CHAPTER 3 – WATER QUALITY

Introduction

The Baird Creek watershed is rapidly transitioning from agricultural to urban land use between Interstate-43 and Northview Road. As shown in Chapter 2, over 25% of the watershed upstream of I-43 and over 60% of the South Branch watershed will be in urban land use by 2022, as compared to only 12.4% and 14.3% in 2000, respectively. Through 2005, most development has occurred in the watershed downstream of the confluence of the North and South Branches and in the South Branch watershed. Visible changes in streamflow and sediment load within the urbanizing tributaries has led to community concern over impacts to water quality and the historically diverse fish community of Baird Creek.

Previous studies have shown that urbanization can detrimentally affect stream ecology and water quality. Increased impervious cover, artificial extension of the drainage network by storm sewers, and the elimination of depressional storage in the landscape combine to cause greater surface runoff, more frequent downstream flooding, and a reduction in groundwater recharge (Nelson and Booth 2002). Stream discharge becomes more “flashy,” with higher peak storm flows and lower average flows between events. Elevated stream velocities cause channel enlargement, increasing stream sediment loads and disrupting habitat for aquatic organisms (Paul and Meyer 2001). Improperly maintained erosion control practices also lead to increased sedimentation during construction activities. Escalations in stream sediment and nutrient loads adversely impact stream biological communities, causing the decline of sensitive species through gill abrasion, loss of spawning habitat, increased biochemical oxygen demand, and limited light penetration (Packman et al. 1999).

Historical Trends in Sediment and Phosphorus Loads

Nutrient and sediment concentrations collected in multiple studies within the Western Lake Michigan Drainage Basin from 1971 to 1990 were summarized by the US Geological Survey (Robertson and Saad 1996). Statistical analysis of samples collected in basins with clay soils over carbonate bedrock showed a median suspended sediment concentration of 50.0 mg/L for agricultural land use (n=139) and 148.0 mg/L for urban areas (n=76). Total phosphorus was heavily sampled within the basin over the two decades, with median concentrations of 0.16 mg/L for agricultural land use (n=831) and 0.11 mg/L for urban areas (n=847).

The Wisconsin Department of Natural Resources conducted a water quality study on Baird Creek from 2001 to 2002 (Reyburn 2003). Samples were collected on a biweekly basis at the railroad bridge downstream of Interstate-43 and on the North Branch at the Green Bay City limits. No attempt was made to sample precipitation events; thus, the maximum discharge sampled was only 44 cfs. Summary statistics for sediment and total phosphorus samples from the WDNR data set are shown in Table 3.1. Analysis of variance showed that total phosphorus concentrations were significantly higher at the City limits on the North Branch than at I-43 for the 95% confidence level. Suspended solids concentrations did not significantly differ between the two sites. Total phosphorus concentrations at the North Branch appeared to be higher than those found in the study of the Western Lake Michigan Drainage Basin, while concentrations at I-43 more closely matched the historical median. However, because neither of these studies directly considered event discharges, observed concentrations may not be representative of high event flows in Baird Creek.

Table 3.1. Summary statistics from the WDNR Baird Creek Watershed Management Study, 2001-2002 (Reyburn 2003).

Parameter	Railroad Bridge at I43	Green Bay City Limits
Discharge (cfs):		
Mean	9.69	7.15
Median	5.65	2.00
Maximum	44.20	35.70
Minimum	0.00	0.00
Suspended Sediment (mg/L):		
Mean	10	14
Median	6	5
Maximum	39	182
Minimum	0	0
Total Phosphorus (mg/L):		
Mean	0.20	0.33
Median	0.17	0.30
Maximum	0.54	0.74
Minimum	0.04	0.10

Research Objectives

The Baird Creek watershed is developing in accordance with local and state regulations for erosion control and water detention. However, visible evidence of sediment loading and bank slumping suggests that these ordinances may not be enough to protect the stream ecosystem. The lack of proper installation, maintenance, and code enforcement of erosion control practices is commonplace at many construction sites across the country. In 2004, the Baird Creek Watershed Stewardship Assessment found that similar problems may exist locally as the City of Green Bay currently does not have enough available staff time for conducting stormwater-related inspections of construction sites (Lake Michigan Forum 2004).

The purpose of this chapter was to investigate the impacts of urbanizing land use on the water quality and stream ecology of Baird Creek. The nine-month study focused on the following objectives:

1) Determine differences in sediment and phosphorus concentrations between agricultural and urbanizing tributaries under event and low-flow conditions.
2) Establish the relative contributions of agricultural and urbanizing subwatersheds to sediment and phosphorus loads in Baird Creek.

Methodology

Low-flow and storm event sampling was conducted from April to December 2004 at three locations on Baird Creek (Figure 3.1). Stations were established on both the North and South Branches within 100 meters of the confluence point. Equipment at these stations consisted of a fixed staff gage, an ISCO Model 1392 Wastewater Sampler, and an internally-logging YSI 6200 multi-parameter sonde (Figures 3.2, 3.3). The third site was located one mile downstream of the confluence at the USGS Station on Superior Road. This site was a fully automated water sampling station with an ISCO 3700R refrigerated sampler, a tipping-bucket rain gauge, a gas-bubble water level measuring system, a YSI 6200 multi-parameter sonde, a data logger, and a modem (Figure 3.4).

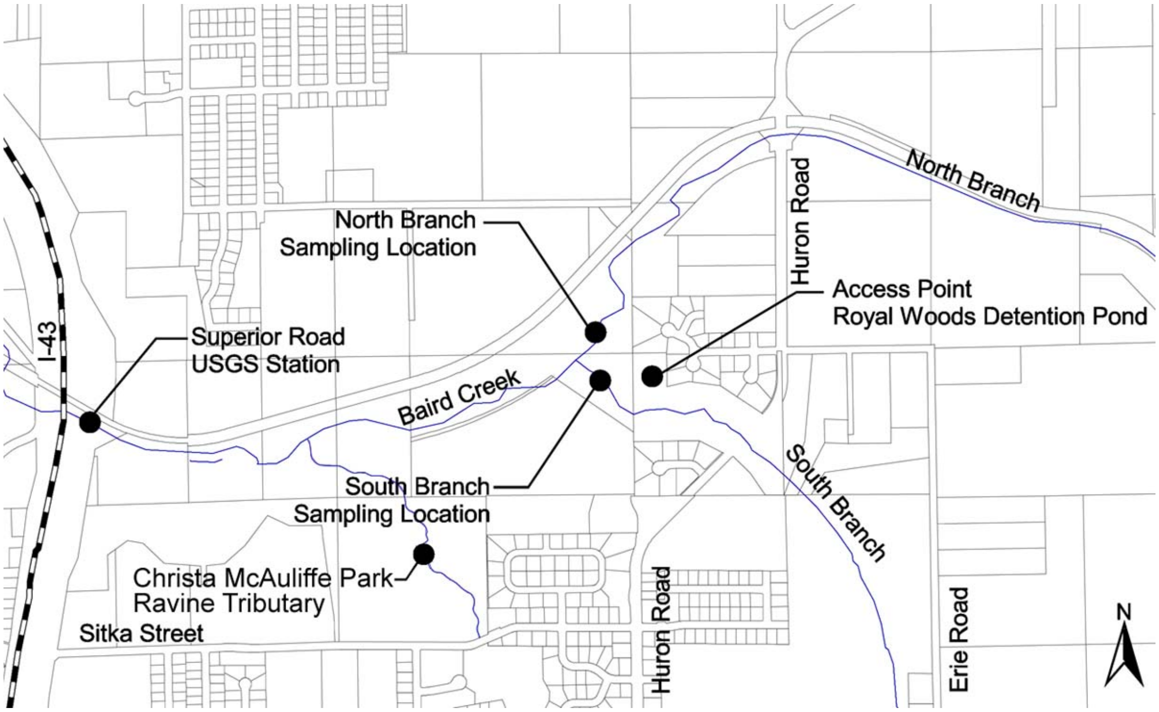

Figure 3.1. Locations of low-flow and storm event sampling sites on the North Branch, South Branch, and main channel of Baird Creek.

Because of the close proximity of the upstream and downstream stations, all precipitation data for the project was collected at the USGS Station. Storm events were defined as periods of precipitation bracketed by 6 hours or more of no rainfall.

Water Quality

Event and Low-Flow Sample Collection

Samplers at the North and South Branch sites were manually activated to collect discrete samples at timed intervals during storm events. Samples were collected at hourly time steps on rising hydrographs to measure concentration fluctuations during the first flush of storm events. The collection interval was changed to two hours on long recessions of event hydrographs where concentrations were more stable. Sample

Figure 3.2. (a) ISCO Model 1392 Wastewater Sampler and (b) view of the North Branch sampling site showing sampler and staff gage.

Figure 3.3. YSI 6200 multi-parameter sonde.

Figure 3.4. Automated USGS monitoring station with ISCO 3700R sampler, gas bubbler, and data logger.

collection at the USGS Station site was conducted by established USGS methods (Shelton 1994). Discrete sampling at this site was triggered by changes in stream gage height, and was structured to be representative of entire event hydrographs. Samples from all sites were collected within 18 hours, and stored on ice for transport to the laboratory for analysis.

Low-flow sampling was conducted at each site on a biweekly basis using the equal width increment (EWI) method (Thornton et al. 1999). Using this method, the sample bottle was first rinsed 3 times in the stream. The stream width was then divided into 6 to 10 equally spaced segments. At each segment centroid, the sampling device was lowered and raised vertically through the water column at a consistent rate, thus weighting each sample by the stream velocity (Figure 3.5).

Sample Analysis

All water samples collected over the project duration were processed in the UW-Green Bay laboratory using methods approved by USGS. As described in Appendix A.1, a Teflon cone splitter was used to divide samples for analysis of total suspended solids

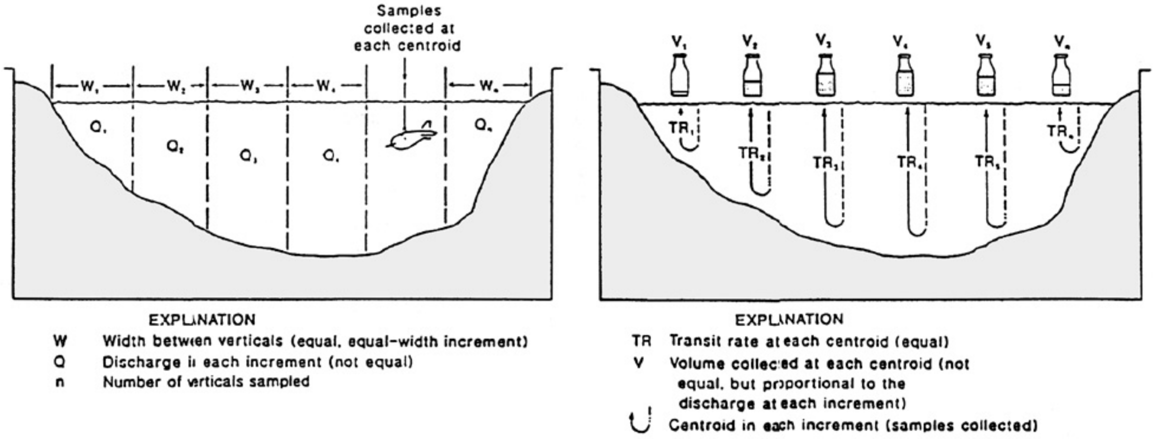

Figure 3.5. Diagram of the equal width increment (EWI) sampling method (Thornton 1999).

(TSS), total phosphorus, and total dissolved phosphorus (Shelton 1994). Prior to splitting, event samples from the North and South Branch were composited over one-hour or two-hour time steps to provide a sufficient quantity for analysis. Dissolved phosphorus samples were vacuum filtered through a 0.45 µm filter to remove particulate matter. Both dissolved and total phosphorus samples were preserved with 3:1 sulfuric acid (H_2SO_4), extending the sample hold time to 28 days. Samples were kept refrigerated at 4°C until transport to the Green Bay Metropolitan Sewage District Laboratory for analysis.

GBMSD analyzed samples for TSS using Standard Method 2540 D (Clesceri et al. 1998). In this procedure, an aliquot is extracted from the TSS sample and filtered through a weighed glass-fiber filter, with the residue then dried to a constant weight at 105°C. Total phosphorus and dissolved total phosphorus were analyzed with colorimetry using Automated Block Digester Method 365.4 from the U.S. EPA Methods for Chemical Analysis of Water and Wastes (US EPA 1983). In this process, the total phosphorus or pre-filtered dissolved phosphorus sample is first acid digested in a sulfuric acid (H_2SO_4), mercuric oxide (HgSO), and potassium sulfate (KSO) solution for 2.5 hours. Using flow injection analysis, the resulting orthophosphate sample is reacted with ammonium molybdate ($(NH_4)_6Mo_7O_{24}\cdot 4H_2O$) and antimony potassium tartrate ($K_2[Sb_2(C_4H_4O_6)_2]\cdot 3H_2O$) to form a blue complex absorbed at 880nm in an ascorbic acid procedure.

Additional analysis for suspended sediment concentration (SSC) was performed on discrete event samples from the North and South Branch sites. Previous USGS studies have shown that TSS analysis of stream water samples underestimated sediment loads for samples containing sand-sized particles (Gray et al. 2000). Because the SSC procedure is performed on the entire sample instead of a subsampled aliquot, SSC is the preferred method for sediment analysis. SSC analysis was performed in the UW-Green Bay laboratory using the procedure outlined in Appendix A.2 (U.S. Forest Service 2002).

Real-time Water Quality Data Collection

YSI multi-parameter sondes were used to provide real-time measurement of stream conditions at all three sampling locations (Ehlinger 2002). UW-Milwaukee laboratory technicians calibrated and installed the sondes, which were placed in the field on approximately 2-month rotations. Sondes were equipped with probes that recorded temperature, pH, dissolved oxygen concentration, turbidity, and conductance. A pressure transducer also measured sonde depth. Data for the various parameters were recorded on 10-minute intervals. Sondes at the North and South Branch sampling sites internally logged data, which were retrieved when equipment was rotated out of the field. Data from the sonde located at the USGS Station site were transferred daily via modem to the internet for online viewing.

Water Quantity

Discharge at the downstream sampling site was calculated by USGS (Rantz 1982). USGS methods were also used to construct flow rating curves for the North and South Branch sites using fixed gage readings, sonde depths, and discharge measurements collected at various stages.

Whenever possible, discharge measurements were sampled via wading using USGS standard methods (Rantz 1982). Stream velocity measurements were taken with a Marsh-McBirney Model 2000 Flo-Mate portable flowmeter (Marsh-McBirney 1994). During high flow conditions, stream velocity at the North Branch site prohibited wading. Discharge measurements for staff gage readings over three feet were taken using the timed-float method (Rantz 1982). Cross-sections were established during low-flow at five transects along a 50-foot reach of stream channel. During events, depths at these locations were estimated using the staff gage reading, and velocity was measured by averaging the time it took an orange to float the length of the reach for three repetitions. Discharge was calculated by multiplying the average cross-sectional area by the average velocity measurement and a correction factor of 0.9 to account for channel bed friction.

Linear regression was used to develop a rating curve for each stream branch by relating stream discharge to gage height. The relationship between sonde depth and gage height was then used to calculate the continuous stream discharge at each site over the study period.

Sediment and Phosphorus Load Calculation

Loads for sediment and phosphorus were estimated by USGS for the downstream sampling location using standard methods (Porterfield 1972). For load estimation performed by USGS, GCLAS software was used as a tool to relate continuous streamflow and instantaneous concentration data from discrete samples. Additional estimation of sediment load at the North Branch and USGS Station sites utilized the relationship established between sonde turbidity measurements and sediment concentrations in Chapter 4 and the following equation:

Equation 3.1

$$\begin{pmatrix}\text{Average}\\ \text{Turbidity}\\ \text{(NTU)}\end{pmatrix}\times\begin{pmatrix}\text{Regression}\\ \text{Coefficient}\\ \text{(mg/L / NTU)}\end{pmatrix}\times\left(\frac{\begin{array}{c}\text{Average}\\ \text{Discharge (cfs)}\end{array}}{35.31\ \text{cf/m}^3}\right)\times$$

$$\left(\text{Time step (day)}\right)\times\left(\frac{86400\ \text{s}}{\text{day}}\right)\times\left(\frac{1000\ \text{L}}{\text{m}^3}\right)\times\left(\frac{1\ \text{metric ton}}{1{,}000{,}000{,}000\ \text{mg}}\right)=\text{metric ton per time step}$$

Total phosphorus loads were calculated for the North Branch using the turbidity-predicted sediment concentrations and the derived relationship between particulate phosphorus, sediment concentrations, and the dissolved phosphorus fraction.

Loads were not calculated at the South Branch site due to a lack of turbidity data. Because only the South Branch and Christa McAuliffe Park Ravine tributaries enter Baird Creek between the North Branch and USGS Station sites (Figure 3.1), the differences between estimated sediment and phosphorus loads at the upstream and downstream locations were considered to be contributed by the urbanizing segment of the watershed.

Statistical Analysis

Descriptive statistics were calculated for the concentration data during precipitation events and low-flow conditions at the three sites, including mean, median, minimum, and maximum values. Median values were more representative of the population center because high flow events skewed the distribution towards greater concentrations. Boxplots were constructed to graphically depict differences in concentrations between sites. Because concentration data were not normally distributed, analyses of variance on the ranks of the data were used in conjunction with the Tukey comparison procedure to determine if differences between sites were significant at the 95% confidence level (Robertson and Saad 1996). All analyses were performed using SAS 9.1 computer software (SAS Institute Inc. 2003).

Results and Discussion

Fourteen precipitation events were sampled over the study period of April to December 2004. Table 3.2 displays event dates and summarizes which sites collected samples during each event. Samples were not collected at the USGS Station site during

Table 3.2. Summary of precipitation events and sites collecting samples over the study period.

Event	North Branch	South Branch	USGS Station
May 8-9, 2004	X	X	
May 20-21, 2004	X	X	X
May 22-28, 2004	X	X	X
May 31-June 5, 2004	X	X	X
June 9-10, 2004	X	X	X
June 11, 2004	X	X	X
June 12-13, 2004	X	X	X
June 13-15, 2004	X	X	X
June 16-20, 2004	X	X	X
September 6, 2004			X
September 15, 2004			X
October 23, 2004			X
October 28, 2004			X
December 10, 2004	X	X	X

the event on May 8 and 9 because the threshold to trigger automated event sampling was set too low. Samples were not collected at the North and South Branch sites during the overnight rain events in September and October because of inaccurate weather forecasting. Also, no real-time stream data were collected by the YSI multi-parameter sondes at the North and South Branch sites until June 8 due to a glitch in the YSI computer software package. Therefore, load comparisons for the North Branch and USGS Station sites were based on the five precipitation events for which upstream discharge and turbidity measurements were available.

In all, 223 samples were collected and analyzed from the three sampling sites over the study duration. Sample results are contained in Appendix B. Table 3.3 shows the number of event and low-flow samples on a monthly basis, and summarizes the number of samples from each site analyzed for TSS, SSC, total phosphorus, and total dissolved phosphorus.

Precipitation

The 2004 sampling season was characterized by heavy spring flooding followed by a period of summer drought (Table 3.4). According to the National Weather Service, May 2004 was the second wettest May on record with 211.1 mm of precipitation. Although the total precipitation for the year was 7% above average, rainfall for the months of July through September was 59% below normal totals (National Weather Service 2004). Because of the lack of late summer and fall sampling events, the effects of seasonality on pollutant concentrations could not be analyzed for the study period.

Table 3.3. Summary of precipitation events, event and low-flow samples, and sample analysis for each Baird Creek sampling site, 2004.

	USGS Station	**North Branch**	**South Branch**
Total Number of Events:	**13**	**10**	**10**
With Sonde / Gage Data	13	5	5
Without Sonde Data	0	5	5
Total Number of Samples:	**63**	**85**	**75**
Event Samples:	**47**	**72**	**62**
April	0	0	0
May	20	32	31
June	20	39	30
July	0	0	0
August	0	0	0
September	2	0	0
October	2	0	0
November	0	0	0
December	3	1	1
TSS Samples	46	34	33
SSC Samples	2	38	29
Total Phosphorus Samples	46	33	31
Dissolved Phosphorus Samples	18	13	14
Low-flow Samples:	**16**	**13**	**13**
TSS Samples	16	13	13
Total Phosphorus Samples	16	13	13
Dissolved Phosphorus Samples	9	7	7

Table 3.4. Summary of 2004 monthly precipitation.
Note: December 2004 precipitation excludes snowfall.

Month	Baird Creek USGS Station	Green Bay National Weather Service	Green Bay 30-year Average	NWS Departure from Average
April 2004	33.3	39.6	65.0	-39%
May 2004	231.6	211.1	69.9	+202%
June 2004	102.4	123.7	87.1	+42%
July 2004	36.1	45.2	87.4	-48%
August 2004	30.7	50.8	95.8	-47%
September 2004	31.2	11.9	79.0	-85%
October 2004	92.5	94.2	55.1	+71%
November 2004	NA	45.7	57.7	-21%
December 2004	NA	57.4	35.8	+60%
Total (mm):		**679.7**	**632.7**	**+ 7%**

Total precipitation and rainfall intensities for the sampled runoff events are shown in Table 3.5. The maximum recorded 10-minute intensity was 65.5 mm/hr for the storm beginning on June 9. The maximum 60-minute intensity was observed for the storm beginning on May 31, closely followed by the events of June 9 and June 16. The high intensity of these precipitation events explained corresponding spikes in stream turbidity as discussed in Chapter 4.

Discharge

Discharge at the downstream sampling site was calculated by USGS for the study period. Figure 3.6 displays continuous discharge and discrete samples collected at the USGS Station site during the high flow events of May and June 2004. The maximum discharge recorded was 444 cfs, which occurred during the event of May 31. The

Table 3.5. Total precipitation depths and intensities observed for sampled runoff events.

Precipitation Start Date	**Total Rainfall (mm)**	**Maximum 10-minute intensity (mm/hr)**	**Maximum 30-minute intensity (mm/hr)**	**Maximum 60-minute intensity (mm/hr)**
5/8/2004	31.8	18.3	12.7	8.6
5/20/2004	22.1	30.5	21.3	13.2
5/22/2004	60.7	32.0	18.3	10.7
5/31/2004	56.6	39.6	30.0	22.9
6/9/2004	36.8	65.5	34.5	17.5
6/11/2004	13.2	6.1	5.1	3.6
6/12/2004	4.8	21.3	8.1	4.1
6/13/2004	15.2	15.2	8.1	5.3
6/16/2004	19.1	27.4	19.8	16.3
9/6/2004	15.2	16.8	9.1	6.6
9/15/2004	15.2	64.0	28.4	14.7
10/23/2004	25.7	21.3	13.2	7.4
10/28/2004	33.5	21.3	18.3	15.0
12/10/2004	NA	NA	NA	NA

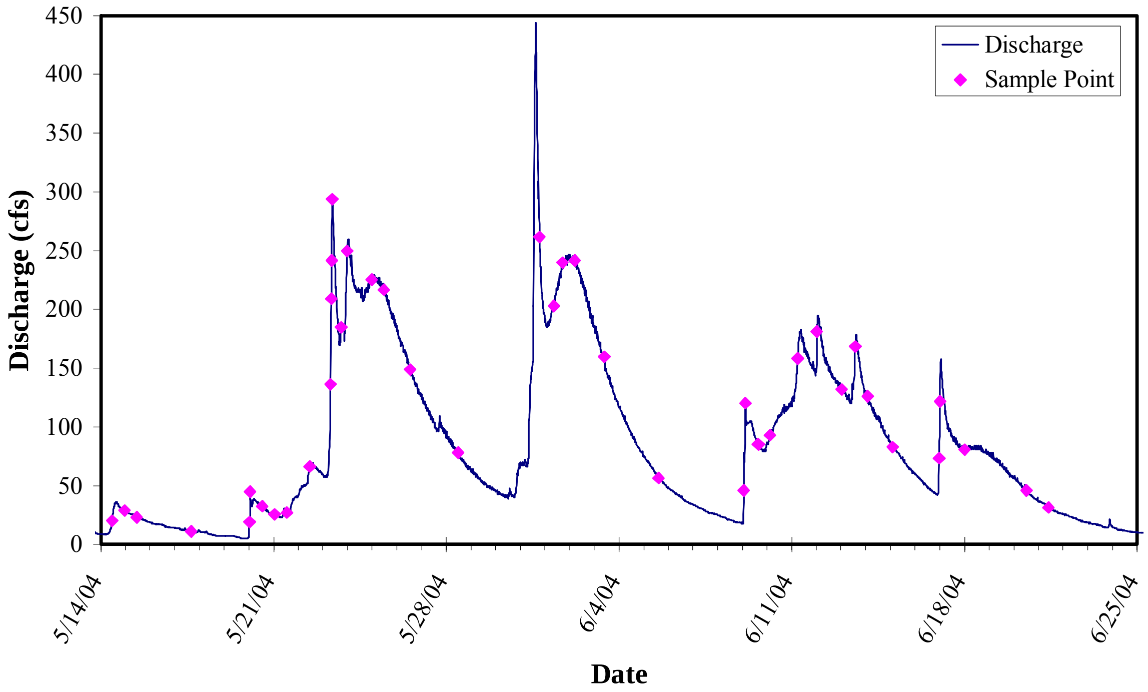

Figure 3.6. Continuous discharge and discrete sample collection points for the USGS Station site, 14 May to 25 June, 2004.

hydrograph pattern for storm events at the USGS Station displayed a unique signature, characterized by a high initial spike, followed by a more rounded peak. It is hypothesized that this pattern was caused by the rapid initial storm flush from the urbanized portions of the watershed, shadowed by the more gradual release of stormwater from the headwater wetlands. The pattern was less visible during the storm events of June 9 through 20, where the daily occurrence of precipitation events exceeded the wetland storage capacity and produced more frequent hydrograph peaks.

Linear regression was used to establish flow rating curves for the North and South Branch sampling sites. Discharge was best explained by a log-log relationship with staff gage height. The North Branch site required separate equations for low and high flow conditions. Equation 3.2 displays the relationship for gage heights greater than 1.78 feet ($R^2 = 0.9949$), followed by Equation 3.3 for gage heights less than or equal to 1.78 feet ($R^2 = 0.8571$):

$$\text{Gage ht.} > 1.78\text{'}: \quad \text{LN(Discharge)} = 3.3636(\text{LN(Gage)}) + 0.6758 \qquad \textit{Equation 3.2}$$

$$\text{Gage ht.} \leq 1.78\text{'}: \quad \text{LN(Discharge)} = 7.3921(\text{LN(Gage)}) - 1.6559 \qquad \textit{Equation 3.3}$$

One equation was sufficient to explain the relationship between gage height and discharge for the South Branch site ($R^2 = 0.9624$):

$$\text{LN(Discharge)} = 2.2874(\text{LN(Gage)}) + 2.3779 \qquad \textit{Equation 3.4}$$

As noted earlier, continuous discharge was only available for the upstream sampling sites beginning June 8, 2004. Figures 3.7 and 3.8 display continuous discharge and discrete samples collected at the North and South Branch sites, respectively, during the high flow events of June 8 to June 20, 2004. The maximum recorded discharge for this time period was 158 cfs at the North Branch site and 38 cfs at the South Branch site. The South Branch hydrograph showed sharper peaks in streamflow in response to precipitation events than the North Branch site. The sharp increases in discharge shown on both branches during events beginning on June 9 and June 16 were in response to the high storm intensities recorded in Table 3.5. The dramatic rise on June 12 occurred in response to relatively light precipitation. However, this rainfall occurred when both stream systems were still saturated from previous events, and antecedent moisture conditions caused high runoff rates and the associated sharp response shown by the streams.

Relative flow contributions of the North Branch and the urbanizing section of the watershed to the USGS Station site were compared for June 9 – 20, 2004 (Table 3.8). Although the North Branch watershed comprised 81.5% of the total area above the USGS Station, the percentage of discharge it contributed to the downstream site ranged from 58% to 78% of the mean daily flow over this period of five precipitation events, with an average of 69%. Therefore, the South Branch and the watershed downstream of the confluence contributed approximately 30% of the average daily discharge during flow events, an amount disproportionate to land area. The additional flow may have resulted from a combination of increased impervious cover, higher connectivity from storm sewers, and steeper topography in the local watershed.

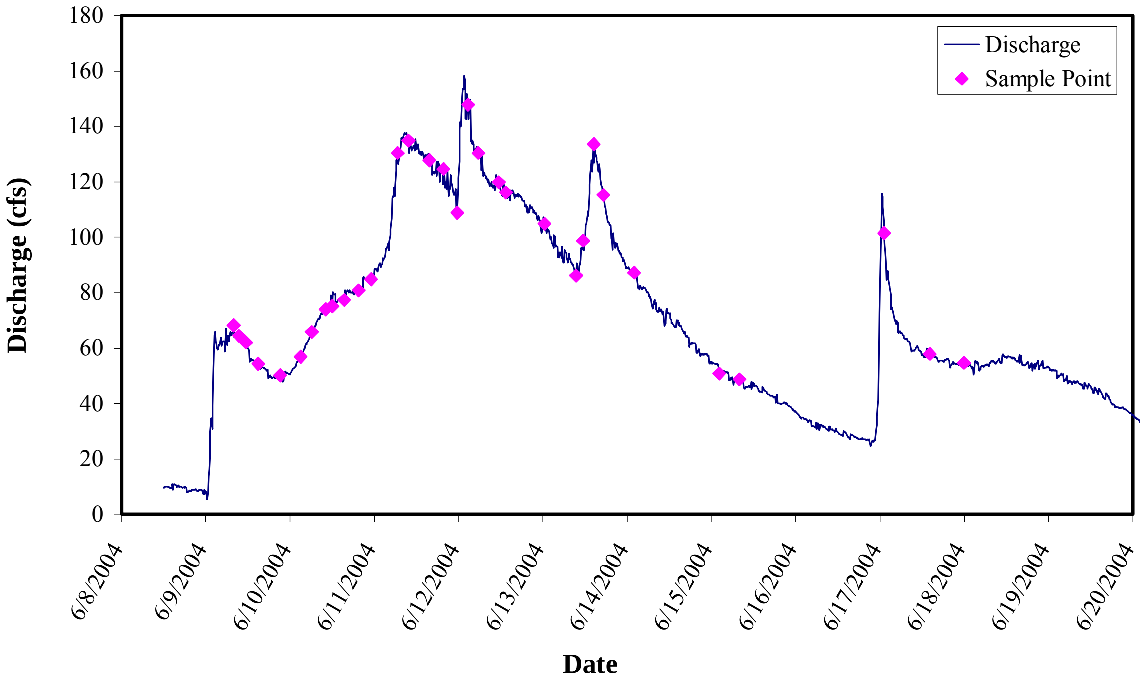

Figure 3.7. Continuous discharge and discrete sample collection points for the North Branch site, 8 June to 20 June, 2004.

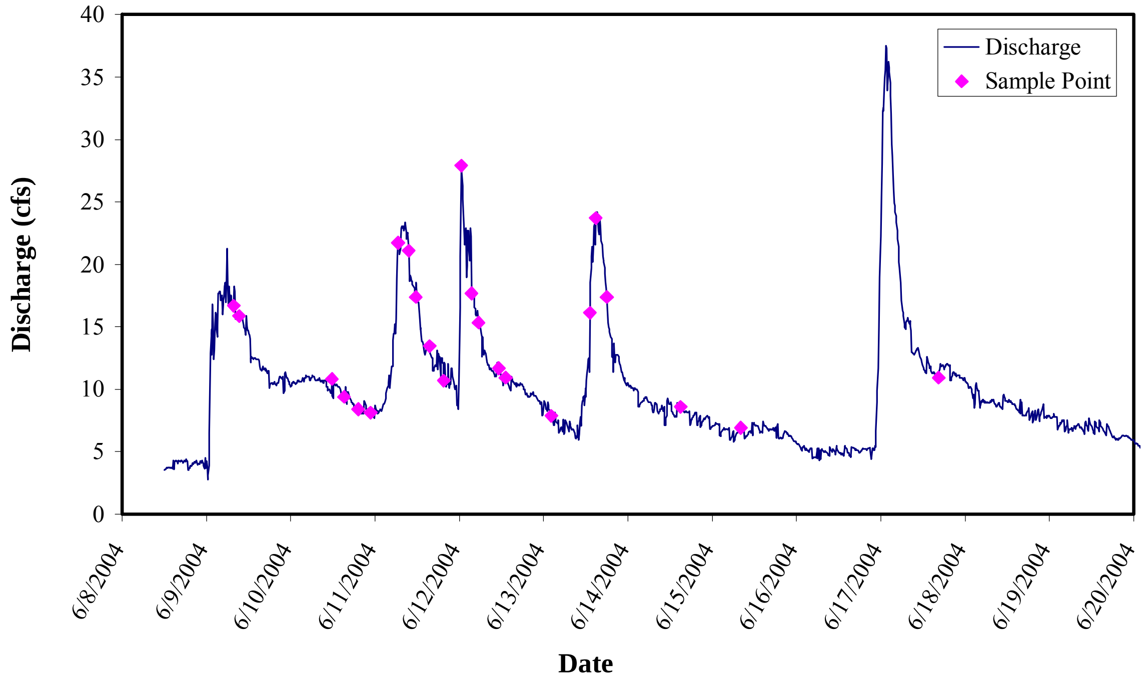

Figure 3.8. Continuous discharge and discrete sample collection points for the South Branch site, 8 June to 20 June, 2004.

Sediment and Phosphorus Concentrations

Descriptive statistics for the concentration data collected during precipitation events and low-flow conditions at the three sites are shown in Table 3.6. Boxplots depicting differences in pollutant concentrations between sites are displayed in Figure 3.9. These plots show the skewed distribution resulting from concentrations sampled during high flow events. Because data were not normally distributed, median values were more representative of the population center. Results from analyses of variance performed on the ranks of the data in conjunction with the Tukey comparison procedure are shown in Table 3.7.

Results for Sediment Comparisons

Median event TSS concentrations for the USGS Station, North Branch, and South Branch sites were 105 mg/L, 72 mg/L, and 182 mg/L, respectively. The highest recorded TSS concentration was 4,920 mg/L, which was collected at the South Branch site on May 23, 2004. Event TSS concentrations were significantly higher at the South Branch site than at the North Branch for the 95% confidence level. However, neither site statistically differed from concentrations observed at the USGS Station site downstream. Median low-flow concentrations for the USGS Station, North Branch, and South Branch sites were 7.9 mg/L, 6.7 mg/L, and 6.7 mg/L, respectively. None of the sites significantly differed at the 95% confidence level under low-flow conditions.

SSC concentrations did not significantly differ from TSS concentrations at the North Branch. This was visually confirmed by the lack of sand-sized particles remaining on the filters. For the South Branch, SSC concentrations were significantly higher than TSS concentrations, which was expected due to the high fraction of sand in the samples.

Table 3.6. Descriptive statistics for event and low-flow sediment and phosphorus samples.

Parameter	Event Samples			Low-flow Samples		
	USGS Station	North Branch	South Branch	USGS Station	North Branch	South Branch
TSS (mg/L):						
Number	46	34	33	16	13	13
Mean	283	154	481	8.75	6.37	6.22
Median	105	72	182	7.90	6.70	6.70
Maximum	1640	996	4920	31	13	10
Minimum	15	13	14	2	2	2
SSC (mg/L):						
Number	-	38	29	-	-	-
Mean	-	164	1665	-	-	-
Median	-	96	690	-	-	-
Maximum	-	720	10151	-	-	-
Minimum	-	24	9	-	-	-
Total Phosphorus (mg/L):						
Number	46	33	31	16	13	13
Mean	0.66	0.62	1.12	0.17	0.20	0.19
Median	0.53	0.54	0.63	0.15	0.15	0.16
Maximum	2.17	2.15	7.60	0.34	0.57	0.42
Minimum	0.15	0.11	0.33	0.07	0.09	0.05
Total Dissolved Phosphorus (mg/L):						
Number	18	13	14	9	7	7
Mean	0.27	0.35	0.28	0.12	0.13	0.14
Median	0.26	0.27	0.27	0.10	0.09	0.11
Maximum	0.41	1.21	0.50	0.23	0.25	0.27
Minimum	0.09	0.16	0.11	0.05	0.08	0.05
Total Dissolved Phosphorus (% Total P):						
Number	18	13	14	9	7	7
Mean	43%	50%	36%	66%	76%	72%
Median	43%	50%	33%	65%	80%	69%
Maximum	89%	93%	81%	83%	100%	100%
Minimum	12%	18%	2%	56%	57%	44%

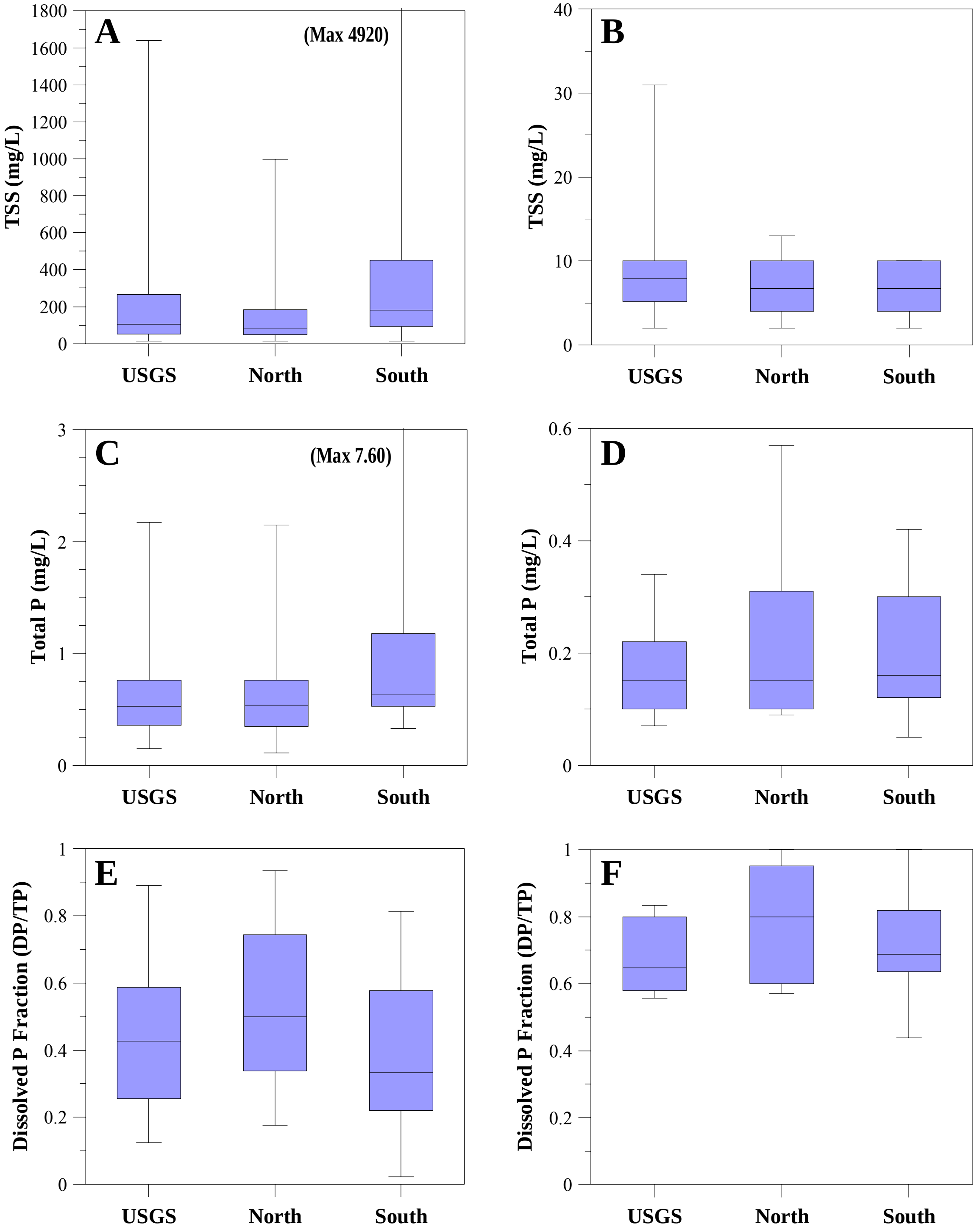

Figure 3.9. Boxplots showing upper limit, 75th quartile, median, 25th quartile, and lower limit values for (a) event TSS concentrations, (b) low-flow TSS concentrations, (c) event total phosphorus concentrations, (d) low-flow total phosphorus concentrations, (e) event dissolved phosphorus fraction, and (f) low-flow dissolved phosphorus fraction.

Table 3.7. Results from statistical analyses of concentration data.

Comparison	F	p-value	Significant?	Result of Tukey Comparison
Event TSS	4.38	0.0142	Yes	South higher than North
Low-flow TSS	0.68	0.5136	No	
Event Total Phosphorus	4.42	0.0143	Yes	South higher than North and USGS
Low-flow Total Phosphorus	0.05	0.9504	No	
Event Dissolved Phosphorus	1.18	0.3178	No	
Low-flow Dissolved Phosphorus	0.67	0.5236	No	
SSC vs TSS - North Branch	1.05	0.3080	No	
SSC vs TSS - South Branch	7.59	0.0078	Yes	South Branch SSC higher than TSS

Results for Phosphorus Comparisons

Median event total phosphorus concentrations for the USGS Station, North Branch, and South Branch sites were 0.53 mg/L, 0.54 mg/L, and 0.63 mg/L, respectively. The highest recorded total phosphorus concentration was 7.60 mg/L, which was collected at the South Branch site on May 23, 2004. This sample also recorded the highest sediment concentration, indicating that most of the phosphorus was in particulate form. Event total phosphorus concentrations were significantly higher at the South Branch site than at either the North Branch or USGS Station sites for the 95% confidence level. However, the North Branch and the USGS Station sites did not statistically differ from each other. Median low-flow total phosphorus concentrations for the USGS Station, North Branch, and South Branch sites were 0.15 mg/L, 0.15 mg/L, and 0.16 mg/L, respectively. None of the sites significantly differed at the 95% confidence level.

Median event dissolved phosphorus concentrations reported as the fraction of total phosphorus for the USGS Station, North Branch, and South Branch sites were 43%, 50%, and 33%, respectively. None of the sites statistically differed at the 95% confidence level. However, the data show that a substantial portion of the phosphorus is in the dissolved form even under high flow conditions. Median low-flow percent dissolved phosphorus concentrations for the USGS Station, North Branch, and South Branch sites were 65%, 80%, and 69%, respectively. Although the dissolved phosphorus fraction appeared higher at the North Branch site, it did not significantly differ at the 95% confidence level, possibly due to the low sample size.

Comparisons to Previous Studies

Nutrient and sediment concentrations collected in this study were compared to those from the 1971 to 1990 USGS study of the Western Lake Michigan Drainage Basin and the 2001 to 2002 WDNR study on Baird Creek (Robertson and Saad 1996, Reyburn 2003). The median value for event suspended sediment concentrations collected in 2004 at the North Branch site (72 mg/L) exceeded the agricultural land use median recorded from the USGS study (50.0 mg/L). Similarly, the South Branch site (182 mg/L) was higher than the median sediment concentration previously recorded for urban areas (148.0 mg/L). Based on watershed land use, the median sediment concentration at the USGS Station site (105 mg/L) corresponds to the earlier study as the observed value lies between the two prior medians for agricultural and urban areas. The median and range of TSS concentrations recorded at all locations in 2004 exceeded values from the prior WDNR study. This was expected due to the lack of event samples from the earlier study.

The median value for event total phosphorus concentrations collected in 2004 at the North Branch site (0.54 mg/L) was over three times the agricultural land use median recorded from the USGS study (0.16 mg/L). Similarly, the South Branch site (0.63 mg/L) and the USGS Station site (0.53 mg/L) far exceeded the median total phosphorus concentration previously recorded for urban (0.11 mg/L) and agricultural land use. The median and range of total phosphorus concentrations recorded at all locations in 2004 also exceeded values from the prior WDNR study.

Load Comparisons

For comparison between upstream and downstream sites, sediment and phosphorus loads were calculated for the period of events with available sonde data from June 9 through June 20. As established in Chapter 4, turbidity-derived load estimates for this time period were within 10% of the sediment loads calculated by USGS using GCLAS software. Therefore, turbidity-based load estimates for sediment and phosphorus were used for comparisons between the USGS Station and North Branch sites. The differences between estimated sediment and phosphorus loads at the upstream and downstream locations were considered to be contributed by the urbanizing segment of the watershed.

Mean daily discharge and sediment loads calculated for the USGS Station and North Branch sites are shown in Table 3.8. The percentage of the sediment load provided by the North Branch ranged from 23% to 83% of the daily load at the USGS Station site over the selected period of events. Although the North Branch provided approximately 60 to 70% of the total flow at the downstream site over this time period, it only contributed 30 to 40% of the overall suspended solids load. The source for the remainder of the sediment load was assumed to be the South Branch and the watershed downstream of the confluence, which were the areas transitioning to urban land use. Therefore, only 18.5% of the total watershed area upstream of the USGS Station contributed 60 to 70% of the total sediment load observed at the site.

Table 3.8. Mean daily discharge and turbidity-derived suspended sediment and total phosphorus loads for the USGS Station and North Branch sites, 9 – 20 June, 2004.

Date	**Mean Daily Discharge, cfs**				**Suspended Solids Load, metric tons**				**Total Phosphorus Load, kg**		
	USGS Station	**North Branch**	**North B. % of USGS Station**		**USGS Station**	**North Branch**	**North B. % of USGS Station**		**USGS Station**	**North Branch**	**North B. % of USGS Station**
06/09/04	84.1	53.6	64%		174	72	41%		200	160	80%
06/10/04	105.0	72.6	69%		38	14	38%		152	107	70%
06/11/04	154.2	119.2	77%		60	17	28%		244	150	62%
06/12/04	155.7	121.6	78%		89	27	31%		209	160	77%
06/13/04	138.8	101.7	73%		62	17	27%		174	127	73%
06/14/04	108.2	71.2	66%		12	4	34%		104	66	63%
06/15/04	73.8	45.8	62%		4	2	58%		76	40	52%
06/16/04	50.7	30.9	61%		3	2	67%		59	28	47%
06/17/04	99.7	63.8	64%		124	28	23%		225	113	50%
06/18/04	81.0	54.5	67%		12	5	41%		91	58	64%
06/19/04	67.9	44.8	66%		4	3	63%		71	41	58%
06/20/04	47.1	27.3	58%		2	1	83%		44	24	54%
Average:	**97.2**	**67.2**	**69%**	**Total:**	**583**	**192**	**33%**	**Total:**	**1649**	**1074**	**65%**

Total phosphorus loads were calculated for the North Branch site using the continuous turbidity-predicted sediment concentrations and the derived relationship between particulate phosphorus, sediment concentrations, and the dissolved phosphorus fraction. The relationship between particulate phosphorus and sediment concentrations for the North Branch was determined using linear regression. One outlying data point with a residual that exceeded 2.5 standard deviations from the predicted line was removed from the set. The final relationship between particulate phosphorus and sediment at the North Branch site was highly significant at the 95% confidence level ($n = 19$; $R^2 = 0.9916$; $p < 0.0001$), and accounted for over 99% of the variance:

$$\text{Particulate Phosphorus} = 0.0013(\text{TSS}) + 0.0334 \qquad \textit{Equation 3.5}$$

Linear regression was also used to establish the relationship between the dissolved phosphorus fraction and total phosphorus concentrations at the North Branch site. One outlying data point with a residual that exceeded 2.5 standard deviations from the predicted line was removed. The final relationship between dissolved phosphorus fraction and total phosphorus at the North Branch required a logarithmic transformation of the dependent variable. The regression was highly significant at the 95% confidence level ($n = 19$; $R^2 = 0.7686$; $p < 0.0001$), and accounted for 77% of the variance:

$$\text{LN(Dissolved P Fraction)} = -0.9687(\text{Total P}) - 0.1252 \qquad \textit{Equation 3.6}$$

Using the above relationships, instantaneous total phosphorus concentrations were calculated for 10-minute continuously-predicted sediment concentrations using the following equation:

$$\text{Total P Concentration} = \left(\frac{\text{Particulate P Concentration}}{1 - (\text{Dissolved P Fraction})} \right) \qquad \textit{Equation 3.7}$$

Predicted instantaneous total phosphorus concentrations and discharge were then used to calculate phosphorus loads for the North Branch site. Table 3.8 displays phosphorus loads at the USGS and North Branch sites for the period of June 9 to 20, 2004. The percentage of the phosphorus load provided by the North Branch ranged from 47% to 80% of the daily load at the USGS Station site over the selected period of events. Overall, the North Branch supplied approximately 60 to 70% of the phosphorus load observed at the USGS Station site for this timeframe. This percentage was disproportionate to the relative size of the North Branch to the overall watershed area, but mirrored the proportion of flow contributed by the North Branch during this time.

Several factors may explain the variability in the proportion of flow and the sediment and phosphorus loads observed over the period of events. Uneven distribution of rainfall across the upper portion of the watershed may account for some of the daily variability in discharge. Also, the proportion of flow provided by the North Branch increased during more frequent storm events, indicating that the storms exceeded the storage capacity of the headwater wetlands and therefore delivered more runoff to the stream. The highest percentages of daily sediment load contributed by the North Branch were observed during hydrograph recessions, showing that the North Branch carried fine sediment particles throughout entire storm events whereas the urbanizing tributaries contributed greater proportions of sediment at the beginning of events. The lowest percentage of sediment contributed by the North Branch occurred on June 17, which may be explained by massive bank failures on the urbanizing tributaries in response to the high storm intensity. Variability in phosphorus loads closely paralleled the daily mean discharge from the North Branch, except on June 9 and June 11. The North Branch contributed a much higher percentage of the phosphorus load than anticipated by discharge on June 9. Because this date was the first of several storm events for the period, the higher levels of phosphorus contributed on this date may have been the "first flush" resulting from easily moved deposits from upstream. Phosphorus loads were relatively low compared to discharge on June 11. This may be explained by the slow rise of the hydrograph over the previous day and this event, which indicated discharge from the upstream wetlands complex that may have carried less phosphorus than typical runoff.

Conclusions

The above results indicate that urbanization is adversely impacting the water quality of Baird Creek. Discharge was proportionally higher from the urbanizing segment of the watershed, with the agricultural North Branch accounting for 81.5% of the total land area but only 60 to 70% of the discharge observed at the downstream station over a period of summer storm events. Statistical analysis showed that event sediment concentrations were significantly higher on the urbanizing South Branch than on the agricultural North Branch at the 95% confidence level, and that the North Branch contributed only 30 to 40% of the total sediment load observed for the selected events. The remaining 60 to 70% of the sediment load was attributed to the South Branch and the watershed downstream of the confluence point. Therefore, although the portion of the watershed actively transitioning to urban land use only comprised 18.5% of the total watershed area, it contributed a disproportionately high amount of the sediment load in Baird Creek.

Despite statistically higher total phosphorus concentrations during storm events on the South Branch, the observed phosphorus load was consistent with the proportion of discharge provided by each branch of the stream. This may be explained by apparently higher dissolved phosphorus concentrations during event flows on the North Branch, although the difference was not statistically significant. However, because discharge was disproportionately higher for the urbanizing segment of the watershed, this area contributed more phosphorus on a per area basis than the agricultural North Branch.

Connection to In-stream Biota Populations

Sediment loading from the urbanizing section of the Baird Creek watershed may also explain changes in the aquatic ecosystem. Studies in 1998, 1999, 2003, and 2004 by St. Norbert College and the University of Wisconsin – Milwaukee (UWM) indicated that the composition of the fish population in Baird Creek is shifting towards more tolerant species (Lake Michigan Forum 2004, LFRWMP 2005). As shown in Table 3.9, intolerant fish species such as redside dace and rosyface shiners dramatically declined in abundance between 1998 and 2004. Although not classified as intolerant by the IBI ranking, the Baird Creek Watershed Stewardship Assessment also labeled the fantail darter as a sensitive species in decline (Lake Michigan Forum 2004). Over the same period, there was a simultaneous increase in the numbers of tolerant species such as green sunfish and blacknose dace. IBI scores for individual fish samples taken in 2004 by UWM at the USGS Station site and on the North and South Branches were 33, 31, and 20, respectively. The scores indicated fair quality ratings for the USGS Station and North

Table 3.9. Fish species collected on Baird Creek as a percentage of total abundance. Sampling conducted by St. Norbert College in 1998 - 1999 and UW-Milwaukee in 2003 - 2004. Tolerance classification from Lyons (1992) indicates intolerant (I), tolerant (T), and unrated (-) species for warmwater streams in Wisconsin.

Species	**IBI Tolerance Classificantion (Lyons 1992)**	**1998**	**1999**	**2003**	**2004**
Redside Dace	I	30%	14%	3%	8%
Rosy Face Shiner	I	0.3%			
Black Bullhead	-			0.7%	
Brook Stickleback	-	7%	6%	5%	17%
Common Shiner	-	5%	1%	2%	0.3%
Fantail Darter	-	2%	1%		0.1%
Johnny Darter	-	11%	6%	3%	7%
Longnose Dace	-		0.2%		
Northern Redbelly Dace	-	4%	0.4%		
Pearl Dace	-		6%	2%	21%
Southern Redbelly Dace	-				0.2%
Blacknose Dace	T	3%	15%	20%	19%
Central Mudminnow	T	2%	5%	2%	3%
Creek Chub	T	27%	43%	44%	21%
Fathead Minnow	T	5%	0.2%		
Green Sunfish	T			0.2%	0.4%
White Sucker	T	4%	2%	19%	3%
Total Sample Size		**393**	**471**	**411**	**1103**

Branch sites, but poor quality on the South Branch. Considering the results of the water quality study, it is unsurprising that the integrity of the aquatic community also appears to be declining.

Implications for Land Use Management

Recent community efforts by the Baird Creek Preservation Foundation have focused on purchasing land within the headwaters of the North Branch watershed in order to protect water quality in the stream. Although this is a worthy goal, this study indicates that any efforts to ensure stream integrity also need to focus on the watershed downstream of the confluence and on the South Branch. Best management practices (BMPs) for mitigating stormwater impacts from existing and future development should be investigated. In particular, practices that provide stormwater infiltration should be highly encouraged to reduce flashy peaks in storm hydrographs and to lessen the potential for stream channel and bank erosion. Example BMPs that could be implemented include providing bioretention swales along flow paths, encouraging rain gardens on individual residential lots, and designing larger retention basins that provide additional storage for more frequent design events.

As shown in Chapter 2, the Baird Creek watershed is currently in transition between agricultural and urban land use. With over 4% of the South Branch and 20% of the Christa McAuliffe Park Ravine watersheds under active construction in May 2004, these conditions may also have contributed to the high sediment concentrations observed in the stream. Although the City of Green Bay requires developers to utilize erosion control practices, higher than average precipitation in May and June 2004 may have complicated efforts to maintain these BMPs over frequent storm events. Because the status and effectiveness of BMPs over the study period were undocumented, future research after watershed build-out may assist in determining relative contributions of sediment due to construction site erosion in this study.

Study Limitations and Opportunities for Future Research

Precipitation did not follow historic patterns during the 2004 sampling season. Heavy spring flooding may have affected concentration and load data for sediment and phosphorus, and the late summer drought and spring sonde equipment failures at the upstream sites eliminated the possibility of examining the effects of seasonality. Although use of specific load and concentration values for detailed modeling efforts should be done with hesitation, the results from this study can still be used to make generalizations about the impacts of urbanization on Baird Creek and can also identify opportunities for further study.

Continuation of sampling at the North Branch site would provide additional data points for comparison and assist with modeling efforts. Due to the difficulty of accurately sampling the South Branch site, it is recommended that any effort to quantify loads from the urbanizing part of the watershed be accomplished by subtraction of the North Branch contribution from the USGS Station site. Characterization of particle-size and phosphorus concentrations of bank materials on the North Branch, South Branch, and other tributaries may also prove valuable in understanding potential sources of sediment and phosphorus. Finally, as the watershed continues to develop, changes in observed concentrations and loads may provide insight on the effectiveness of BMPs in controlling erosion and protecting predevelopment hydrology.