Burnsville Stormwater Retrofit Study

Prepared for
City of Burnsville

June 2006

Prepared by
Barr Engineering Company

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1.0 Introduction

In an ongoing effort to protect Crystal Lake from excess phosphorus and large volumes of stormwater runoff from surrounding hard surfaces, the Metropolitan Council, along with the City of Burnsville, Minnesota and the Dakota County Soil and Water Conservation District funded a prototypic rainwater garden system to infiltrate street runoff. While the City had been interested for some time in constructing rainwater gardens, questions about their effectiveness remained. To better document the effect of rainwater garden implementation, this project involved the completion of a "paired watershed" study, in which two very similar residential areas are monitored —one was the study's control site and the other treatment watershed employs 17 new rainwater gardens within a 25-lot, 5.3-acre neighborhood with traditional curb and gutter (see Figure 1). The project, a retrofit of a 1980s neighborhood, involved individual designs for each resident-participant's property and close attention to homeowner education and easy maintenance. The gardens were primarily designed to capture street runoff through the installation of curb cuts at each garden. The depressions feature gradual side slopes, limestone retaining walls, and colorful plantings. They were carefully sized to, at a minimum, accept the first 0.9 inches of rainfall runoff from the impervious surfaces in the subwatershed for each storm event.

Existing soils and utilities were surveyed in 2002 to identify potential garden sites. Seventeen sites were identified in the treatment watershed; thirteen along Rushmore Drive and four in a backyard swale that drains to Rushmore Drive (see Figure 2). Each garden along the street was designed to have a curb cut to capture street runoff. Individual homeowners were involved in creating final planting designs for each basin. Gardens were constructed in September 2003. Curb cuts were installed in May 2004. The contractor cut the sod, excavated below grade, backfilled with topsoil/compost mix, and installed edging and retaining walls. Homeowners planted plants in September 2003. After planting, the contractor placed shredded wood mulch and sod to finish gardens.

Both the control and treatment watersheds were monitored before and after rainwater garden construction to facilitate the statistical evaluation of the paired watershed data.

Figure 1 Paired Watershed Study Area

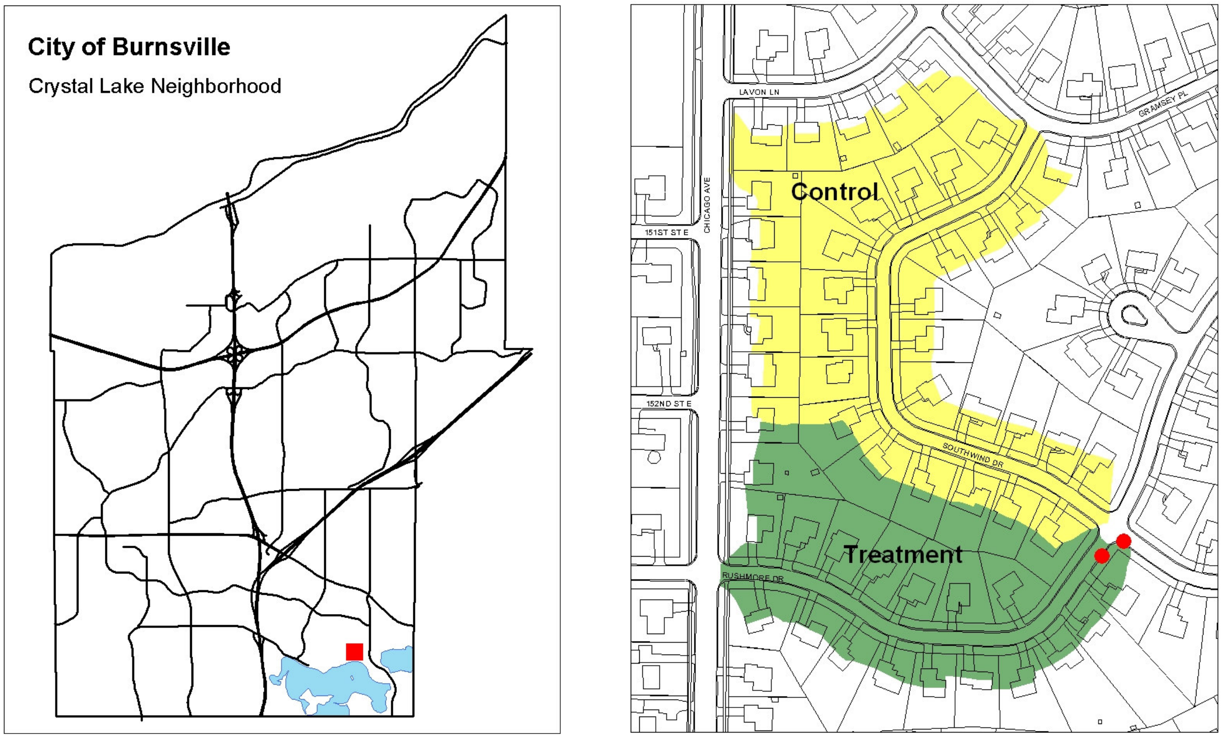


Figure 2 Treatment Watershed Rainwater Garden Layout

2.0 Study Methodology

2.1 Paired Watershed Approach

Clausen and Spooner (1993) describe the paired watershed approach for conducting nonpoint source water quality studies. The basic approach requires a minimum of two watersheds – control and treatment – and two periods of study – calibration and treatment. The control watershed accounts for year-to-year or seasonal climate variations, and the management practices remain the same during the study. The treatment watershed has a change in management or implementation of a Best Management Practice (BMP) during the study. During the calibration period, the two watersheds are treated identically and paired data are collected. During the treatment period, the treatment watershed undergoes the implementation of a BMP while the control watershed remains the same as during the calibration period (see Table 1).

Table 1 Typical Paired Watershed Schedule of BMP Implementation (Clausen and Spooner, 1993)

Period	Watershed	
	Control	Treatment
Calibration	No BMP	No BMP
Treatment	No BMP	BMP

This "paired watershed" study was conducted by selecting two similar and adjacent subwatersheds in the Crystal Lake watershed—one to serve as the study control and the other to be the site of 17 rainwater gardens (Figure 1). Stormwater runoff was monitored both prior to and after installation of the gardens. As per Clausen and Spooner (1993), a linear regression and analysis of variance was conducted on the paired data from the calibration period to evaluate the significance of the relationship. At the end of the treatment period the significance of the effect of the rainwater gardens was determined by completing an analysis of variance on the treatment regression equation and comparing the difference between the slopes, and confidence levels of the calibration and treatment regressions.

2.2 Stormwater and Rainfall Monitoring

For the calibration period, stormwater and rainfall monitoring began in 2002 and continued through the spring of 2004 to fully establish the relationship between the control and treatment watersheds. The treatment period occurred between the summer of 2004 and the fall of 2005 to determine the treatment efficiency of the gardens. Runoff rates and volumes were collected using area-velocity flow meters in the storm sewer pipe at the outlet of each watershed (see Figure 1). Automatic samplers were also set up to collect water quality samples at each of the watershed monitoring locations. Due to several instances of equipment malfunction during the calibration period and low runoff rates from the treatment watershed during the treatment period, there was not enough paired data from the study to conduct meaningful statistical analyses on the water quality treatment associated with the rainwater gardens. A tipping bucket rain gauge, which recorded the data electronically, was set up within the study area for the entire period of record.

The monitoring data from the flow meters and rain gauge were downloaded on a regular basis and used to determine the flow and rainfall volumes associated with each of the runoff events at each monitoring location. The paired flow volume data that was available from both watershed monitoring locations was compiled in a spreadsheet, along with the rainfall data associated with each runoff event. In each case the runoff volume was also expressed as runoff, in inches, and as a runoff coefficient by dividing the flow volumes by the watershed area, and then by the rainfall amount from each runoff event.

3.0 Results and Discussion

3.1 Stormwater Monitoring Results

The stormwater monitoring data, collected during the calibration and treatment periods, were compared in two separate ways: 1) an overall comparison of the rainfall/runoff results from the treatment and control watersheds; and 2) a statistical analysis of the rainfall/runoff relationships between the two watersheds both before and after rainwater garden implementation.

Appendix A provides a summary of each of the rainfall/runoff events during the calibration and treatment periods. Figure 3 shows the linear regression that was conducted on the paired runoff volume data from the calibration period (shown in Appendix A) to evaluate the significance of the relationship. The graph shows that there was very good agreement between the runoff volumes collected at each site during the calibration period, since the regression coefficient of determination is high ($R^2 = 0.89$) and the y-intercept is low (0.05). Figure 3 also shows the 95 percent confidence levels around the slope of the linear regression. Since the confidence level was within 15 percent of the slope of the regression line, it indicated that there was enough data available from the calibration period to justify the construction of the rainwater gardens and transition to the treatment period.

The rainwater gardens were constructed in the fall of 2003 and brought on-line with curb cuts later in the spring of 2004. The treatment period monitoring began at the end of May, 2004 (see Appendix A). Figures 4 and 5 shows how the runoff hydrographs and volumes varied at each monitoring site during the calibration and treatment periods for moderate and larger rainfall events. Both figures show that, for similar rainfall events, the runoff rate and volume from the treatment watershed (with the rainwater gardens) was greatly reduced relative to the data from the control watershed. The variability of the runoff volumes from the control watershed for similar rainfall events, as shown in Figures 4 and 5, also underscore the importance of using a paired watershed approach to accurately evaluate the changes due to BMP implementation.

Figure 3 Linear Regression of Runoff Volume Data for Calibration Period

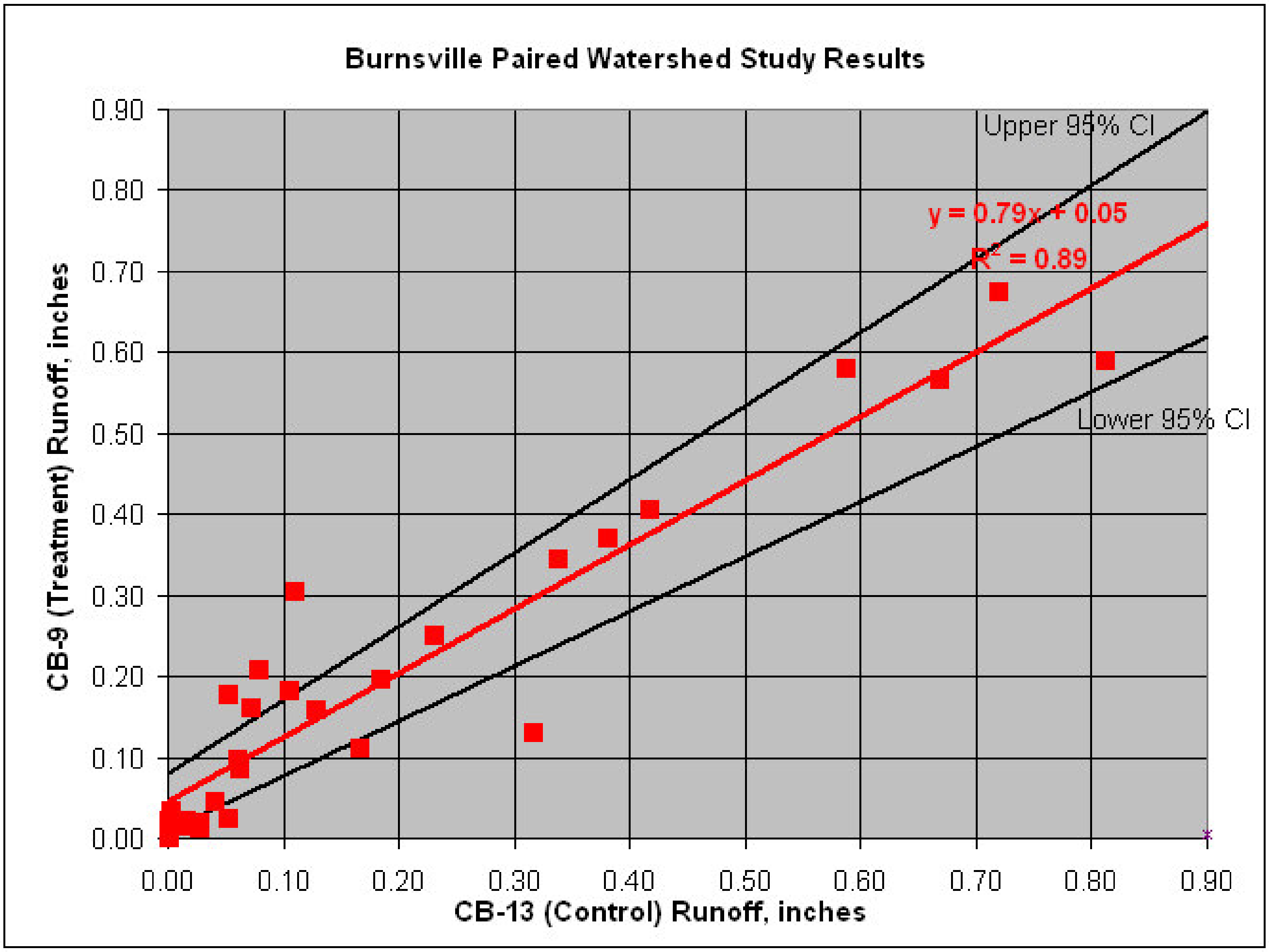
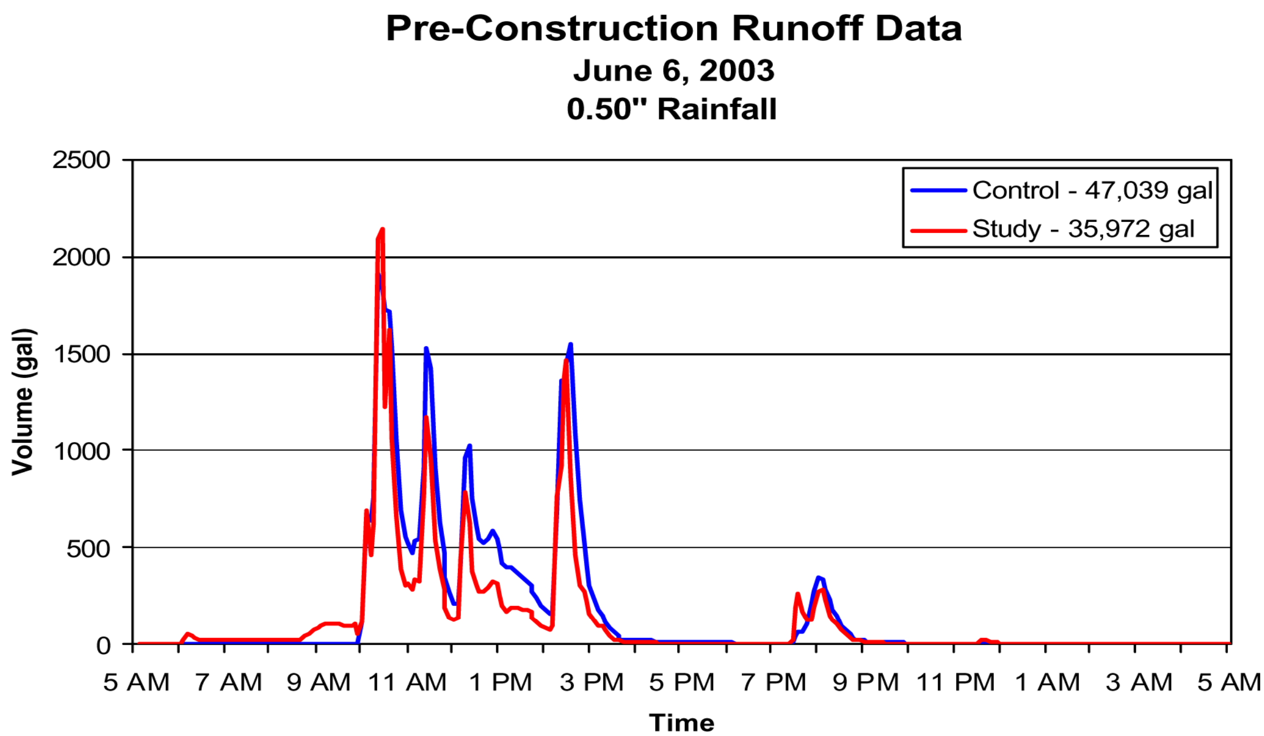


Figure 4 Calibration and Treatment Period Runoff Hydrographs from Moderate Rainfalls



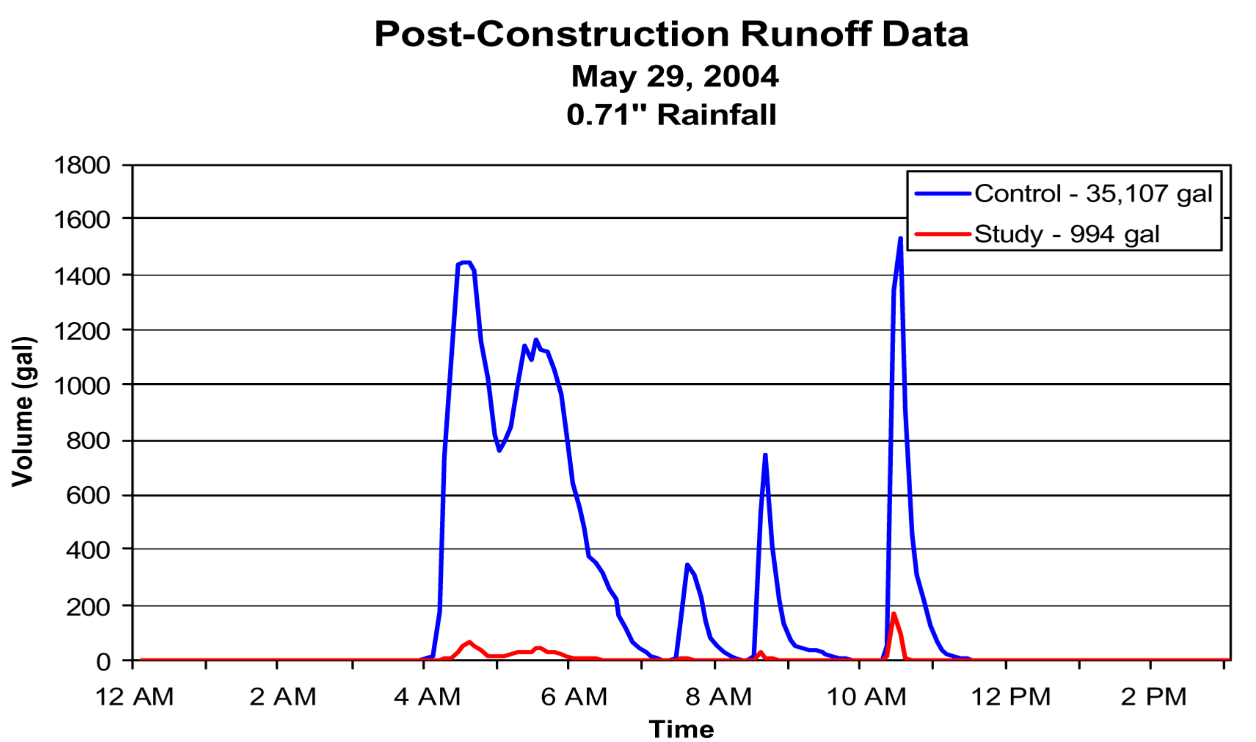
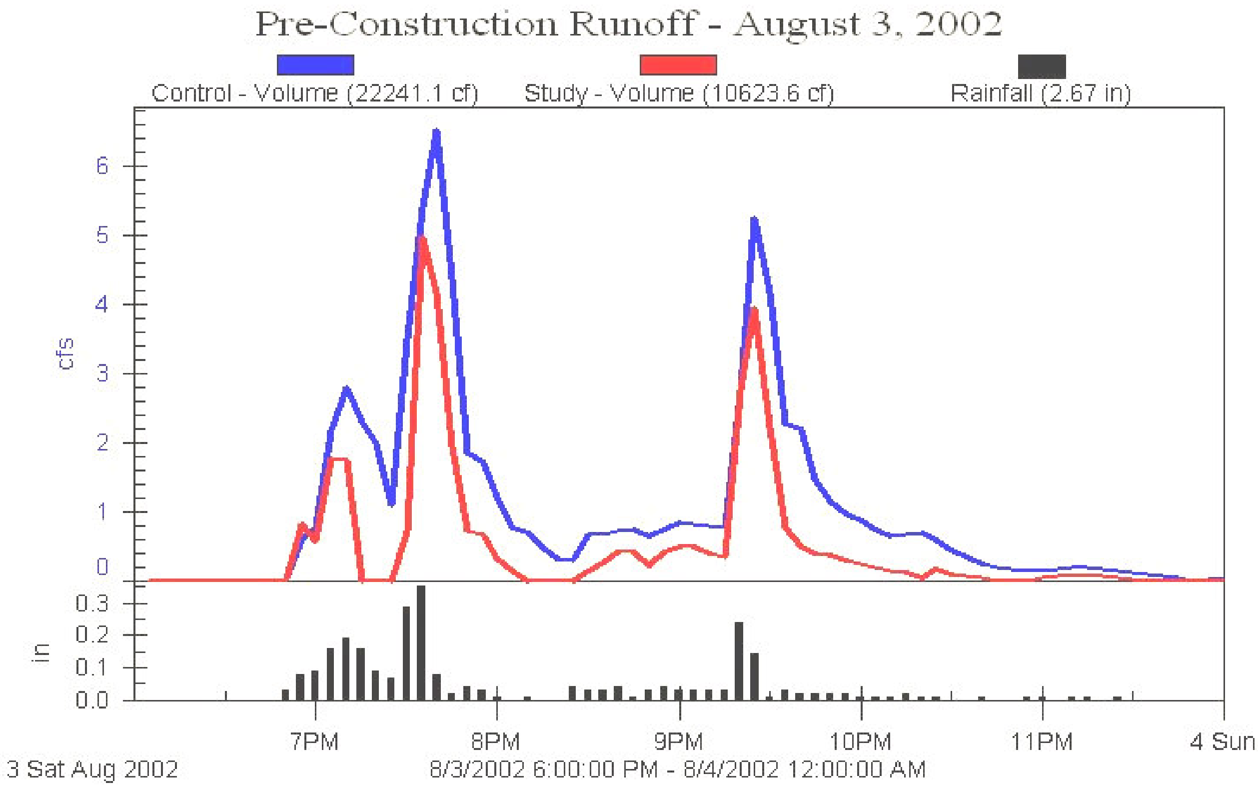


Figure 5 Calibration and Treatment Period Runoff Hydrographs from Larger Rainfalls



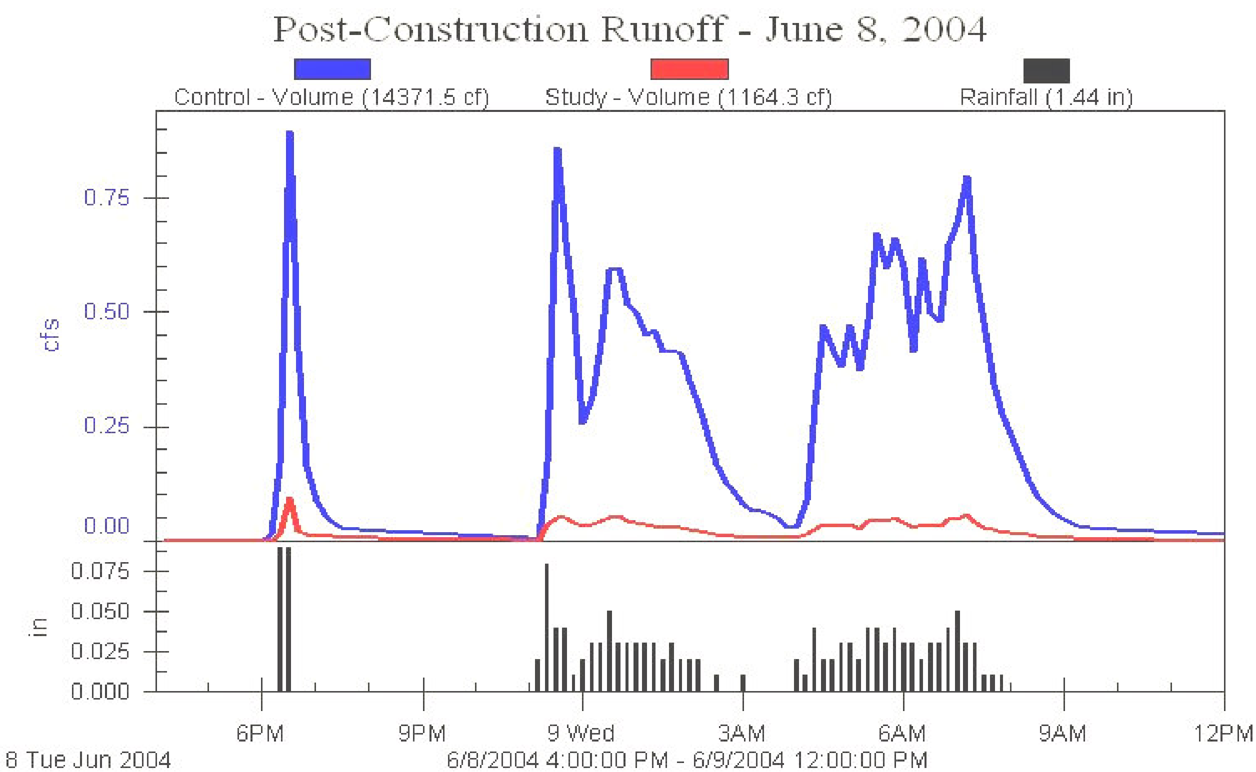
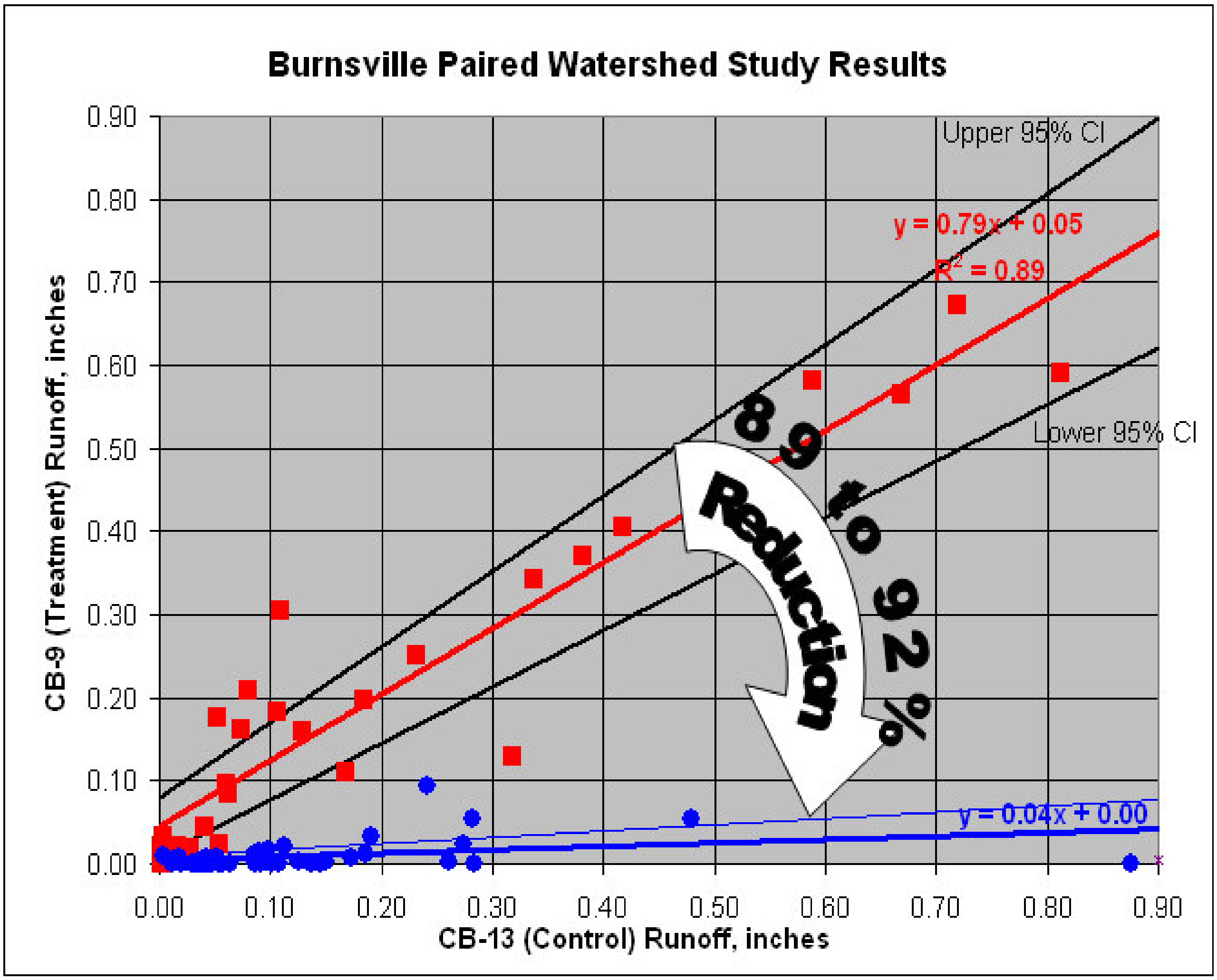


Figure 6 provides a comparison between the confidence levels associated with the slopes of the calibration and treatment period regressions. The results show that there is an 89 to 92 percent reduction in the runoff volumes from the treatment watershed associated with the rainwater gardens, and the difference in the slope of the linear regressions is statistically significant at greater than the 95 percent confidence level.

Figure 6 Linear Regressions of Runoff Volume Data for Calibration and Treatment Periods



The following summary of the runoff event data from Appendix A and Figure 7 show that there is a 93 percent reduction in the overall runoff volume from the treatment watershed since the rainwater gardens were installed:

<u>Pre-construction (2002-2004)</u>

28 rainfall events = 23.77 inches total

Control Watershed (7.5 acres) = 153,313 cu. ft. runoff (5.69”)

Treatment Watershed (5.5 acres) = 111,120 cu. ft. runoff (5.78”)

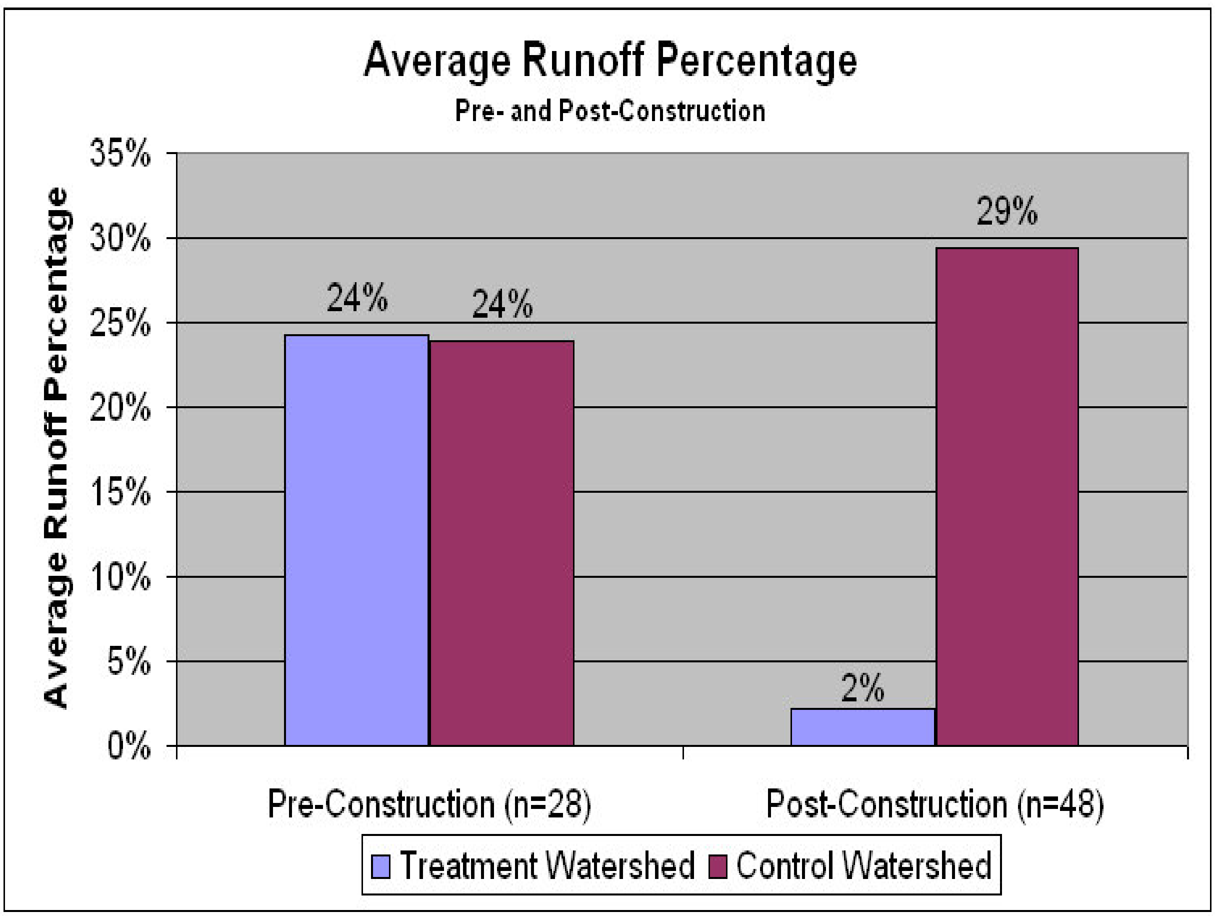
<u>Post-construction (2004-2005)</u>

48 rainfall events = 18.97 inches total

Control Watershed (7.5 acres) = 151,897 cu. ft. runoff (5.58”)

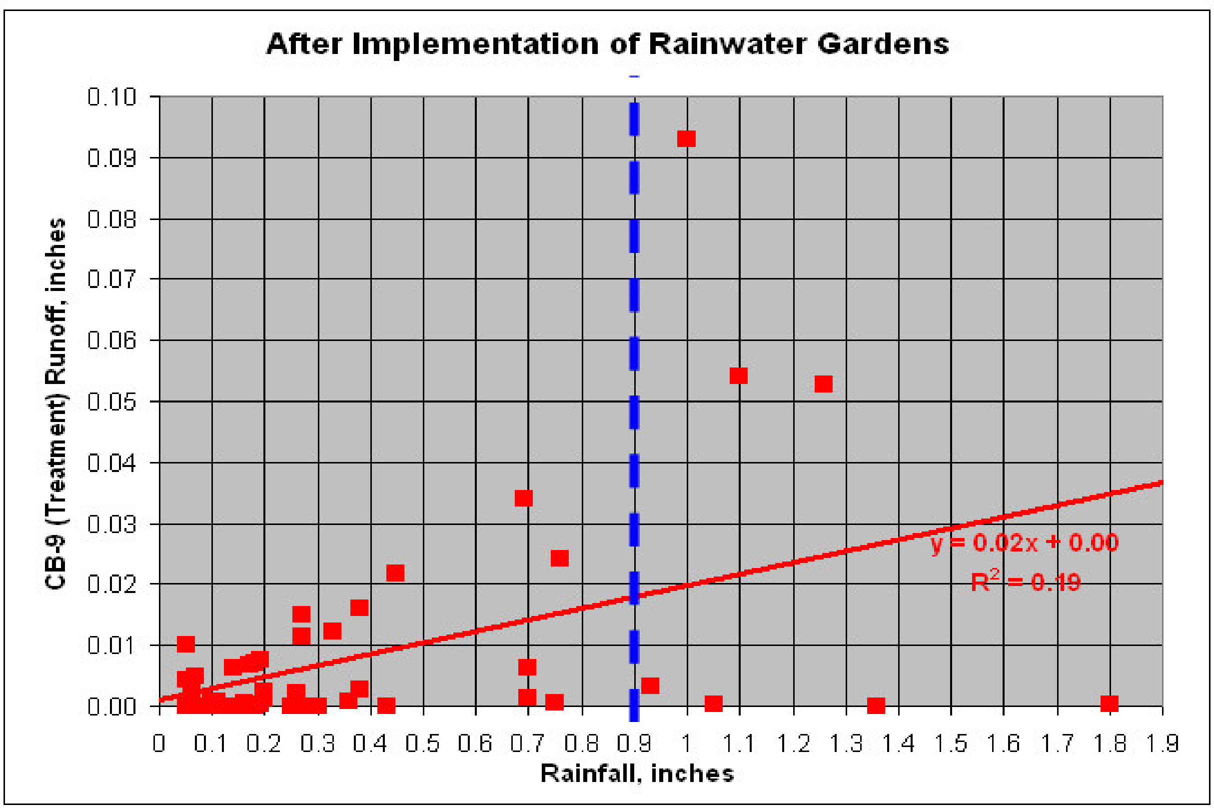
Treatment Watershed (5.5 acres) = 7,861 cu. ft. runoff (0.41”)

Figure 7 Runoff Volume Reduction Associated with Rainwater Gardens



As discussed in Section 1.0, the rainwater gardens were sized to, at a minimum, accept the first 0.9 inches of rainfall runoff from the impervious surfaces in the treatment watershed for each storm event. Figure 8 was developed to show whether the rainwater gardens were removing the runoff volume for which they had been designed. The data for some of the largest rainfall events indicates that the infiltration rate of the rainwater gardens was able to keep up with and treat all of the runoff, or at the very least, treat more than 0.9 inches of rainfall runoff from the watershed in nearly all cases. Figure 8 and Appendix A show that there were seven events during the treatment period where the rainfall amount exceeded 0.9 inches, three of which resulted in more measurable runoff volumes from rainfalls between 1.0 and 1.3 inches. The other four rainfall events, with precipitation amounts between 0.9 and 1.8 inches, did not produce measurable runoff volumes because they represented lower rainfall intensity events. The regression shown in Figure 8 indicates that, with the limited number of larger rainfall events from the treatment period, there currently is a limited ability to show a strong relationship between rainfall and runoff volumes from the treatment watershed. Future monitoring efforts that capture larger, more intense rainfall events will enable the same data shown in Figure 8 to be used to estimate the actual treatment volume associated with the rainwater gardens.

Figure 8 Observed Rainfall/Runoff Relationships Associated with Rainwater Gardens



3.2 Conclusions and Recommendations for Further Study

This paired watershed study has determined, with greater than 95 percent confidence, that the rainwater gardens designed to capture 0.9 inches of rainfall over the tributary impervious area have reduced the runoff volumes by approximately 90 percent. This project confirms that existing residential neighborhoods with sandy soils, gradual slopes and 15-foot rights-of-way (from the back of curb) can be successfully retrofitted with rainwater gardens and provide very high levels of runoff reduction and stormwater quality improvement. In addition, the greater than 80 percent rainwater garden participation rate by the homeowners in the treatment watershed, and that they are well maintained, indicates that this BMP can be viewed as an amenity to property owners.

While the results of the monitoring from this study provided statistically significant conclusions, it is recommended that the City repeat the exact same monitoring program again every three to five years to document the long-term functionality of rainwater gardens in a residential setting.

References

Clausen, J.C., and J. Spooner. 1993. Paired Watershed Study Design. Prepared for U.S. Environmental Protection Agency. Office of Water. Washington, D.C. 841-F-93-009.

Appendix A

Rainfall/Runoff Events Summary for Calibration and Treatment Periods

Rainfall/Runoff Events Summary--Calibration Period

		Time period	CB-9 (Treatment)			CB-13 (Control)		
Event #	Rainfall(in.)		Total flow(ft.^3)	Runoff(in.)	Runoff Coeff.	Total flow(ft.^3)	Runoff(in.)	Runoff Coeff.
1	2.68	8/3/2002 6:50:00 PM-8/4/2002 12:05:00 AM	11350	0.59	0.22	22111	0.81	0.30
2	2.11	8/16/2002 7:35:00 PM-8/17/2002 1:55:00 AM	7812	0.41	0.19	11379	0.42	0.20
3	2.16	8/20/2002 3:45:00 PM-8/21/2002 1:40:00 PM	10876	0.57	0.26	18208	0.67	0.31
4	0.39	9/1/2002 6:10:00 PM-9/1/2002 8:15:00 PM	870	0.05	0.12	1122	0.04	0.11
5	1.97	9/5/2002 4:40:00 PM-9/6/2002 8:05:00 AM	12949	0.67	0.34	19592	0.72	0.37
6	0.05	9/10/2002 4:35:00 AM-9/10/2002 5:50:00 AM	17	0.00	0.02	25	0.00	0.02
7	0.1	9/14/2002 1:10:00 AM-9/14/2002 2:25:00 AM	410	0.02	0.21	66	0.00	0.02
8	0.16	9/14/2002 6:50:00 AM-9/14/2002 9:30:00 AM	641	0.03	0.21	73	0.00	0.02
9	0.76	9/25/2002 9:40:00 AM-9/25/2002 5:00:00 PM	3512	0.18	0.24	2876	0.11	0.14
10	0.16	9/25/2002 10:20:00 PM-9/26/2002 1:10:00 AM	393	0.02	0.13	435	0.02	0.10
11	0.24	9/26/2002 6:50:00 AM-9/26/2002 9:50:00 AM	208	0.01	0.05	777	0.03	0.12
12	1.72	10/4/2002 2:35:00 AM-10/4/2002 3:10:00 PM	2477	0.13	0.07	8649	0.32	0.18
13	0.95	10/5/2002 8:55:00 PM-10/6/2002 5:45:00 AM	2140	0.11	0.12	4562	0.17	0.18
14	0.48	10/10/2002 12:00:00 AM-10/10/2002 3:45:00 AM	1859	0.10	0.20	1643	0.06	0.13
15	0.13	10/18/2002 2:10:00 AM-10/18/2002 6:05:00 AM	273	0.01	0.11	370	0.01	0.10
16	2.41	4/15/2003 5:05:00 PM-4/16/2003 9:35:00 PM	7117	0.37	0.15	10385	0.38	0.16
17	0.46	4/18/2003 6:10:00 PM-4/20/2003 5:35:00 AM	3773	0.20	0.43	3551	0.18	0.40
18	2.31	5/10/2003 4:50:00 PM-5/11/2003 2:30:00 PM	11170	0.58	0.25	16013	0.59	0.25
19	0.64	5/14/2003 12:10:00 AM-5/14/2003 1:35:00 PM	3104	0.16	0.25	1995	0.07	0.11
20	0.54	5/19/2003 9:35:00 AM-5/19/2003 11:00:00 PM	3049	0.16	0.29	3502	0.13	0.24
21	0.07	5/22/2003 9:05:00 AM-5/22/2003 5:55:00 PM	1627	0.08	1.21	1695	0.06	0.89
22	0.23	5/30/2003 1:50:00 AM-5/22/2003 8:15:00 PM	468	0.02	0.11	1459	0.05	0.23
23	0.56	6/6/2003 6:05:00 AM-6/7/2003 1:30:00 AM	4809	0.25	0.45	6283	0.23	0.41
24	0.3	6/24/2003 2:35:00 AM-6/25/2003 8:00:00 PM	6597	0.34	1.14	9207	0.34	1.13
25	0.31	7/21/2003 11:55:00 PM-7/22/2003 5:30:00 AM	378	0.02	0.06	747	0.03	0.09
26	0.74	4/18/2004 8:05:00 PM-4/19/2004 6:30:00 AM	5841	0.30	0.41	2991	0.11	0.15
27	0.71	4/20/2004 2:50:00 PM-4/21/2004 12:45:00 PM	4009	0.21	0.29	2155	0.08	0.11
28	0.43	4/24/2004 7:05:00 PM-4/25/2004 7:00:00 AM	3387	0.18	0.41	1441	0.05	0.12
Totals	23.77		111,120	5.78	0.24	153,313	5.69	0.24
Avg Rainfall	0.85							

Rainfall/Runoff Events Summary--Treatment Period

		Time period	CB-9 (Treatment)			CB-13 (Control)		
Event #	Rainfall(in.)		Total flow(ft.^3)	Runoff(in.)	Runoff Coeff.	Total flow(ft.^3)	Runoff(in.)	Runoff Coeff.
1	0.7	5/29/2004 3:05:00 AM-5/29/2004 11:30:00 AM	122	0.01	0.01	4707	0.17	0.25
2	0.38	5/30/2004 1:50:00 AM-5/30/2004 5:40:00 AM	309	0.02	0.04	2661	0.10	0.26
3	0.19	5/30/2004 7:50:00 AM-5/30/2004 10:45:00 AM	148	0.01	0.04	1424	0.05	0.28
4	0.14	5/30/2004 7:00:00 PM-5/30/2004 9:30:00 PM	119	0.01	0.04	1132	0.04	0.30
5	0.27	6/1/2004 2:10:00 AM-6/1/2004 8:55:00 PM	217	0.01	0.04	2342	0.09	0.32
6	0.45	6/5/2004 8:05:00 PM-6/6/2004 1:15:00 AM	417	0.02	0.05	3076	0.11	0.25
7	0.18	6/8/2004 6:15:00 PM-6/8/2004 10:05:00 PM	135	0.01	0.04	1383	0.05	0.28
8	1.26	6/8/2004 11:10:00 PM-6/9/2004 10:45:00 AM	1017	0.05	0.04	13061	0.48	0.38
9	0.27	6/11/2004 6:20:00 AM-6/11/2004 12:25:00 PM	287	0.01	0.06	2456	0.09	0.33
10	0.76	6/11/2004 6:10:00 PM-6/11/2004 8:15:00 PM	463	0.02	0.03	7455	0.27	0.36
11	0.38	7/3/2004 2:40:00 PM-7/3/2004 10:05:00 PM	52	0.00	0.01	4075	0.15	0.39
12	0.33	7/6/2004 11:25:00 AM-7/7/2004 2:25:00 AM	233	0.01	0.04	5068	0.19	0.56
13	0.2	7/21/2004 6:25:00 AM-7/21/2004 10:55:00 AM	47	0.00	0.01	977	0.04	0.18
14	0.07	08/01/2004 10:45:00 AM-08/01/2004 05:00:00 PM	95	0.00	0.07	366	0.01	0.19
15	0.06	08/03/2004 03:30:00 PM-08/03/2004 08:15:00 PM	69	0.00	0.06	376	0.01	0.23
16	0.16	08/07/2004 04:35:00 AM-08/07/2004 06:50:00 AM	9	0.00	0.00	1280	0.05	0.29
17	0.13	08/07/2004 12:25:00 PM-08/07/2004 01:30:00 PM	1	0.00	0.00	801	0.03	0.23
18	0.69	08/15/2004 11:00:00 PM-08/16/2004 11:15:00 AM	652	0.03	0.05	5188	0.19	0.28
19	0.06	08/22/2004 04:25:00 AM-08/22/2004 06:15:00 AM	15	0.00	0.01	294	0.01	0.18
20	0.05	09/05/2004 06:10:00 AM-09/05/2004 10:45:00 AM	82	0.00	0.09	459	0.02	0.34
21	1	09/05/2004 04:15:00 PM-09/05/2004 11:40:00 PM	1789	0.09	0.09	6586	0.24	0.24
22	1.1	09/13/2004 11:45:00 PM-09/14/2004 08:25:00 AM	1040	0.05	0.05	7657	0.28	0.26
23	0.05	09/14/2004 11:55:00 AM-09/14/2004 05:10:00 PM	195	0.01	0.20	74	0.00	0.05
24	0.17	09/23/2004 01:40:00 PM-09/23/2004 07:50:00 PM	131	0.01	0.04	490	0.02	0.11
25	0.19	4/15/2005 11:14:00 PM-4/16/2005 4:18:00 AM	4	0.00	0.00	1235	0.05	0.24
26	0.7	4/16/2005 9:54:00 AM-4/16/2005 9:32:00 PM	26	0.00	0.00	7111	0.26	0.37
27	0.36	4/19/2005 7:36:00 AM-4/19/2005 7:00:00 PM	17	0.00	0.00	3743	0.14	0.38
28	0.11	4/26/2005 12:14:00 AM-4/26/2005 3:34:00 AM	0	0.00	0.00	849	0.03	0.28
29	1.8	5/10/2005 5:48:00 PM-5/13/2005 11:42:00 PM	4	0.00	0.00	23842	0.88	0.49
30	0.1	5/14/2005 9:00:00 AM-5/14/2005 6:40:00 PM	0	0.00	0.00	2741	0.10	1.01
31	0.06	5/21/2005 8:58:00 AM-5/21/2005 9:26:00 PM	1	0.00	0.00	1151	0.04	0.70
32	0.2	5/25/2005 3:32:00 PM-5/25/2005 7:16:00 PM	19	0.00	0.01	2332	0.09	0.43
33	0.11	5/26/2005 5:22:00 PM-5/26/2005 9:06:00 PM	16	0.00	0.01	2338	0.09	0.78
34	0.1	5/27/2005 12:04:00 PM-5/27/2005 3:18:00 PM	14	0.00	0.01	1745	0.06	0.64
35	0.05	5/27/2005 9:06:00 PM-5/27/2005 10:00:00 PM	0	0.00	0.00	816	0.03	0.60
36	0.26	6/4/2005 10:22:00 AM-6/4/2005 4:30:00 PM	41	0.00	0.01	2518	0.09	0.36
37	1.05	6/8/2005 12:02:00 AM-6/8/2005 9:14:00 AM	6	0.00	0.00	3938	0.14	0.14
38	0.93	8/3/2005 11:44:00 PM-8/4/2005 1:38:00 AM	60	0.00	0.00	3407	0.13	0.13
39	0.18	8/8/2005 6:12:00 AM-8/8/2005 9:42:00 AM	0	0.00	0.00	536	0.02	0.11
40	0.75	8/9/2005 3:16:00 PM-8/9/2005 4:28:00 PM	8	0.00	0.00	2494	0.09	0.12
41	0.13	8/11/2005 12:18:00 PM-8/11/2005 6:30:00 PM	0	0.00	0.00	898	0.03	0.25
42	0.43	8/18/2005 6:50:00 AM-8/18/2005 2:36:00 PM	0	0.00	0.00	2950	0.11	0.25
43	0.25	9/3/2005 5:14:00 PM-9/3/2005 7:16:00 PM	0	0.00	0.00	1096	0.04	0.16
44	0.15	9/19/2005 4:36:00 AM-9/19/2005 7:28:00 AM	0	0.00	0.00	978	0.04	0.24
45	0.27	9/21/2005 9:28:00 PM-9/22/2005 1:50:00 AM	0	0.00	0.00	1542	0.06	0.21
46	1.36	9/24/2005 8:28:00 PM-9/25/2005 10:36:00 AM	0	0.00	0.00	7703	0.28	0.21
47	0.08	9/25/2005 6:14:00 PM-9/25/2005 11:32:00 PM	0	0.00	0.00	1062	0.04	0.49
48	0.3	9/28/2005 7:18:00 AM-9/28/2005 12:18:00 PM	0	0.00	0.00	1480	0.05	0.18
Totals	18.97		7,861	0.41	0.02	151,897	5.58	0.29
Avg Rainfall	0.40							