

## **APPENDIX A**

### **DRAINAGE CALCULATIONS**

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**PRE-DEVELOPMENT  
HYDROLOGY**

# Hydrograph Return Period Recap

Hydraflow Hydrographs by Intelisolve v9.2

Hyd. No.	Hydrograph type (origin)	Inflow Hyd(s)	Peak Outflow (cfs)								Hydrograph description
			1-Yr	2-Yr	3-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	
1	SCS Runoff	—	—	3.880	—	—	14.68	—	—	34.72	Subc 1 PRE
2	SCS Runoff	—	—	2.735	—	—	10.06	—	—	23.20	Subc 2 PRE
3	Combine	1, 2	—	6.532	—	—	24.59	—	—	57.45	Subc 1+2 PRE
4	Reach	3	—	6.353	—	—	24.09	—	—	56.93	Reach 5 subc 1+2
5	SCS Runoff	—	—	0.691	—	—	2.722	—	—	6.561	Subc 4 PRE
6	Reach	5	—	0.548	—	—	2.333	—	—	5.840	Reach 8 subc 4
7	Reach	6	—	0.184	—	—	0.929	—	—	2.776	Reach 7 subc 4
8	SCS Runoff	—	—	3.234	—	—	10.36	—	—	22.57	Subc 5 PRE
9	Combine	7, 8	—	3.239	—	—	10.49	—	—	23.41	4 + 5 PRE
10	Reach	9	—	3.055	—	—	10.08	—	—	22.80	Reach 6 subc 4+5
11	SCS Runoff	—	—	2.860	—	—	12.00	—	—	29.30	Subc 3 PRE
12	SCS Runoff	—	—	0.861	—	—	4.398	—	—	11.87	Subc 8 PRE
13	Reach	12	—	0.779	—	—	4.187	—	—	11.47	Reach 9 subc 8
14	Combine	4, 10, 11, 13	—	12.64	—	—	49.27	—	—	118.15	Subc 1,2,3,4,5,8
15	Reach	14	—	11.05	—	—	44.83	—	—	111.12	Reach 4 Subc 1,2,3,4,5,8
16	SCS Runoff	—	—	6.645	—	—	20.28	—	—	43.35	Subc 6 PRE
17	SCS Runoff	—	—	2.288	—	—	11.19	—	—	29.58	Subc 7 PRE
18	Combine	15, 16, 17	—	17.44	—	—	70.32	—	—	173.05	Subc 1,2,3,4,5,6,7,8
19	Reach	18	—	17.27	—	—	70.03	—	—	172.96	Reach 3 subc 1-8
20	Reach	19	—	16.20	—	—	67.19	—	—	168.39	Reach 2 subc 1-8
21	SCS Runoff	—	—	11.67	—	—	32.85	—	—	68.78	Subc 9 PRE
22	Combine	20, 21	—	25.54	—	—	97.77	—	—	234.25	Subc 1-9
23	Reach	22	—	25.31	—	—	97.27	—	—	233.61	Reach #1 Subc 1-9
24	SCS Runoff	—	—	5.716	—	—	20.01	—	—	46.09	Subc 11 PRE
25	SCS Runoff	—	—	4.699	—	—	13.47	—	—	28.04	Subc 10 PRE
26	SCS Runoff	—	—	1.406	—	—	3.792	—	—	7.670	Subc 12 PRE
27	Reach	26	—	1.274	—	—	3.472	—	—	7.178	Reach 13 subc 12
28	Reach	27	—	1.166	—	—	3.263	—	—	6.819	Reach 12 subc 12
29	Combine	25, 28	—	5.383	—	—	15.52	—	—	32.88	Subc 10+12
30	Reach	29	—	4.220	—	—	12.99	—	—	28.58	Reach 11 subc 10+12
31	Reach	30	—	4.213	—	—	12.96	—	—	28.58	Reach 10 subc 10+12
32	Combine	23, 24, 31	—	33.88	—	—	126.52	—	—	302.33	Total Pre

Proj. file: 3283 Hydro07 PRE3.gpw

Friday, Jun 6, 2008

**POST-DEVELOPMENT  
HYDROLOGY**

# Hydrograph Return Period Recap

Hydraflow Hydrographs by Intelisolve v9.2

Hyd. No.	Hydrograph type (origin)	Inflow Hyd(s)	Peak Outflow (cfs)								Hydrograph description
			1-Yr	2-Yr	3-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	
1	SCS Runoff	---	---	15.83	---	---	---	---	---	---	Subc 1 Post
2	Diversion1	1	---	0.370	---	---	---	---	---	---	Subc 1 Basin Inf
3	Diversion2	1	---	15.46	---	---	---	---	---	---	Subc 1 Runoff
4	SCS Runoff	---	---	1.646	---	---	---	---	---	---	Subc 9 Post
5	Reservoir	4	---	0.158	---	---	---	---	---	---	BASIN 9
6	Reach	5	---	0.157	---	---	---	---	---	---	Reach #18 Subc 9 post
7	SCS Runoff	---	---	4.322	---	---	---	---	---	---	Subc 2 Post
8	Diversion1	7	---	0.170	---	---	---	---	---	---	Subc 2 Basin Inf
9	Diversion2	7	---	4.152	---	---	---	---	---	---	Subc 2 Runoff
10	Combine	6, 9	---	4.161	---	---	---	---	---	---	Subc 2,9 Post
11	Reach	10	---	3.910	---	---	---	---	---	---	Reach #5 Subc 2,9 Post
12	SCS Runoff	---	---	4.285	---	---	---	---	---	---	Subc 13 Post
13	Reservoir	12	---	0.491	---	---	---	---	---	---	BASIN 13
14	SCS Runoff	---	---	1.089	---	---	---	---	---	---	Subc 6 Post
15	Reach	14	---	0.883	---	---	---	---	---	---	Reach #9 Subc 6 Post
16	Reach	15	---	0.798	---	---	---	---	---	---	Reach #8 Subc 6 Post
17	SCS Runoff	---	---	1.226	---	---	---	---	---	---	Subc 7 Post
18	SCS Runoff	---	---	1.040	---	---	---	---	---	---	Subc 12 Post
19	Reservoir	18	---	0.483	---	---	---	---	---	---	BASIN 12
20	Diversion1	19	---	0.052	---	---	---	---	---	---	Basin 12 Exfiltration
21	Diversion2	19	---	0.430	---	---	---	---	---	---	Discharge Basin 12
22	Combine	16, 17, 21	---	1.744	---	---	---	---	---	---	Subc 6,7,12
23	Reach	22	---	1.627	---	---	---	---	---	---	Reach #7 Subc 6,7,12 Post
24	SCS Runoff	---	---	1.670	---	---	---	---	---	---	Subc 10 Post
25	Reservoir	24	---	0.368	---	---	---	---	---	---	BASIN 10
26	Reach	25	---	0.365	---	---	---	---	---	---	Reach #16 Subc 10 Post
27	SCS Runoff	---	---	3.558	---	---	---	---	---	---	Subc 8 Post
28	Diversion1	27	---	0.070	---	---	---	---	---	---	Subc 8 Basin Inf
29	Diversion2	27	---	3.488	---	---	---	---	---	---	Subc 8 Runoff
30	SCS Runoff	---	---	4.294	---	---	---	---	---	---	Subc 11 Post
31	Reservoir	30	---	0.506	---	---	---	---	---	---	BASIN 11
32	Combine	23, 26, 29, 31	---	3.932	---	---	---	---	---	---	Subc 6,7,8,10,11,12
33	Reach	32	---	3.474	---	---	---	---	---	---	Reach #6 Subc 6,7,8,10,11,12
34	SCS Runoff	---	---	0.826	---	---	---	---	---	---	Subc 14 Post

# Hydrograph Return Period Recap

Hydraflow Hydrographs by Intelisolve v9.2

Hyd. No.	Hydrograph type (origin)	Inflow Hyd(s)	Peak Outflow (cfs)								Hydrograph description
			1-Yr	2-Yr	3-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	
35	SCS Runoff	—	—	1.469	—	—	—	—	—	—	Subc 17 Post
36	Combine	34, 35	—	2.261	—	—	—	—	—	—	Subc 14 + 17
37	Reservoir	36	—	0.401	—	—	—	—	—	—	Basin 17
38	SCS Runoff	—	—	1.336	—	—	—	—	—	—	Subc 18 Post
39	Diversion1	38	—	0.040	—	—	—	—	—	—	Subc 18 Basin Inf
40	Diversion2	38	—	1.296	—	—	—	—	—	—	Subc 18 Runoff
41	Reach	40	—	1.275	—	—	—	—	—	—	Reach #15 Subc 18
42	Combine	37, 41	—	1.502	—	—	—	—	—	—	Subc 14,17,18
43	Reach	42	—	1.474	—	—	—	—	—	—	Reach #14 Subc 18
44	Combine	11, 13, 33, 43	—	8.631	—	—	—	—	—	—	Subc 2,6,7,8,9,10,11,12,13,14,17,18
45	Reach	44	—	8.582	—	—	—	—	—	—	Reach #4 Subc 2,6,7,8,9,10,11,12,1
46	SCS Runoff	—	—	3.914	—	—	—	—	—	—	Subc 15 Post
47	Reservoir	46	—	0.739	—	—	—	—	—	—	Basin 15
48	Combine	3, 45, 47	—	23.39	—	—	—	—	—	—	Subc 1,2,6-15,17,18
49	Reach	48	—	23.18	—	—	—	—	—	—	Reach #3 Subc 1,2,6-15,17,18
50	SCS Runoff	—	—	1.664	—	—	—	—	—	—	Subc 3 Post
51	Reservoir	50	—	0.251	—	—	—	—	—	—	Pond 3
52	SCS Runoff	—	—	1.075	—	—	—	—	—	—	Subc 4 Post
53	Reservoir	52	—	0.554	—	—	—	—	—	—	Pond 14
54	SCS Runoff	—	—	1.364	—	—	—	—	—	—	Subc 5 Post
55	Combine	53, 54	—	1.383	—	—	—	—	—	—	Subc 4 + 5
56	Reservoir	55	—	0.659	—	—	—	—	—	—	Pond 15 (Subc 4+5)
57	SCS Runoff	—	—	5.027	—	—	—	—	—	—	Subc 16 Post
58	Reservoir	57	—	1.091	—	—	—	—	—	—	Basin 16
59	Diversion1	58	—	0.148	—	—	—	—	—	—	Exfiltration Basin 16
60	Diversion2	58	—	0.943	—	—	—	—	—	—	Discharg Basin 16
61	SCS Runoff	—	—	1.334	—	—	—	—	—	—	Subc 22 Post
62	Combine	60, 61	—	1.334	—	—	—	—	—	—	Subc 16 + 22
63	Reservoir	62	—	0.585	—	—	—	—	—	—	Basin 22
64	Diversion1	63	—	0.079	—	—	—	—	—	—	Basin 22 Exfiltration
65	Diversion2	63	—	0.506	—	—	—	—	—	—	Basin 22 Discharge
66	Combine	49, 56, 65	—	23.53	—	—	—	—	—	—	Subc 1,2,4-18,22
67	Reach	66	—	21.78	—	—	—	—	—	—	Reach #2 Subc 1,2,4-18,22
68	SCS Runoff	—	—	2.352	—	—	—	—	—	—	Subc 27 Post

Proj. file: 3283b POST rev2 combo.gpw

Monday, Jun 9, 2008

# Hydrograph Return Period Recap

Hydraflow Hydrographs by Intelisolve v9.2

Hyd. No.	Hydrograph type (origin)	Inflow Hyd(s)	Peak Outflow (cfs)								Hydrograph description
			1-Yr	2-Yr	3-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	
69	Reservoir	68	---	0.975	---	---	---	---	---	---	Basin 27
70	Diversion1	69	---	0.063	---	---	---	---	---	---	Basin 27 Exfiltration
71	Diversion2	69	---	0.912	---	---	---	---	---	---	Discharge Basin 27
72	SCS Runoff	---	---	1.320	---	---	---	---	---	---	Subc 29 Post
73	Reservoir	72	---	0.571	---	---	---	---	---	---	Basin 29
74	Diversion1	73	---	0.023	---	---	---	---	---	---	Exfiltration Basin 29
75	Diversion2	73	---	0.548	---	---	---	---	---	---	Discharge Basin 29
76	SCS Runoff	---	---	1.572	---	---	---	---	---	---	Subc 28 Post
77	Combine	71, 75, 76	---	2.892	---	---	---	---	---	---	Subc 27,28,29 (into Basin 28)
78	Reservoir	77	---	0.543	---	---	---	---	---	---	Basin 28
79	Reach	78	---	0.515	---	---	---	---	---	---	Reach #19 Subc 27,28,29
80	SCS Runoff	---	---	4.283	---	---	---	---	---	---	Subc 19 Post
81	Diversion1	80	---	0.220	---	---	---	---	---	---	Subc 19 Basin Inf
82	Diversion2	80	---	4.063	---	---	---	---	---	---	Subc 19 Runoff
83	SCS Runoff	---	---	2.344	---	---	---	---	---	---	Subc 20 Post
84	Reservoir	83	---	0.387	---	---	---	---	---	---	Basin 20
85	Diversion1	84	---	0.247	---	---	---	---	---	---	Exfiltration Basin 20
86	Diversion2	84	---	0.140	---	---	---	---	---	---	Basin 20 Discharge
87	SCS Runoff	---	---	6.647	---	---	---	---	---	---	Subc 26 Post
88	Combine	67, 79, 82, 86, 87	---	27.74	---	---	---	---	---	---	Subc 1,2,4-20,22,26-29
89	SCS Runoff	---	---	1.140	---	---	---	---	---	---	Subc 21 Post
90	Reservoir	89	---	0.466	---	---	---	---	---	---	Basin 21
91	Diversion1	90	---	0.158	---	---	---	---	---	---	Exfiltration Basin 21
92	Diversion2	90	---	0.308	---	---	---	---	---	---	Basin 21 Discharge
93	SCS Runoff	---	---	5.903	---	---	---	---	---	---	Subc 23 Post
94	SCS Runoff	---	---	2.089	---	---	---	---	---	---	Subc 24 Post
95	Reach	94	---	1.989	---	---	---	---	---	---	Reach #13 Subc 24
96	Reach	94	---	1.896	---	---	---	---	---	---	Reach #12 Subc 24
97	Reach	96	---	1.331	---	---	---	---	---	---	Reach #11 Subc 24
98	Reach	97	---	1.321	---	---	---	---	---	---	Reach #10 Subc 24
99	Combine	88, 92, 93, 98	---	33.15	---	---	---	---	---	---	Total Runoff

# Hydrograph Return Period Recap

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			1-Yr	2-Yr	3-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	
1	SCS Runoff	—	—	—	—	—	44.21	—	—	90.76	Subc 1 Post
2	Diversion1	1	—	—	—	—	0.370	—	—	0.370	Subc 1 Basin Inf
3	Diversion2	1	—	—	—	—	43.84	—	—	90.39	Subc 1 Runoff
4	SCS Runoff	—	—	—	—	—	4.014	—	—	7.341	Subc 9 Post
5	Reservoir	4	—	—	—	—	0.727	—	—	2.033	BASIN 9
6	Reach	5	—	—	—	—	0.715	—	—	1.996	Reach #18 Subc 9 post
7	SCS Runoff	—	—	—	—	—	12.70	—	—	26.72	Subc 2 Post
8	Diversion1	7	—	—	—	—	0.170	—	—	0.170	Subc 2 Basin Inf
9	Diversion2	7	—	—	—	—	12.53	—	—	26.55	Subc 2 Runoff
10	Combine	6, 9	—	—	—	—	12.67	—	—	27.33	Subc 2,9 Post
11	Reach	10	—	—	—	—	12.23	—	—	26.80	Reach #5 Subc 2,9 Post
12	SCS Runoff	—	—	—	—	—	10.73	—	—	17.96	Subc 13 Post
13	Reservoir	12	—	—	—	—	2.314	—	—	10.98	BASIN 13
14	SCS Runoff	—	—	—	—	—	3.439	—	—	7.501	Subc 6 Post
15	Reach	14	—	—	—	—	2.968	—	—	6.730	Reach #9 Subc 6 Post
16	Reach	15	—	—	—	—	2.790	—	—	6.446	Reach #8 Subc 6 Post
17	SCS Runoff	—	—	—	—	—	2.623	—	—	4.774	Subc 7 Post
18	SCS Runoff	—	—	—	—	—	2.266	—	—	3.713	Subc 12 Post
19	Reservoir	18	—	—	—	—	1.316	—	—	2.288	BASIN 12
20	Diversion1	19	—	—	—	—	0.078	—	—	0.103	Basin 12 Exfiltration
21	Diversion2	19	—	—	—	—	1.238	—	—	2.184	Discharge Basin 12
22	Combine	16, 17, 21	—	—	—	—	5.412	—	—	11.50	Subc 6,7,12
23	Reach	22	—	—	—	—	5.136	—	—	10.98	Reach #7 Subc 6,7,12 Post
24	SCS Runoff	—	—	—	—	—	3.763	—	—	6.841	Subc 10 Post
25	Reservoir	24	—	—	—	—	1.386	—	—	3.201	BASIN 10
26	Reach	25	—	—	—	—	1.375	—	—	3.183	Reach #16 Subc 10 Post
27	SCS Runoff	—	—	—	—	—	8.282	—	—	15.45	Subc 8 Post
28	Diversion1	27	—	—	—	—	0.070	—	—	0.070	Subc 8 Basin Inf
29	Diversion2	27	—	—	—	—	8.212	—	—	15.38	Subc 8 Runoff
30	SCS Runoff	—	—	—	—	—	9.317	—	—	16.23	Subc 11 Post
31	Reservoir	30	—	—	—	—	1.994	—	—	4.931	BASIN 11
32	Combine	23, 26, 29, 31	—	—	—	—	10.56	—	—	23.52	Subc 6,7,8,10,11,12
33	Reach	32	—	—	—	—	10.49	—	—	23.37	Reach #6 Subc 6,7,8,10,11,12
34	SCS Runoff	—	—	—	—	—	3.711	—	—	8.183	Subc 14 Post

# Hydrograph Return Period Recap

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			1-Yr	2-Yr	3-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	
35	SCS Runoff	—	—	—	—	—	3.208	—	—	5.641	Subc 17 Post
36	Combine	34, 35	—	—	—	—	6.881	—	—	13.82	Subc 14 + 17
37	Reservoir	36	—	—	—	—	3.702	—	—	13.61	Basin 17
38	SCS Runoff	—	—	—	—	—	4.748	—	—	10.46	Subc 18 Post
39	Diversion1	38	—	—	—	—	0.040	—	—	0.040	Subc 18 Basin Inf
40	Diversion2	38	—	—	—	—	4.708	—	—	10.42	Subc 18 Runoff
41	Reach	40	—	—	—	—	4.650	—	—	10.39	Reach #15 Subc 18
42	Combine	37, 41	—	—	—	—	8.190	—	—	22.48	Subc 14,17,18
43	Reach	42	—	—	—	—	8.032	—	—	22.40	Reach #14 Subc 18
44	Combine	11, 13, 33, 43	—	—	—	—	30.64	—	—	80.16	Subc 2,6,7,8,9,10,11,12,13,14,17,18
45	Reach	44	—	—	—	—	30.58	—	—	80.14	Reach #4 Subc 2,6,7,8,9,10,11,12,1
46	SCS Runoff	—	—	—	—	—	8.899	—	—	14.97	Subc 15 Post
47	Reservoir	46	—	—	—	—	2.894	—	—	6.526	Basin 15
48	Combine	3, 45, 47	—	—	—	—	72.70	—	—	171.60	Subc 1,2,6-15,17,18
49	Reach	48	—	—	—	—	72.21	—	—	171.36	Reach #3 Subc 1,2,6-15,17,18
50	SCS Runoff	—	—	—	—	—	7.029	—	—	17.23	Subc 3 Post
51	Reservoir	50	—	—	—	—	0.743	—	—	1.644	Pond 3
52	SCS Runoff	—	—	—	—	—	4.838	—	—	12.42	Subc 4 Post
53	Reservoir	52	—	—	—	—	1.509	—	—	1.986	Pond 14
54	SCS Runoff	—	—	—	—	—	3.299	—	—	6.410	Subc 5 Post
55	Combine	53, 54	—	—	—	—	3.792	—	—	7.800	Subc 4 + 5
56	Reservoir	55	—	—	—	—	1.753	—	—	2.479	Pond 15 (Subc 4+5)
57	SCS Runoff	—	—	—	—	—	11.70	—	—	19.77	Subc 16 Post
58	Reservoir	57	—	—	—	—	11.51	—	—	19.42	Basin 16
59	Diversion1	58	—	—	—	—	0.166	—	—	0.171	Exfiltration Basin 16
60	Diversion2	58	—	—	—	—	11.34	—	—	19.25	Discharg Basin 16
61	SCS Runoff	—	—	—	—	—	3.185	—	—	6.094	Subc 22 Post
62	Combine	60, 61	—	—	—	—	13.78	—	—	24.64	Subc 16 + 22
63	Reservoir	62	—	—	—	—	5.349	—	—	15.24	Basin 22
64	Diversion1	63	—	—	—	—	0.121	—	—	0.160	Basin 22 Exfiltration
65	Diversion2	63	—	—	—	—	5.228	—	—	15.08	Basin 22 Discharge
66	Combine	49, 56, 65	—	—	—	—	78.11	—	—	188.46	Subc 1,2,4-18,22
67	Reach	66	—	—	—	—	75.22	—	—	182.86	Reach #2 Subc 1,2,4-18,22
68	SCS Runoff	—	—	—	—	—	4.272	—	—	6.980	Subc 27 Post

# Hydrograph Return Period Recap

Hydraflow Hydrographs by Intelisolve v9.2

Hyd. No.	Hydrograph type (origin)	Inflow Hyd(s)	Peak Outflow (cfs)								Hydrograph description
			1-Yr	2-Yr	3-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	
69	Reservoir	68	---	---	---	---	2.433	---	---	5.113	Basin 27
70	Diversion1	69	---	---	---	---	0.072	---	---	0.080	Basin 27 Exfiltration
71	Diversion2	69	---	---	---	---	2.362	---	---	5.033	Discharge Basin 27
72	SCS Runoff	---	---	---	---	---	2.274	---	---	3.588	Subc 29 Post
73	Reservoir	72	---	---	---	---	2.189	---	---	3.538	Basin 29
74	Diversion1	73	---	---	---	---	0.025	---	---	0.026	Exfiltration Basin 29
75	Diversion2	73	---	---	---	---	2.164	---	---	3.512	Discharge Basin 29
76	SCS Runoff	---	---	---	---	---	3.264	---	---	5.832	Subc 28 Post
77	Combine	71, 75, 76	---	---	---	---	6.792	---	---	12.57	Subc 27,28,29 (into Basin 28)
78	Reservoir	77	---	---	---	---	2.321	---	---	3.648	Basin 28
79	Reach	78	---	---	---	---	2.141	---	---	3.606	Reach #19 Subc 27,28,29
80	SCS Runoff	---	---	---	---	---	14.42	---	---	32.05	Subc 19 Post
81	Diversion1	80	---	---	---	---	0.220	---	---	0.220	Subc 19 Basin Inf
82	Diversion2	80	---	---	---	---	14.20	---	---	31.83	Subc 19 Runoff
83	SCS Runoff	---	---	---	---	---	8.800	---	---	20.47	Subc 20 Post
84	Reservoir	83	---	---	---	---	7.383	---	---	20.29	Basin 20
85	Diversion1	84	---	---	---	---	0.255	---	---	0.262	Exfiltration Basin 20
86	Diversion2	84	---	---	---	---	7.128	---	---	20.03	Basin 20 Discharge
87	SCS Runoff	---	---	---	---	---	12.75	---	---	21.62	Subc 26 Post
88	Combine	67, 79, 82, 86, 87	---	---	---	---	98.29	---	---	236.61	Subc 1,2,4-20,22,26-29
89	SCS Runoff	---	---	---	---	---	3.721	---	---	8.314	Subc 21 Post
90	Reservoir	89	---	---	---	---	1.283	---	---	6.416	Basin 21
91	Diversion1	90	---	---	---	---	0.340	---	---	0.432	Exfiltration Basin 21
92	Diversion2	90	---	---	---	---	0.943	---	---	5.984	Basin 21 Discharge
93	SCS Runoff	---	---	---	---	---	21.71	---	---	49.60	Subc 23 Post
94	SCS Runoff	---	---	---	---	---	4.635	---	---	8.596	Subc 24 Post
95	Reach	94	---	---	---	---	4.488	---	---	8.420	Reach #13 Subc 24
96	Reach	94	---	---	---	---	4.350	---	---	8.179	Reach #12 Subc 24
97	Reach	96	---	---	---	---	3.272	---	---	6.465	Reach #11 Subc 24
98	Reach	97	---	---	---	---	3.247	---	---	6.441	Reach #10 Subc 24
99	Combine	88, 92, 93, 98	---	---	---	---	114.29	---	---	271.93	Total Runoff

**WATER QUALITY VOLUME  
CALCULATIONS**

**Water Quality Calculations:**

Project: THE RESIDENCE AT QUAIL RIDGE, LLC  
 Location: ACTON, MA

By BRE Date 6/2/08  
 Checked \_\_\_\_\_ Date \_\_\_\_\_

**Subcatchment 9**

Storage  
 Impervious: 37,026 sf  
 Required Water Quality Volume(1/2"): 1,481 cf

Filtration  
 Filtration rate w/ 4"Loam,6" Sand (Est.) = 5.34 in/hr  
 1.24E-04 cfs/sf

Stormwater Basin 9  
 Water Quality Swale

filtration time = 24 hrs  
 Filter Area = 520 sf  
 Volume = 2,221 cf

ELEV	Area sf	Cumm Volume cf
228	520	0
229	1,375	948
230	2,128	<u>1,752</u>
Storage Volume =		2,699

Storage Volume + Filtered Volume = Treated Volume  
 2,699 + 2,221 = 4,920 > 1,481 OK

**Subcatchment 13**

Impervious: 91,912 sf  
 Required Water Quality Volume(1/2"): 3,678 cf

Stormceptor sized to treat > 80%

**Subcatchment 11**

Storage  
 Impervious: 81,893 sf  
 Required Water Quality Volume(1/2"): 3,276 cf

Filtration  
 Filtration rate w/ 4"Loam,6" Sand (Est.) = 5.34 in/hr  
 1.24E-04 cfs/sf

Stormwater Basin 11  
 Water Quality Swale

filtration time = 24 hrs  
 Filter Area = 681 sf  
 Volume = 2,909 cf

ELEV	Area sf	Cumm Volume cf
213	681	0
214	1,745	1,213
215	3,551	<u>2,648</u>
Storage Volume =		3,861

Storage Volume + Filtered Volume = Treated Volume  
 3,861 + 2,909 = 6,770 > 3,276 OK

**Subcatchment 12**

Storage  
 Impervious: 21,780 sf  
 Required Water Quality Volume(1/2"): 871 cf

Infiltration  
 Volume = 1,409 cf (from Hydrology 1 yr)

Stormwater Basin 12  
 Infiltration Basin

ELEV	Area sf	Cumm Volume cf
221	214	0
221.5	221	109
Storage Volume =		109

Storage Volume + Infiltrated Volume = Treated Volume  
 109 + 1,409 = 1,518 > 871 OK

Water Quality Calculations:

Project: THE RESIDENCE AT QUAIL RIDGE, LLC  
 Location: ACTON, MA

By BRE Date 6/2/08  
 Checked \_\_\_\_\_ Date \_\_\_\_\_

Subcatchment 10

Storage			Filtration		
Impervious:	30,056	sf	Filtration rate w/ 4"Loam,6" Sand (Est.) =	5.34	in/hr
Required Water Quality Volume(1/2"):	1,202	cf		1.24E-04	cts/sf
Stormwater Basin 10			filtration time =	24	hrs
Water Quality Swale			Filter Area =	235	sf
			Volume =	1,004	cf
ELEV	Area	Cumm Volume			
	sf	cf			
218	235	0			
219	544	390			
220	1,130	837			
Storage Volume =		1,227			
Storage Volume	+	Filtered Volume	=	Treated Volume	
1,227	+	1,004	=	2,230	> 1,202 OK

Subcatchments 17

Storage			Filtration		
Impervious:	25,285	sf	Filtration rate w/ 4"Loam,6" Sand (Est.) =	5.34	in/hr
Required Water Quality Volume(1/2"):	1,011	cf		1.24E-04	cts/sf
Stormwater Basin 17			filtration time =	24	hrs
Water Quality Swale			Filter Area =	242	sf
			Volume =	1,034	cf
ELEV	Area	Cumm Volume			
	sf	cf			
213	242	0			
214	567	405			
215	1,324	946			
Storage Volume =		1,350			
Storage Volume	+	Filtered Volume	=	Treated Volume	
1,350	+	1,034	=	2,384	> 1,011 OK

Subcatchment 15

Storage			Filtration		
Impervious:	74,052	sf	Filtration rate w/ 4"Loam,6" Sand (Est.) =	5.34	in/hr
Required Water Quality Volume(1/2"):	2,962	cf		1.24E-04	cts/sf
Stormwater Basin 15			filtration time =	24	hrs
Water Quality Swale			Filter Area =	436	sf
			Volume =	1,863	cf
ELEV	Area	Cumm Volume			
	sf	cf			
192	436	0			
193	913	675			
194	2,263	1,588			
Storage Volume =		2,263			
Storage Volume	+	Filtered Volume	=	Treated Volume	
2,263	+	1,863	=	4,125	> 2,962 OK

Subcatchment 16

Impervious:	87,991	sf			
Required Water Quality Volume(1/2"):	3,520	cf			
Infiltration					
Volume =	9,255	cf (from Hydrology 1 year storm)			
Treated Volume	9,255	>	3,520	OK	

Subcatchment 22

Impervious:	18,295	sf			
Required Water Quality Volume(1/2"):	732	cf			
Infiltration					
Volume =	7,533	cf (from Hydrology 1 year storm)			
Treated Volume	7,533	>	732	OK	

Subcatchments 26,27,28,29

Impervious:	153,418.00	sf			
Required Water Quality Volume(1/2"):	6,137	cf			
Stormceptor sized to treat 80%					

## **Water Balance Calculations**

**Water Balance Calculations**

SM-3283B

SHEET 1 OF 4

Project: Residences at Quail Ridge

By GD

Date 6/3/08

Location: Acton, MA

Checked JEM

Date \_\_\_\_\_

**Pre-development recharge**

CN= 61.9  
 From Figure 1, infiltration= 19.30 in./year  
 Drainage Area= 7,567,243 s.f. (includes offsite area for simplicity)  
 Recharge= 7,567,243 x 19.30 /12 in/ft = 12,170,649 c.f./year

**Post-development recharge**

CN= 66.9  
 From Figure 1, infiltration= 18.00 in./year  
 Drainage Area= 7,567,243 s.f.  
 Recharge= 7,567,243 x 18.00 /12 in/ft = 11,350,865 c.f./year

**Irrigation**

(32.8+- ac to irrigate)  
 1,428,768 sf x 16 weeks x 0.04 ft/week = 914,412 cf/year  
 685,809 cf/year  
 w/25% deep infiltration (DEP SMP)

Difference to Recharge= 12,170,649 - 11,350,865 + 685,809 = 1,505,593 c.f./year must be recharged

**Sewage flow**

Total Design Flow 31,910 gpd  
 onventional Trenches (1/3 of Flow) 9,950 gpd x 365 days/year x 0.134 cf/gal = 485,528 cf/year  
 Drip Distribution (2/3 Flow) 21,960 gpd x 150 Non-Growing Season (days/year) x 0.134 cf/gal = 441,396 cf/year

**Stormwater Recharge**

from calculations =

1,310,928 cf/year  
 TOTAL = 2,237,852 cf/year

2,237,852 cf/year > 1,505,593 cf/year OK

**Overall CN Calculations**

SM-3286B

SHEET 2 OF 4

Project: Residences at Quail Ridge  
 Location: Acton, MA

By GD Date 6/3/08  
 Checked JEM Date \_\_\_\_\_

**Pre-development CN**

subcatchment	Area (acres)	CN	Product
1	18.62	60.5	1126.4
2	10.69	61.3	655.27
3	14.69	59.47	873.6
4	3.62	59.92	216.92
5	9.50	63.39	602.16
6	17.66	64.24	1134.44
7	18.74	57.24	1072.61
8	7.73	56.66	438.02
9	33.53	65.34	2190.95
10	10.90	65.41	712.99
11	25.21	61.28	1544.84
12	2.83	66.82	189.1
<hr/>			
	173.72		10757.30
Overall CN:	61.9		

**Post-development CN**

subcatchment	Area (acres)	CN	PRODUCT
1	38.52	66.1	2546.172
2	10.59	64.9	687.74
3	8.68	59.4	515.35
4	8.08	57.8	467.07
5	1.97	69.5	136.95
6	3.54	64.3	227.5856
7	1.40	73.7	103.14
8	4.12	71.7	295.404
9	2.00	73.3	146.6
10	2.00	73.8	147.6
11	4.34	77.0	334.18
12	0.88	82.0	72.16
13	4.10	80.0	328
14	3.21	63.1	202.551
15	3.73	79.8	297.654
16	4.60	79.2	364.32
17	1.42	76.1	108.062
18	5.02	63.0	316.4323
19	13.95	62.6	872.59
20	9.56	61.0	583.08
21	4.31	62.5	269.26
22	1.71	70.1	119.871
23	20.8	61.6	1280.74
24	2.63	72.3	190.149
SUB 25 ROOFS	0.66	98.0	64.68
26	5.48	79.1	433.74
27	1.53	82.1	125.58
28	1.85	75.0	138.82
29	0.69	85.1	58.719
30	0.11	94.6	10.41
31	1.23	66.4	81.672
32	0	0.0	0
33	0.23	98.0	22.54
34	0.15	90.6	13.59
35	0	0.0	0
36	0.09	85.7	7.71
SUB 24 ROOFS	0.08	98.0	7.84
SUB 29 ROOFS	0.06	98.0	5.88
SUB 26 ROOFS	0.07	98.0	6.86
SUB 7 ROOFS	0.07	98.0	6.86
SUB 12 ROOFS	0.08	98.0	7.84
SUB 17 ROOFS	0.1	98.0	9.8
SUB 18 ROOFS	0.08	98.0	7.84
<hr/>			
	173.72		11623.04
Overall CN:	66.9		

Project: Residences at Quail Ridge  
 Location: Acton, MA

By GD Date 6/3/08  
 Checked JEM Date 07/17/06

**INFILTRATION OF ROOF RUNOFF:**

Area of roofs being infiltrated for 100 year storm: 23,522 sf  
 Runoff from Roofs (CN=98): 30.5 in/year  
 Total Runoff from roofs being infiltrated: 59,788 cf/year

**INFILTRATION IN BASINS:**

**BASIN 12:**  
 Subcatchment Area: 38,333 sf  
 Subcatchment CN: 82.0  
 Infiltration volume for 1 year storm (2.6 in): 1,409 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.44 in  
 Rainfall to generate Runoff: 1.74 in (TR55)  
 % of Annual rainfall infiltrated: 80 % (figure 2)  
 From Graph 1, Annual runoff : 6 in/year  
 Annual Runoff x %infiltrated x Area = 15,333 cf/year

**BASIN 16:**  
 Subcatchment Area: 200,376 sf  
 Subcatchment CN: 79.2  
 Infiltration volume for 1 year storm (2.6 in): 9,255 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.55 in  
 Rainfall to generate Runoff: 2.05 in (TR55)  
 % of Annual runoff infiltrated: 88 % (figure 2)  
 From Graph 1, Annual runoff : 6.4 in/year  
 Annual Runoff x %infiltrated x Area = 94,043 cf/year

**BASIN 22:**  
 Subcatchment Area: 274,864 sf  
 Subcatchment CN: 78.7  
 Infiltration volume for 1 year storm (2.6 in): 7,533 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.33 in  
 Rainfall to generate Runoff: 2.2 in (TR55)  
 % of Annual runoff infiltrated: 90 % (figure 2)  
 From Graph 1, Annual runoff : 5.4 in/year  
 Annual Runoff x %infiltrated x Area = 111,320 cf/year

**BASIN 27:**  
 Subcatchment Area: 68,847 sf  
 Subcatchment CN: 82.1  
 Infiltration volume for 1 year storm (2.6 in): 3,121 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.56 in  
 Rainfall to generate Runoff: 1.85 in (TR55)  
 % of Annual runoff infiltrated: 83 % (figure 2)  
 From Graph 1, Annual runoff : 7.6 in/year  
 Annual Runoff x %infiltrated x Area = 35,034 cf/year

**BASIN 29:**  
 Subcatchment Area: 30,056 sf  
 Subcatchment CN: 85.1  
 Infiltration volume for 1 year storm (2.6 in): 1,284 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.51 in  
 Rainfall to generate Runoff: 1.47 in (TR55)  
 % of Annual runoff infiltrated: 75 % (figure 2)  
 From Graph 1, Annual runoff : 10 in/year  
 Annual Runoff x %infiltrated x Area = 18,785 cf/year

**BASIN 20:**  
 Subcatchment Area: 416,434 sf  
 Subcatchment CN: 61.0  
 Infiltration volume for 1 year storm (2.6 in): 8,090 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.23 in  
 Rainfall to generate Runoff: 2.6 in (TR55)  
 % of Annual runoff infiltrated: 100 % (figure 2)  
 From Graph 1, Annual runoff : 1.4 in/year  
 Annual Runoff x %infiltrated x Area = 48,584 cf/year

**BASIN 21:**  
 Subcatchment Area: 187,744 sf  
 Subcatchment CN: 62.5  
 Infiltration volume for 1 year storm (2.6 in): 1,165 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.07 in  
 Rainfall to generate Runoff: 1.9 in (TR55)  
 % of Annual runoff infiltrated: 85 % (figure 2)  
 From Graph 1, Annual runoff : 1.8 in/year  
 Annual Runoff x %infiltrated x Area = 23,937 cf/year

Project: Residences at Quail Ridge  
 Location: Acton, MA

By GD Date 6/3/08  
 Checked JEM Date 07/17/07

**Pond 3**

Subcatchment Area: 378,101 sf  
 Subcatchment CN: 59.4  
 Infiltration volume for 1 year storm (2.6 in): 6,101 cf (from Hydrology)  
 Depth of runoff over drainage area: 0.19 in  
 Rainfall to generate Runoff: 2.6 in (TR55)  
 % of Annual runoff Infiltrated: 100 % (figure 2)  
 From Graph 1, Annual runoff : 2.6 in/year  
 Annual Runoff x %infiltrated x Area = 81,922 cf/year

**BASINS ON COURSE:**

Misc. Basins on Course:	Tributary		Depth of Runoff Over drain area (in) TR55*	Rainfall to gen runoff (in) (TR55)	% of Annual Runoff Infiltrated	From Graph 1 Annual runoff in/year	Annual Infiltration (in)
	Infiltration Area* (CF)(1yea (SF)	CN					
Subcatchment 1:	16,278 514,042	66.1	0.38	2.6	100	1.4	59,972
Subcatchment 2:	6,551 238,218	64.9	0.33	2.6	100	2.0	39,703
Subcatchment 8:	2,907 60,145	71.7	0.58	2.6	100	3.7	18,545
Subcatchment 18:	1,734 74,314	63.0	0.28	2.6	100	1.8	11,147
Subcatchment 19:	8,020 356,444	62.6	0.27	2.6	100	1.7	50,496

\*Proportions tributary area to accomodate 2.6" storm

**INFILTRATION TRENCHES:**

Designed for 100 year storm (6.4 in Rain)	Subcatchment Area* (SF)	CN	% of Annual Runoff Infiltrated	From Graph 1 Annual runoff in/year	Annual Infiltration (in)
Subcatchment 30 IMP:	4,356	98.0	100	30.5	11,072
Subcatchment 30 OS:	436	61.0	100	1.4	51
Subcatchment 31:	53,579	66.4	100	2.4	10,716
Subcatchment 32:	0	0.0	100	3.4	0
Subcatchment 33:	10,019	98.0	100	30.5	25,464
Subcatchment 34:	6,534	90.6	100	15.0	8,168
Subcatchment 35:	0	0.0	100	4.6	0
Subcatchment 36 IMP:	2,614	98.0	100	30.5	6,643
Subcatchment 36 OS:	1,307	61.0	100	1.4	152
CB's ON QR DRIVE IMP:	64,904	98.0	100	30.5	164,964
CB's ON QR DRIVE OS:	47,045	61.0	100	1.4	5,489
CB54 IMP:	15,246	98.0	100	30.5	38,750
CB54 OS:	5,227	61.0	100	1.4	610

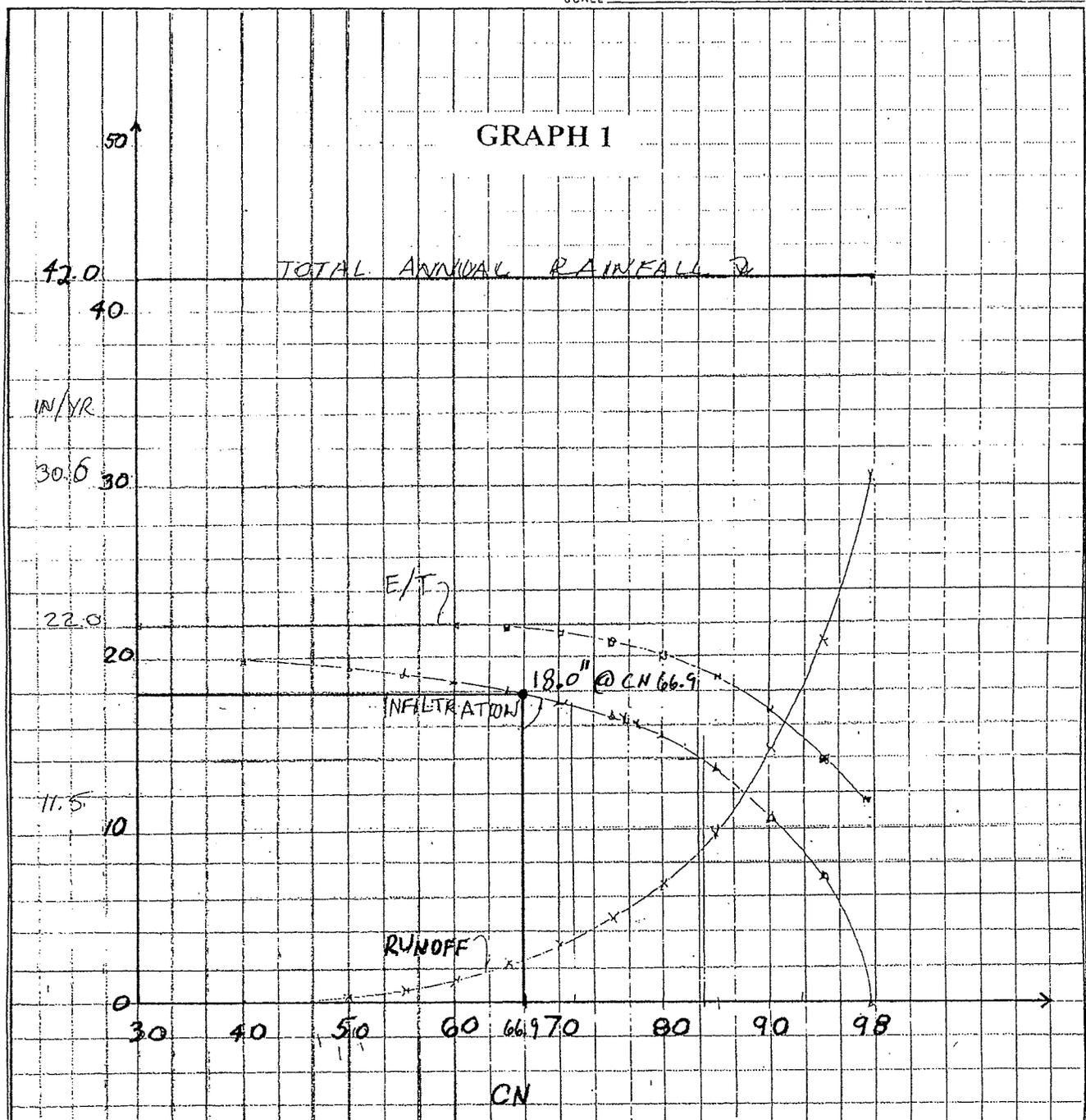
**ADDITIONAL INFILTRATION OF ROOF RUNOFF:**

Area of roofs being infiltrated for 1 year storm: 124,482 sf  
 Runoff from Roofs (CN=98): 30.5 in/year  
 Total Runoff from roofs being infiltrated: 316,392 cf/year

**DECK INFILTRATION**

AREA OF DECKS WITH CRUSHED STONE  
 (OR PORCHES WITH DRIPEDGES)  
 Runoff from Roofs (CN=98): 30.5 in/year  
 Total Runoff from roofs being infiltrated: 53,850 cf/year

GRAPH 1



NOTE: GRAPH COMPILED FROM DATA PUBLISHED BY NOAA (1984-1988)  
 (SEE REPORT FROM STAMSKI & McNARY, INC. SUBMITTED W/TOWN OF ACTON ENG. DEPT.)

## **APPENDIX B**

### **Report – *Design and Performance of Drip Dispersal Systems in Freezing Environments***

**By: Scott D. Wallace, P.E.**

# DESIGN & PERFORMANCE OF DRIP DISPERSAL SYSTEMS IN FREEZING ENVIRONMENTS

Scott D. Wallace, P.E.\*

## ABSTRACT

Four different drip dispersal systems in Minnesota were instrumented to determine temperatures at a number of different locations within each system. Temperatures were recorded throughout the winter of 2000/2001. Generally speaking soil temperatures at the emitter line (7.5 to 30 cm of cover) were below freezing throughout the winter. Temperatures at the emitter line tended to be slightly colder (except during dosing events) than the soil temperature at a comparable depth between emitter lines on lightly loaded systems.

Different strategies for insulating of air relief valve boxes were investigated. Designs that insulate the top of the valve box while maximizing the transfer of heat from below were the most successful.

All four systems operated successfully through the Minnesota winter, despite freezing soil conditions. This can be attributed to the proper use of insulation and drainback design strategies.

## INTRODUCTION

Subsurface drip distribution is gaining widespread acceptance as wastewater disposal method, especially in situations where pressure dosing is needed. However, use of drip distribution technology in northern climates has been tempered due to concerns about freezing.

Existing design manuals are derived from experience with landscape irrigation in warm climates. Drip dispersal systems used for wastewater distribution face a very different set of challenges. In freezing environments, designs must be modified substantially from the standard landscape irrigation approach.

Minnesota is considered to have a severe winter climate with winter temperatures (December through February) averaging -11.3 deg C (11.6 deg F) (NOAA, 2001). However, initial drip distribution applications indicated that freezing would not be a concern. Data collected by the Sauk River Watershed District during the winter of 1995/1996 indicated that emitter tubing with as little as 17.5 cm (7 inches) of cover would stay above freezing (Mostad, 1998). A study conducted by the University of Minnesota Natural Resources Institute during the winter of 1996/1997 reported above-freezing temperatures for emitter lines at depths between 15 and 60 cm (6 to 24 inches), although some freezing with the headworks unit was reported, despite being in a heated enclosure (McCarthy et al., 1997).

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\*Scott D. Wallace P.E., Vice President North American Wetland Engineering P.A., Forest Lake Minnesota.

These positive reports resulted in the installation of a number of drip distribution systems, often by designers and installers with little or no prior experience with drip. The winters of 1998/1999 and 1999/2000 were much more severe, leading to numerous reports of frozen drip systems. Because drip was a new and highly visible technology, regulatory officials began to question the suitability of drip systems (although many other onsite systems, including mounds, also froze during this period).

In retrospect, the positive early reports occurred during winters with heavy snowfall. Most importantly, snow arrived early in the winter season, effectively insulating the ground. In contrast, more recent winters have had very cold weather early in the season with no snow cover. This causes the ground to freeze quickly, creating “worst-case” conditions for onsite system freezing (Kadlec, 2000).

Several studies were done to assess frozen systems and find common causes of system failure (Golly, 2000). The most common causes of freezing were systems that did not drain back, with standing water in the system freezing, and above-ground air/vacuum relief valves which froze. Frozen air relief valves that do not open on drainback create very slow drainage conditions that contribute to system freezing, as well as other problems. Raised bed systems also appear to be more susceptible to freezing than in-ground systems.

### COLD-CLIMATE DRIP SYSTEM CONFIGURATION

In 1997, North American Wetland Engineering (NAWE) began development of a “new” cold-climate drip system. Several design changes were made in 1997 and 1998 to improve system performance. Since 1998, this layout has resulted in excellent cold-weather performance.

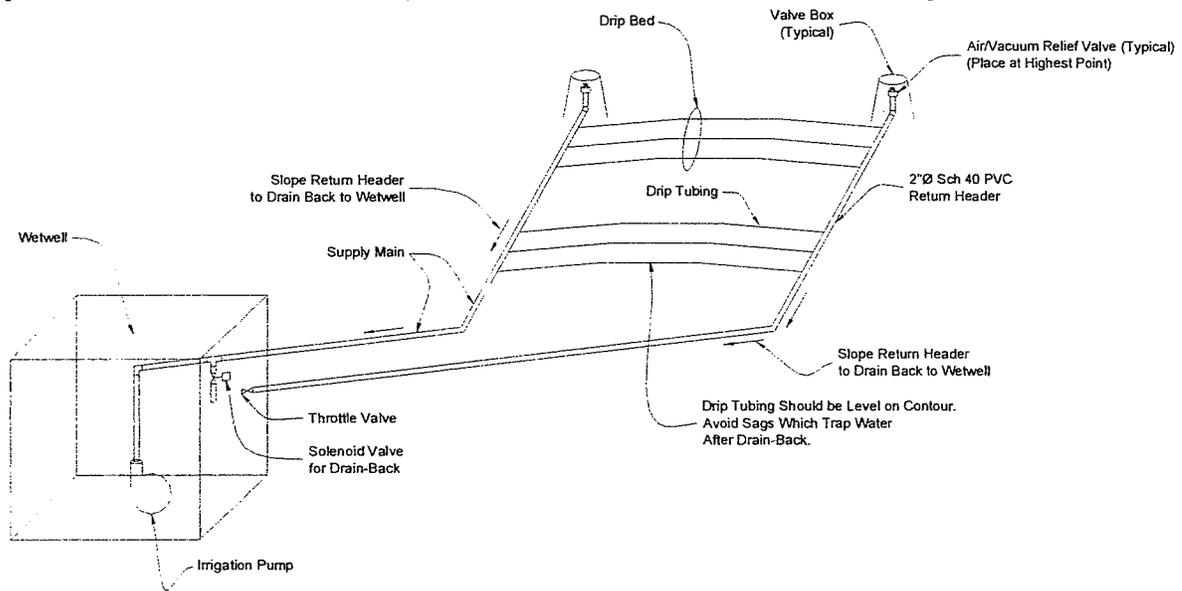


Figure 1. NAWE Cold-Climate Drip System Schematic.

This drip system design is substantially different than other commercially available systems in that there is no headworks to freeze. Eliminating the headworks results in a much simpler system, although one pump per zone is needed. On very large systems, this multiplicity of pumps may be more expensive than a headworks system.

The drip system is designed to completely drain back to the wet well. A motorized drain valve on the supply main opens when the pump shuts off, draining the system. To maintain water movement through the system, a continuous flush on the return header is used. Field pressure is manually set by throttling the return valve. Air/vacuum relief valves on both the supply main and return header are employed to permit rapid drain back. The objective of this design is to completely drain the system in 3 minutes or less. System design and installation recommendations are discussed in detail elsewhere (Wallace, 2000).

For the supply main and return header piping, 2-inch schedule 40 PVC is used to allow a high-pressure steamer hose to be inserted in the event of freezing. Other details of the system layout generally follow current design practice (Burton et al, 2001).

## **SYSTEM PERFORMANCE**

Four systems were selected in 2000 for temperature monitoring. The objective of this study was to:

- Effectively document successful performance of drip distribution systems in cold-climate applications.
- Gain a better understanding of the heat flow within the drip system.

The four systems selected were The Greens of Dellwood, Bornholdt Residence, Columbus Elementary School, and Golly Residence. Temperatures at each site were recorded using 4-channel HOBO or submersible StowAway Tidbit data loggers. The HOBO loggers were equipped with external temperature probes with an accuracy of 0.5 deg C, while the StowAway loggers have an integral temperature sensor with an accuracy of 0.2 deg C (Onset Computer Corporation, 2000).

### The Greens of Dellwood

This is a 11-home residential cluster system employing a septic tank effluent pump (STEP) collection system, a horizontal subsurface flow wetland with Forced Bed Aeration™, and 2-zone drip irrigation system. The system was designed by NAWA in 1997. Emitter tubing was plowed into a 60 cm (24 inch) sand blanket on top of native clay soils to provide 90 cm (36 inches) of vertical separation as required under Minnesota Rules Chapter 7080. The drip system was insulated with 15 cm (6 inches) of peat. Wasteflow PC tubing manufactured by Geoflow, Inc., was installed 60 cm (24 inches) on center, with emitters spaced every 60 cm (24 inches) along the emitter tube. The drip system has a design hydraulic loading rate of 13.8 lpd/sm (0.34 gpd/sf). The linear loading rate from the zone layout is 273 lpd/m (22 gpd/lf).

Because only one home was occupied during the study period, flows were very low relative to the design capacity of the system.

The cover material (peat) was manipulated on two plots, one to provide 7.5 cm (3 inches) of cover, the other to provide 30 cm (12 inches) of cover. Temperatures were measured at the emitter, in between emitter lines (at the same depth as the emitter line), and at a depth of 85 cm (34 inches) below ground surface. Temperatures at the return header air/vacuum relief valve was monitored for each zone, as well as air temperatures and the water temperature in the pump tank. There was one temperature probe at each monitoring point listed above. Logging frequency was every 6 hours (4 times per day).

For clarity, not all data channels are charted. Temperatures at the emitter lines vs. air temperature are summarized in Figure 2. For these two data channels, all data point are charted, however individual data point markers have been omitted to make the chart more legible.

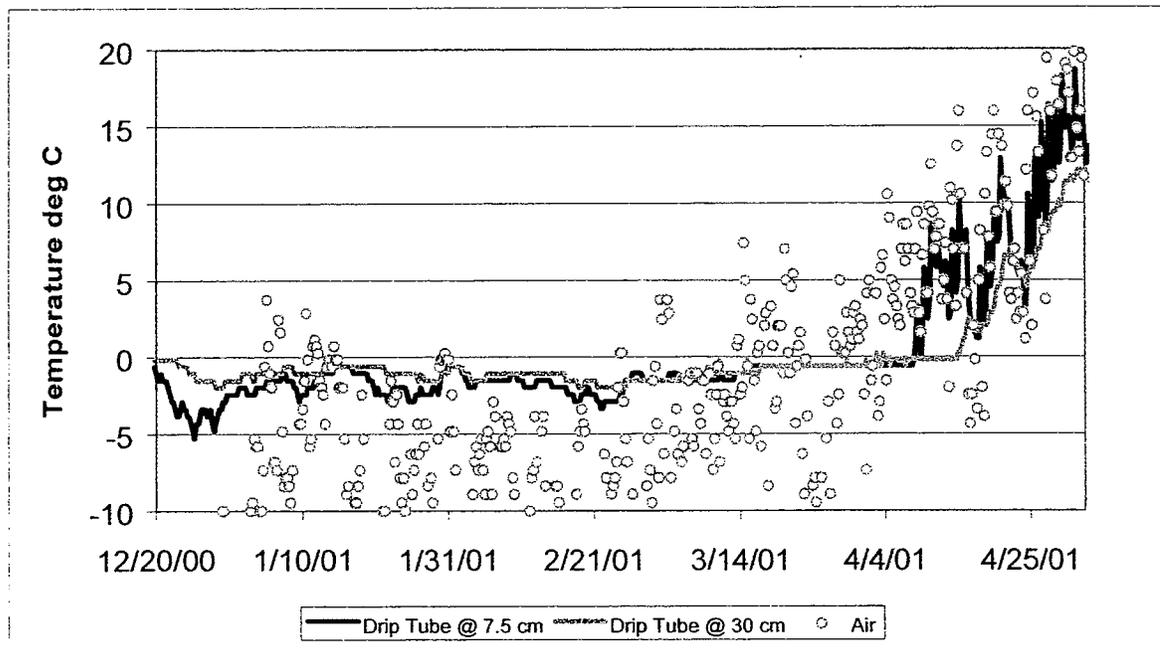


Figure 2. The Greens of Dellwood. Temperature of the Emitter Lines with 7.5 cm and 30 cm of Peat Cover.

### Bornholdt Residence

This is a 5-bedroom home using a septic tank, vertical flow wetland, and one-zone drip dispersal system. The onsite system was designed by NAWA in 1998 to replace an existing non-compliant (straight pipe) system. Wastflow PC tubing as manufactured by Geoflow Inc., was plowed into the native soil (fine sand) at a depth of 15 cm (6 inches). Emitter line spacing was 60 cm (24 inches), with emitters spaced every 60 cm (24 inches) along the tubing. The system received a variance from the Minnesota Pollution Control Agency to discharge into soils with less than 90

cm (36 inches) of vertical separation. The drip system has a design hydraulic loading rate of 45 lpd/sm (1.1 gpd/sf). The linear loading rate from the zone layout is 207 lpd/m (16.7 gpd/lf). The system has no operational difficulties since installation in the fall of 1999.

Temperatures were monitored at the emitter line, in between emitter lines (at same depth of 15 cm), under the drip field at a depth of 85 cm (34 inches) below ground surface, at the supply main and return header air/vacuum relief valves, and at the pump tank, in addition to air temperature. There was one temperature probe per monitoring location. For clarity, not all data channels are charted. Logging frequency was every 6 hours (4 times per day). Temperature at the emitter line compared to air temperature is summarized in Figure 3:

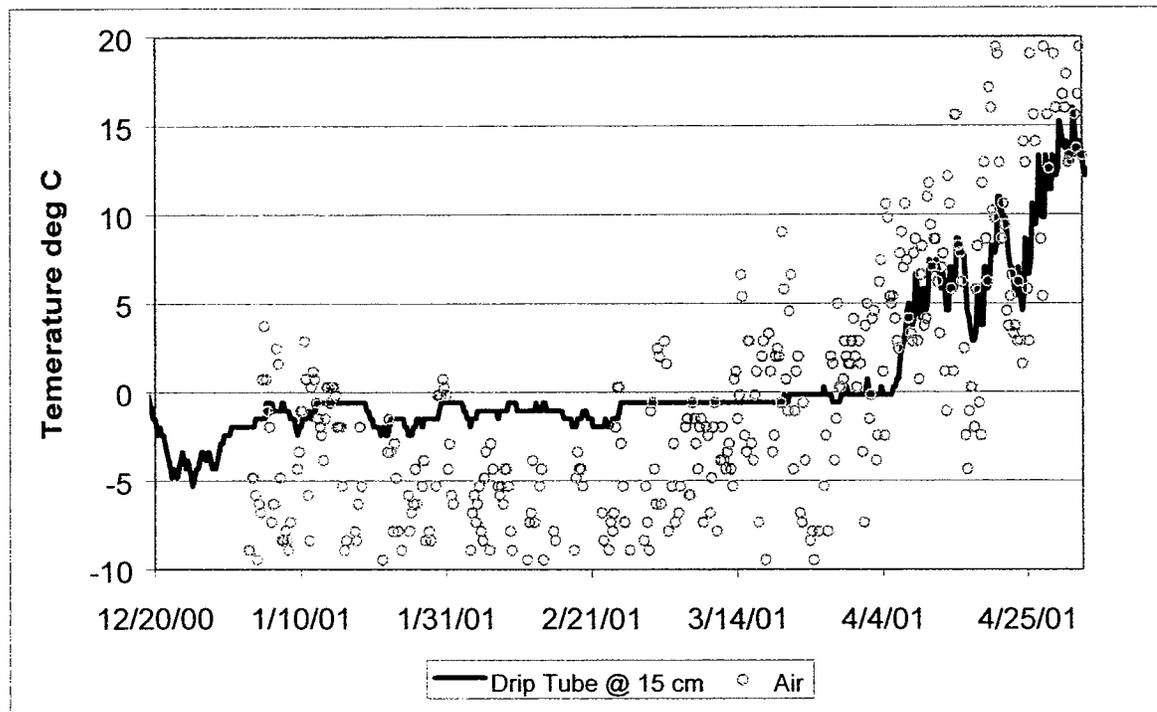


Figure 3. Bornholdt Residence. Temperature at the Emitter Lines with 15 cm of Soil Cover.

Columbus Elementary School

This is a 600-student elementary school with a design flow of 28,085 lpd (7,420 gpd). In 1999, a new onsite system was constructed to replace an existing drainfield system. The new onsite system was designed by NAWA in 1998. This replacement system consisted of re-using the existing septic tank, a 1,115 sm (12,000 sf) single-pass sand filter and a 1,672 sm (18,000 sf) 2-zone drip dispersal system. To maintain 30 cm (12 inches) of vertical separation, Wasteflow PC tubing as manufactured by Geoflow, Inc., was plowed into the native soil (fine sand) at a depth of 15 cm (6 inches). Emitter line spacing was 60 cm (24 inches), with emitters every 60 cm (24 inches) along the length of the tubing. The system has a design hydraulic loading rate of 16.7 lpd/sm (0.4 gpd/sf) and a linear loading rate of 329 lpd/m (26.5 gpd/lf).

One of the two drip zones froze in January 2000 when the contractor removed the drainback valves. With the valves absent, the pumps could not pressurize the system and the water level in the pump tank eventually got high enough to flood the nearest drip zone. With standing water in the emitter lines, the system quickly froze. This system has also experienced several surfacing events that were the result of installation problems or gopher damage.

Temperatures were monitored at the ground surface (under the snow blanket), at the emitter line, in-between the emitter lines (at the same 15 cm depth), and under the drip field at a depth of 90 cm (36 inches) below ground surface. There was one temperature probe per monitoring location. Logging frequency was every 30 minutes (48 times per day). Air temperatures were obtained from the nearby Bornholdt residence. For clarity, not all data channels are charted. Temperature at the emitter line vs. air temperature is summarized in Figure 4:

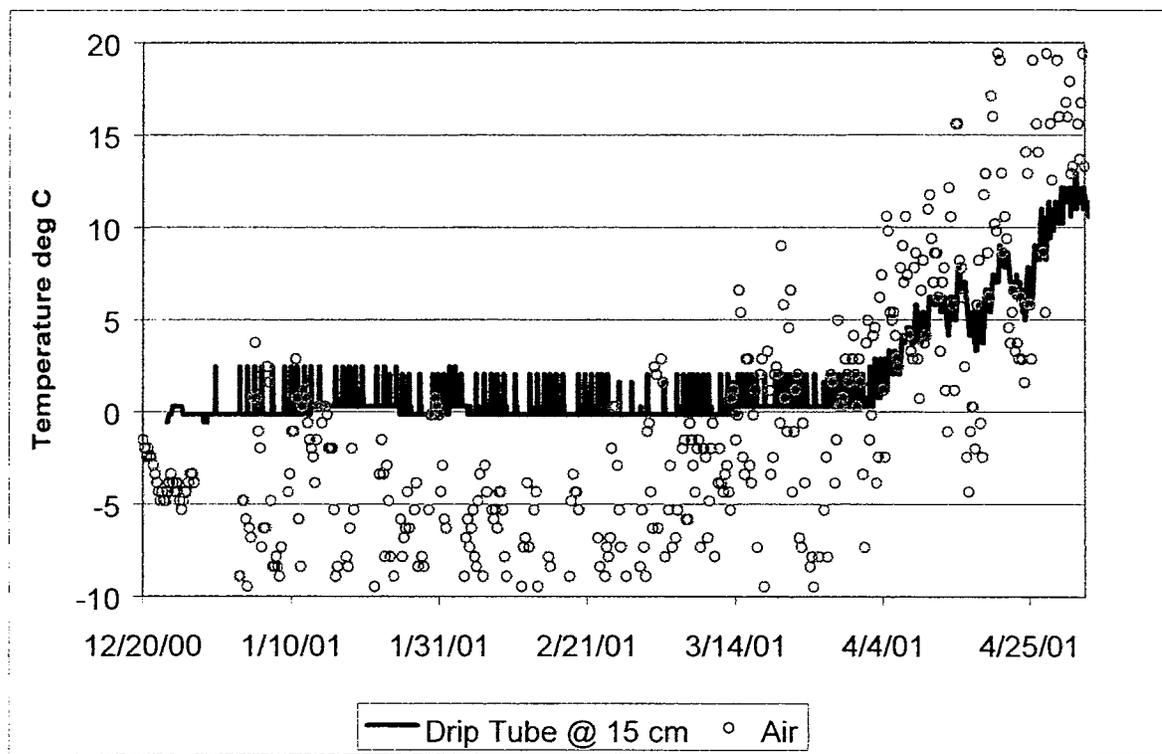


Figure 4. Columbus Elementary School. Temperature of the Emitter lines with 15 cm of Soil Cover.

#### Golly Residence

This is a new 3-bedroom residence using a 500-gallon trash tank, a Delta Whitewater DF50 aerobic treatment unit, and a one-zone drip dispersal system. The onsite system was designed by Mr. Wayne Golly. Wasteflow Classic (non-pressure compensating) tubing, as manufactured by Geoflow Inc., was plowed into native soil (sandy loam) at a depth of 15 cm (6 inches) to

maintain a vertical separation of at least 90 cm (36 inches). The drip system has a design hydraulic loading rate of 40.6 lpd/sm (1.0 gpd/sf). The linear loading rate from the zone layout is 86 lpd/m (6.9 gpd/lf). The system is designed for complete drain-back, which is very similar to the NAWES system schematic shown in Figure 1.

Temperatures were monitored at the supply main, emitter line, in between emitter lines (at an equivalent soil depth), below the drip field at a depth of 90 cm (36 inches), return header, return header air/vacuum relief valve, and at the pump tank, in addition to air temperature. For clarity, not all data channels are charted. Logging frequency was every 6 hours (4 times per day). Temperature at the emitter line compared to air temperature and the pump tank is summarized in Figure 5:

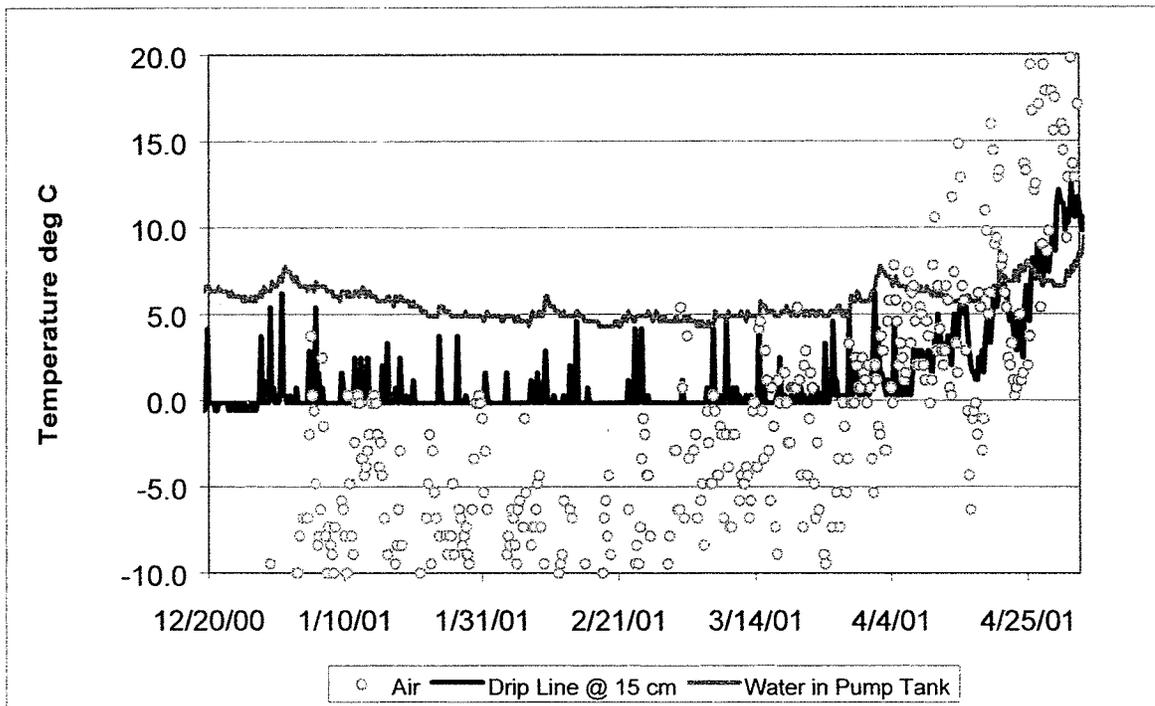


Figure 5. Golly Residence. Temperature of the Emitter Lines with 15 cm of Soil Cover. (Note temperature “spikes” representing dosing events. Temperature during dosing events closely matches the temperature of the effluent in the pump tank.)

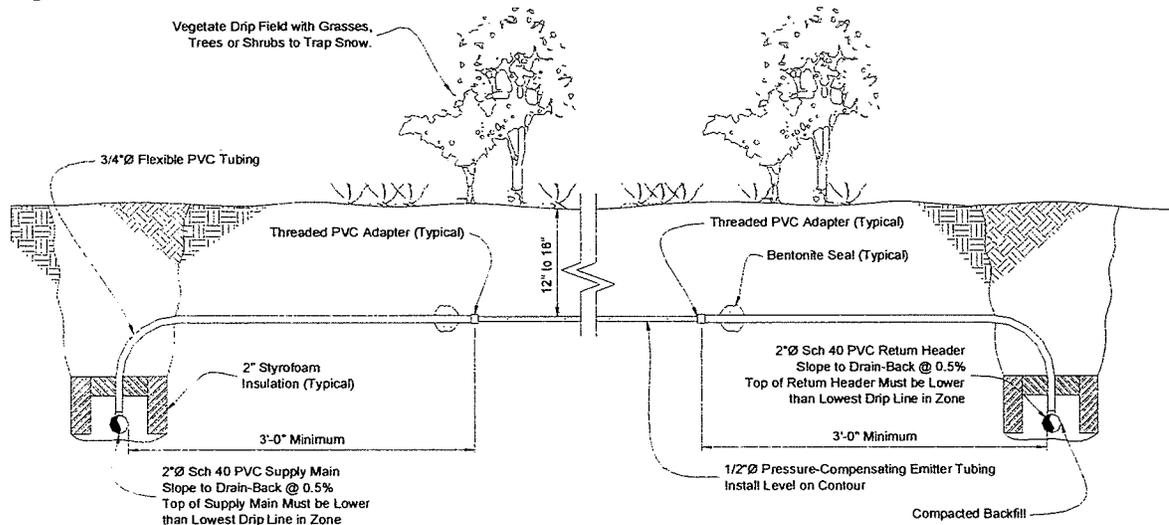
## RESULTS AND DISCUSSION

Monitoring results obtained during this study were similar to data collected by Bohrer and Converse (2001) in the sense that all systems were discharging to “frozen” soils with ambient temperatures less than 0 deg C. However, the four systems studied generally had longer and

more consistent periods of freezing, which can be attributed to the colder winter conditions in Minnesota as compared to Wisconsin.

Bohrer (2000) does an excellent job of summarizing exactly what “frozen” soil means. In the context of this study, core sampling indicated that there were frost crystals in the soil matrix; however macropores were open and could conduct liquid water. The “deep” temperature probes (at a depth of 85 to 90 cm) on all four systems consistently logged temperatures well above freezing, so liquid water discharged by the emitters would not have to travel far (downward) to encounter ambient soil temperatures above freezing. Also, gas transport (including sublimation) is a significant process, even in “frozen” soils. From a practical standpoint, none of the systems experienced hydraulic failure due to “clogging” of the soil macropores by ice crystals.

Most significantly from a design standpoint, all four of these systems would have failed had they not been designed to completely drain the emitter lines. Some designers consider the emitter tubing to be “self-draining”. However in the context of freeze resistance, the rate of “self-drainage” needs to be taken into account. If the emitter lines do not drain before the next scheduled dosing event, there will always be some water in the emitter lines. This is compounded by the internal drainage between high and low emitter lines. To combat this, supply mains and return headers should be well below the depth of the emitter lines. Unless the supply mains and return headers are below the frost line, they should be insulated, as shown in Figure 6.



Drip Tubing Installation Section View

Figure 6. Recommended Configuration of Supply Mains and Return Headers to Avoid Freezing of Emitter Lines.

Practical experience by the author has shown that zones that take more than 20 minutes to drain back are susceptible to progressive freezing failure in Minnesota.

## Heat Contribution by the Effluent

At the initiation of this study, there was considerable speculation by the author about the heat contribution of the effluent being delivered to the drip field. Was the heat from the effluent keeping the drip field from freezing? If so, was over-designing the drip field (using a more conservative hydraulic loading rate) “bad” in the sense that the effluent heat was spread out more broadly, making the system more susceptible to failure?

In light of the results obtained to date, the heat contribution from the effluent appears to be very small relative to ambient heat fluxes in the soil profile. When heat is contributed by the effluent, the result is short-term temperature “spikes”. These temperature spikes closely match the effluent temperature in the pump tank, as noted for the Golly Residence in Figure 5. However, heat contributed during the dosing event fails to substantially affect the average temperature at the emitter line (see Figures 4 and 5). Similar heat spikes were documented by Bohrer (2000).

This study went a step beyond Bohrer (2000) and Bohrer and Converse (2001) in that temperatures in between emitter lines (at the same depth as the emitter lines) was also logged. If heat from the effluent was substantially changing the temperature of the soil around the emitter lines, then the emitter lines should be consistently warmer than the soil (at the same depth) between the emitter lines.

Data collected to date indicates that, if anything, the reverse is generally true. Three of the four systems had average emitter line temperatures consistently **colder** than the soil between emitter lines. Only the heavily-loaded Golly Residence system (using relatively warm ATU effluent) was immune to this effect. The systems with the lightest loading (The Greens of Delwood and Bornholdt Residence) had the coldest emitter line temperatures. Differences between emitter line and soil temperatures is summarized in Figure 7.

One explanation for the colder temperatures at the emitter lines is convective airflow through the air/vacuum relief valves. When the system is not in operation, these valves are open. Air warmed by the ambient soil temperatures around each emitter line could escape through an open air/vacuum relief valve. This convective air flow would be facilitated by the recommended practice of having two air/vacuum relief valves per zone. Warm air could exit the higher valve, while cold air could enter the lower valve. This hypothesis has yet to be substantiated. However, since the time periods between dosing events are much longer than the dosing events themselves, convective air flow has the potential to more than offset any heat gains resulting from effluent dosing.

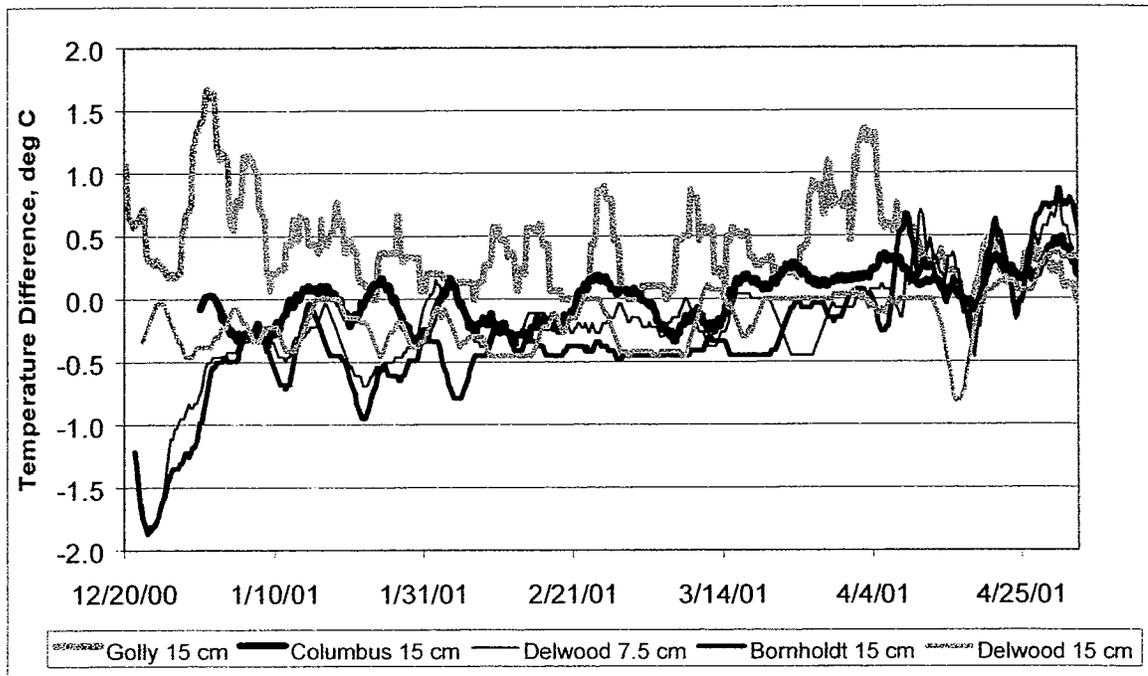


Figure 7. Temperature Difference Between the Emitter Line and the Soil Between the Emitter Lines. (Negative numbers indicate the emitter line is colder than the soil between emitter lines. Data presented is a running 3-day average of logged temperature readings).

#### Air/Vacuum Relief Valve Insulation

One objective of this study was to evaluate different strategies of insulating the air/vacuum relief valve enclosure. This was felt to be especially important since earlier studies (Golly, 2000) had implicated frozen air/vacuum relief valves (and associated slow drainbacks) as a major factor in drip system freezing.

Since 1997, NAWA has experimented with a number of different insulation methods. Early designs used no insulation (consistent with drip manufacturers design guidelines). Freezing of the air/vacuum relief valves in the winter of 1997/1998 resulted in insulation to the underside of the valve box lid. This design continued to evolve, until by 2000 the recommended insulation design was loose-fill insulation (perlite) in a plastic bag filling the valve box cavity, with 5 cm (2 inch) Styrofoam board under the valve box.

For this study, two existing air/vacuum relief valve boxes were modified to see if increasing the rate of exchange of heat from the warm soils underlying the valve boxes could be used to warm the boxes themselves. To this end, a cavity under the valve box was excavated and a 19-liter (5-gallon) bucket was installed upside-down and filled with pea gravel. In the first installation (The Greens of Dellwood) the entire bottom of the bucket was cut away. This proved to be a mistake, as the annular space between the valve box and the bucket allowed cold air to infiltrate the

bucket cavity. In the second installation, the hole in the bucket bottom was cut smaller than the diameter of the valve box, resulting in superior performance. The recommended bucket insulation method is shown in Figure 8. Temperature performance of this configuration is summarized in Figure 9.

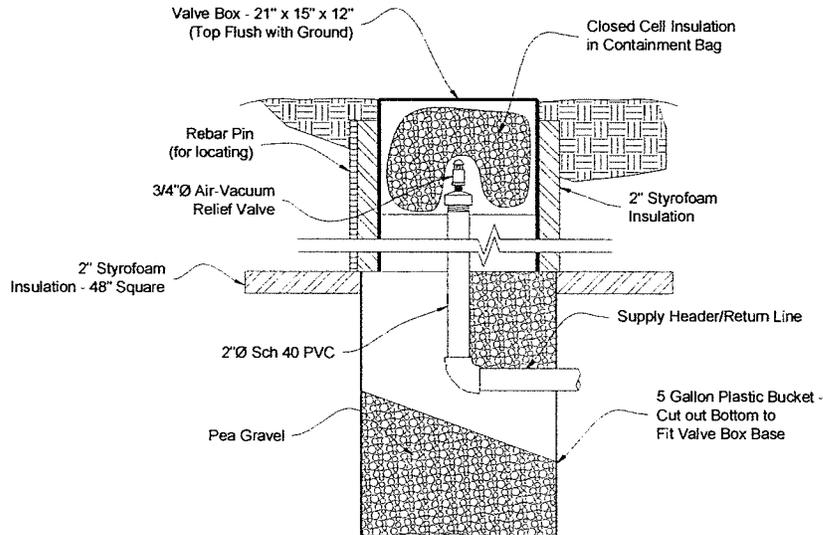


Figure 8. Recommended Air/Vacuum Relief Valve Box Insulation Method.

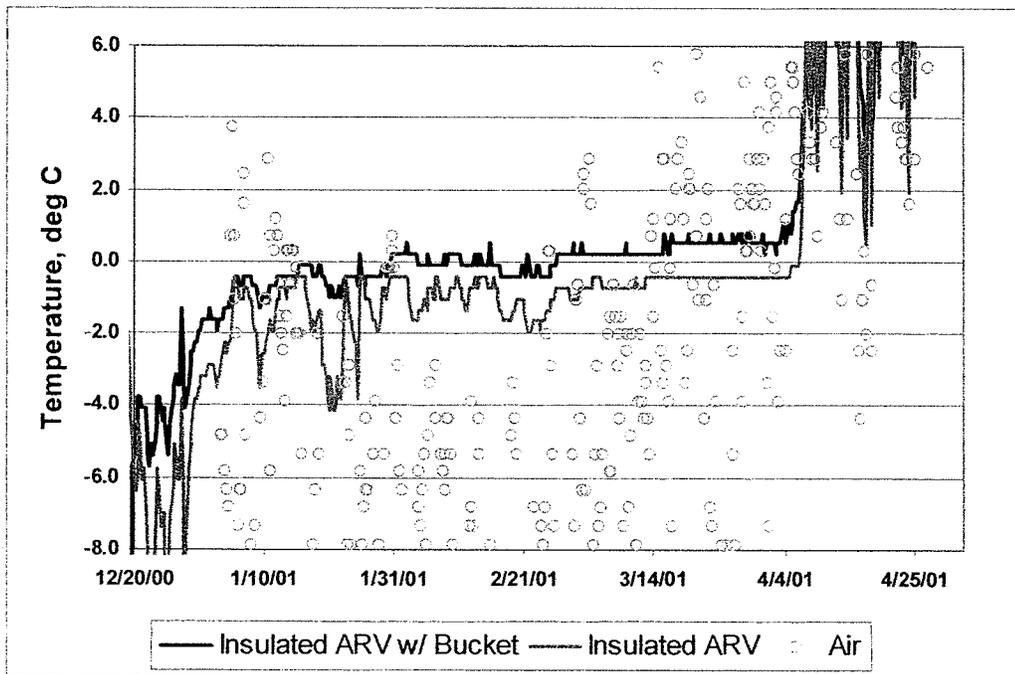


Figure 9. Performance of Valve Box Insulation Designs.

## **CONCLUSIONS AND RECOMMENDATIONS**

Whether or not a specific drip system will experience frozen soil conditions during any given winter appears to be entirely a function of climatic events. Winters with ample early snowfall prevent the soil from freezing; winters with early cold and no snowfall create the severest freezing potential.

Both this study and the work of Bohrer and Converse (2001) indicate that drip dispersal systems must be capable of discharging effluent to "frozen" soils (ambient soil temperature less than 0 deg C) to operate successfully in cold climates. While "frozen" soils appear to be capable of accepting wastewater effluent (either through macropore movement and/or sublimation/gas transport), to sustain this, the drip dispersal system itself must not freeze. This appears, at a minimum, to entail that the drip system not be full of standing water (i.e., drainback occurs between dosing events). To date, there is not a design consensus as to how to create acceptable drainback conditions.

The speculation that application of wastewater effluent will prevent soil freezing does not appear to be valid. In three of the four systems studied, average temperatures at the emitter lines were actually colder than soils at the same depth between emitter lines. Heat loss through convective air movement through the emitter lines between dosing events is hypothesized to account for this net heat loss,

Additional work to quantify heat transfer rates is needed before system freezing can be considered to be a predictive science.

## **ACKNOWLEDGEMENTS**

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