


Figure G.5-2 Automated Hydrologic Modeling

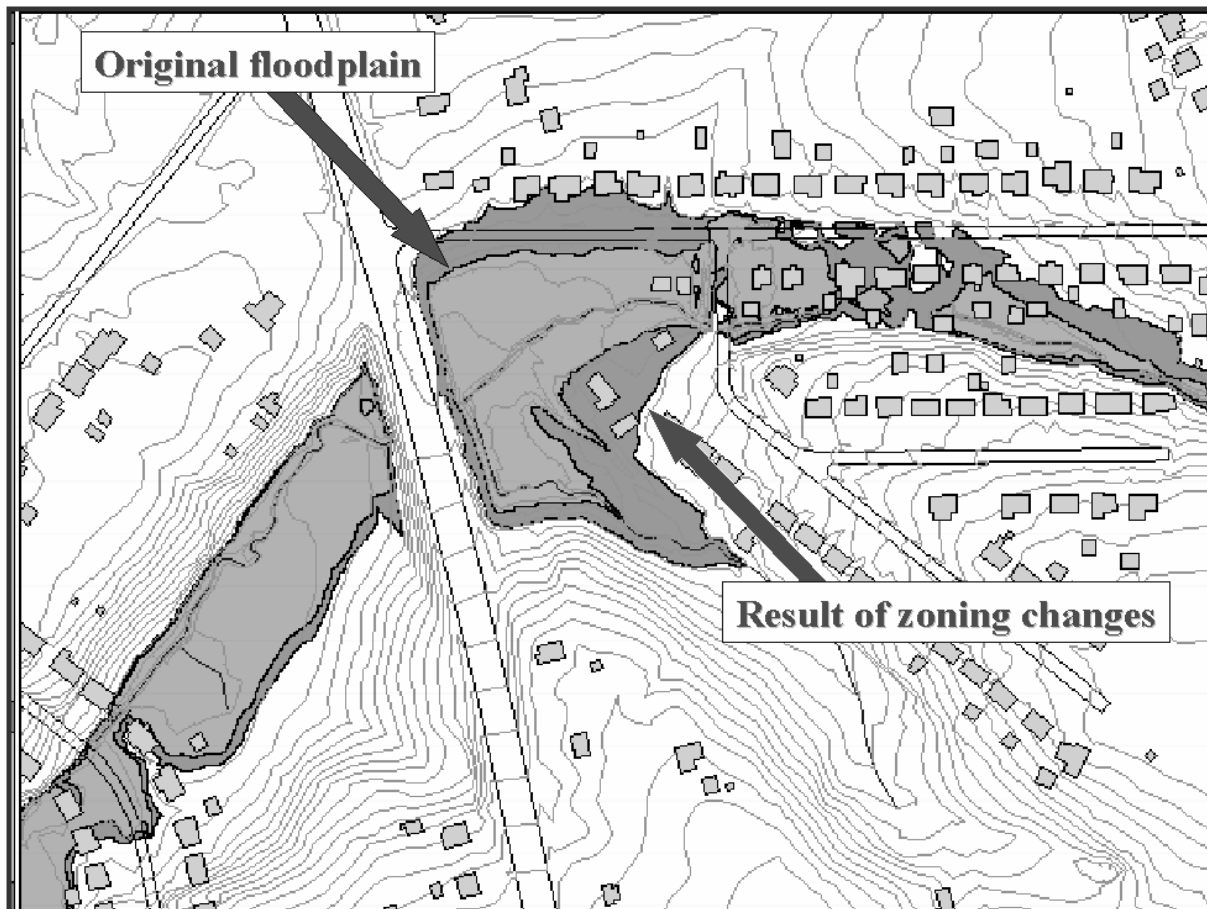


Figure G.5-3 Use of a GIS to Map Current and Potential Floodplains

Communities often make the mistake of making enormous expenditures on data, hardware, and software and databases but little on planning, staff familiarization, training, graphical user interface (GUI), and applications development. The end result is often an unusable system accessible by only a few who have the resources to learn the system, hire competent staff, and develop applications. It is often better to target the GIS implementation to certain needs and quickly roll-out applications that work for these needs even prior to the complete development of the database and overall system.

Proper implementation of GIS applications for storm water management involves planning for both "storm water only" applications and to integrate these applications with other potential uses within the municipality.

Other Related Technologies

GIS is closely related to several other types of information systems, and can be used with these other information tools, including:

- *Computer-Assisted Design (CAD)* – CAD systems evolved to create designs and plans of buildings and infrastructure. The systems are designed to do very detailed drafting and drawing but have only limited capability to attach data fields to the electronic drawing. As a result these systems do not have the capability to perform spatial analysis. Fortunately these drawings can be input to a GIS saving significant digitizing efforts. Once in a GIS, attribute data can then be added to the graphic features.

- *Database Management Systems (DBMS)* – These systems specialize in the storage and management of all types of data including geographic data. DBMSs are optimized to store and retrieve data and many GISs rely on them for this purpose. They do not typically have the analytic and visualization tools common to GIS.
- *Supervisory Control and Data Acquisition System (SCADA)* –These systems combine the ability to monitor information (e.g. rainfall, stream flow, flood level, etc.) remotely through telemetry. SCADA systems can also execute commands to do such things as open gates or close valves from a distance. Examples of the use of SCADA include automating storm water pump station operation, automated alarms for flood warning, and automated lowering of traffic control barrier arms during high water periods. SCADA systems can be combined with GIS to create comprehensive tracking systems.

G.5.2 Global Positioning Systems (GPS)

The Global Positioning System (GPS) is a space satellite based radio positioning system for obtaining accurate positional information for mapping or navigational purposes. GPS is made up of three distinct parts:

- *Satellites* – A constellation of satellites orbiting the earth continuously emit a timing signal, provided by on-board atomic clocks. The differential timing of satellite signals is used to calculate the distance from each satellite to the receiver.
- *Receiver* – A GPS receiver located on the ground converts satellite signals into position, velocity, and time estimates.
- *Ground Control* – The U.S. Department of Defense (DOD) developed and currently manages the maintenance of the satellite system. The DOD uses tracking antennas to constantly monitor the precise position of the NAVSTAR satellites. These positions can be used to correct for errors in the calculated positions of the roving receivers.

The GPS was built and is maintained by the U.S. government. The satellites orbit at an altitude of approximately 12,000 miles in a 12-hour pattern that provides coverage to the entire earth. The system is capable of serving an unlimited number of users free of charge.

A GPS receiver uses information from at least 4 satellites to precisely triangulate its position on the earth with about one meter accuracy. Special techniques can be used to obtain sub-meter accuracy. If a receiver cannot "see" four satellites, it can calculate a less-accurate estimate based on three satellites. Virtually all GPS receivers display basic positional information including latitude, longitude, elevation, and speed (if moving). Most receivers also display time, heading, the number of satellites in view, where those satellites are positioned in the sky, and signal quality. GPS receivers for data collection can collect both the location (coordinates) and the attribute data of a given geographical feature.

GPS Applications to Storm Water

Storm water infrastructure inventories can be conducted more easily and in far less time using GPS. In the past, traditional geodetic surveying was used to locate and map storm water system components. A transit survey requires traversing between a known point to the point of interest. GPS surveying is much more efficient, possibly taking as little as a few seconds to map each point. Using bicycle or car-mounted equipment, a community may be able to survey up to 500 points per day. Obviously, the users must be trained and knowledgeable of the GPS devices and the objectives of the inventory to insure accuracy of the data.

GPS inventory work can be integrated with GIS application software. For example, a GIS layer of structural control locations can be created using GPS data and linked to a maintenance database. GPS data can also be used in computer modeling activities for storm water management.

G.5.3 Remote Sensing

Remote Sensing is a technique for collecting observations of the earth using airborne platforms (airplanes and satellites) which have on-board instruments, or sensors. These sensors record physical images based on light, temperature, or other reflected electromagnetic energy. This sensor data may be recorded as either analog data, such as photos or digital image data. Figure G.5-4 gives an example of low (25-meter), medium (5-meter) and high (1-meter) resolution satellite imagery.



Figure G.5-4 Low, Medium and High Resolution Satellite Imagery

Source: Space Imaging, Inc.

Ground reference data is then applied to aid in the analysis and interpretation of the sensor data, to calibrate the sensor, and to verify the information extracted from the sensor data. Remotely sensed images have a number of advantages to on-the-ground observation, including:

- Remote sensing can provide a regional view.
- Remote sensing can provide repetitive looks at the same area over time.
- Remote sensors "see" over a broader portion of the electromagnetic spectrum than the human eye.
- Sensors can focus on specific bandwidths in an image and can also look at a number of bandwidths simultaneously.
- Remote sensors often record signals electronically and provide geographically referenced data in digital format.
- Remote sensors operate in all seasons, at night, and in bad weather.

The airborne platforms that carry remote sensing instruments can be any kind of aircraft or satellite observing the Earth at altitudes anywhere from a few thousand feet to orbits of hundreds of kilometers. Satellites may employ a variety of sensors for numerous of applications. Currently, no single sensor is sensitive to all wavelengths. All sensors have fixed limits of spectral sensitivity and spatial sensitivity, the limit on how small an object on the earth's surface can be seen. The common types of sensors aboard satellites include:

- *Multispectral Scanner (MSS) Sensors* – Data are sensed in as many as six bands including UV, visible, near-IR, mid-IR and thermal)
- *Thematic Mapper (TM) Sensors* – Data are sensed in seven spectral bands simultaneously including blue, green, red, near-infrared, and two in mid-infrared. The seventh band detects only the thermal portion of the spectrum.
- *Radio Detection and Ranging (RADAR)* – Examples are Doppler radar systems used in weather and cloud cover predictions.

The appropriate band or combination of MSS bands should be selected for each interpretive use. For example bands 4 (green) and 5 (red) are usually best for detecting cultural features such as urban areas, roads, new subdivisions, gravel pits, and quarries. The TM bands are more finely tuned for vegetation discrimination than those of the MSS due in part to the narrower width of the green and red bands.

Examples of the growing number of remote sensing satellites include the U.S. Landsat satellites, the Indian Remote Sensing (IRS) satellites, Canada's RADARSAT, and the European Space Agency's Radar Satellite. Images from these satellites have spatial resolutions ranging from approximately 100 meters to 15 meters or better. The first commercial satellite capable of resolving objects on the ground as small as one meter in diameter was recently launched. Several competing companies have similar offerings. For example, the IKONOS-2 features high spatial resolutions of 1-meter panchromatic (black and white) and 4-meter multispectral (color). Panchromatic data has a higher resolution while multispectral data provides better interpretation. Additionally, the 1-meter panchromatic spatial content can be combined with the spectral content of the 4-meter multispectral data. This 1-meter accuracy allows for a wide range of applications in storm water management at a price typically less than \$500 per square mile (with some minimum order restrictions).

Digital Orthophoto Quarter Quadrangles (DOQQ's)

Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. Unlike standard aerial photography, relief displacement in orthophotos has been removed displaying ground features in their true ground position, thus allowing for direct measurement of distance, area, angles, and positions.

The National Aerial Photography Program (NAPP) is the primary source of aerial photography used in the production of 1-meter digital orthophotos. The North Central Texas Council of Governments (NCTCOG) maintains a database of digital aerial photography known as digital orthophoto quarter quadrangles (DOQQ's). More information can be found at www.nctcog.org/ris/gis/index.asp.

Figure G.5-5 illustrates a section of a DOQQ. Local government organizations that do not have access to their own digital aerial photography can acquire this data. The details concerning DOQQ's are:

- A standard DOQQ image covers an area of 3.75 x 3.75 minutes or ¼ of a USGS quadrangle with some overlap
- 1-meter pixel resolution (1-meter resolution provides the minimum resolution needed for capturing smaller impervious features within the 200 sq. ft. to 100 sq. ft. range)
- Projected in Universal Transverse Mercator (UTM) with units in meters
- Available in TIFF format
- Coverage for the entire state of Texas
- Images were captured between 1994 and 1997
- DOQQ images for all of North Central Texas can be obtained at the www.tnris.state.tx.us/digitaldata/doq.htm.



Figure G.5-5 Example DOQQ

Remote Sensing Applications for Storm Water

Satellite imagery offers a diverse set of mapping products for projects ranging from land use/land cover evaluation to urban and regional planning, tax assessment and collection, and growth monitoring. In the case of storm water runoff, multispectral imagery can be used to measure impervious surfaces, such as rooftops, streets, and parking lots. Pervious surfaces, such as tree- and grass-covered areas can also be measured or delineated. Applying runoff coefficients to the area of each surface type can provide the best available estimates for nonpoint source water pollution. By adding parcel boundaries, it is possible to provide estimates of runoff per parcel in order to calculate storm water user fees. Similarly, designated land use categories can be applied to the area of each surface type and in combination with the known soil coverage can be used to calculate hydrologic curve numbers. Flood boundaries can be measured within a few meters accuracy in areas without tree cover using submeter multispectral fused imagery. Individual buildings and parcel boundaries can also be identified in order to assess flood vulnerability.

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Dams and Reservoirs in Texas

The Texas Commission on Environmental Quality (TCEQ) regulates the construction of dams in Texas that are six feet or more in height as per the Texas Administrative Code (Title 30, Part 1, Chapter 299 – Dams and Reservoirs). Approval from the TCEQ of plans and specifications is required for construction of a dam. The TCEQ also has the authority to inspect existing dams, and if necessary, require unsafe dams to be upgraded or removed. The Dam Safety Program is administered under the Field Operations Division of the Office of Compliance and Enforcement. Forms, Guidelines, Rules, Regulations, and many other resources can be found on-line at www.tnrcc.state.tx.us/enforcement/dam_safety/intro2.html.

H.1 Overview

Structures constructed for the purpose of the impounding water either on a temporary or permanent basis, which are over six feet in height are regulated by the State. The Texas Commission on Environmental Quality (TCEQ) is the regulatory agency responsible for administration of the State dam safety laws in Texas. Dams are classified according to size and the potential for loss of human life and/or property damage within the area downstream of the dam. The State regulates the design, construction, operation, and maintenance of dams, and this chapter provides an overview of some of the pertinent criteria.

H.2 Symbols and Definitions

The following words and terms, when used in this chapter, shall have the following meanings, unless the context clearly indicates otherwise:

Dam--Any barrier, including one for flood detention, designed to impound liquid volumes and which has a height of dam greater than six feet. This does not include highway, railroad, or other roadway embankments, including low water crossings that may temporarily detain floodwater, levees designed to prevent inundation by floodwater, closed dikes designed to temporarily impound liquids in the event of emergencies, or off-channel impoundments authorized by the commission in accordance with the Texas Water Code, Chapter 26, or the Texas Solid Waste Disposal Act, Texas Civil Statutes, Article 4477-7.

Effective crest of the dam--The elevation of the lowest point on the crest of the dam excluding spillways.

Existing dam--

- (A) any dam constructed in accordance with necessary authorizations of the TCEQ;
- (B) any existing dam exempt under the Texas Water Code, §11.142.

Height of dam--The vertical distance from the effective crest of the dam to the lowest elevation on the centerline or downstream toe of the dam, including the natural stream channel.

Maximum storage capacity--The volume of the impoundment created by the dam at the effective crest of the dam, usually expressed in acre-feet.

Normal storage capacity--The volume of the impoundment created by the dam at the lowest uncontrolled spillway crest, usually expressed in acre-feet.

Probable maximum flood (PMF)--The flood magnitude that may be expected from the most critical combination of meteorologic and hydrologic conditions that are reasonably possible for a given watershed.

Probable maximum precipitation (PMP)--Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year.

Proposed dam--Any dam, constructed or to be constructed, which is not included in the definition of existing dam.

Spillway design flood (SDF)--The flood criteria that needs to be considered in the design of a proposed project.

Spillway evaluation flood (SEF)--The flood criteria that needs to be considered in the hydrologic evaluation of an existing structure.

H.3 Dam Classifications

Texas Administrative Code, Chapter 299 – DAMS AND RESERVOIRS

In accordance with the Texas Administrative Code, Chapter 299, the State of Texas considers a dam any barrier designed to impound liquid volumes that has a height greater than six feet. Dams in Texas are classified based on their size (height), hazard potential (failure consequences), and hydrologic criteria (spillway capacity).

H.3.1 Size

The Texas Administrative Code classifies the size of a dam as small, intermediate, or large depending upon the height of the dam and the storage volume of the reservoir or pond created by the dam. The height of a dam is the vertical distance from the lowest point on the dam crest, excluding the spillway, to the lowest elevation on the centerline or downstream toe of the dam, including the natural stream channel. The storage capacity in acre-feet is the volume of the pond when the water level is at the crest of the service spillway. A “rule of thumb” is that the storage capacity of a pond in acre-feet is equal to the surface area of the pond in acres times 40 percent of the maximum depth of the pond in feet. Once the dam height and pond volume are known, the size classification of the dam is determined by the following table:

SIZE CLASSIFICATION		
<u>Category</u>	<u>Storage (Ac-Ft) Impoundment</u>	<u>Height (Ft.)</u>
Small	Less than 1,000	Less than 40
Intermediate	Equal to or Greater than 1,000 & less than 50,000	Equal to or Greater than 40 & less than 100
Large	Equal to or Greater than 50,000	Equal to or Greater than 100

H.3.2 Hazard Potential

Hazard classification pertains to potential loss of human life and/or property damage within either existing or potential developments in the area downstream of the dam in event of failure or malfunction of the dam or appurtenant facilities. Hazard classification does not indicate any condition of the dam itself. Dams in the low hazard potential category are normally those in rural areas where failure may damage farm buildings, limited agricultural improvements, and county roads. Significant hazard potential category dams are usually those in predominantly rural areas where failure would not be expected to cause loss of human life, but may cause damage to isolated homes, secondary highways, minor railroads, or cause interruption of service or use (including the design purpose of the facility) of relatively important public utilities. Dams in the high hazard potential category are usually those in or near urban areas where failure would be expected to cause loss of human life, extensive damage to agricultural, industrial, or commercial facilities, important public utilities (including the design purpose of the facility), main highways, or railroads.

The Texas Administrative Code's hazard classifications for dams include the classifications of *low*, *significant* or *high* according to the criteria listed in the following table:

HAZARD POTENTIAL CLASSIFICATION		
<u>Category</u>	<u>Loss of Human Life</u>	<u>Economic Loss</u>
Low	None expected (No Permanent structures for human habitation)	Minimal (Underdeveloped to occasional structures or agricultural improvements)
Significant	Possible, but not expected (A small number of inhabitable structures)	Appreciable (Notable agricultural, industrial or commercial development)
High	Expected (Urban development or large number of inhabitable structures)	Excessive (Extensive public, industrial, commercial or agricultural development)

H.3.3 Hydrologic Criteria

Uncontrolled floodwaters are one of the most powerful and destructive forces in nature. Dams that are not designed to withstand major storms may be destroyed by them, increasing flood damage downstream. This damage is too often catastrophic. In order to protect lives and property downstream, the Texas Administrative Code requires that dams be constructed to safely handle an appropriate percentage of the Probable Maximum Flood (PMF). This percentage varies according to the height of the dam, size of the impoundment, and extent and severity of damage possible upon failure. The requirements established in Texas are similar to those used in other states, and historical records of significant storms and dam failures this century verify that the design criteria are reasonable.

H.3.4 Development of the PMP

Scientists use both meteorological methods and historical records to determine the greatest amount of precipitation that is theoretically possible within a region. The historical data consists of point precipitation amounts measured at rain gages throughout the region being studied or a region with very similar meteorologic and topographic characteristics. These rainfall data are subsequently maximized through "moisture maximization" and other numerical methods. Moisture maximization is a process in which the maximum possible atmospheric moisture for a region is applied to rainfall data from a historic storm. This process increases the rainfall depths, bringing them closer to their potential maximum.

Probable maximum precipitation amounts vary slightly throughout Texas because of variations in topography and meteorology. The PMP is greatest in the eastern portion of the state. Furthermore, not

all storms have the same duration. Using the methods mentioned above, the PMP has been determined for different storm periods, generally ranging from six to seventy two hours.

H.3.5 Development of the PMF

The Probable Maximum Flood is the flood that is a direct result of the Probable Maximum Precipitation. However, drainage areas with the same PMP may have different PMFs. This is possible because the amount of flooding which results from a given rainfall amount depends upon the characteristics of the drainage basin. For this reason, the PMF, not the PMP, must be used as a design criterion for a dam. Some important characteristics include soil type, land use, size and shape of the watershed, and average watershed slope. Both the volume and rate of runoff are affected. For example, water will run off of steep slopes more quickly than gentle ones. More water will infiltrate sandy soils than clay.

H.3.6 Application of the PMF

The percentage of the PMF that a dam must be designed to withstand depends upon its classification. The Texas Administrative Code's hydrologic criteria for dams are shown in the table below.

HYDROLOGIC CRITERIA FOR DAMS		
Classification		-
Hazard	Size	Minimum Flood Hydrograph
Low (No. 3)	Small	1/4 PMF
	Intermediate	1/4 PMF to 1/2 PMF
	Large	PMF
Significant (No. 2)	Small	1/4 PMF to 1/2 PMF
	Intermediate	1/2 PMF to PMF
	Large	PMF
High (No. 1)	Small	PMF
	Intermediate	PMF
	Large	PMF

The exact percent of the PMF to be passed is determined by a straight-line interpolation of the dam height in the range. For example, a small, significant hazard dam would be between 6 to 40 feet high. If the dam has a height of 20 feet, the hydrologic criteria would be that the dam spillway should pass 25% + $(20'-6') \times (50\%-25\%) / (40'-6')$ or 35.3% of the PMF.

There are some exemptions to minimum hydrologic criteria. Proposed low hazard dams exempt under the Texas Water Code, §11.142, (see below) are exempt from the minimum criteria. Any other proposed structure may be exempt from the minimum criteria if properly prepared dam breach analyses show that existing downstream improvements or known or planned future improvements will not be adversely affected. A properly prepared breach analysis should include at least three events, the normal storage capacity nonflood event, the barely overtopping event, and the PMF event. Data on additional flood magnitudes may be provided as necessary to document other conditions or conclusions. Downstream flooding differentials of one-foot or less between breach and nonbreach simulations are not considered to be adverse.

H.3.7 Water Rights

The Texas Water Code requires anyone appropriating State Water or beginning work to store or divert State Water to obtain a permit from the Texas Commission on Environmental Quality (TCEQ). Private developments with ponds that contain 200 acre-feet or less of storage and that are used exclusively for domestic and livestock purposes are exempt from this requirement (11.142–Permit Exemptions). This exemption is based in part on the premise that all such ponds would by their nature of construction and due to their location on ranches or farms, be *low* hazard dams. However, as soon as the purpose for and use of these ponds change, there is a requirement to inform the TCEQ and obtain a water rights permit. Usually the downstream water rights holders do not challenge these new storage permits for existing small ponds; however notifications are sent out and public hearings could be held if there are objections to the permit. All dams that are classified as *significant* or *high* hazard must have a permit.

If any other use of the stored water were contemplated, such as using the pond water for irrigation purposes, then another water right authorization would be required. Authorization for a permit to divert State Water for other than domestic and livestock uses from a reservoir permitted for storage only should be requested pursuant to Texas Water Code, 11.143.

H.4 Design Criteria

Preparation of all plans and specifications for the construction, enlargement, alteration, repair, or removal of dams subject to TCEQ review shall be under the supervision of an engineer licensed in Texas. Construction of a dam or the enlargement, repair, or alteration of an existing dam requiring TCEQ authorization shall not be commenced prior to the executive director's written approval of final construction plans and specifications. Construction plans and specifications shall be submitted to the executive director and shall be as completely detailed as necessary for submission to the contractors bidding on the proposal. The proper design of a dam involves a complex combination of engineering applications.

Failure of an impoundment structure and the sudden release of water is referred to as a dam breach. A breach may occur during flooding or in fair weather due to effects of erosion or seepage. The hydrologic and hydraulic design determines what the potential impacts of a dam breach might be and what volume and flow rate a structure must withstand.

The geotechnical and structural design must consider that the structure can safely withstand the hydraulic forces imposed by the estimated hydrologic and hydraulic design. The following steps are necessary for the design of an embankment or concrete dam and each step must be thoroughly evaluated and documented.

1. Hydrologic and Hydraulic Design

Determination of controlling design conditions and associated storm runoff.

Setting of spillway and stilling basin widths and elevations, top of dam elevation, and normal pool elevation if necessary.

2. Structural and geotechnical design of embankments, concrete structure, spillways, and drawdown structures.
3. Development of operation and maintenance procedures.

H.4.1 Hydrologic and Hydraulic Design

The height of the dam, the amount of freeboard, and the size and capacity of the spillways must be designed to balance the hydrologic and hydraulic properties. The structure must be designed based on the size and classification of the dam. The hydrologic and hydraulic modeling is discussed elsewhere in the manual. General considerations include the sizing of the capacity of the outlet works and spillway.

H.4.2 Geotechnical Considerations

Information concerning geology, seismicity, foundation conditions, and construction materials is essential for any size structure. It is necessary for the stability of the structure that the material used in the embankment, the foundation, and adjacent earth have the necessary structural properties to withstand the hydrostatic forces required by the design. The foundation for these structures may vary significantly, and will affect the general shape and configuration of the embankment. In addition, the potential for seepage should be identified and provided for in the design. The embankment should also be adequately protected from surface erosion.

Field investigations to determine the soils and groundwater conditions for stability and seepage control must be considered. Stability analysis should consider after construction conditions based on shear strength parameters as determined by laboratory tests.

H.4.3 Structural Considerations

Structural designs should be prepared in accordance with generally accepted structural engineering practices. Components of the dam, spillway, or outlet structures should resist the most critical loading considering buoyancy, sliding, hydrostatic uplift, overturning, soil and water pressure forces, impact forces, and other loads.

Embankment dams are the most common type of dam constructed today. They generally have a trapezoidal shape with side slopes of two horizontal to one vertical or flatter. The ability of an embankment dam to resist the hydrostatic pressure caused by the water in the reservoir or detention pond is primarily the result of the weight of the materials and the strength of the materials which are used.

The embankment must be stable and resistant to movement under all operating conditions including rapid drawdown. Seepage through the embankment, abutments, and foundation should be controlled so that piping or surface slides do not occur. The embankment must be safe from overtopping by flow and surface erosion, or protected to allow these flows. The embankment must be safe from damage due to wave action or rain.

Concrete structures use many of the same considerations in the design. Concrete dams generally use their own weight as the primary resistance to sliding. Other considerations include the strength of the concrete, the hydrostatic uplift on the structure, silt load which may accumulate on the upstream toe, and overturning and impact forces.

H.4.4 Seepage Considerations

Embankment materials vary with the site. Their water retention capability is due to the low permeability of the embankment material whether it is a homogeneous mass of material or a zone of low permeability material in the structure. Materials used for the construction of embankment dams can include soil or rock. If the difference between the permeability of the core section of the embankment and the downstream shell is great, an internal drainage system is probably not needed. If the variation in permeability is not great, then the entire embankment section can become saturated and that condition reduces the stability of the structure. The drainage system could consist of a chimney drain, a toe drain, a blanket drain, finger drains, or a combination of these items.

Concrete structures are also subject to seepage. Seepage can be present at the dam foundation interface reducing the sliding resistance. A line of drain holes away from the upstream face can relieve seepage pressure under the structure.

H.4.5 Other Considerations

Slopes for most embankment sections can be as steep as two horizontal to one vertical, however if the slope is designed with grass and will need to be mowed, a three horizontal to one vertical is about as steep as can be maintained without special equipment. The higher the plasticity index of the material in the embankment section, the greater the possibility for slope failures; therefore, flatter slopes should be used. Compaction of materials in the construction process is another critical item for consideration. The need for rock riprap or other type of slope protection is usually evaluated on a case specific need depending on the potential for wave or water erosion. Grass on the slopes, particularly the downstream slope, generally provides adequate protection for structures where overtopping is not an issue.

Slopes for concrete structures, especially if they are designed for overtopping, need to consider the difference between headwater and tailwater, the potential for a hydraulic jump, and overturning stability.

There are many resources available for the design of dams. Design of Small Dams by the Bureau of Reclamation is a good resource for both embankment structures and concrete dams.

The forms and checklist included after Section H.5 must be submitted to the TCEQ to obtain approval for a dam.

H.5 Operation and Maintenance

Once completed, the structure must be kept in good condition by regular maintenance. This includes periodic inspection of the structure. Evaluating the structural condition of an existing dam includes, but is not limited to, visual inspections and evaluations of potential problems such as seepage, cracks, slides, conduit and control malfunctions, erosion, rodent damage, spillway blockage, and other structural and maintenance deficiencies which could lead to failure of a structure. In addition, existing dams may need to be re-evaluated in consideration of continuing downstream development.

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TEXAS DAM SAFETY PROGRAM
DIVISION OF FIELD OPERATIONS - OFFICE OF COMPLIANCE & ENFORCEMENT
12100 PARK 35 CIRCLE BUILDING A, MC-174
Austin, Texas 78753

**ENGINEER'S NOTIFICATION OF COMPLETION OF CONSTRUCTION, MODIFICATION,
REPAIR OR REMOVAL OF A DAM**

(PLEASE PRINT OR TYPE)

PLEASE CHECK ONE: New___, Modification___, Repair___, Removal___, Rebuild

(Please see 30 TAC 299 Rules for Dam Safety and Dam Construction, and attach the AAs-Built@ drawings)

NAT ID: _____ County: _____

Adjudication Number: _____ Region: _____

Name of Dam: _____

Name of Project: _____

Owner:

Name _____, Street or P.O. Box _____

City _____, State TX, Zip Code _____

Phone Number () _____, Emergency Contact Phone () _____

Fax Number () _____ Email _____

Engineering Firm:

Engineering Firm Name _____

Engineer Name _____, Title _____, TX P.E. License No _____

Engineering Firm Address _____

City _____, State _____ Zip Code _____

Phone () _____, Fax () _____, Email _____

The project was completed on _____, 20____. To the best of my knowledge, the Project was constructed in substantial conformance with plans, specifications, and change orders filed with the approved by the Texas Commission on Environmental Quality.

name. P.E.

Form DS-1005-Cert

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**TEXAS DAM SAFETY PROGRAM
DIVISION OF FIELD OPERATIONS - OFFICE OF COMPLIANCE & ENFORCEMENT
12100 PARK 35 CIRCLE BUILDING A, MC-174
Austin, Texas 78753**

**APPLICATION FOR REVIEW OF PLANS AND SPECIFICATIONS FOR THE NEW
CONSTRUCTION, MODIFICATION, REPAIR OR REMOVAL OF A DAM**

(PLEASE PRINT OR TYPE APPLICATION)

PLEASE CHECK ONE: New___, Modification___, Repair___, Remove___, Rebuild___

(SEE 30 TAC 299 Rules for Dam Safety and Dam Construction)

SECTION 1: OWNER INFORMATION

I, _____, owner, hereby accept and approve the enclosed plans
(Name of Legal Owner)

and specifications for submittal to the TCEQ Dam Safety Program in accordance with 30 TAC Chapter 299. I certify that I will notify TCEQ immediately any changing from this application.

(Signature of Owner)

(Date)

Street or P.O. Box: _____

City _____, State _____, Zip Code _____

Phone Number () _____, Emergency Contact Phone () _____,

Fax Number () _____ Email _____

Owner Code (Please check one): Federal (F), _____ Local Government (L), _____ Utility (U), _____ Private (P) _____,

State(S), _____, Others (O), please specify _____

Dam and Reservoir Use: _____, Year to build _____

(Augmentation, Diversion, Domestic, Erosion Control, Evaporation, Flood Control, Fire Control, Fish, Hydroelectric, Industrial, Irrigation, Mining, Municipal, Pollution Control, Recreation, Stock water, Settling Ponds, Tailings, Waste Disposal)

Engineering Firm _____

Engineer Name _____, Title _____, Texas P.E. License Number _____

Engineering Firm Address _____

City _____, State _____, Zip _____

Phone () _____, Fax () _____, Email _____

SECTION 2: GENERAL INFORMATION

Name of Dam _____

Other Name(s) of Dam _____

Reservoir Name _____

Location: _____ Texas _____ Region _____, Latitude _____, Longitude _____,

County _____, Stream Name: _____, Tributary _____,

River Basin _____, Topographic Map no. _____,

Nearest City/Town _____, Distance from Nearest City/Town _____,

TX Number (if known) _____, Water Rights Number (if known) _____,

Date of Emergency Action Plan (EAP), if having _____

SECTION 3: RESERVOIR & DAM STRUCTURES**Reservoir:**

Large _____, Medium _____, Small _____, High Hazard _____, Significant Hazard _____, Low Hazard _____,

No. of Population at Risk _____, Specify if needed _____

Type of Dam – (e.g. Earthfill, Homogeneous):

Concrete _____ Gravity _____ Arch _____

Earthfill _____ Zoned _____ Homogeneous _____

Rockfill _____ Masonary _____ Impervious Membrane _____

Other (Specify) _____

Dam Structure: (Dimensions to nearest tenth of foot, volume to nearest acre-foot or cubic-yard, areas to nearest acre):

Jurisdictional Height _____ ft. (Natural surface of ground to bottom of emergency spillway at longitudinal centerline)

Embankment Height _____ ft. (Jurisdictional height plus emergency spillway freeboard)

Structural Height _____ ft. (Bottom of cutoff trench to crest of dam at centerline)

Crest Length _____ ft. Crest Width _____ ft, Crest Elev. _____ ft. M.S.L.,

Pool Elevation _____ ft. M.S. L., Principal Elevation _____ ft. M.S.L., Emergency Elevation _____ ft. M.S.L.,

Top Dam Elevation _____ ft. M.S.L., Embankment Volume _____ C.Y.

Maximum Impoundment Capacity _____ Acre-Feet (to crest of dam)

Normal Reservoir Capacity _____ Acre-Feet (at high waterline)

Reservoir Surface Area _____ Acres (at high waterline)

Upstream (U)/Downstream (D), Facing Material (Place U or D as appropriate):

Concrete Dam _____, Concrete Facing _____, Clay _____, Gabions _____, Gravel _____,
 Hand placed riprap _____, Masonry Dam _____, Natural _____, Planted _____,
 riprap with bedding _____, riprap with no bedding _____, Rock Zone _____, Soil Cement _____, Steel _____,
 Wood _____, Other? (Describe) _____

Outlet:

Outlet Diameter: _____ Inches/Feet, Type:

Maximum Discharge Capacity: _____ cfs (Reservoir at high waterline).

Principal Spillway:

Material: _____ (i.e., Natural, Riprap, Concrete, CMP, RCP, etc.)

Width (Diam): _____ ft., Freeboard: _____ ft., Capacity: _____ cfs

Emergency Spillway:

Material: _____ (i.e., Natural, Riprap, Concrete, CMP, RCP, etc.)

Width (Diam): _____ ft., Freeboard: _____ ft., Capacity: _____ cfs

Total Spillway Capacity: _____ cfs, (Crest of the dam)

SECTION 4: HYDROLOGIC DATA *

Full PMF _____, 0.75PMF _____, 0.50PMF _____, 0.25PMF _____, Other _____

Drainage Area: _____ Acres, or _____ Sq. Miles

Inflow Design Flood: _____, (i.e., 100-year %PMP, etc.) Duration _____ Hrs.

Type: _____, (i.e., Thunderstorm, General, Snowmelt, Combination)

Data Source Ref.

Peak Discharge _____ cfs; Volume _____ A., F., Basin lag time (Tc): _____ Hrs.

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HYDROLOGIC AND HYDRAULIC (H&H) EVALUATION SUMMARY(Please complete all sections , or otherwise specified)

Name of Dam:

TCEQ Dam Safety Project No.:

County:

Year to Build:

Maximum Record Precipitation (Inches):

Record Area (County/City):

Duration (Hrs):

Date of Record (MM/DD/YY):

Source Ref. (FEMA, National Weather...):

Downstream Dam Toe (ft-msl)		Normal Reservoir Capacity (ac-ft)	
Normal Pool (ft-msl)		Maximum Reservoir Capacity (ac-ft)	
Principal Spillway (ft-msl)		Reservoir Surface Area (ac)	
Emergency Spillway (ft-msl)		Drainage Area (ac)	
Top of Dam (ft-msl)		Outlet Diameter (In)	

Storm	Peak Inflow (cfs)	Peak Outflow (cfs)	Max. Stage (ft-msl)	Comments (if needed)
100-Yr				
25%PMF				
50%PMF				
75%PMF				
100%PMF				
PMF Breach				

To the best of my knowledge, I certify the above data is correct. I will provide the Hydrologic and Hydraulic Reports to Texas Commission on Environmental Quality upon request.

(Seal)

 (Signature & Date)

Form DS-1007-HH

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