Three Rivers Park District
Administration Center Rain Garden

Introduction

There are significant changes to the hydrologic regime and nutrient loading following urban and industrial development. The post-development conditions are often characterized by an increase in impervious surface area. This increase in impervious surface often reduces infiltration and ground water recharge. Consequently, the lower water table can impact flow to existing wetlands and reduce the water available for stream base flow. Similarly, there is a corresponding decrease in the time of concentration that reduces the time available for water to infiltrate. This can simultaneously result in increased runoff volume and higher peak flows. These changes in the hydrologic balance can accelerate erosion processes that degrade water quality conditions for downstream water bodies.

Conventional storm water management efforts implemented for urban and industrial areas have primarily focused on curb and gutter systems that collect and convey runoff through a network of pipes that discharge directly to receiving water bodies. To minimize impacts from changes in the hydrologic balance, conventional storm water management practices typically incorporate ponds or detention basins at the end of the storm water network drainage. These best management practices are primarily designed to accommodate the storage volume and peak flow requirements established by local water resource regulatory agencies. The ponds and detention basins also provide nutrient and sediment removal for downstream water bodies. In order for the ponds and detention basins to be efficient, the ponds need to be sized appropriately to accommodate the estimated change in run-off volume and discharge rate. This may require constructing a large pond in locations that have considerable space constraints and limitations. Another disadvantage with ponds or detention basins is that they provide minimal infiltration capacity for ground water recharge. Despite these disadvantages, very few alternative management strategies are considered when meeting specific water quantity and quality criteria for proposed changes in the hydrologic balance due to development.

A storm water management approach that has been receiving more consideration recently has been the concept of low-impact development. The low-impact design approach uses integrated storm water management controls distributed throughout the site at the source (i.e. within individual lots of the development) to compensate for hydrologic alterations. Management practices that are suited to low-impact development include bioretention facilities, filter/buffer strips, grassed swales, infiltration trenches, and rain gardens. These management practices do not require a large amount of area to implement and often become functionally-aesthetic components of the landscape. The low-impact development approach also has the potential to emulate the predevelopment hydrologic conditions by maximizing infiltration capacity. Management practices that operate through maximizing infiltration capacity provide runoff volume control, peak runoff rate control, flow frequency/duration control, and water quality benefits.

Consequently, the low-impact design concept has become a more viable method with respect to maintaining predevelopment hydrologic conditions.

The Three Rivers Park District incorporated a low-impact design concept to accommodate the expansion of an existing parking lot at the Administrative Center located in the City of Plymouth. The City of Plymouth required that water quality treatment be provided on site as a condition of permitting the parking lot expansion. Consequently, a rain garden was constructed to capture runoff from the increase in impervious surface area. The rain garden was primarily designed to reduce nutrient loading for water quality benefits, but also reduced runoff volume by providing infiltration capacity. The nutrients and water captured by the rain garden are beneficial for the establishment of native plant species. The removal efficiencies for rain gardens are typically estimates that have been determined from modeling efforts. Very few studies have actually monitored rain garden removal efficiencies from a nutrient removal and water retention perspective. The Three Rivers Park District monitored the nutrient loading and runoff volume for the rain garden at the Administrative Center to estimate removal efficiencies. The monitoring data was used to determine whether a P8 model could be calibrated to simulate the observed conditions.

Study Site

The Three Rivers Park District rain garden was located at the Administrative Center in the City of Plymouth near the intersection of Xenium Lane North and Northwest Blvd (Hwy 61). The rain garden was constructed in the fall of 2002 in conjunction with the expansion of the Administrative Center parking lot. Native vegetation was planted in the rain garden in the spring of 2003 by Three Rivers Park District horticulture staff.

The Three Rivers Park District Administrative Center parking lot is divided into two sub-watershed areas that discharge to separate catch basins (Figure 1). The southern sub-watershed area (RG1) diverts surface runoff to a catch basin on the eastern edge of the parking lot. A sampling station (RG1) was located at this southern sub-watershed catch basin (Figure 1). Runoff entering this catch basin bypasses the rain garden through a 15-inch pipe that drains to the northwest. The northern sub-watershed area (RG2) sheet flows over the cut-out curb sections along the sides and ends of the rain garden complex where it is collected in a vegetated depression (Figure 1). The depression is gently sloped toward the outlet structure located at the north end of the garden. When runoff exceeds the infiltration capacity of the rain garden, water pools at the northern end of the rain garden until the water level reaches the elevation of the perforated holes in the riser outlet structure (Figure 2). The overflow from the rain garden drains into the existing 15-inch pipe that also receives runoff collected by the upstream catch basin (RG1). The water continues to flow northwest where it outlets into the main storm sewer discharge pipe at the catch basin located along the northern edge of the property. A second sampling station (RG2) was located at this northern sub-watershed catch basin (Figure 1). The water outlets from the catch basin pipe to a wetland area north of the parking lot. This wetland complex eventually drains to Plymouth Creek.

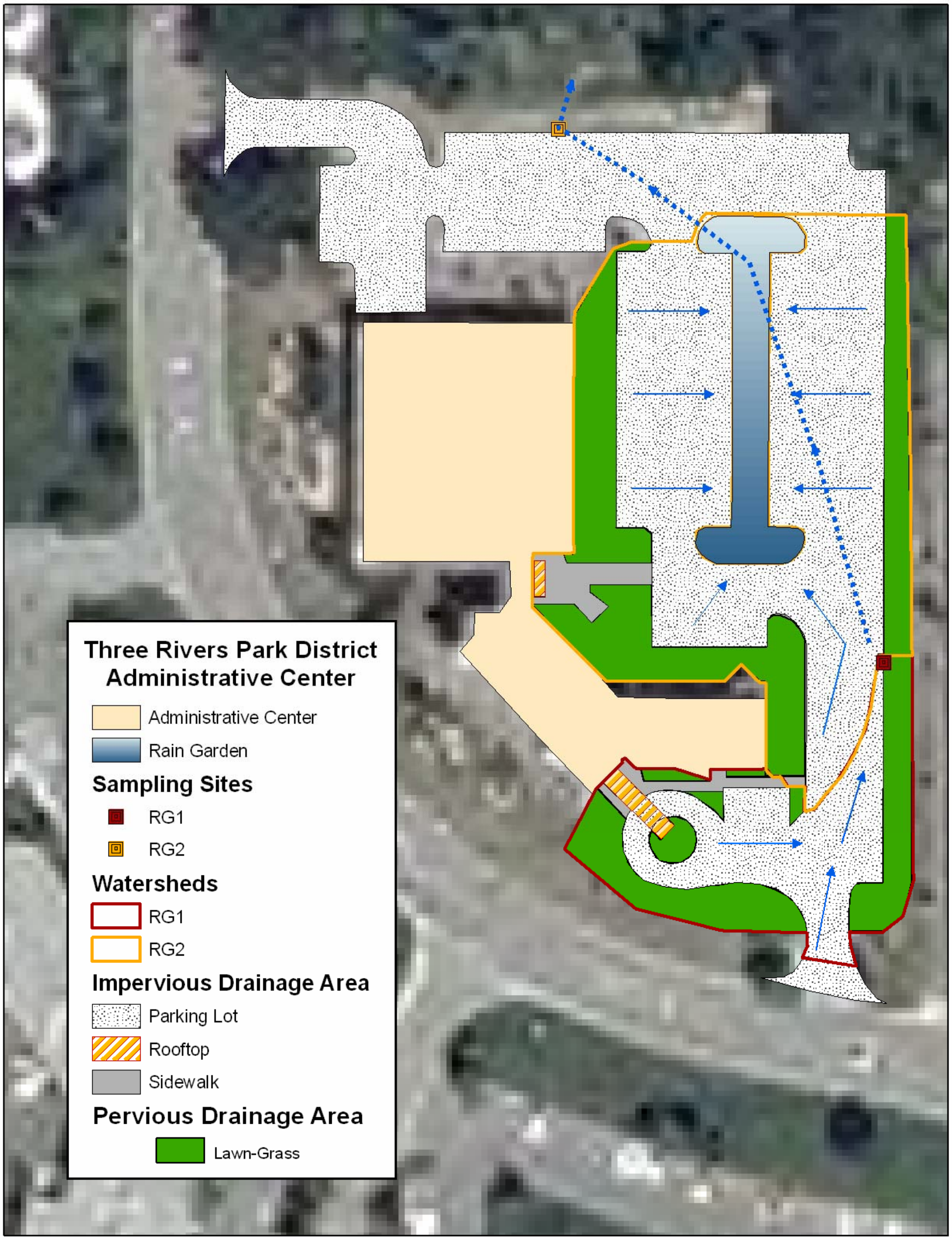

Figure 1: Three Rivers Park District Administrative Center Rain Garden Design.

Methods

The Three Rivers Park District monitored the hydrologic and nutrient dynamics of the Administrative Center rain garden to estimate potential removal efficiency. The nutrient removal efficiency is typically calculated using a mass balance equation that incorporates the nutrient loading entering and leaving the rain garden. The amount of nutrient loading is dependent upon the flow volume and nutrient concentration. It was necessary to have reliable measurements of the runoff volume and nutrient concentrations entering and leaving the rain garden to accurately determine nutrient removal efficiency.

The runoff entering the rain garden is exclusively surface sheet flow from the parking lot area. Consequently, the run-off volume that drains directly to the rain garden was estimated because the inflow could not be monitored at a specific location. The volume of water entering the rain garden was estimated by multiplying the watershed area by the amount of precipitation. A tipping bucket rain gauge was installed to measure the amount of precipitation at 1-minute intervals. The calculation of inflow to the rain garden assumes that infiltration and evaporation are minimal. This is a reasonable assumption because the primary watershed area is impervious surface that has minimal depression storage capacity. Although flow volume entering the rain garden could not be monitored, surface run-off samplers were installed within the rain garden to measure concentration of nutrients in the run-off water. These surface runoff samplers followed similar designed standards that were used by the U.S. Geological Survey and Wisconsin Department of Natural Resources (personal communication Roger Bannerman). The surface runoff samplers were installed along the curb cut-out sections of the rain garden to collect water quality samples from sheet flow.

When runoff exceeded the infiltration capacity of the rain garden, excess volume overflowed through the outlet structure (slotted PVC pipe) and empties into a storm sewer pipe. The water flowed northwest where it outlet into the main storm sewer discharge pipe at the catch basin located along the northern edge of the property. A sampling site (RG2) was installed at this northern catch basin to monitor the rain garden outflow. However, the storm sewer pipe outlet at the RG2 sampling site also received runoff from a catch basin located upstream of the rain garden. Consequently, another sampling site (RG1) was installed at the catch basin upstream from the rain garden to account for the additional runoff volume. At each of the monitoring stations, an automated sampler/data logger was installed. Each monitoring station measured water level, velocity, and flow at one-minute intervals. During each site visit, flow meter data was downloaded by a field laptop computer. All of the data loggers were programmed to initiate sample collection after a predetermined increase in water level was obtained. After sampling was initiated, flow weighted composite water samples were sequentially collected to encompass the entire storm distribution.

Three Rivers Park District staff collected water quality samples within 24-hours after each storm event. All samples were labeled immediately after collection, stored in a cooler with ice, and delivered to the Three Rivers Park District laboratory for analysis. The water quality samples were analyzed for total phosphorus, soluble reactive phosphorus, total nitrogen, and total suspended solids according to protocol described in The Standard Methods for the Examination of Water and Wastewater (1995). Sample analysis was prioritized by parameter holding time to ensure that analyses are completed within the recommended time interval. Samples were stored at 4° C in a refrigerator until all analysis was completed. A quality assurance and quality control protocol was followed to ensure the precision and accuracy of laboratory data analysis.

The flow meter data and water quality data were used to determine the nutrient loading. The nutrient loading for each storm event was calculated as the product of the flow volume and nutrient concentration. The nutrient loading entering the rain garden was calculated with the estimated flow volume and the measured nutrient concentration data collected from the surface run-off samplers in the rain garden. The nutrient concentrations from the surface run-off samplers were also compared with the concentrations from the RG1 sampling site. The nutrient loading leaving the rain garden was estimated using the loading calculations from the RG1 and RG2 sampling sites. The RG2 sampling site represented the combined flow from the rain garden and the furthest upstream sampling site (RG1). Any differences observed between the two automated sampling sites (upstream from the rain garden-RG1 & downstream of the rain garden RG2) was attributable to overflow from the rain garden. Characterizing the rain garden inflow and outflow enabled calculation of the percent nutrient removal efficiency. The nutrient removal efficiency was calculated using a standard mass balance equation.

$$\textbf{\% Removal Efficiency} = [(\text{Input} - \text{Output})/\text{Input}] * 100$$

The data collected from the monitoring sites was further used to calibrate a P8 model. The P8 model was calibrated to mimic flow and nutrient loading conditions that were observed during the sampling interval. The model was only calibrated with flow and nutrient concentration data that was considered reliable. The model was used to simulate potential nutrient loading and determine nutrient removal efficiencies for variations in precipitation conditions. Removal efficiencies were determined for total phosphorus, total nitrogen, and suspended solids. The nutrient removal efficiencies estimated by the P8 model were compared to the observed conditions. The details pertaining to model calibration are described in the following section.

Rain Garden
Model Calibration

A P8 model was used to determine the annual removal efficiency of the rain garden. The model was calibrated using monitoring data collected from the sampling sites for discrete rainfall events. The parameters entered into the model included the pervious and impervious watershed characteristics (Table 1). The model allows the user to specify a particular treatment device that reduces nutrient loading within a particular watershed. However, the model does not provide an option to specifically identify rain gardens as a treatment device. The rain garden was designed to provide infiltration capacity for storm events that produce less than 2.5 inches of precipitation. Consequently, the morphological characteristics of the rain garden were modeled as an infiltration device (Table 2 & Figure 2). The rainfall data collected hourly at the monitoring site was used for model application; and a daily average temperature file was also developed from data collected at Crystal Airport in 2005 (Appendix). The flow network diagram further describes how the P8 model was set-up for the Administrative Center rain garden (Figure 3).

The model was initially calibrated to mimic the observed flow conditions at each of the monitoring sites. The automated samplers/data loggers installed at the RG1 and RG2 sampling sites provided reliable continuous flow data. Consequently, the model was calibrated using the data collected from the RG1 and RG2 monitoring sites in 2005. Calibrating the model for the RG1 sampling site provided an estimate of the runoff volume that by-passed the rain garden and outlet at the RG2 sampling site. After calibration of the RG1 sampling site, it was assumed that the model would also provide a reasonable estimate of runoff volume entering the rain garden because watershed characteristics were very similar. These model estimates were further corroborated through the calibration of the RG2 sampling site. The RG2 sampling site received runoff from the upstream sampling site (RG1) as well as from the rain garden. As discussed previously, the difference between the RG2 and RG1 sampling site yielded an estimation of the runoff volume leaving the rain garden. To calibrate the model for the RG2 sampling site, the infiltration coefficient of the rain garden was adjusted to mimic the observed flow. After calibration, the modeled total rain garden discharge (infiltration volume + overflow volume) yielded an estimate similar to runoff volumes entering the rain garden. A paired t-test was used to determine whether there was a significant difference at the 0.05 level between the observed and modeled flow volumes for each storm event.

The process used for calibrating the model for flow was similar to the procedures used for calibration of nutrient loading. The model was adjusted to mimic the observed nutrient loading for the RG1 and RG2 monitoring site. The scale factor for each water quality parameter was adjusted in the particle file (NURP50.PAR) until the model predicted nutrient loads similar to observed conditions. After the model was calibrated for nutrient loading, the nutrient concentrations predicted by the model were also compared to the concentrations observed at each monitoring site. The modeled estimates of nutrient loading for the RG1 and RG2 sampling sites were used to determine the

loading inputs and outputs of the rain garden. The procedures used for estimating the loading inputs and outputs of the rain garden were similar to the previous flow calculations.

The P8 model was used to determine the annual nutrient removal efficiency of the rain garden after calibration for flow and loading. The model uses a mass balance equation to calculate nutrient removal efficiency. The nutrient removal efficiency was calculated for each parameter for rainfall conditions observed in 2005. The model was re-run with a rainfall file that was representative of average precipitation conditions for the Minneapolis, Minnesota area. The nutrient loading and removal efficiency of the rain garden were estimated for these average precipitation conditions.

Table 1: Administrative Center Sub-watershed characteristics.

Sub-Watershed Characteristics								
Sub-Watershed	Land Use	Total Acres	Impervious Acres	Impervious %	Pervious Acres	Pervious %	Treatment Type	Treatment Acres
RG1	Commercial	0.39	0.224	57	0.167	43	None	0
RG2	Commercial	1.148	0.737	64	0.411	36	Rain Garden	0.12

Table 2: Administrative Center Rain Garden Characteristics.

Administrative Center Rain Garden Characteristics								
	Morphology					Storage Capacity		Infiltration
Device	Length (ft)	Width (ft)	Side Slope	Slope to Outlet	Outlet Elevation	Area (Acres)	Volume (Acre-ft)	Rate (inch/hr)
Rain Garden	152	20	4 to 1	2%	937.04	0.073	0.091	0.03

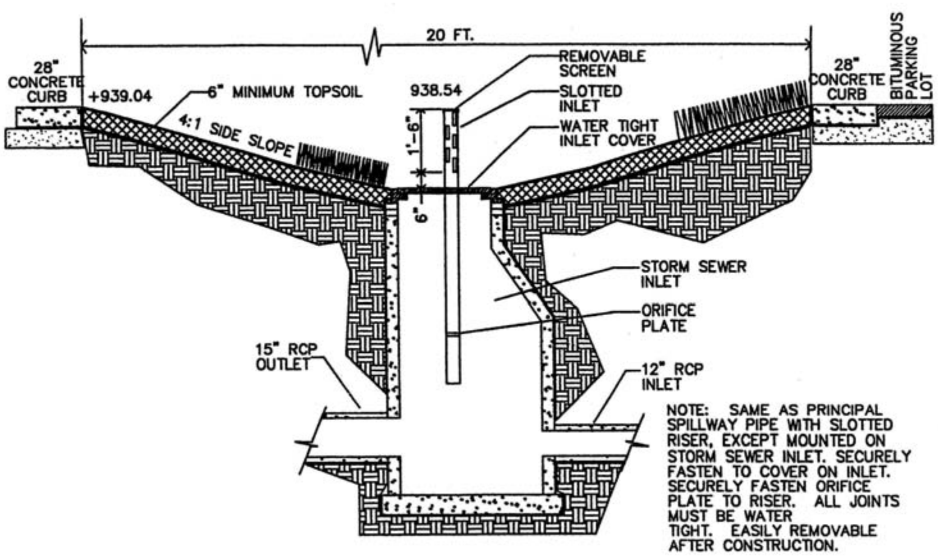

Figure 2: Administrative Center Rain Garden Cross Section.

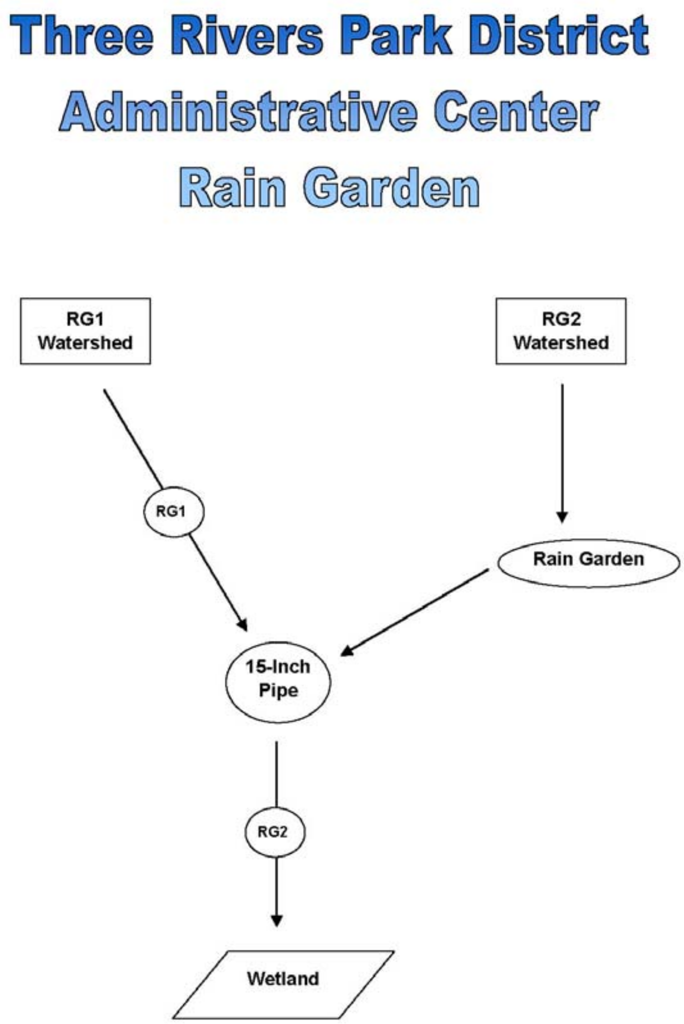

Figure 3: Three Rivers Park District Administrative Center Rain Garden.

Three Rivers Park District Rain Garden
Results and Discussion

Three Rivers Park District monitored the performance of the Administrative Center rain garden that was designed to accommodate additional runoff for expansion of the parking lot. The sampling sites were monitored from May 26 through October 13 in 2005. During the monitoring interval, the rain gauge recorded 21.8 inches of precipitation. There were 28 individual precipitation events that produced sufficient runoff volume for sample collection. Water quality samples collected at each of the two monitoring sites represented approximately 55% to 90% of the total rainfall volume during the sampling time interval. There were 40 water quality samples collected from the RG1 and RG2 monitoring sites in 2005, and there were an additional 20 water quality samples collected from the surface run-off samplers within the rain garden. Although water quality samples were not collected for each precipitation event, the samples were representative of the rainfall distribution with respect to the amount and intensity of precipitation observed in 2005. The sampling sites appeared to provide reliable data for calibration of the P8 model.

The P8 model was initially calibrated to simulate flow volumes that were observed for each sampling site. The model appeared to over predict the total flow volume for the RG1 sampling site (Table 3). However, the model estimated total flow volumes that were similar to the observed conditions for the RG2 sampling site (Table 3). The reason for the discrepancy between the two sampling sites became evident after reviewing the following equation:

RG1 Total Flow + Rain Garden Overflow = RG2 Total Flow

In order for the model to estimate flow volumes similar to observed conditions for RG2, the model underestimated the amount of Rain Garden discharge to compensate for over predicting flow volumes from the RG1 sampling site. These differences became apparent after comparing the hydrographs for observed versus predicted daily flow volumes (Figure 4 & 5). Unfortunately, the model could not be reasonably adjusted to estimate total flow volumes similar to the observed conditions for the RG1 sampling site. Despite the discrepancy between observed and predicted flow volumes, these differences do not appear to be very significant for each sampling site. A paired t-test analysis indicates that the differences between the observed versus predicted flow volumes are not significant at the 0.05 level (Table 4 & 5). Based on the paired t-test results, the model was considered adequate in simulating the hydrologic flow regime of the watershed.

Table 3: Annual Run-off Volumes in 2005 for Observed vs. Modeled.

Site	Observed	Modeled
	Flow Volume (Acre-ft)	Flow Volume (Acre-ft)
RG1	0.27	0.36
RG2	1.05	1.05

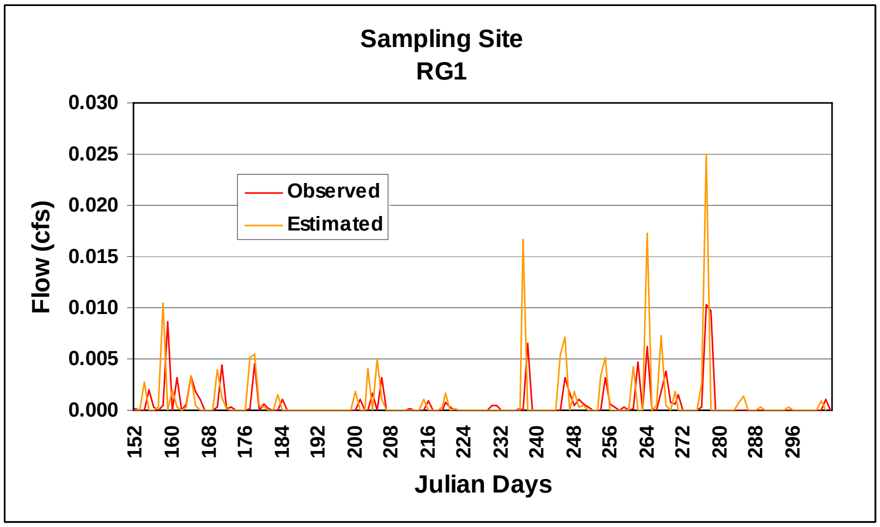

Figure 4: Flow hydrograph for RG1 sampling site.

Table 4: RG1 paired t-test results for observed and estimated average daily flow.

RG1 - Paired Samples t-test							
Data	Average Flow (cfs)	N	Standard Deviation	Standard Error	df	t-value	Significance
Observed	0.00070	152	0.0017	0.00014	151	-1.572	0.118
Estimated	0.00100	152	0.0032	0.00030			

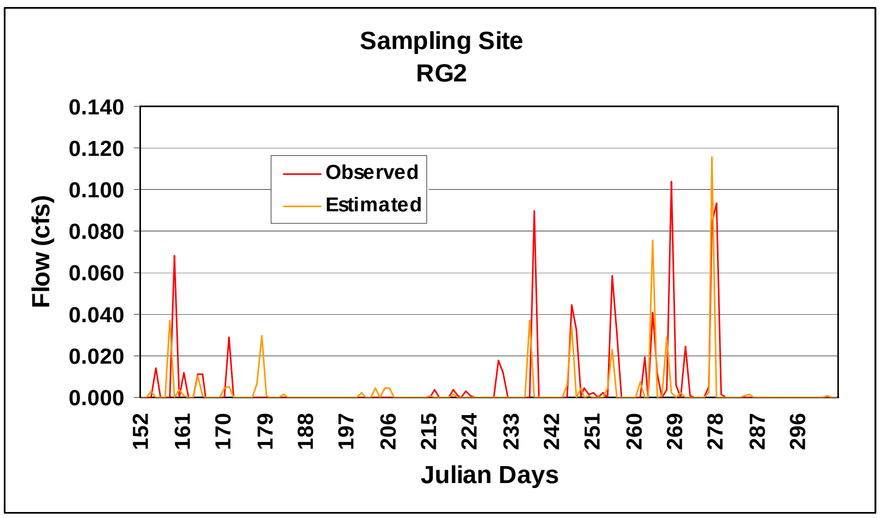

Figure 5: Flow hydrograph for RG2 sampling site.

Table 5: RG2 paired t-test results for observed and estimated average daily flow.

RG2 - Paired Samples t-test							
Data	Average Flow (cfs)	N	Standard Deviation	Standard Error	df	t-value	Significance
Observed	0.00550	153	0.01752	0.00142	152	1.814	0.072
Estimated	0.00310	153	0.01261	0.00102			

Although the P8 model appeared to be adequate for simulating the hydrologic flow regime, the model calibration was further refined to accurately estimate nutrient loading. The model was calibrated to simulate the nutrient loading estimates provided by the RG1 & RG2 sampling sites. The model appeared to calculate total phosphorus and total nitrogen loading estimates that were similar to the observed RG1 & RG2 sampling sites (Table 6). However, the model had a tendency to over estimate the total suspended solids for the RG1 sampling site; and under estimated the total suspended solids for the RG2 sampling site (Table 6). The differences between the observed versus predicted conditions for total suspended solids were primarily due to the variations in concentrations (Table 7). It was difficult to adjust scale factors for total suspended solids that were representative of the nutrient loading and concentration for both sampling sites. These discrepancies in total suspended solids may be attributed to an insufficient number of samples collected that represented majority of the storm events. There were occasions in which samples were not collected during a particular storm event or the parameter was not analyzed for a specific sample. The number of samples analyzed for total suspended solid represented a smaller proportion of the total rainfall volume in comparison to samples collected for other water quality parameters (Table 8). Therefore, the samples collected for total phosphorus and total nitrogen were more representative of the total rainfall volume (Table 8). All estimates for nutrient loading were extrapolated to account for the volume of rainfall that was missed during the sampling interval. The model was adjusted for each parameter to provide the most reasonable nutrient loading estimates that were representative of the total rainfall volume.

Table 6: Annual Nutrient Loadings in 2005 for Observed and Modeled.

Site	Observed			Modeled		
	TP (lbs)	TN (lbs)	TSS (lbs)	TP (lbs)	TN (lbs)	TSS (lbs)
RG1	0.15	0.78	21.60	0.15	0.79	67.43
RG2	0.48	3.51	184.02	0.43	2.60	110.26

Table 7: Average Nutrient Concentrations in 2005 for Observed and Modeled.

Site	Observed			Modeled		
	TP (µg/L)	TN (mg/L)	TSS (mg/L)	TP (µg/L)	TN (mg/L)	TSS (mg/L)
RG1	238	2.2	45.09	149	0.80	69.16
RG2	180	1.84	62.0	153	0.92	38.76

Table 8: Summary of sample collection relative to rainfall volume in 2005.

Parameters	Number of Samples Analyzed		Sampled Precipitation (inches)		Total Precipitation (inches)	% Total Precipitation Sampled	
	RG1	RG2	RG1	RG2		RG1	RG2
TP	20	19	17.49	14.15	19.31	91	73
TN	16	15	15.41	11.84	19.31	80	61
TSS	12	12	13.2	10.54	19.31	68	55

The total nutrient loading estimates were used to determine the nutrient removal efficiency from the rain garden. The removal efficiencies were calculated using a mass balance equation that incorporated the nutrient loading entering and leaving the rain garden. The nutrient loading difference between the two sampling sites (RG2-RG1) was used to calculate loading attributable to overflow from the rain garden.

Rain Garden Output = RG2 Nutrient Loading – RG1 Nutrient Loading

As previously discussed, the nutrient loading entering the rain garden could not be directly monitored because the runoff was primarily surface sheet flow. The flow volume entering the rain garden was calculated by multiplying the watershed area by the amount of rainfall. Initially, the nutrient concentrations from the surface samplers were used to calculate nutrient loading. However, the concentrations from the first flush of nutrients were significantly diluted due to sample bottle overflow from the excessive amount of runoff volume from the impervious surface area. The surface samplers appear to be more applicable for situations that typically do not receive as much runoff volume (i.e. lawn runoff). Consequently, it was assumed that concentrations from the RG1 sampling site were similar to concentrations entering the rain garden. This is a reasonable assumption since the runoff entering the rain garden and RG1 catch basin was from parking lot surface area. The nutrient loading entering the rain garden was calculated using the estimated flow volumes and RG1 concentrations from each storm event. The rain garden nutrient removal efficiencies were calculated from these nutrient loading estimates, and were compared to the annual nutrient removal efficiencies estimated by the P8 model.

The rain garden appears to be effective at reducing nutrient loading. The rain garden was designed to have approximately 60% nutrient removal efficiency. According to the model, the rain garden provided 75% and 70% removal efficiency of total phosphorus and total nitrogen (Table 9). The modeled annual removal efficiencies are similar to the observed estimates in which the rain garden provided 62% and 72% removal of total phosphorus and total nitrogen for 2005 rain events (Table 9). The estimates suggested that the rain garden was more effective at removing total phosphorus and total nitrogen in comparison to the anticipated design criteria. The rain garden was also efficient at removing total suspended solids. However, there is a discrepancy between the modeled and observed removal estimates for total suspended solids. The model predicted that the rain garden was 92% efficient at removing total suspended solids. This modeled estimate was considerably higher than the observed removal efficiency of 58% for total suspended solids. The differences were attributed to the difficulties previously mentioned in calibrating the model for total suspended solids. Based on the total phosphorus and total nitrogen removal efficiencies, the 92% total suspended solids removal seems more accurate. Despite the discrepancy between the observed and modeled removal efficiencies for total suspended solids, the rain garden appears to adequately reduce the amount of total suspended solids (Table 9).

Table 9: Three Rivers Park District Rain Garden Removal Efficiency for 2005.

Conditions	Flow (Acre-ft)		Nutrient Loading (pounds)						Percent (%) Removal Efficiency			
			TP		TN		TSS					
	In	Out	In	Out	In	Out	In	Out	Flow	TP	TN	TSS
Observed	1.82	1.41	0.87	0.33	9.86	2.73	385.9	162.4	23	62	72	58
Modeled	1.33	0.69	1.25	0.29	6.77	1.84	583.0	44.0	48	75	70	92

Note: Calibrated Model Conditions are based on 2005 data.

The model was re-run incorporating a precipitation file that was representative of average rainfall conditions in Minneapolis, Minnesota. The modeling for average precipitation conditions provided similar results in comparison to 2005 model simulation. The rain garden provided 80% removal efficiency for total phosphorus; 77% removal efficiency for total nitrogen; and 95% removal efficiency for total suspended solids (Table 10). The removal efficiencies modeled for average precipitation conditions are slightly higher than conditions modeled in 2005. The differences in model conditions are attributed to below average precipitation conditions in 2005. Despite these differences, it appears that the rain garden was extremely efficient at reducing the volume of water through infiltration as well as reducing the amount of nutrient loading.

Table 10: Rain Garden Removal Efficiency for Average Precipitation Conditions.

Flow (Acre-ft)		Nutrient Loading						Percent (%) Removal Efficiency			
		TP (g)		TN (g)		TSS (g)					
In	Out	In	Out	In	Out	In	Out	Flow	TP	TN	TSS
1.51	0.57	1.48	0.25	7.98	1.56	701.90	38.10	63	80	77	95

Note: Average conditions based on an annual rainfall of 28 inches.

Rain Garden Plantings and Maintenance

The costs related to the planting and maintenance of the rain garden involved the initial planting and the application of mulch. Approximately, $900 was spent on a variety of plant species for the rain garden. The rain garden's vegetation primarily consisted of herbaceous plant species in addition to a few tree and shrub species. After the garden was planted, approximately $500 was spent on mulching the garden. Currently, mulching the rain garden has only been applied once. The general maintenance and weeding of the rain garden is preformed every couple weeks. There has also been a couple of replanting efforts around the edges of the garden due to high stress on the plants from higher volumes of runoff.