Preliminary Watershed Assessment: Deer Creek Watershed

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Executive Summary

The Deer Creek watershed, located in Ottawa and Muskegon Counties in west Michigan, is relatively small in area (~ 9,050 ha or 22,362 acres), yet faces a number of severe environmental problems. An assessment of nutrient loading was conducted to provide preliminary information to assess the magnitude of the problem and identify critical areas for remediation and/or additional investigations. The assessment included the following elements:

- An inventory of current land cover and land use
- Water quality analyses at selected locations in the watershed for temperature, major nutrients, *E. coli*, and stream discharge
- Development of nutrient and suspended sediment loading estimates related to the sampling sites and their respective drainage areas
- Identification of key issues and areas of concern in the Deer Creek watershed

The GIS analysis revealed that agricultural land use dominated the landscape (85%) followed by forest (8%), wetland (3%), and urban (3%). Riparian zones exist, but they have been modified and no longer protect the adjacent habitat. Consequently, the hydrology and water quality of Deer Creek were impacted by agricultural nonpoint source pollution. Although the watershed has a highly modified land cover, the temperature regime of Deer Creek is still capable of supporting a cool water fishery.

High concentrations of suspended sediment, nutrients and *E. coli* were found at all eight locations that spanned the course of the main branch of Deer Creek. Total phosphorus concentrations were above levels recommended by the EPA to prevent eutrophication. Stream discharge and nutrient loadings also were examined. In the limited sampling conducted, a 30-fold difference between stream discharge at base flow and high flow was noted. These conditions indicate unstable hydrology that responds dramatically to rain events. Unstable hydrology coupled with agricultural land use and limited natural cover in riparian zones have resulted in a stream that was highly impacted by erosion and sedimentation. Adverse hydrological conditions also promote the excessive loading of nutrients in Deer Creek. Two major problem areas were identified with respect to nutrient loads:

- The subwatershed area between Roosevelt St and Cleveland St, including the subwatershed of Beaver Creek, was the major source of loadings for most nutrients.
- The small subwatershed area from Pin Oak (near I-96) to Garfield St produces the largest nutrient loadings per unit area.

The development of a comprehensive watershed management plan that addresses the above issues in conjunction with a basin wide strategy to limit runoff by stabilizing hydrology through BMPs is essential for the restoration of water quality in Deer Creek.

1.0 Introduction

1.1 Watershed Background

Deer Creek is a third-order stream located in the lower Grand River basin (Figure 1.1). The stream drains a 9,050 hectare (22,362 acre) watershed situated in southeastern Muskegon and northeastern Ottawa Counties in western Michigan. The Grand River is part of the Lake Michigan basin and is the lake's largest contributor of suspended sediment and total phosphorus loads (Robertson 1997). Significant agricultural activity has resulted in extreme hydrologic fluctuations, nutrient loadings, oxygen depletion, and sedimentation in Deer Creek (MDEQ 2000 a and b). Most of the creek is included in the Michigan Department of Environmental Quality's Section 303(d) list for not meeting designated uses related to benthic invertebrates, fish kills, nutrient enrichment, and pathogens (MDEQ 2000a). Previously, the inclusion of Deer Creek on the 303(d) list was related to excessive sewage discharges from the Coopersville wastewater treatment lagoons. This discharge was removed from the creek in the mid 1990s and rerouted to the Grand River. The soils in the watershed are mostly loams, and the dominant land use is agriculture. The watershed consists of four tributaries: Deer Creek, Little Deer Creek, McEwan Creek, and Beaver Creek, and a number of smaller tributaries and county drains (Fig. 1.2).

Deer Creek is similar to many midwestern watersheds that are impacted by agricultural and urban runoff. Common stressors present in these systems are induced by changing land use patterns (Beaulac and Reckhow 1982, Wiley et al. 1997, Carpenter et al. 1998, Vanni et al. 2001). Specific challenges facing the Deer Creek watershed include riparian zone destruction, sheet and rill erosion, runoff from manure storage areas and farm fields, sedimentation, excessive temperature variation, and habitat loss. A four-year water quality assessment of Pigeon Creek, a similar watershed within Ottawa County, found stream discharge and nutrient loading followed a seasonal pattern with high flows and loadings in March - May and lower flow and loading in the summer period (McDonald et al. 2001). Water quality improved during the summer with the predominance of groundwater accrual. In contrast, excessive nutrient loading during low flow periods in Deer Creek has resulted in fish kills due to oxygen depletion (MDEQ 2000b). An investigation of nutrient loading in the Deer Creek watershed that examines spatial and temporal trends has not been conducted. This information is essential to the development of water quality management strategies to reduce nutrient loadings and improve land use practices in the watershed. By conducting these assessments on a subwatershed basis, the significance of tributary sources can be determined with the goal of reducing nutrient loads to the Grand River and Lake Michigan.

1.2 Project Objectives and Task Elements

The objectives of this project were to conduct a preliminary assessment of sediment and nutrient loading in the Deer Creek watershed and to identify areas of significant change

Figure 1.1. Location of Deer Creek Watershed.

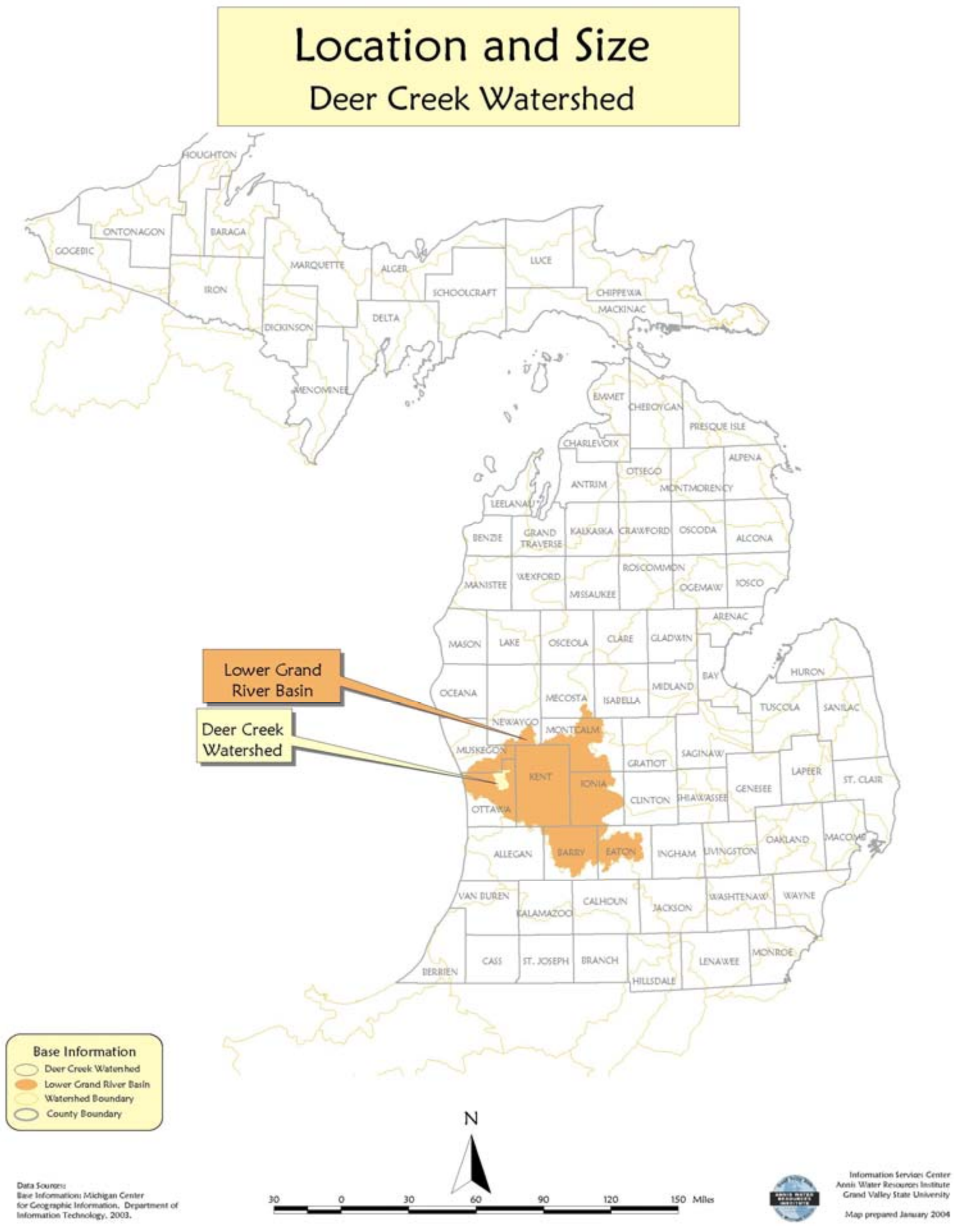
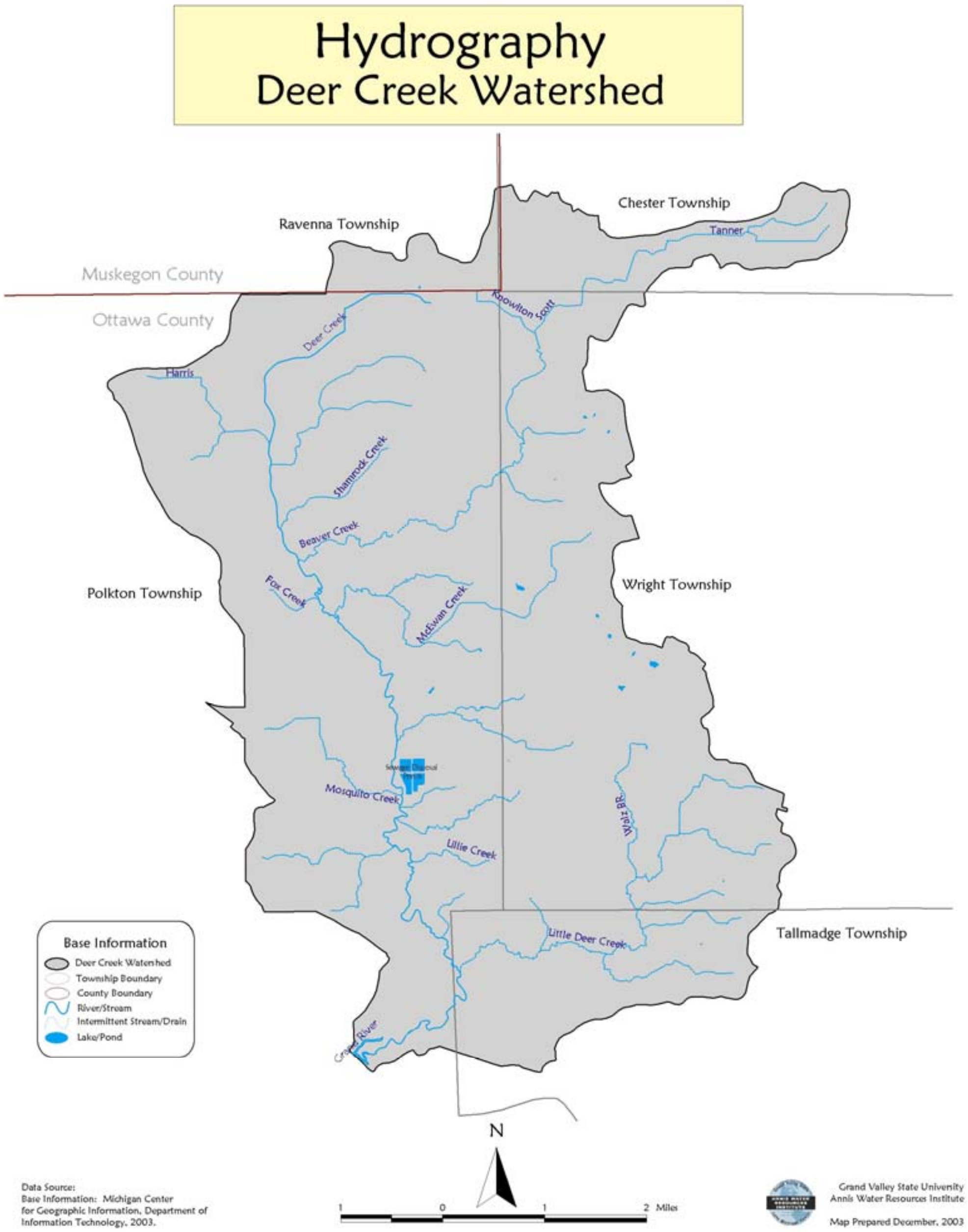


Figure 1.2. Hydrography of Deer Creek Watershed.



and degradation. A series of water chemistry samples were collected to evaluate nutrient and bacteria concentrations at eight locations from May – October 2003. Stream flow measurements also were conducted to develop estimates of nutrient loading. These samples were collected to assist in our understanding of the contribution of selected areas in the watershed to the problem of nutrient loading. Land use and watershed characteristics were based on GIS data (Michigan Center for Geographic Information, MCGI), developed by AWRI's Information Services Center. Specific objectives and task elements are summarized below:

- Inventory land cover and land use conditions and develop an assessment of current status.
- Sample and analyze selected locations in the watershed for suspended sediment, major nutrients, *E. coli*, and stream discharge.
- Develop preliminary estimates of suspended sediment and nutrient loadings related to the sampling sites and their respective drainage areas.
- Identify key issues and areas of concern in the Deer Creek watershed.

In this investigation, estimates of suspended sediment, nutrient loads, and concentration trends were developed during a seven month time period with limited sampling. Because of the hydrological variability present in the watershed, the project results provide a preliminary estimate of loadings. Since the project did not include rain event sampling and collections during the spring thaw and late fall, the results probably underestimate actual conditions. In addition, spring/summer monthly precipitation was less in 2003 than the previous year. Consequently, a more detailed investigation over multiple years would be required to adequately define the temporal and spatial nutrient loads and develop an annual estimate.

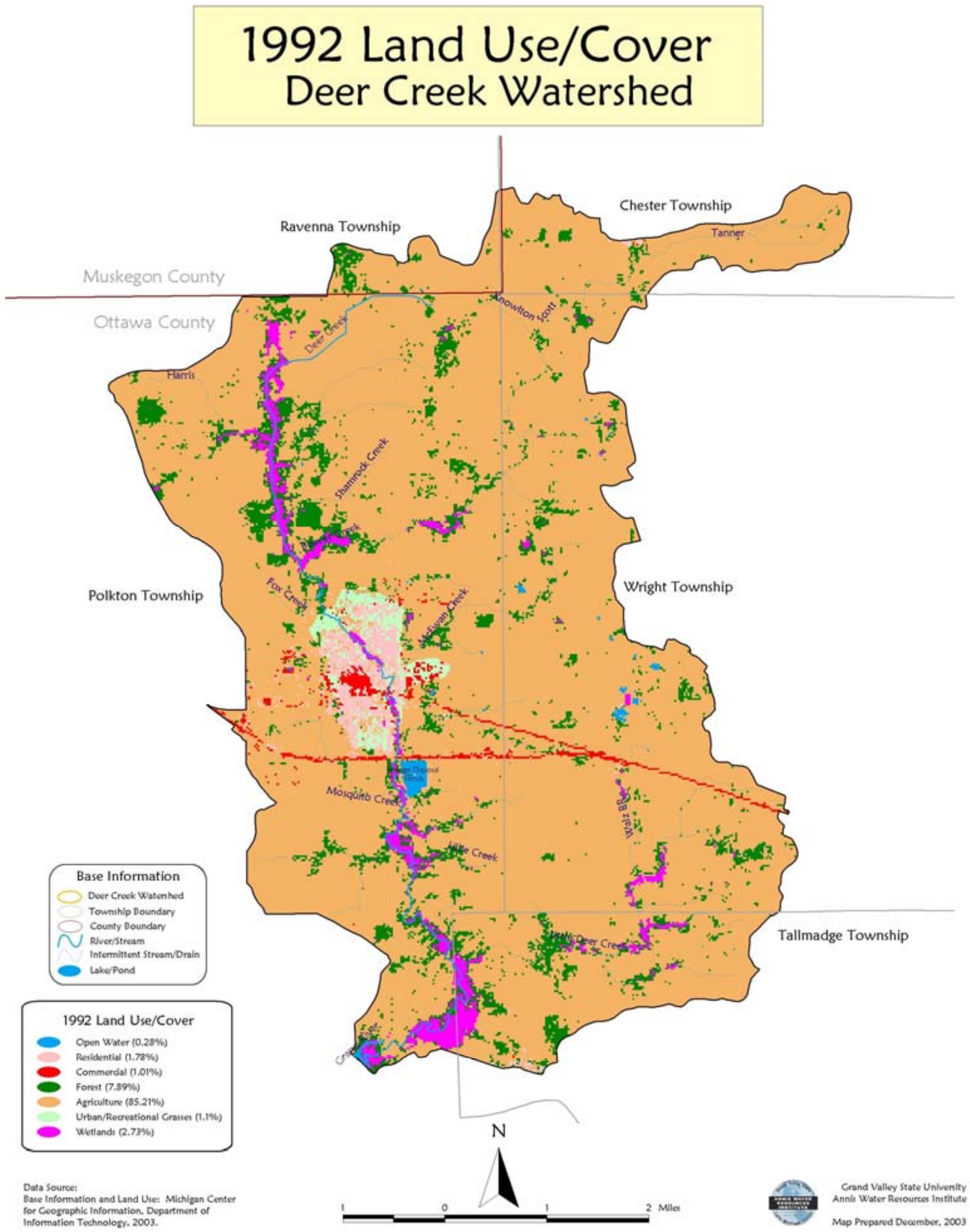
2.0 Land Use/Land Cover

Land cover analyses were conducted for the entire watershed using the 1992 National Land Cover Data Set developed by the United States Geological Survey (USGS) provided by MCGI. These data are presented in Table 2.1 and Figure 2.1. It should be emphasized that

Table 2.1. Major land use/land cover categories in Deer Creek watershed (1992).

Category	% Total	Acres
Forest	7.9	1,789
Agricultural	85	19,008
Wetlands	2.7	447
Residential/Commercial/Industrial	4.4	1,118

Figure 2.1. Land Use/Land Cover from 1992 for the Deer Creek Watershed.



although these are the most recent data available, land use changes in this watershed continue to take place. New commercial, retail, and residential developments are occurring in the Coopersville area and more producers are selling agricultural land for development. Polkton Township (40% of the watershed area) is the only governmental unit that restricts residential development in agricultural areas with zoning. Agricultural lands make up a majority of the watershed (85%) and follow the distribution of loamy soils (Figure 2.2). The city of Coopersville is the only predominantly urban area and accounts for a majority of the residential/commercial/industrial development (4.4%). Woodlots are scattered throughout the watershed in a discontinuous pattern. Some of the forested areas are located along the riparian zones of Little Deer Creek and Deer Creek. A majority of the riparian zones in the headwaters and smaller tributaries have limited vegetative cover. Wetlands are located along the main channel of Deer Creek in northern Polkton Township and near the confluence with the Grand River. Smaller wetland areas are present in the headwaters of Little Deer Creek. Limited forested riparian vegetation is present to buffer wetlands from agricultural operations. While most of the soils are classified as loams, clay deposits are common along the stream banks in the southern part of the watershed (Figure 2.2). Clay soils are exposed in areas where channel cutting has eroded the overlying loams and exposed the base material. The exposure of the clay base results in high turbidity levels and provides limited opportunity for infiltration in the riparian zone. In summary, the extensive agricultural land use, absence of riparian buffers, and the exposure of the native clay layer adjacent to the stream create an environment that is highly influenced by nonpoint source runoff. These factors result in a watershed that is subject to flashy hydrology and excessive inputs of nutrients, suspended sediment, and enteric bacteria.

3.0 Sampling and Analytical Methods

Samples from 8 locations (Figure 3.1) on Deer Creek were collected and analyzed for suspended sediment, *E. coli*, and 7 nutrient parameters from May – October 2003. Sites were selected to cover the spatial extent of the watershed and include potential sources of agricultural runoff. The drainage area for each location is shown in Figure 3.2. The Wilson St site (Site 1) was located in a highly cultivated region in the headwaters. The sampling location was at a roadside agricultural drain adjacent to a cultivated field. Stream widths varied from 2.1-3.9 m with maximum depths ranging from 0.03-0.12 m. The Roosevelt St site (Site 2) was located within a densely forested wetland area approximately 1.2 km outside of the city of Coopersville. Stream width ranged from 3.7-5.2 m with maximum depths ranging between 0.18-0.76 m. Cleveland St (Site 3), Randall St (Site 4), and Pin Oak St (Site 5) sites were located within the Coopersville city limits. These three sites were in wooded riparian zones with vegetative cover along the stream banks. The land use was residential/urban. The Cleveland site was located downstream of a major tributary that drains several highly cultivated sub-basins. One bank was adjacent to the Ottawa County Road Commission facility and parking area. The facility's side had sparse vegetation while the other bank was moderately wooded. Stream width and depth ranged from 3.3-5.8 m and 0.23-0.67 m, respectively. The Randall site was located in a wooded area within the city. Riparian vegetation was

Figure 2.2. Soil Types Present in the Deer Creek Watershed.

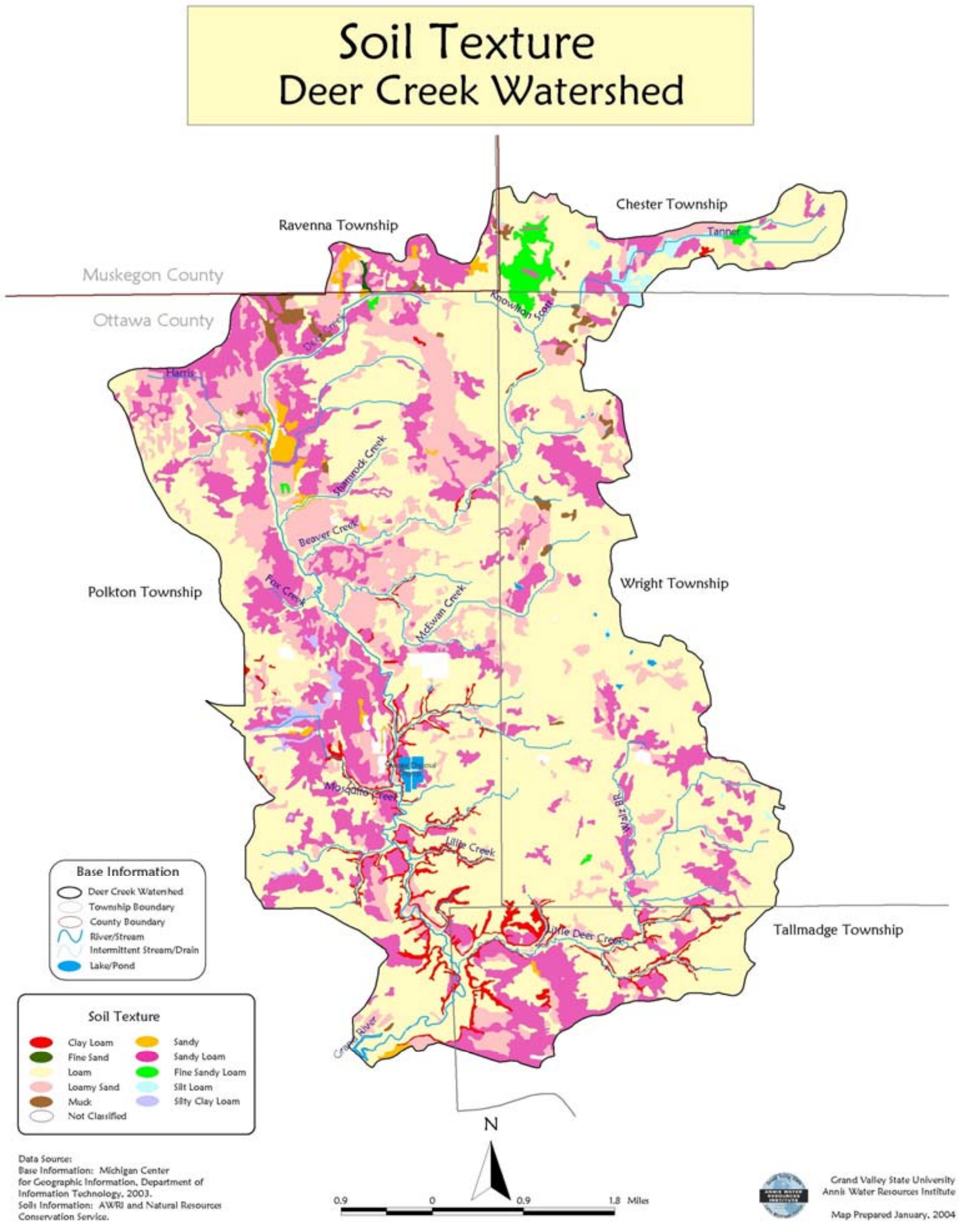


Figure 3.1. Locations Sampled in the Deer Creek Watershed (2003).

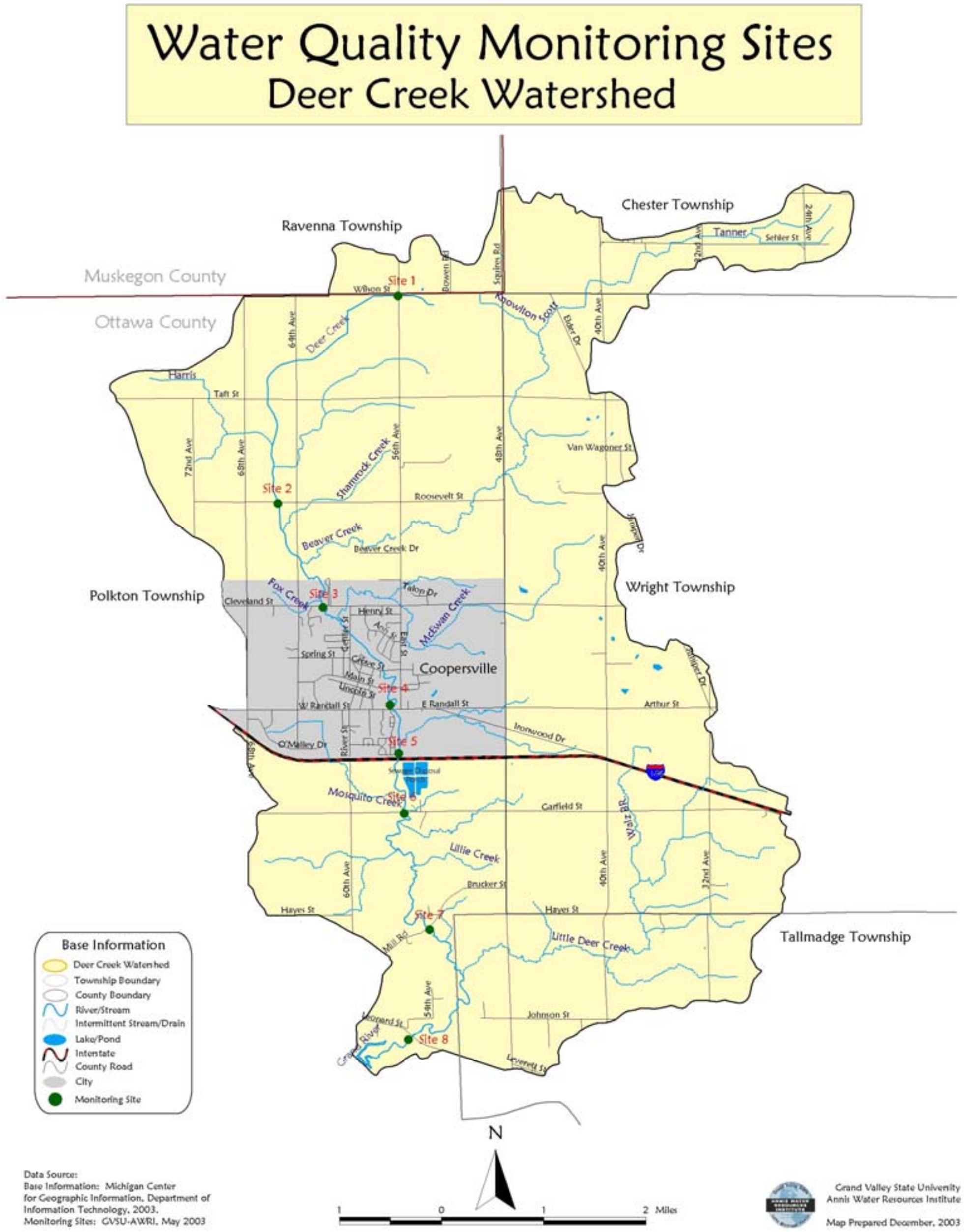
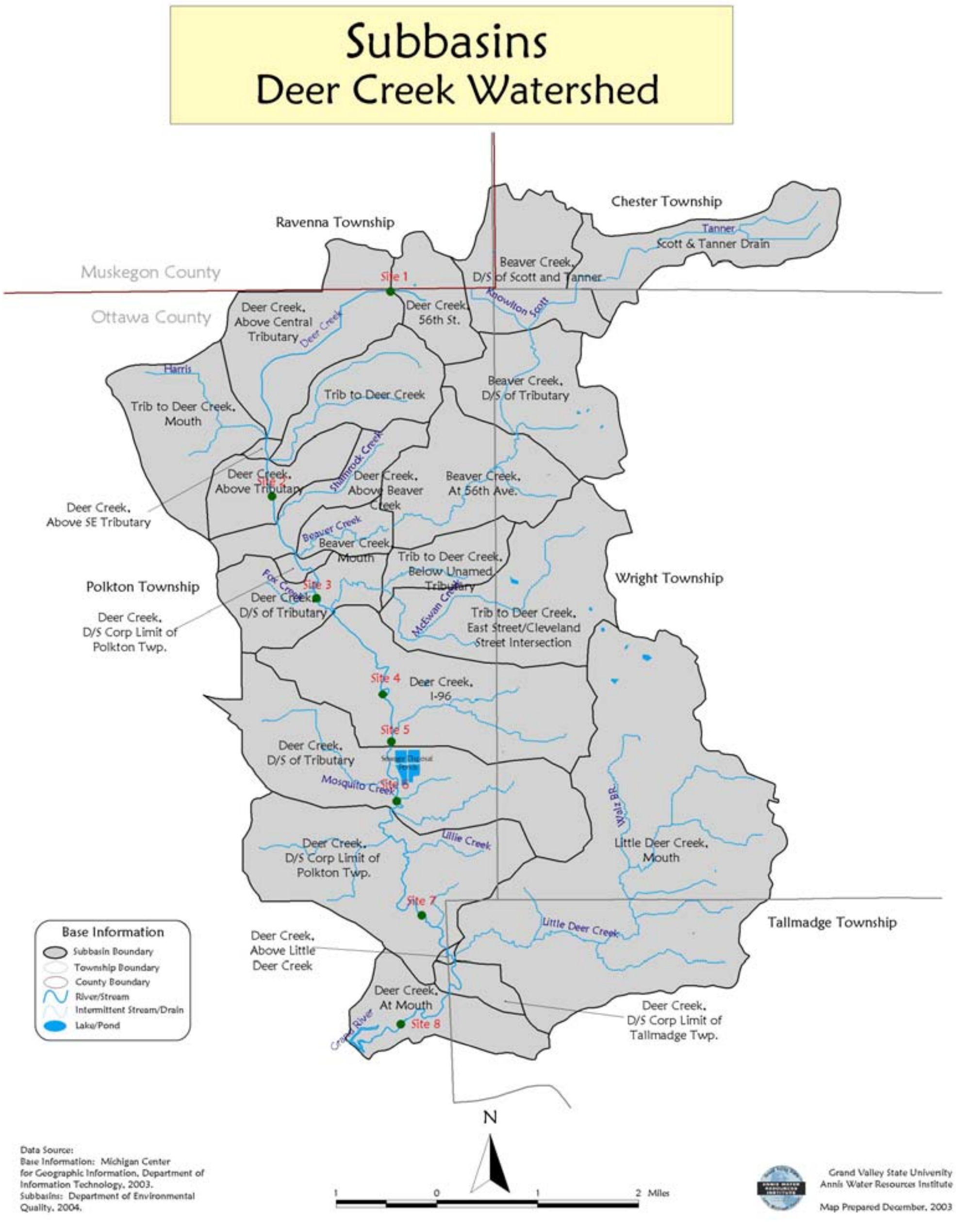


Figure 3.2. Drainage Area for the Deer Creek Sampling Stations (2003).



complete on both stream banks with stream width and depth ranging from 7.0-8.1 m and 0.46-1.07 m, respectively. The Pin Oak St site was located just upstream of I-96 in a sparsely wooded area behind a mobile home park. At this location, stream width and depth ranged from 5.8-7.9 m and 0.55-1.19 m, respectively. The remaining three sampling locations were located south of I-96. Land use switches back to agricultural south of the interstate and continues to the banks of the Grand River. The Garfield Ave site (Site 6) was located about 1 km downstream of the Pin Oak Site with rural/residential land use on both sides of the stream. Ottawa Farms Landfill and the Coopersville Wastewater Lagoons were located in the drainage area west of this site. Stream widths ranged from 7.0- 8.5 m while depths varied between 0.52-1.13 m. The Mill St site (Site 7) was located in a densely forested wetland area 3.2 km upstream of the stream's convergence with the Grand River. Stream widths varied from 8.5-10.8 m and stream depths varied between 0.58-0.94 m. Agricultural fields were located immediately adjacent to the wetlands with moderately sloped banks. The final site, Leonard St (Site 8) was located 1 km from the confluence with the Grand River. Stream width averaged 21.9 to 23.7 m with depths exceeding 3 m. The site was bordered on one side by an agricultural field and a wooded park area on the opposite side.

Water samples and discharge related measurements were collected according to United States Geological Survey protocols (USGS 1994). Grab samples were collected midstream by submerging the container in the upstream direction. Nutrients were collected in 1-liter acid washed bottles and microbiological samples were taken in sterilized 100 ml plastic vials. Stream flow and depth measurements were taken at a minimum of 10 points along the channel width. Current velocity was measured with a Marsh-McBirney Flow-Mate Flowmeter 2000. One to three samples per month were collected from each sample site throughout the 6-month sampling period. An Onset StowAway TidbiT Temperature Logger was installed at each site to record temperature at 2 hr intervals during the investigation. Temperature loggers were enclosed in galvanized pipe fittings in order to submerge and prevent damage to the loggers while still allowing for direct exposure to the creek. Pipe fittings were fastened to bricks and secured within the water column using metal cable. Precipitation measurements were recorded at two sites using a Davis Rain Collector II equipped with an Onset HOBO Event Data Logger. Rain gauges were located in Coopersville and in Eastmanville near the Grand River (Figure 3.3). Precipitation data were collected from May 30 – October. Data from May 1 – 29 were unavailable due to equipment problems.

Chemical analyses for suspended sediment, total phosphorus (TP-P), soluble reactive phosphorus (SRP-P), nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN-N), sulfate, and chloride were conducted on the water samples. Details of each analytical procedure are listed in Table 3.1. Nutrient analyses were performed on a BRAN+LUEBBE Autoanalyzer (AA) or a Dionex Ion Chromatograph (IC). *E. coli* concentrations were evaluated using EPA standard laboratory testing protocols (2000b).

Figure 3.3. Rain Gauge Locations for the Deer Creek Investigation (2003).

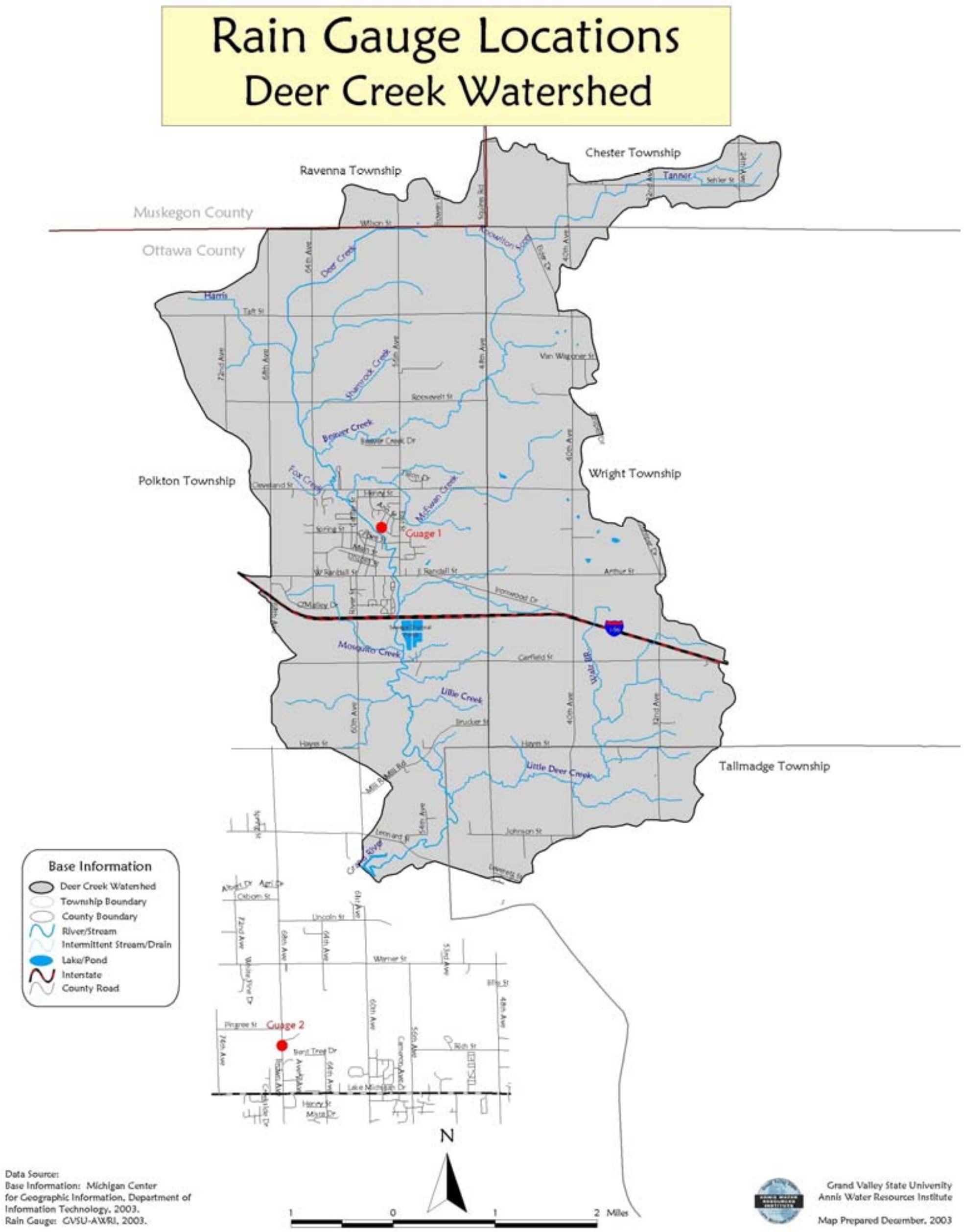


Table 3.1. Analytical Methods for Chemical Analyses.

Parameter	Preparation	Preservation	Holding Time (d)	Method	Reference
NH_3-N	--	H_2SO_4 Cool to 4°C	28	AA	350.1*
NO_3-N	0.45 µm filter - lab	Freeze –10°C	28	IC	4110**
SRP-P	0.45 µm filter - lab	Freeze –10°C	28	AA	365.4*
TP-P	--	Cool to 4°C	28	AA	365.4*
TKN-N	--	H_2SO_4 Cool to 4°C	28	AA	351.1*
Chloride and Sulfate	0.45 µm filter - lab	Freeze -10°C	28	IC	4110**
E. coli	0.45 µm filter - lab	Cool to 4°C	6 hrs	mTEC Agar	***

* USEPA (1983), **AWWA (1989), ***USEPA (2000)

4.0 Results and Discussion

4.1 Temperature

A complete summary of temperature data for this investigation is included in Appendix 1. Water temperature data from Deer Creek were collected and analyzed in order to (1) determine the variation in summer mean temperature and (2) determine the suitability of thermal conditions for fish species at seven specific stream locations. Deer Creek is designated as a warm water stream according to the Michigan Department of Environmental Quality (MDEQ 2000b). The landscape-based ecological classification system for river valley segments in Lower Michigan (MI-VSEC), however, classifies Deer Creek as having a cool mean temperature (19°C to <22°C), with moderate variation (5°C to <10°C) (Seelbach et al. 1997). Wehrly et al. (2003) developed a habitat classification to describe relationships between thermal regimes and the distribution patterns of fish populations. Using this classification system, water temperature data from Deer Creek were analyzed to determine whether thermal conditions at the eight sampling locations provided suitable conditions for warm water and cool water fish species. Thermal profiles at each sampling station were analyzed according to the Wehrly et al. (2003) model. The model plots summer average temperature and temperature range in a 3 × 3 matrix, providing nine thermal categories. Weekly mean temperatures are classified according to three categories; cold (<19°C), cool (19°C to <22°C), and warm (≥22°C). Temperature fluctuations are also classified in three categories; stable (<5°C), moderate (5°C to <10°C), and extreme (≥10°C). Using these thermal regimes, suitable habitats for various cold, cool, and warm water fish species can be determined. Average weekly temperature and weekly temperature range for each site were calculated for the June-November 2003 data. Average weekly temperature was calculated by averaging the four mean weekly temperatures for the month. The weekly temperature range was calculated by averaging the difference between maximum and minimum temperatures for each week. The results of temperature calculations for Deer Creek are shown in Figure 4.1. Daily temperature results are included in Appendix A.

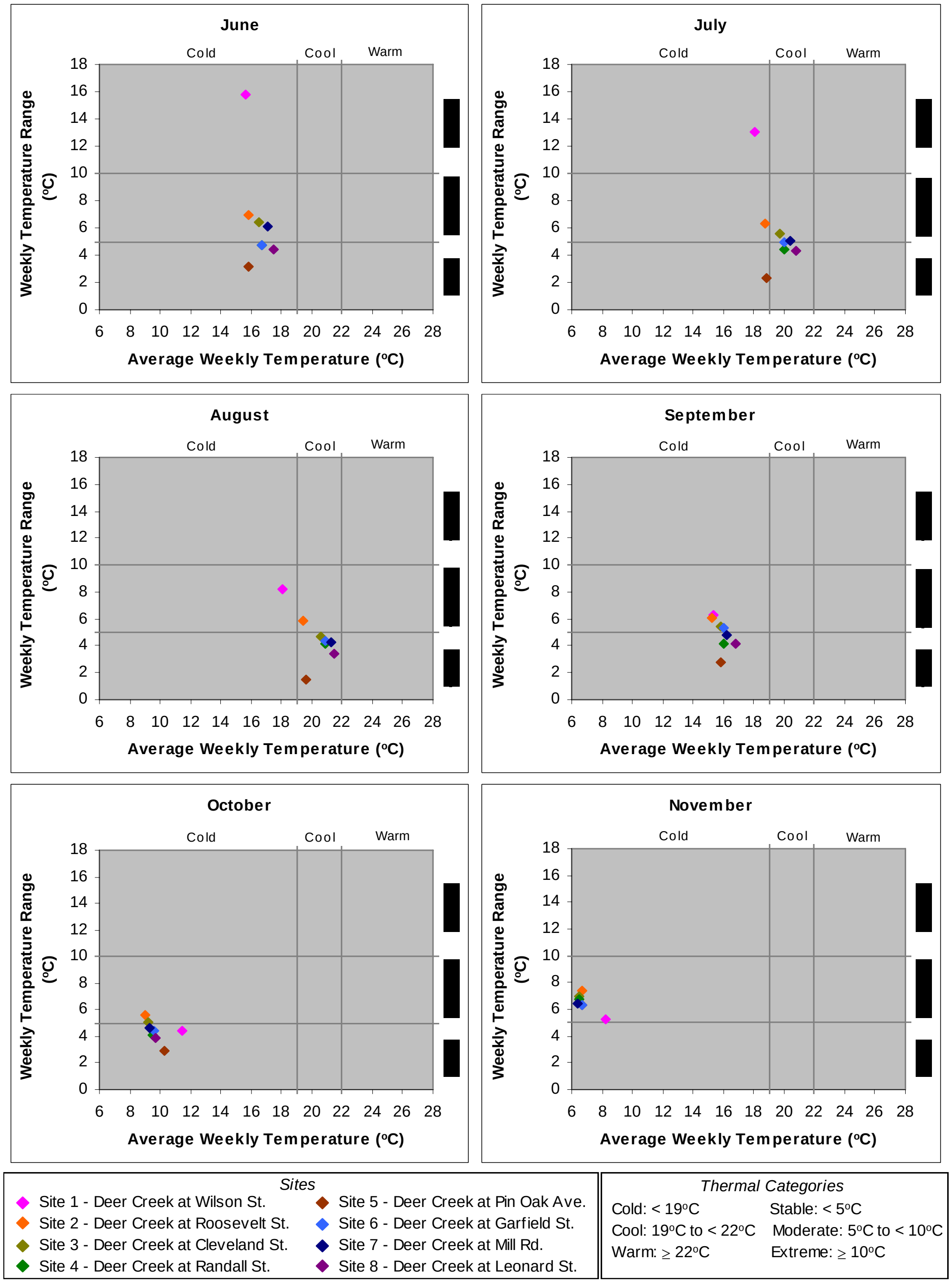
With the exception of the Wilson site (Site 1), the weekly temperature ranges in June - August were < 7 ^{o}C, indicating a moderate to stable thermal regime. As discussed previously, Deer Creek at Wilson St is a channelized culvert with no riparian vegetation to shade the stream. The lack of vegetative cover contributes to the temperature instability at this site. Most stations transition from cold to cool water classification as weekly temperatures averaged from 19 ^{o}C to 22 ^{o}C. Weekly averages indicative of warm water fisheries were not encountered during this investigation (>22 ^{o}C); however, daily averages exceeded this threshold on several occasions (Appendix 1). The MDEQ (2000b) classified Deer Creek as a warm water stream based on 1999 temperature data. Weekly summer temperatures at Mill St exceeded 22 ^{o}C during a three week period in 1999. No sample sites in 2003 would be classified as a warm water stream (Figure 4.1). Four sample sites remained in the cool thermal regime during July and August. Roosevelt and Pin Oak were in the cold thermal regime in July but not in August. The Wilson station was the only location that remained in the cold thermal regime during both July and August. Its temperature range was ranked as extreme. These results would be expected in a headwater location, like the Wilson site, where the influx of cold groundwater is countered by the absence of shade cover from riparian vegetation.

The MDEQ (2000b) also conducted a biological survey of Deer Creek in 1999 and found that 68 to 100% of fish communities were dominated by taxa tolerant of degraded conditions including Central mudminnow, Creek chub, Bluntnose minnow, White sucker, and Johnny darter. With respect to thermal requirements, the following cool and cold water species were present:

Species	Thermal Requirement Classification (Wehrly et al. 2003)
Green sunfish	cool-moderate
Blacknose dace	cold-moderate
White sucker	cool-moderate
Creek chub	cold-extreme
Central mudminnow	cool-moderate

Even though fish populations indicate highly degraded conditions, an assemblage of cool/cold water species was present. The results of this investigation indicated that Deer Creek has the potential to become a cold/cool water stream if temperature fluctuations were stabilized. Increasing the density and continuity of riparian vegetation has been shown to effectively stabilize and lower stream temperatures by providing shading from sunlight (Rabeni and Sowa 1996, Allan et al. 1997, Hawkins et al. 2000). Even though appropriate thermal conditions may be present to support a cool water fishery, the unstable hydrology (Section 4.2), poor habitat, and high nutrient loading (Section 5) of Deer Creek are the dominant factors contributing to the degraded condition of its fish population. A detailed study of habitat and food resources would be necessary to develop a fisheries restoration plan for Deer Creek.

Figure 4.1. Weekly Average Temperatures and Ranges for the Deer Creek Sampling Stations (June-November 2003).

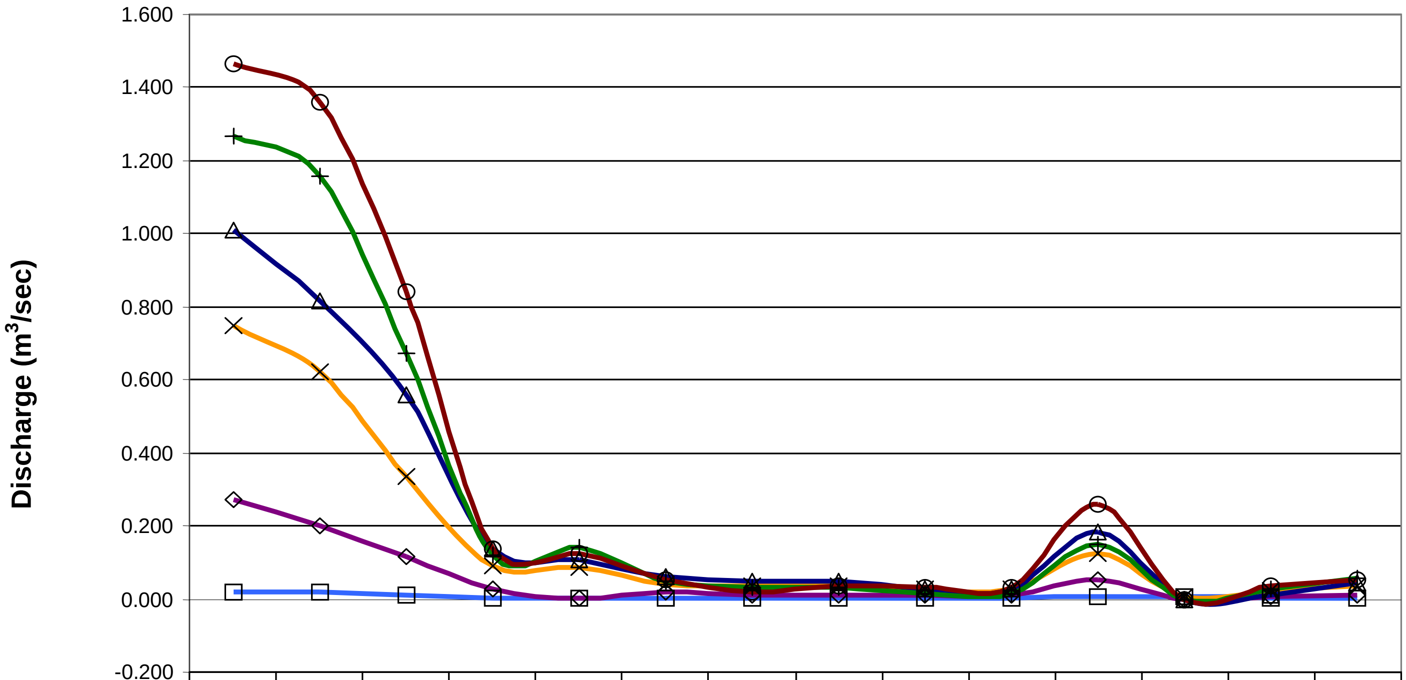


4.2 Stream Discharge

The stream discharge of Deer Creek measured at the sampling stations is displayed in Figure 4.2.1. Rainfall amounts recorded during the investigation (May-October) are presented in Figure 4.2.2 and summarized in Appendix B. Flow measurements were not collected at Leonard St due to the deep water conditions. Flow measurements were collected at Randall St; however, a series of woody debris jams were discovered upstream of the sampling site that interfered with velocity measurements. Three distinct flow regimes were present during the study period. High flow conditions occurred on May 8, 14, and 21. During this period, flows measured at the downstream location, Mill St, were 1.466 m^3/sec, 1.358 m^3/sec, and 0.841 m^3/sec, respectively. Moderate stream flows occurred on June 4, June 11, and Aug 5. The corresponding discharge values calculated for Mill St were 0.139 m^3/sec, 0.126 m^3/sec, and 0.260 m^3/sec, respectively. Low flow conditions occurred during the remainder of the investigation and were < 0.06 m^3/sec at Mill St. No measurable flow was recorded at four of the six stations on September 11. Very small flow was visually noted on this date; however, it was below the response limit of the instrumentation. High flows were the result of early spring precipitation events that occurred prior to installation of the rain gauges. Most of the precipitation events during the investigation were less than 0.3 inches/hr which account for the stable, low flow conditions encountered (Figure 4.2.2). The increase in flow measured on August 5 was a result of rain events of 0.5 –1.1 in/hr that occurred on August 3 and 4. Significant rain events also occurred on July 10, 20, and 21. The July measurements in this investigation were collected on the 9th and 16th and were not influenced by the rain event. Average discharge measurements for the three flow periods are shown in Figure 4.2.3. During low flow conditions, stream discharge increases from Wilson to Cleveland indicating groundwater accrual. After Cleveland St, the flow remains relatively constant, suggesting that evaporation/transpiration losses are balanced by groundwater influx. This pattern also is shown in the normalized cumulative flows between sampling locations (stream segments) in Figure 4.2.4. Normalization of the data was performed by dividing the incremental flow increases between stations by the corresponding drainage area. The drainage areas for the stream segment are summarized below:

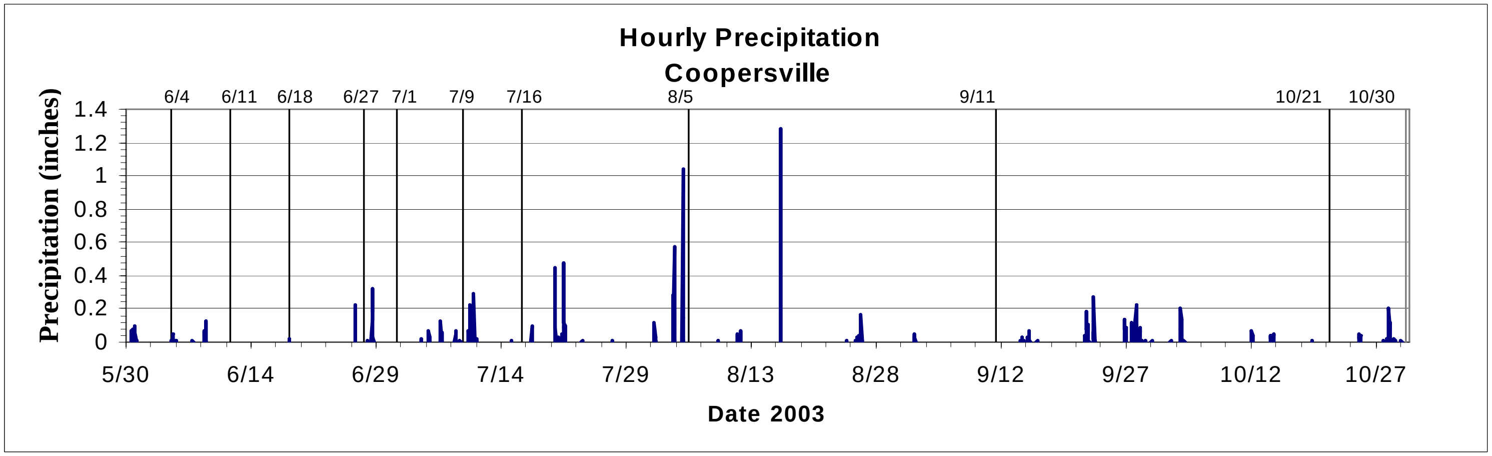
Stream Segment	Cumulative Drainage area (ha)
Wilson-Roosevelt	1445
Roosevelt-Cleveland	2187
Cleveland-Pin Oak	1751
Pin Oak-Garfield	270
Garfield-Mill	972

Figure 4.2.1. Discharge Measurements Recorded at the Deer Creek Sampling Stations (2003).



	May 8	May 14	May 21	June 4	June 11	June 18	June 27	July 1	July 9	July 16	Aug 5	Sept 11	Oct 21	Oct 30
Wilson	0.020	0.018	0.010	0.003	0.003	0.003	0.002	0.001	0.002	0.002	0.007	0.005	0.003	0.003
Roosevelt	0.274	0.200	0.115	0.027	0.004	0.020	0.013	0.012	0.009	0.009	0.054	0.000	0.006	0.012
Cleveland	0.750	0.624	0.335	0.090	0.086	0.042	0.037	0.038	0.027	0.027	0.124	0.005	0.025	0.038
Pin Oak	1.010	0.816	0.558	0.138	0.107	0.061	0.047	0.050	0.029	0.029	0.186	0.000	0.009	0.045
Garfield	1.265	1.157	0.672	0.121	0.143	0.051	0.033	0.030	0.015	0.015	0.150	0.000	0.028	0.058
Mill	1.466	1.358	0.841	0.139	0.126	0.053	0.020	0.037	0.031	0.031	0.260	0.000	0.035	0.053

Figure 4.2.2. Hourly Precipitation Measured at Coopersville and the Grand River near Eastmanville (2003). (Vertical Bars Denote Sampling Events).



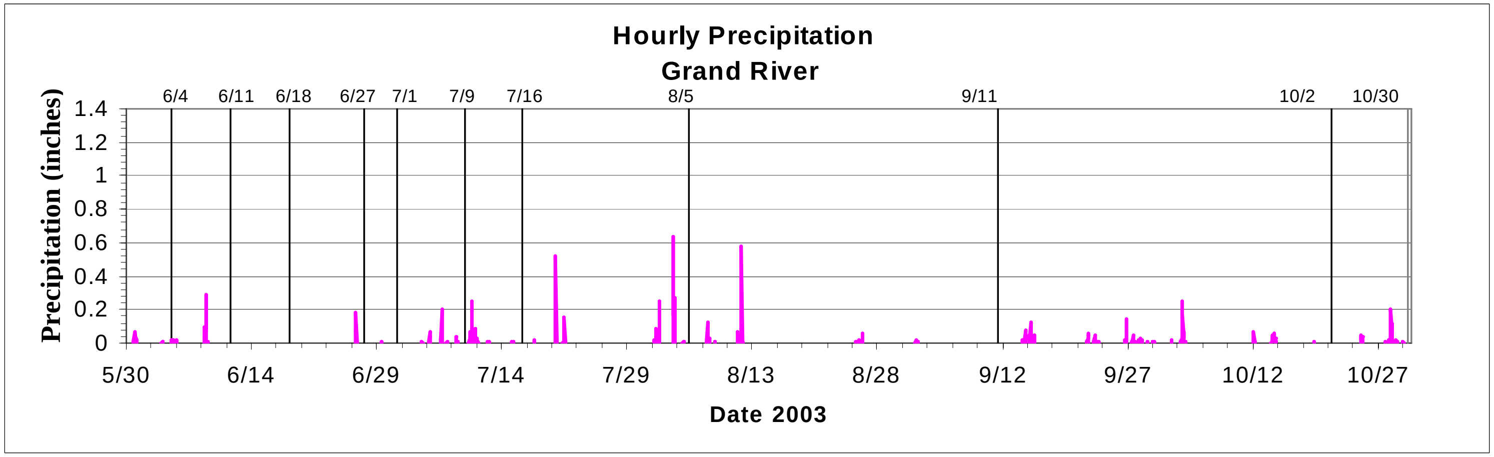
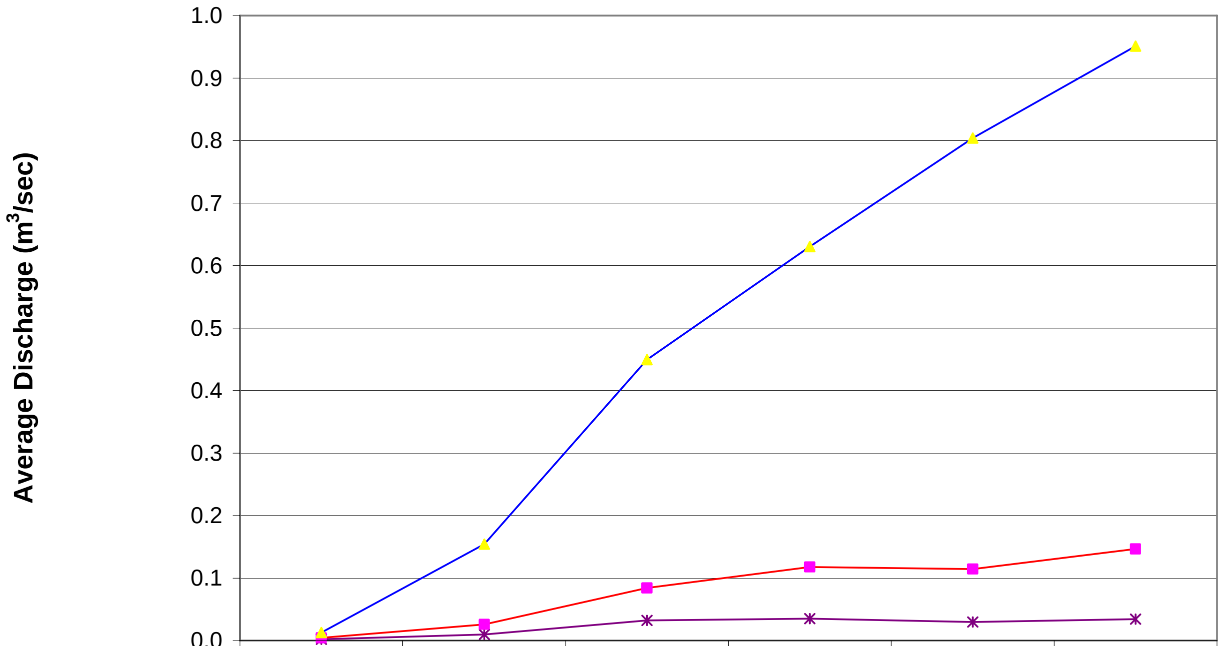
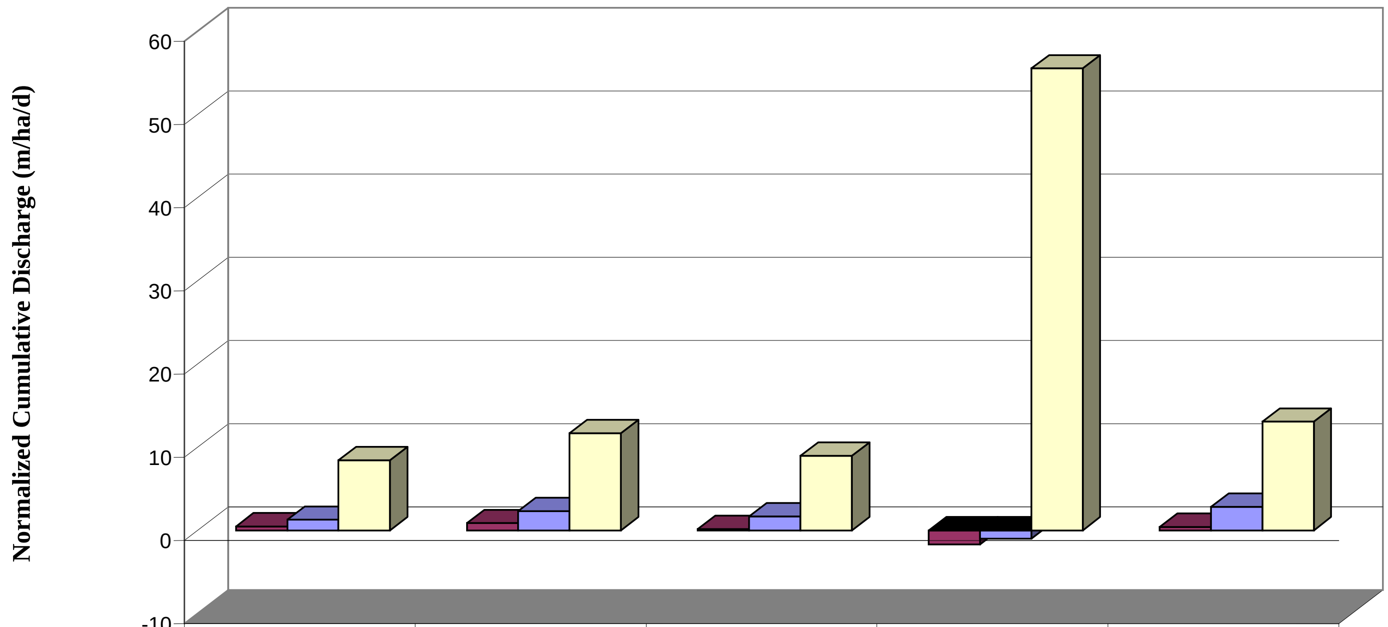


Figure 4.2.3. Average Discharge Measurements During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow	0.0022	0.0100	0.0320	0.0350	0.0297	0.0345
Medium Flow	0.004	0.026	0.084	0.118	0.115	0.146
High Flow	0.01	0.15	0.45	0.63	0.80	0.95

Figure 4.2.4. Cumulative Discharge Normalized by Site Drainage Area During High, Medium, and Low Flow Periods at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.0-0.53 m^3/sec.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
Low Flow	0.467	0.871	0.147	-1.677	0.420
Medium Flow	1.28	2.31	1.69	-0.997	2.84
High Flow	8.44	11.66	8.94	55.52	13.07

In low flow conditions, the greatest incremental increase in discharge occurs between the Roosevelt and Cleveland stations. The Beaver Creek tributary enters above the Cleveland station (Figure 1.2) and may account for some of the increase. The wetland areas that border Deer Creek and Beaver Creek also may be the source of the additional flow accrual.

Medium and high flow regimes show a different pattern as significant incremental increases in normalized discharge are noted in the stations downstream of Cleveland St (Figure 4.2.3). Under medium flow conditions, similar incremental increases in discharge occur in the Roosevelt to Cleveland and Garfield to Mill segments (2.31 m^3/ha/d and 2.84 m^3/ha/d, respectively) (Figure 4.2.4). The reach from Pin Oak to Garfield shows no incremental discharge increase. Since this section includes runoff from I-96, flows may peak earlier than the other locations because of the rapid response of impervious surfaces and the short distance between stations (0.8 km). In contrast, high flow conditions show that the greatest incremental flow increase occurs between Pin Oak and Garfield (55.52 m^3/ha/d) in contrast to flows ranging 8.44 – 13.07 m^3/ha/d at the other locations. A large amount of overland flow per unit surface area enters Deer Creek in the Pin Oak-Garfield segment. This segment includes drainage from I-96 and three tributaries (Figure 3.1). A more detailed investigation of flow within this stream segment would be required to determine the contribution from each source. The ratio of high flow to low flow indicates the degree of flashiness present in river systems (Robertson 1997). For Deer Creek, the ratio of high/low flow at the Cleveland St crossing results in a flashiness value of 14. At the farthest downstream site measured (Mill St), the flashiness increases to 28, indicating that one day of high flow is equivalent to a month at baseflow. Robertson (1997) estimated the flashiness of the Grand River and Muskegon River to be 8 and 5, respectively. The results of this investigation underestimate the flashiness of Deer Creek. A rain event in early November resulted in unwadeable stream levels at all of the sampling stations downstream of Wilson St. Based on visual observations and estimates made on site, the November flows were at least five times greater than the discharge measurements conducted during May.

Stream flashiness is directly linked to landscape modifications that impede infiltration and promote uncontrolled runoff (Richards 1989 and 1990). In Deer Creek, the elimination of most of the natural vegetative cover (Hunsaker and Levine 1995, Smith et al. 1997), the proliferation of agriculture (Omernik et al. 1981, Herlihy et al. 1998), and impervious surfaces (Burns 1972, Harden 1992, Arnold and Gibbons 1996, Ploft et al. 1997) contribute to the hydrologic instability observed in the discharge data. The degree of flow instability in an agricultural watershed has been correlated with the export of sediment and nutrients (Brenner and Mondok 1995, Jordan et al. 1997).

4.3 Water Chemistry

The mean value and ranges for the water quality and nutrient parameters measured at the Deer Creek sites are listed in Tables 4.3.1-4.3.9. Changes in chemical parameters are provided in Figures 4.3.1-4.3.9. Chemical and flow data are summarized in Appendix C.

4.3.1 Chloride

Chloride is a common parameter found in urban and agricultural runoff, sewage, and industrial wastes. The most common source of chloride in the Deer Creek watershed is from the application of salt to roads for deicing and septic systems. The USEPA (1988) ambient water criteria for chloride is 230 mg/l. Mean chloride concentrations were relatively consistent among all sites (Table 4.3.1) and well below the USEPA Criterion. The Wilson and Roosevelt sites showed the most variability (Fig. 4.3.1). These locations have lower discharges and ambient concentrations may be influenced to a greater extent by runoff or groundwater quality. Chloride at the Wilson site peaked after the rain event on 8/5 while most of the other sites exhibited a drop in concentration. A summer rain event should have diluted ambient chloride concentrations. A point source such as the discharge from a residential water softener may have been responsible for the increase in chloride observed. Increases in nutrients were not observed at Wilson suggesting the chloride spike was unrelated to agricultural sources. Since the investigative samples were collected from May – October, the results do not reflect the direct contribution from road salt application and underestimate the actual range and means for chloride in the system

Table 4.3.1. Mean and Range (minimum to maximum) Values for Chloride in Deer Creek (May - October 2003).

Chloride Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	52	23	-	128
Roosevelt	42	23	-	97
Cleveland	39	27	-	56
Pin Oak	54	35	-	91
Garfield	60	39	-	95
Mill	60	37	-	97
Leonard	61	32	-	98

4.3.2 Sulfate

Sulfate is found in local groundwater and surface soils due to the presence of gypsum deposits. The USEPA drinking water standard for sulfate is 250 mg/l. Mean sulfate concentrations were similar among all sites (Table 4.3.2). Seasonal differences were not present in the data (Figure 4.3.2). A decrease in sulfate concentrations was noted for the locations south of I-96 after the rain event on the 8/5 sampling. The introduction of rainwater would tend to dilute ambient concentrations from local groundwater entering the system. The fact that sulfate remained constant in the upper watershed, but declined at sites lower in the watershed, suggests that infiltration is recharging the shallow aquifer that maintains the creek at base flow.

Figure 4.3.1. Chloride Concentrations in Deer Creek (May - October 2003).

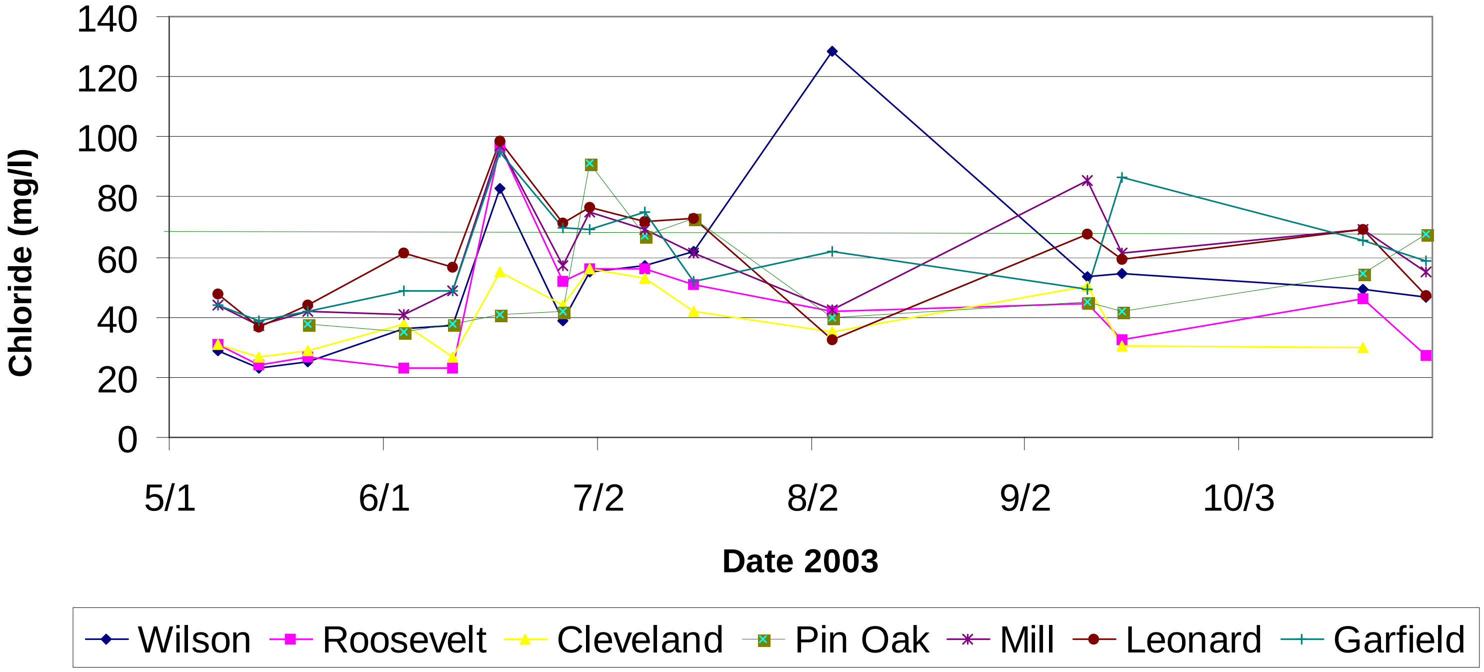


Table 4.3.2. Mean and Range (minimum to maximum) Values for Sulfate in Deer Creek (May - October 2003).

Sulfate Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	36.9	30.0	-	44.1
Roosevelt	39.9	35.0	-	44.0
Cleveland	42.3	36.2	-	53.7
Pin Oak	38.2	23.3	-	48.0
Garfield	38.3	22.8	-	46.9
Mill	39.2	24.1	-	46.2
Leonard	40.8	17.1	-	50.1

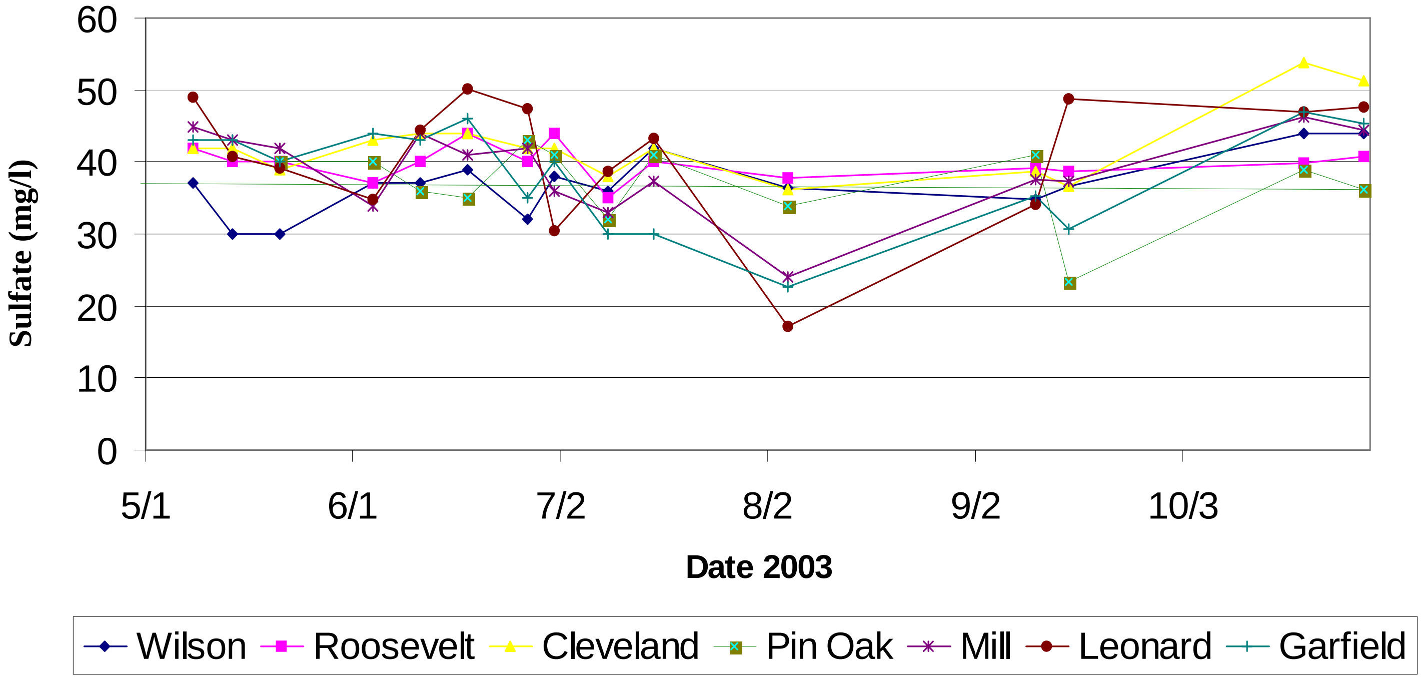
4.3.3 Total Suspended Solids

Total Suspended Solids (TSS) enter streams by erosional losses from surface runoff and channel cutting. In addition, the input of organic matter from internal and external sources is reflected in the measurement of TSS. Suspended sediment increases turbidity, which has a negative effect on aquatic life. When the suspended particles settle, the resulting sedimentation creates an unstable habitat for benthic invertebrates and adversely impacts fisheries (Newcombe and MacDonald 1991, Newcombe and Jensen 1996). Mean suspended solids were somewhat variable at the sampling locations (Table 4.3.3).

Table 4.3.3. Mean and Range (minimum to maximum) Values for Total Suspended Solids in Deer Creek (May - October 2003).

Total Suspended Solids Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	7	0	-	21
Roosevelt	5	0	-	15
Cleveland	9	0	-	28
Pin Oak	12	0	-	84
Garfield	12	1	-	80
Mill	15	1	-	29
Leonard	14	2	-	35

Figure 4.3.2. Sulfate Concentrations in Deer Creek (May - October 2003).



The locations farthest upstream (Wilson and Roosevelt) had the lowest mean TSS concentrations and exhibited the least variability. Locations south of Coopersville were higher and more variable. The Garfield site showed the greatest response to the August rain event as TSS spiked upward to 80 mg/l (Figure 4.3.3). As discussed previously, discharge did not show an increase at this location (Figure 4.2.3). Since an increase in discharge was noted at the Pin Oak station, the rise in TSS at Garfield may be related to in-channel erosion. Deer Creek passes through a culvert under I-96 that alters the stream velocity. The absence of additional discharge at Garfield suggests that the influx of nonpoint source runoff from the immediate drainage areas is unlikely. TSS concentrations at Pin Oak peaked on September 16 with no apparent rain event as their source. Construction activity or another form of local disturbance in the city of Coopersville may have caused this increase. The impact of this event must have been localized since TSS declined 400% by the next downstream site.

4.3.4 Nitrate-N

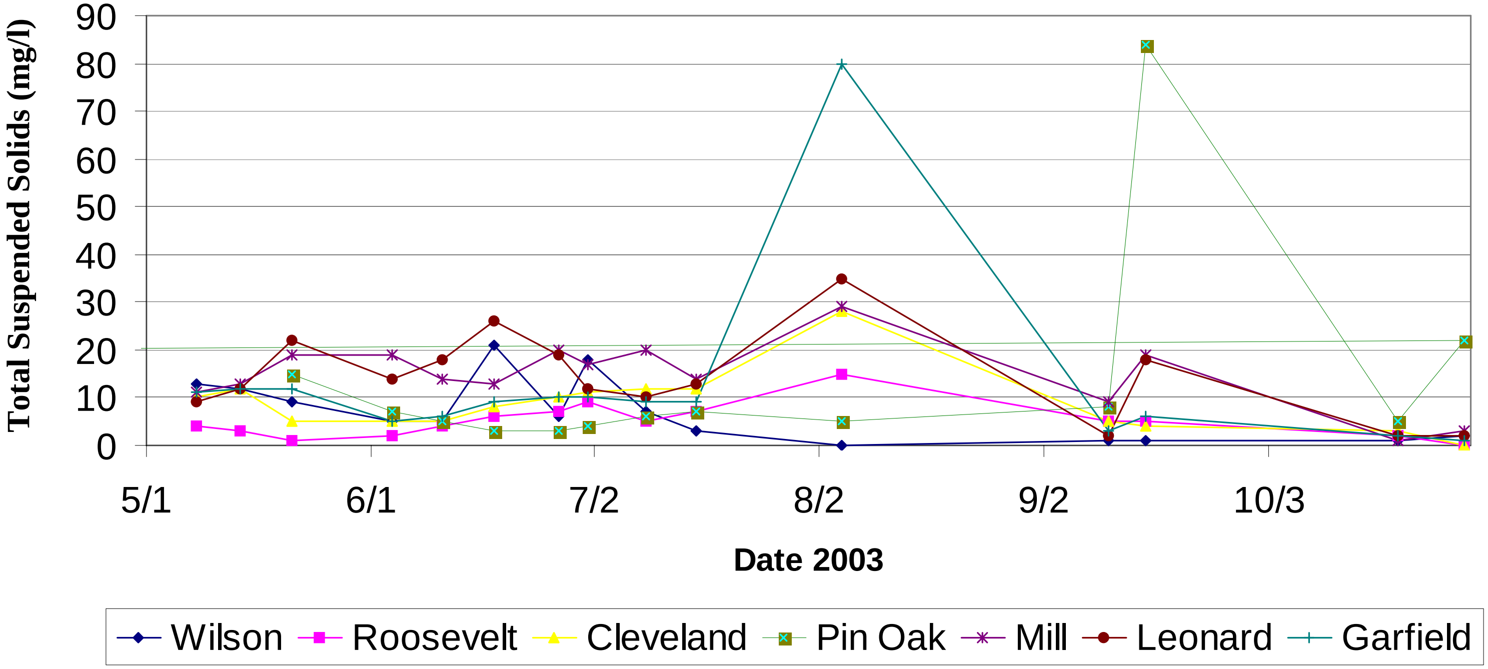
Nitrate is a common nutrient found in fertilizer, agricultural runoff, sewage and septic field leachate. Since nitrate exists as a soluble ion, elevated levels in surface water can be related to runoff and groundwater sources (Hem 1985). Background levels of nitrate in surface water are typically low (less than 1 mg/l). The USEPA safe drinking water standard is 10 mg/l of Nitrate-N. Mean nitrate concentrations declined in a monotonic fashion from upstream to downstream in the watershed (Table 4.3.4).

Table 4.3.4. Mean and Range (minimum to maximum) Values for Nitrate-N in Deer Creek (May - October 2003).

Nitrate-N Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	4.29	3.11	-	5.72
Roosevelt	3.85	2.40	-	6.21
Cleveland	3.31	1.63	-	5.41
Pin Oak	1.95	0.54	-	4.80
Garfield	1.87	0.52	-	4.87
Mill	1.65	0.20	-	5.07
Leonard	1.26	0.06	-	4.15

With the exception of the Wilson station, Nitrate-N maxima occurred during latter May and early June and were in excess of 4 mg/l (Figure 4.3.4). A declining trend in concentration was noted at these locations from June to November. The Wilson site showed a decrease in Nitrate-N concentrations after the August rain event and a subsequent increase in September. These results are consistent with the influx of rainwater causing an initial dilution in the stream, followed by the transport of nitrate in the soil to the shallow groundwater by infiltration. Similar patterns were noted by Kemp and Dodds (2001) in Kansas streams as nitrate concentrations and flow were negatively correlated.

Figure 4.3.3. Total Suspended Solids Concentrations in Deer Creek (May - October 2003).



Nitrate-N concentrations cluster in two groups in the summer and fall months (Figure 4.3.4). The upper watershed stations (Wilson, Roosevelt, and Cleveland) remain above 2 mg/l while the remainder of the stations are <2 mg/l. Differences in groundwater quality and/or instream utilization of nitrate may be responsible for the reduced concentrations observed in the lower watershed. Jones et al. (2001) found nitrate concentrations followed a seasonal pattern with the highest concentrations in the summer months.

4.3.5 Ammonia-N

Ammonia is a byproduct of decomposition and a common fertilizer. This form of nitrogen is readily oxidized in the summer by bacterial action and exists in a temperature and pH dependent equilibrium between ionized and unionized forms (Arthur et al. 1987). Unionized ammonia is 1000x more toxic than the ionized form. Persistent ammonia concentrations during the summer can be problematic because the combination of higher temperatures and pH elevation from photosynthesis can shift the equilibrium to favor the unionized form (Arillo et al. 1981).

Mean Ammonia-N levels were variable in Deer Creek (Table 4.3.5). The lowest concentrations were consistently observed at Wilson, Roosevelt, and Pin Oak. The first two stations were consistently high in nitrate (Figure 4.3.4) indicating oxidizing conditions. The Pin Oak site is influenced by the city of Coopersville and is not subject to agricultural influences like the other locations. Ammonia levels peaked after the August rain event indicating the possible influx of animal waste material. With respect to this rain event, the highest concentration was observed at the Cleveland site. In consideration of the low concentrations observed at Roosevelt, the influx of water from the Beaver Creek subwatershed to the main branch of Deer Creek may be the source of the ammonia spike. The highest ammonia level measured was at the Garfield site during the 7/9 sampling event (0.62 mg/l). The lower watershed stations were consistently higher in ammonia than the upper locations. The presence of riverine wetlands at Mill and Leonard may contribute to the difference observed between the upper and lower watershed.

Table 4.3.5. Mean and Range (minimum to maximum) Values for Ammonia-N in Deer Creek (May - October 2003).

Ammonia-N Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	0.02	0.01	-	0.07
Roosevelt	0.05	0.01	-	0.19
Cleveland	0.07	0.01	-	0.35
Pin Oak	0.08	0.01	-	0.17
Garfield	0.11	0.01	-	0.62
Mill	0.08	0.01	-	0.28
Leonard	0.11	0.01	-	0.19

Figure 4.3.4. Nitrate-N Concentrations in Deer Creek (May - October 2003).

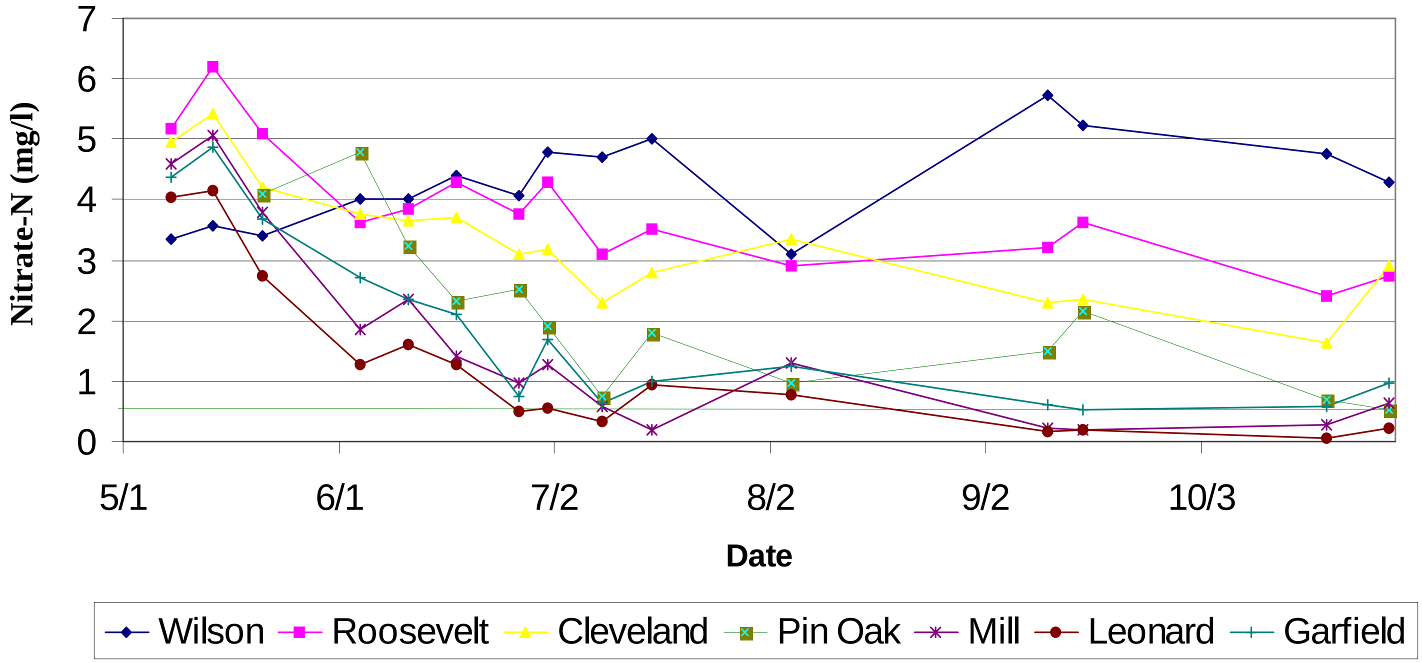
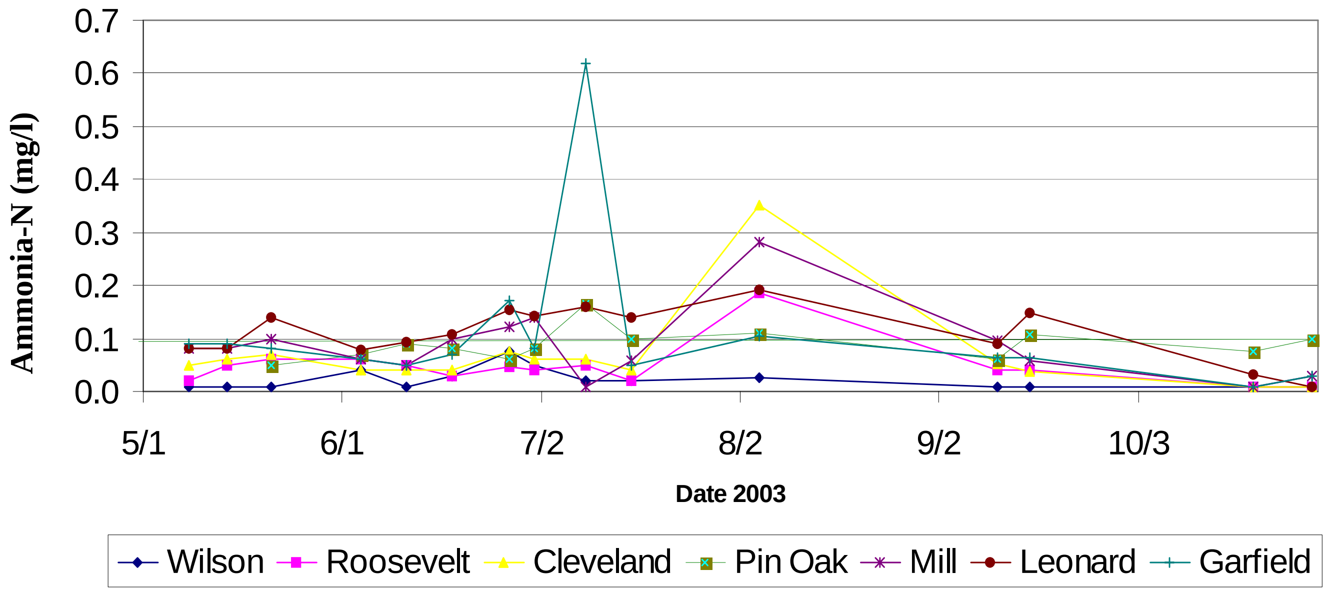


Figure 4.3.5. Ammonia-N Concentrations in Deer Creek (May - October 2003).



4.3.6 Total Kjeldahl Nitrogen-N

Total Kjeldahl Nitrogen (TKN-N) is a measurement of the amount of organic nitrogen and ammonia in a sample. Organic forms include nitrogen incorporated in plant and animal cells in addition to reduced organic compounds released by excretion and/or decomposition. Mean TKN-N concentrations were similar at all sites (Table 4.3.6). Concentrations follow a seasonal pattern with higher levels observed in the spring followed by declining values in the summer and fall (Figure 4.3.6). Following a similar trend as the other parameters, a spike in concentration was observed after the August rain event. Additional TKN-N spikes were noted in July at Leonard and in September at Pin Oak and Wilson. The origin of these increases cannot be determined from the data.

Table 4.3.6. Mean and Range (minimum to maximum) Values for Total Kjeldahl Nitrogen-N in Deer Creek (May - October 2003).

Total Kjeldahl Nitrogen-N Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	0.63	0.24	-	1.47
Roosevelt	0.81	0.25	-	2.16
Cleveland	0.84	0.20	-	2.10
Pin Oak	0.81	0.27	-	1.37
Garfield	0.78	0.36	-	1.43
Mill	0.80	0.31	-	1.59
Leonard	0.90	0.32	-	1.86

4.3.7 Soluble Reactive Phosphorus-P

Soluble reactive phosphorus (SRP-P) is an estimate of the bioavailable phosphorus in water. Since other bioavailable forms of phosphorus (organic and polyphosphates) are excluded from the measurement, SRP-P represents a subset of P-containing compounds that are biologically available (Dodds 2001). Although high concentrations are indicative of enrichment, low concentrations can be caused by nutrient poor conditions and highly productive environments where available nutrients are rapidly consumed and in short supply. Therefore, it is important to evaluate SRP in combination with other nutrients. Mean SRP-P levels were lower in the watershed area above Cleveland and ranged from 0.08 – 0.10 for the remainder of the channel (Table 4.3.7). Seasonal patterns were not present in the data (Figure 4.3.7). Castillo et al. (2000) also noted the absence of seasonal and spatial trends in SRP-P data from the River Raisin.

Figure 4.3.6. Total Kjeldahl Nitrogen-N Concentrations in Deer Creek (May - October 2003).

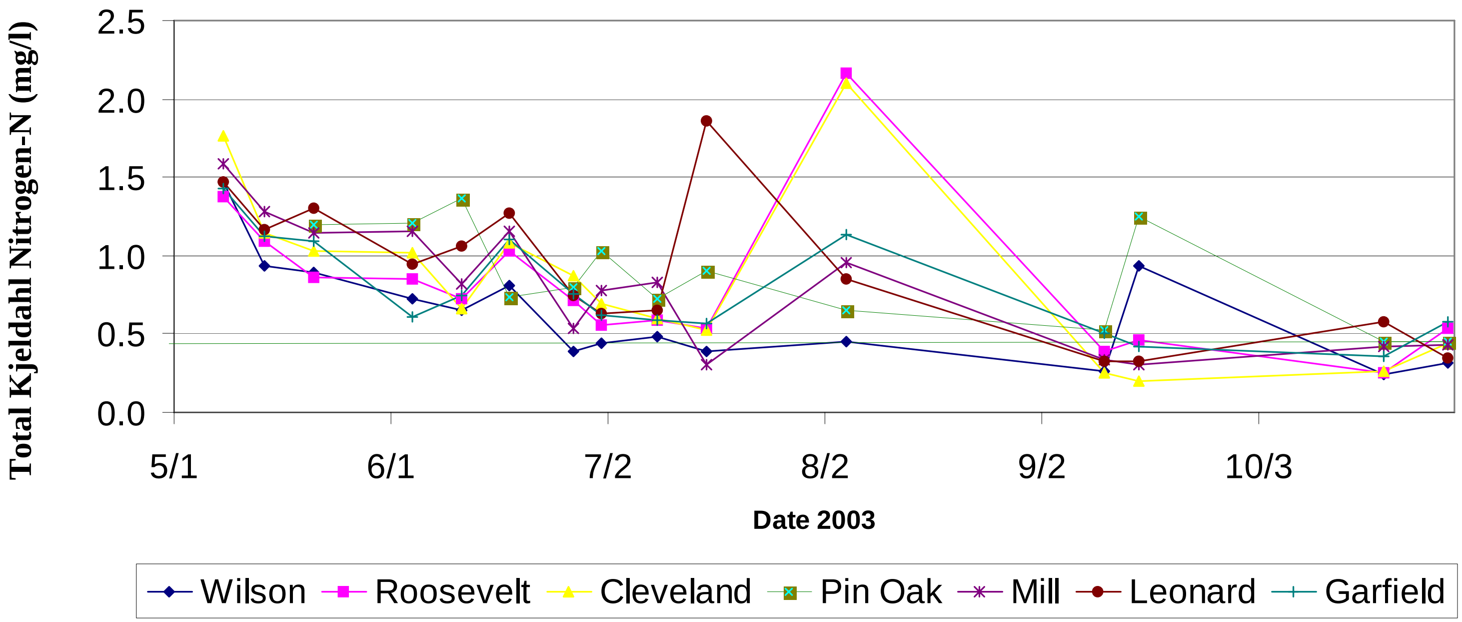


Figure 4.3.7. Soluble Reactive Phosphorus-P Concentrations in Deer Creek (May - October 2003).

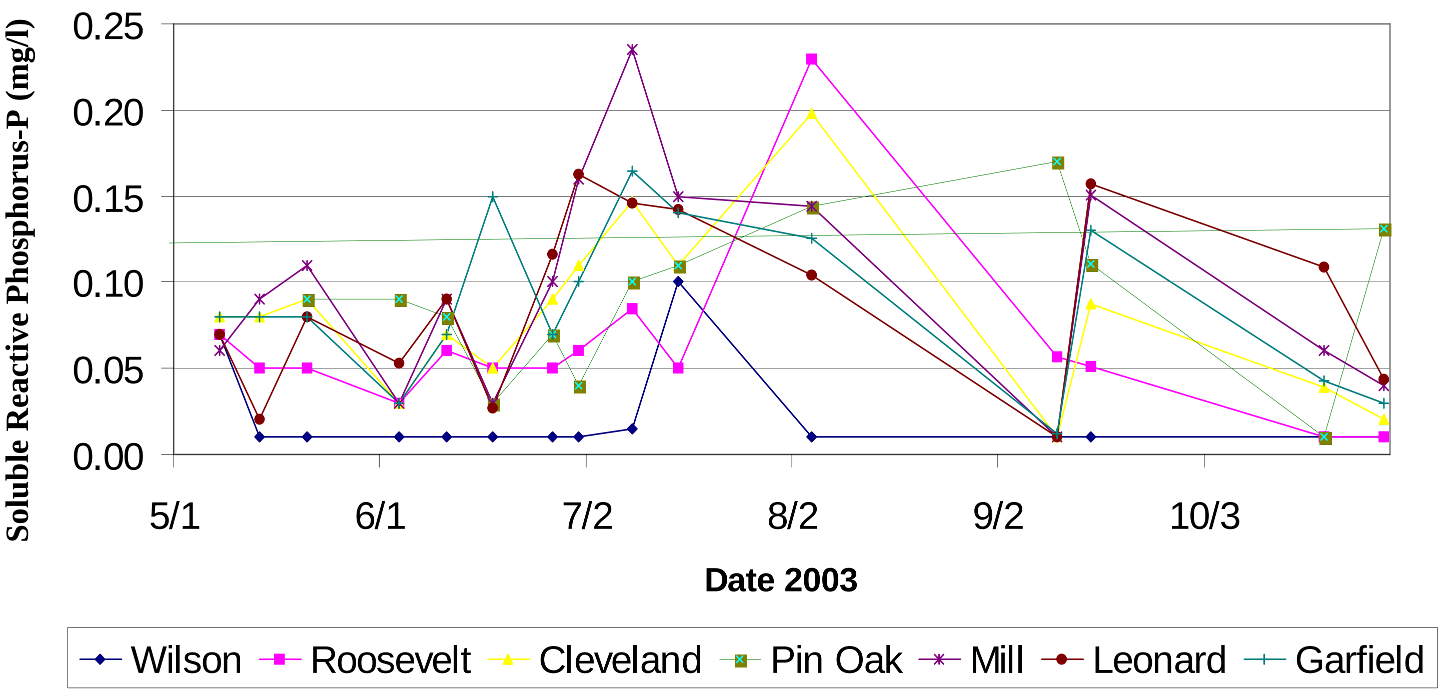


Table 4.3.7. Mean and Range (minimum to maximum) Values for Soluble Reactive Phosphorus-P in Deer Creek (May - October 2003).

Soluble Reactive Phosphorus-P Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	0.02	0.01	-	0.10
Roosevelt	0.06	0.01	-	0.23
Cleveland	0.08	0.01	-	0.20
Pin Oak	0.08	0.01	-	0.17
Garfield	0.09	0.01	-	0.16
Mill	0.10	0.01	-	0.24
Leonard	0.09	0.01	-	0.16

4.3.8 Total Phosphorus-P

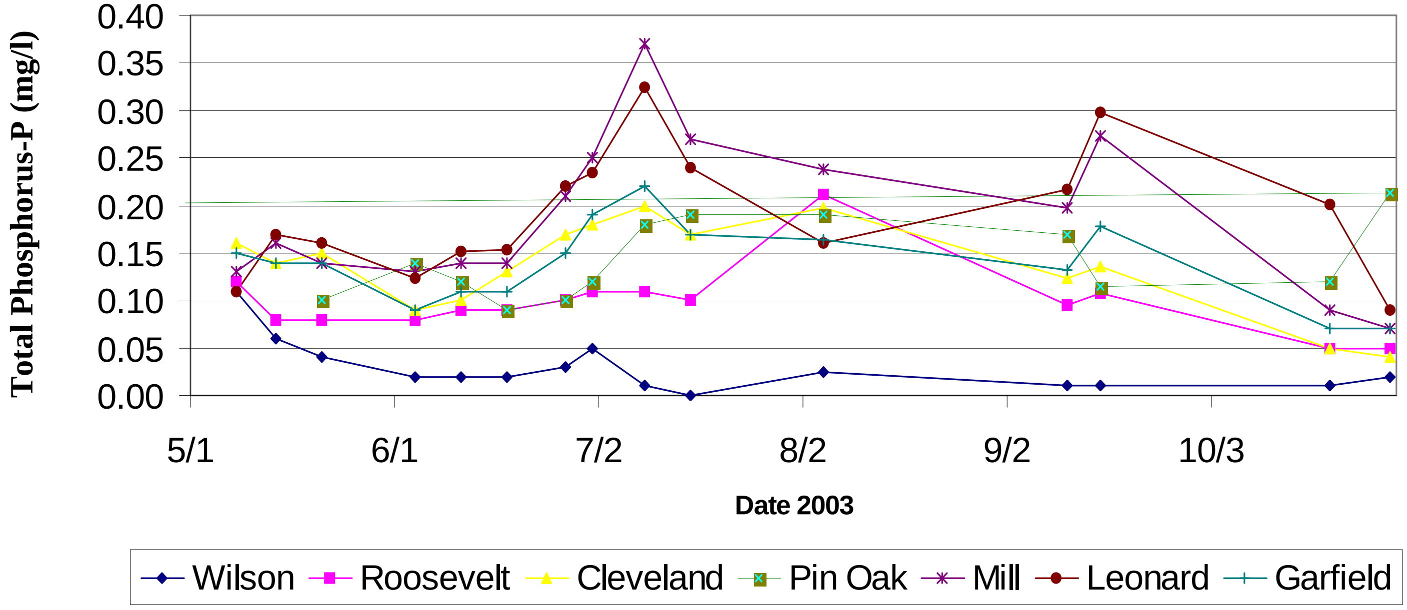
Total phosphorus (TP-P) is a measurement of all the various forms of phosphorus (inorganic, organic, dissolved, and particulate) in the water. A criterion of 0.10 mg/l has been established by the EPA (1986) for rivers not entering reservoirs. Concentrations as low as 0.025 mg/l can cause excessive algal blooms in lakes (EPA 1986).

Mean TP-P concentrations follow an increasing trend with distance downstream (Table 4.3.8). Mean TP-P concentrations increase by a factor of 3 from Wilson to Roosevelt. Mean concentrations then increase by 40% at Cleveland and remain constant to Garfield. A second 40% increase is noted at the Mill and Leonard sites. The highest maximum TP-P levels also were observed at these two stations. A number of patterns are present in the TP-P data (Figure 4.3.8). The Wilson station is the only location that peaked in May and declined throughout the investigation. The Roosevelt station peaked in concentration after the August rain event while a majority of the other stations exhibited maximum concentrations during the low flows recorded in July and September. With mean concentrations at 5 of 7 stations exceeding the EPA criterion of 0.10 mg/l, the results show that Deer Creek has phosphorus levels indicative of biological impairment. While levels of this magnitude would stimulate primary productivity, the turbid nature of the creek from excessive TSS limits plant growth.

Table 4.3.8. Mean and Range (minimum to maximum) Values for Total Phosphorus-P in Deer Creek (May - October 2003).

Total Phosphorus-P Concentration (mg/L)				
Site	Mean	Range (Min-Max)		
Wilson	0.03	0.01	-	0.11
Roosevelt	0.10	0.05	-	0.21
Cleveland	0.14	0.04	-	0.20
Pin Oak	0.13	0.06	-	0.21
Garfield	0.14	0.07	-	0.22
Mill	0.19	0.07	-	0.37
Leonard	0.19	0.09	-	0.32

Figure 4.3.8. Total Phosphorus-P Concentrations in Deer Creek (May - October 2003).



4.3.9 *E. coli*

Escherichia coli bacteria enter streams from agricultural runoff, sewage effluents, failed septic systems, and animals with direct access to the watercourse. In Deer Creek, agricultural runoff and animal access are the principle sources of *E. coli***.** The State of Michigan uses the following *E. coli* standards for beaches:

- Swimming - 130 colonies/100 mls as the 30 day geometric mean
- Swimming - 300 colonies/100 mls as the daily maximum for the geometric mean of three samples
- Partial Body Contact – 1,000 colonies/100 mls as the daily maximum for the geometric mean of three samples

While the above standards apply to beaches monitored under a defined program, the concentrations of *E. coli* measured in Deer Creek (Figure 4.3.9) are clearly a cause for concern from a human exposure standpoint when compared to this benchmark. Mean *E. coli* concentrations ranged from 768 – 1323 cfu/100 ml. Concentrations of > 6,000/100 ml are estimates of samples that were too numerous to count based on the smallest dilution (1 ml) and the maximum number of colonies that could be counted (60). Most stations had *E. coli* concentrations of > 6,000/100 ml after the August rain event. The remaining dates and stations with concentrations that were > 6,000/100 ml follow no apparent seasonal pattern, suggesting random releases of animal waste from agricultural facilities or livestock access are contributing excessive amounts of *E. coli* to the system. The high concentration recorded at Pin Oak on September 16 corresponded to a very high level of suspended solids (Figure 4.3.3).

Table 4.3.9. Mean and Range (minimum to maximum) Values for *E. coli* in Deer Creek (May - October 2003).

E. coli Concentration (#/100ml)				
Site	Mean	Range (Min-Max)		
Wilson	819	33	-	> 6000
Roosevelt	1125	33	-	> 6000
Cleveland	1323	17	-	> 6000
Pin Oak	1206	17	-	> 6000
Garfield	1185	33	-	> 6000
Mill	1253	17	-	> 6000
Leonard	768	17	-	> 6000

E. coli concentrations appear to be linked to stream flow at most stations. Figure 4.3.10 shows the relationship between bacterial concentrations and high, medium, and low flow regimes discussed in Section 4.2. With the exception of Wilson St, *E. coli* concentrations were greatest during the medium flow regime. As mentioned previously, the Wilson station appears to be influenced to a greater extent by groundwater infiltration than runoff. Consequently, a small rain event, like the one in August, would not be capable of washing fecal bacteria into the creek. At the remaining stations, the data

Figure 4.3.9. Mean *E. coli* Concentrations in Deer Creek (May - October 2003).

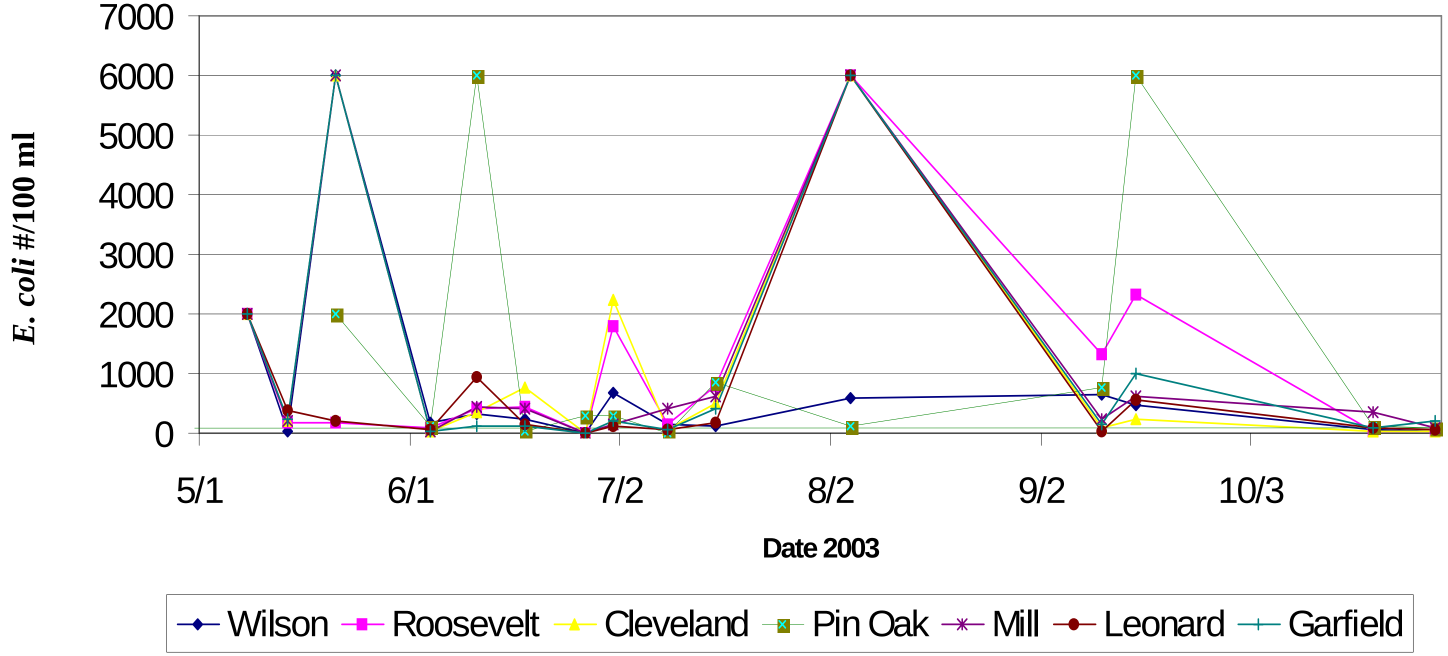
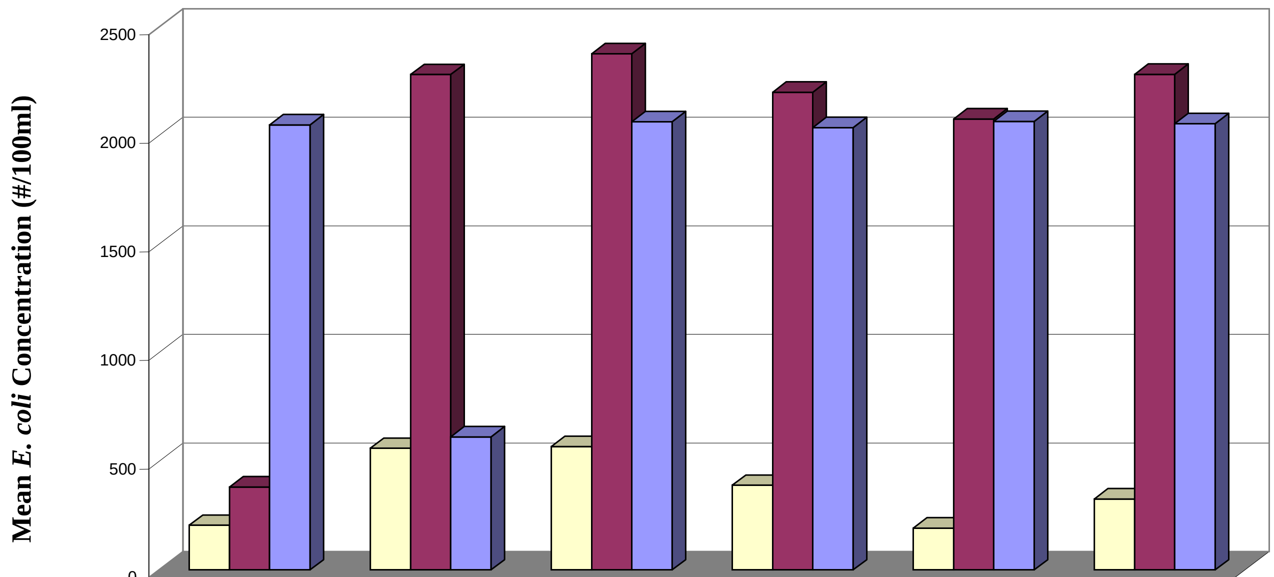


Figure 4.3.10. ***E. coli*** **Concentrations During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)**



	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow (#/100ml)	206	560	568	390	192	327
Medium Flow (#/100ml)	382	2,280	2,375	2,199	2,075	2,281
High Flow (#/100ml)	2,049	613	2,062	2,037	2,064	2,054

suggest that a moderate rain event can export high concentrations of bacteria. Lower concentrations observed during spring high flows also reflect dilution from increased discharge.

5.0 Nutrient Loading

5.1 Introduction

While concentration data are useful for evaluating water quality, it is necessary to examine the total amount of nutrients present at a given time and site to determine the relative contribution of sources in the system. The calculation of pollutant loads (concentration multiplied by discharge) provides an estimate of mass/time, which can be ranked with relative contributions from other locations. Sites with very high concentrations may result in localized impacts to the watershed, but if their discharges are low, the overall amount of material they contribute to Deer Creek will be relatively low. In contrast, sources with high discharges may have relatively modest concentrations, but because their total load is so high, they have considerable influence on nutrient export in the system. Even a small decrease in contaminant concentration in these high load locations may result in a large reduction in the overall mass of the contaminants entering Deer Creek. By determining nutrient loads within stream reaches, it is possible to identify locations that contribute the most contaminants to Deer Creek and to prioritize areas for further evaluation and remediation.

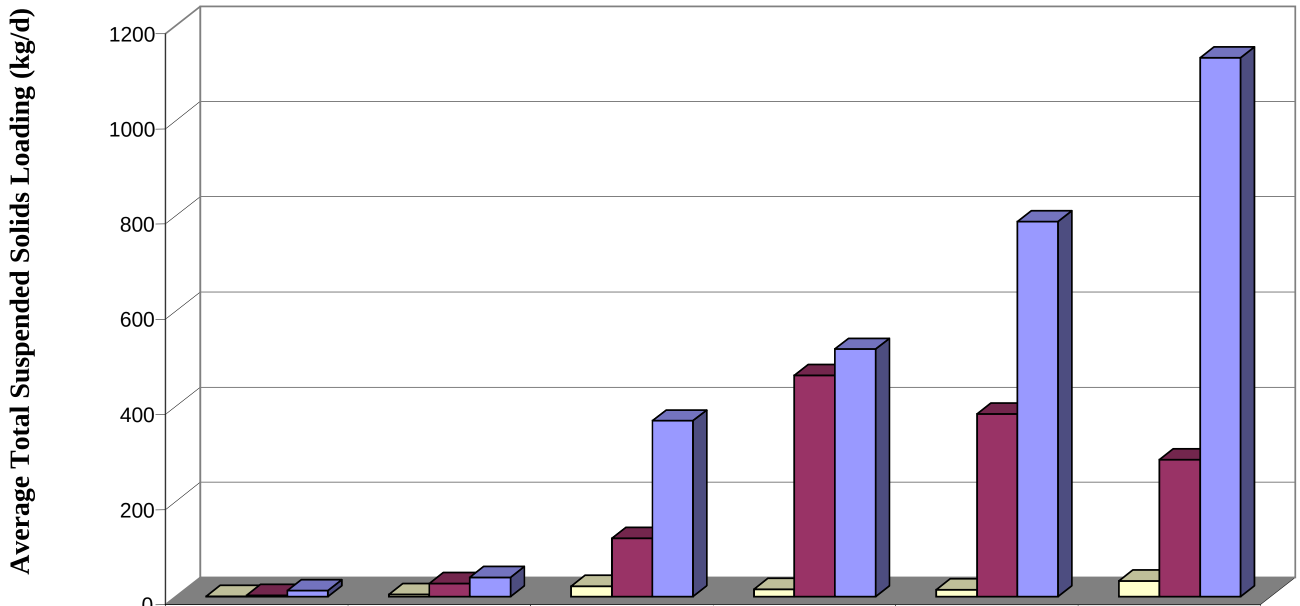
In this investigation, nutrient loadings were examined by three metrics. First, nutrient loadings were determined at each station by the multiplication of concentration and discharge. Cumulative loadings were then determined as the incremental amount of nutrient added or lost between stations. Finally, yields were calculated as the incremental amount of nutrient added or lost per day in the stream segment between stations divided by corresponding drainage area. The drainage areas for each location were provided in Section 4.1. A similar approach was used by Robertson (1997) to assess the significance of tributary loading to Lake Michigan. By using these three metrics, it is possible to identify and rank nutrient sources by the amount and by the watershed area that produced the loading. These data are important for prioritizing future investigations and the cost effective development of remediation strategies. Since concentration and discharge measurements were conducted only on the main branch of Deer Creek, the specific source(s) of nutrient loadings cannot be determined within each of the drainage areas. A more detailed investigation involving the tributaries and local groundwater would be required to develop nutrient loading budget for the individual sources in the watershed.

5.2 Total Suspended Solids Loading

Average total suspended solids loading for each station during high, medium, and low flow regimes are shown in Figure 5.2.1. Under high flow conditions, TSS loading increases dramatically at the Cleveland site, and by the time the water reaches the Mill St crossing, it is carrying 1,132 kg/d of suspended sediment. Under the medium flow regime, loadings increase from Cleveland to Pin Oak and then decline at the downstream stations. The low flow conditions show a steady increase to the Cleveland site, followed by a decrease from Pin Oak to Mill and then a doubling of TSS levels at Mill. The incremental increases between stations in Figure 5.2.2 indicates that the greatest gains in TSS occur between Roosevelt and Cleveland (329 kg/d) and Garfield and Mill (344 kg/d) under high flow. The Roosevelt-Cleveland segment contains the Beaver Creek subwatershed, which appears to be a major contributor of TSS. The agricultural land between Garfield and Mill also appears to supply a significant load of suspended sediment. It should be noted that stream channel cuts into the native clay layer in this part of the creek and channel erosion could make a significant contribution to TSS loads. During medium flow conditions, the Cleveland-Pin Oak segment contributes the greatest load. Since this segment passes through the city of Coopersville, the observed differences in loading may be related to the rapid response of impervious surfaces to rain events in contrast to agricultural land (Arnold and Gibbons 1996). It is also possible that runoff from local construction sites may also have influenced the observed loading. It is also interesting to note that the downstream reaches of Deer Creek appear to function as a sink during medium and low flows. These data suggest that sections of the watershed are subject to both sedimentation and scour as a result of the unstable hydrology. Water quality and habitat related impacts for the combination of scouring and sedimentation are common in Midwestern agricultural streams (Richards and Grabow 2003). The incremental increase in TSS loading at Mill must be viewed with caution. This station contains a riverine wetland and with the low flow and high nutrient concentrations (Figure 4.3.8), the suspended solids may be due to primary production and not related to sediment transport. Loadings can also be used to measure flashiness for each parameter. Based on the high/low ratio of TSS loading, one day of high flow is equivalent to 34 days of base flow (flashiness of 34). Robertson (1997) estimated the Grand River to have a TSS flashiness of 34.

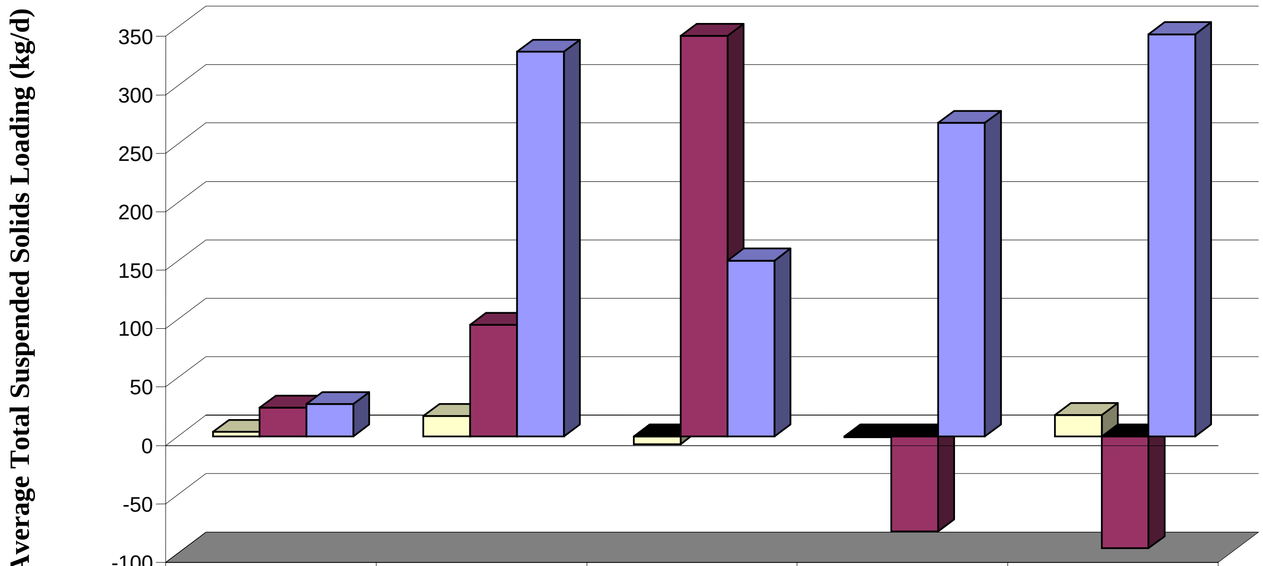
The yields of suspended solids shown in Figure 5.2.3 indicate that the small subwatershed from Pin Oak to Garfield contributes the greatest amount of suspended sediment per hectare. Almost 1 kg/d/ha is lost from this drainage area during high flow. This stream segment also has the greatest normalized incremental discharge during high flow, indicating a large amount of surface runoff is taking place (Section 4.2). The Pin Oak-Garfield segment includes runnoff from I-96, the subwatershed of Mosquito Creek that drains the sanitary landfill (expansion area under construction), and some pasture land. The presence of significant sources of erodable materials and hydrologic instability in a relatively small drainage area (272 hectares) provide the conditions for this location to have the greatest TSS yield. Even though the Roosevelt-Cleveland segment produced a high TSS load, the process of export is spread over a 2,187 ha area, resulting in a corresponding lower yield. Since TSS loading and stream discharge can vary over the duration of a storm event, time integrated composite sampling over a 24 hr period would be necessary to provide a more accurate estimate.

Figure 5.2.1. Average Total Suspended Solids Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



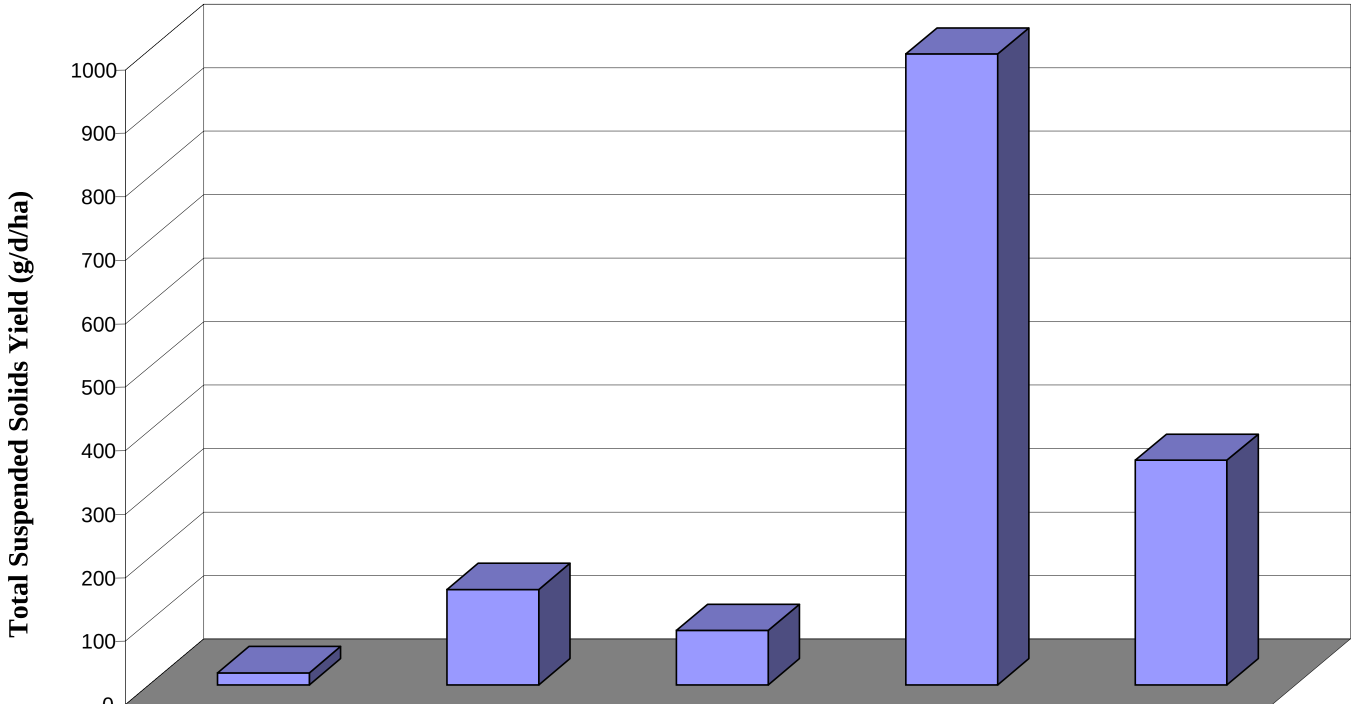
	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow (kg/d)	0.73	4.49	21.8	15.2	14.6	32.8
Medium Flow (kg/d)	2.46	27.1	122	465	384	288
High Flow (kg/d)	12.8	40.3	369	520	788	1132

Figure 5.2.2. Cumulative Average Total Suspended Solids Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
Low Flow (kg/d)	3.76	17.3	-6.6	-0.6	18.2
Medium Flow (kg/d)	24.7	95	343	-81	-96
High Flow (kg/d)	27.5	329	150	268	344

Figure 5.2.3. Total Suspended Solids Yields for the Deer Creek Sampling Stations During High Flow (2003). (High Flow is based on 0.8 – 1.5 m^3/sec recorded at Mill St.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
High Flow (g/d/ha)	19.0	150	86	994	354

Linear regression analysis was conducted on the data set to determine the degree of correlation between TSS and nutrient loading. The results are presented below:

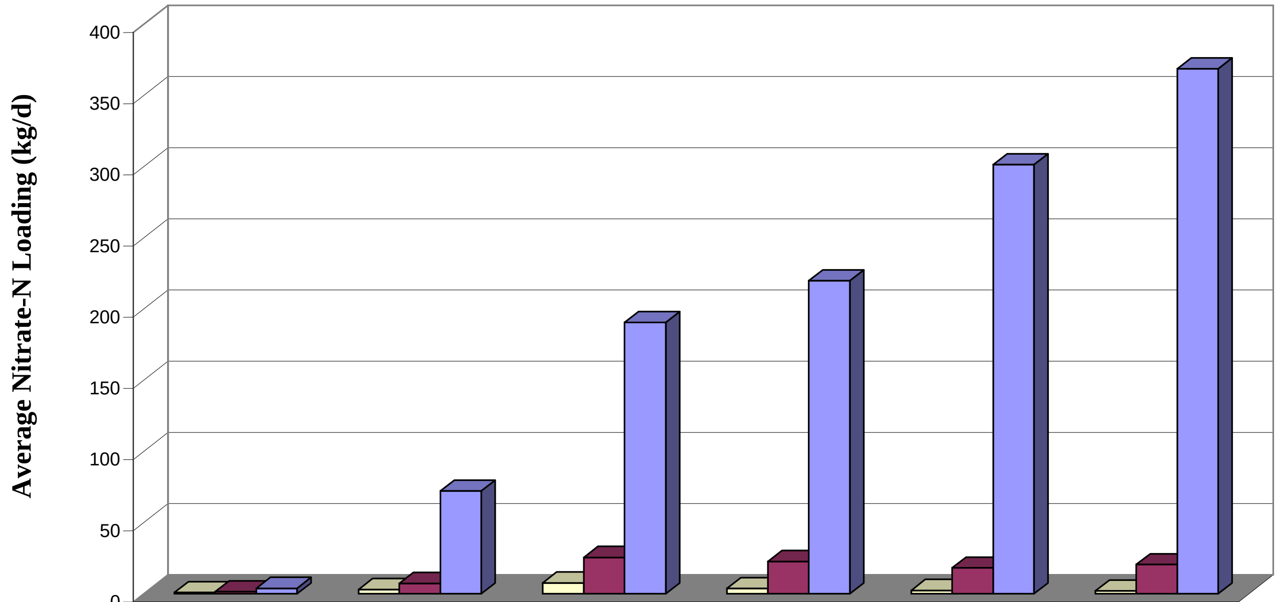
Parameters	Coefficient of Determination (r^2)	Correlation Coefficient (r)	Linear Regression p-value
TSS and Discharge	0.759	0.871	0.000
TSS and TP-P	0.752	0.867	0.000
TSS and SRP-P	0.807	0.898	0.000
TSS and TKN	0.718	0.847	0.000
TSS and Ammonia-N	0.761	0.872	0.000
TSS and Nitrate-N	0.696	0.834	0.000

Poff et al. (1997) found a strong relationship between flow regimes and the export of nutrients and sediment. Agricultural watersheds with impacted flow regimes exhibit high inputs of sediment during peak flows due to erosional losses from cultivated fields (Brenner and Mondok 1995). In this investigation, significant positive correlations were obtained for the loading of nutrients and suspended solids and for the loading of suspended solids and discharge. These correlations demonstrate a strong link between erosional loss of sediment and export of nutrients within the Deer Creek watershed.

5.3 Nitrate-N Loading

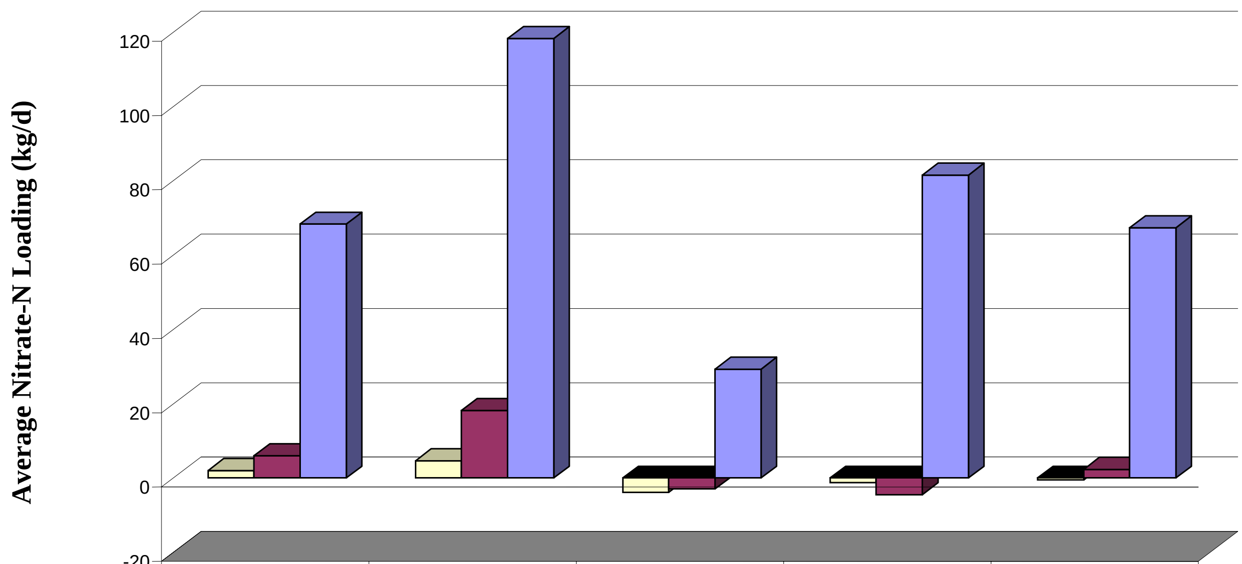
Average Nitrate-N loadings for each station during high, medium, and low flow regimes are shown in Figure 5.3.1. Under high flow conditions, Nitrate-N loading increases at the Roosevelt site, and by the time Deer Creek reaches the Mill St crossing, it is carrying 369 kg/d of the nutrient. Under the medium flow regime, loadings increase from Wilson to Cleveland and then remain relatively constant for the remainder of the stream course. The low flow conditions show a steady increase to the Cleveland site, followed by a decrease from Pin Oak to Mill. The incremental increases between stations in Figure 5.3.2 indicate that the greatest gains in Nitrate-N occur between Roosevelt and Cleveland (118 kg/d) and Pin Oak and Garfield (82 kg/d) under high flow. Wilson-Roosevelt and Garfield-Mill also contributed significant incremental increases (68 and 62 kg/d, respectively). Results from the Cleveland-Pin Oak segment show that the city of Coopersville makes a moderate contribution to Nitrate-N loadings during high flow (29 kg/d) and adds no incremental amount during medium and low flow periods. The stream segment from Wilson to Cleveland accounts for virtually all of the nitrate loading under low flow and 90% of the nutrient additions under medium flow. Based on the results for Nitrate-N and TSS, the Beaver Creek subwatershed appears to be the source area for these parameters. The stream segment from Roosevelt to Cleveland on the main branch of Deer Creek passes through a wetland area with a wooded buffer (Figure 2.1). A wetland area is also located on Beaver Creek near the confluence with the main branch of Deer Creek. Additional sampling and analysis of the Beaver Creek tributary and Deer Creek above the confluence would be required to determine the extent each segment contributes to the loadings observed at Cleveland St. Nitrate-N yields shown in Figure 5.3.3 again indicate that the small drainage basin from Pin Oak to Garfield contributes the greatest amount of this nutrient per hectare (302 g/d/ha) under high flow conditions. The incremental discharge data presented in Figure 4.2.2 show that this 272 hectare drainage

Figure 5.3.1. Average Nitrate-N Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



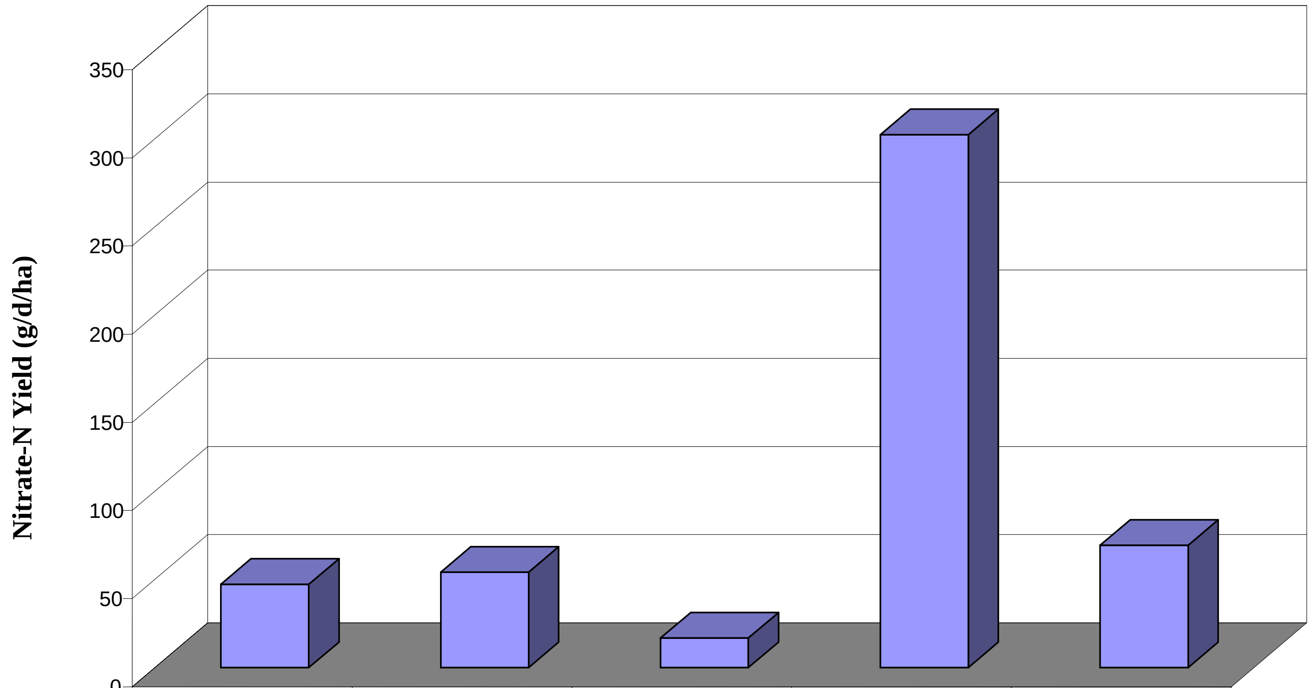
	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow (kg/d)	0.85	2.92	7.55	3.72	2.47	1.94
Medium Flow (kg/d)	1.37	7.37	25.5	22.6	18.1	20.5
High Flow (kg/d)	3.89	72.2	191	220	301	369

Figure 5.3.2. Cumulative Average Nitrate-N Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
Low Flow (kg/d)	2.06	4.63	-3.83	-1.24	-0.54
Medium Flow (kg/d)	6.00	18.2	-2.96	-4.49	2.38
High Flow (kg/d)	68.4	118	29	82	67

Figure 5.3.3. Nitrate-N Yields for the Deer Creek Sampling Stations During High Flow (2003). (High Flow is based on 0.8 – 1.5 m^3/sec recorded at Mill St.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
High Flow (g/d/ha)	47.3	54.1	16.7	302	69.3

area adds the same amount of water (0.17 m^3/s) as the Cleveland-Pin Oak section (0.18 m^3/s), which is seven times larger in area (1,751 ha). Since the Pin Oak-Garfield reach contributed negligible incremental discharge during medium and low flow regimes, groundwater influx is not a significant water source. As with suspended solids, overland flow represents the most likely source of nitrate export during and after rain events. The Cleveland-Pin Oak reach has the lowest yield (16.7 g/ha/d) while the remainder of the segments range from 47-69 g/d/ha. These data show that urban runoff makes a minor contribution to the nitrate budget for Deer Creek. The predominant source of nitrate in this watershed is agricultural nonpoint source pollution from two sources:

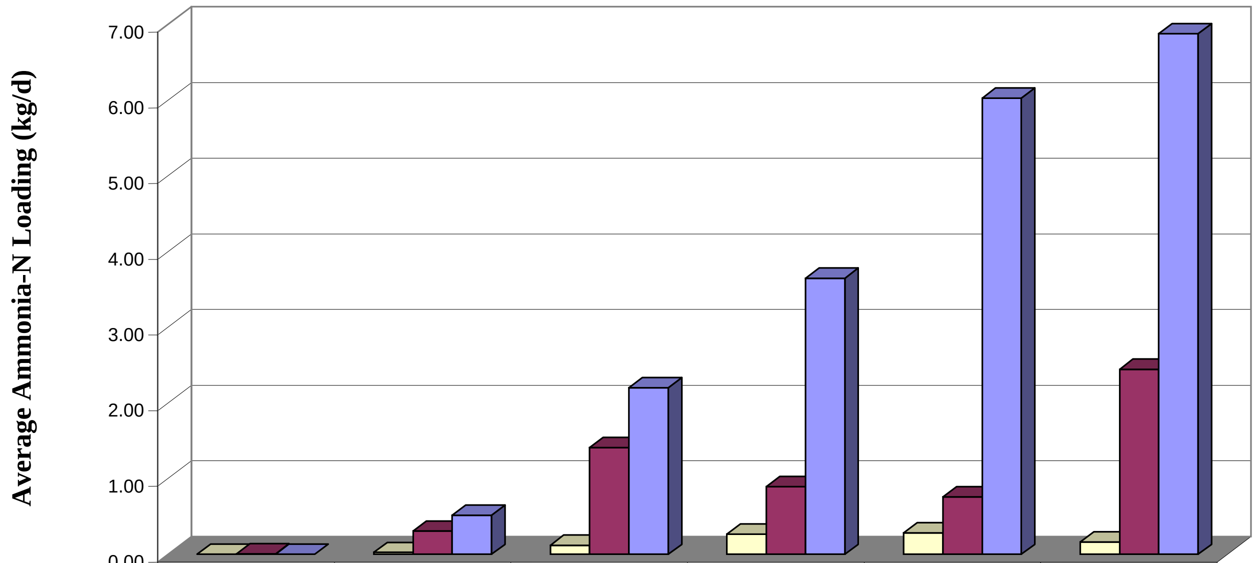
- Nitrate-N in the watershed soils that are exported to the stream during storm events.
- Nitrate-N in the groundwater that supplies the stream during base flow

Atmospheric deposition also may play a significant role in the Deer Creek watershed due to the high degree of cultivation and the prevailing westerly winds. These observations are consistent with previous studies where Nitrate-N export was strongly linked to groundwater influx in headwater streams and overland flow during storm events (Vanni et al. 2001).

5.4 Ammonia-N Loading

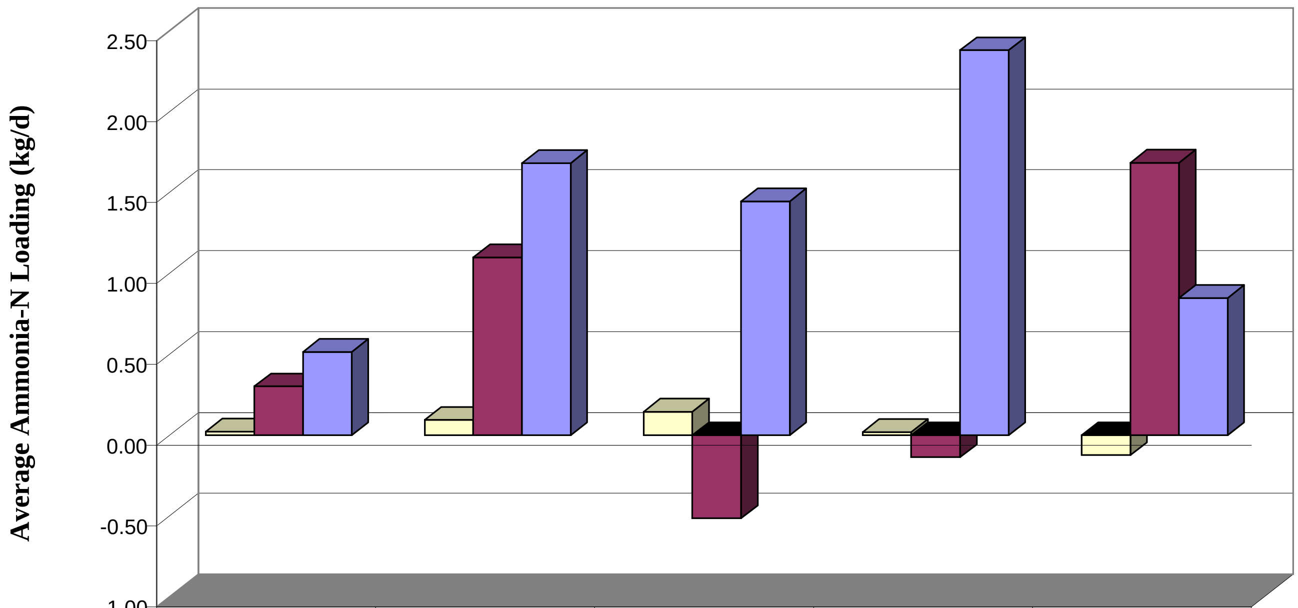
Average Ammonia-N loadings for each station during high, medium, and low flow regimes are shown in Figure 5.4.1. Under high flow conditions, Ammonia-N loading shows an almost four-fold increase between Roosevelt and Cleveland (0.52 kg/d to 2.2 kg/d), and by the time Deer Creek reaches the Mill St crossing, it is carrying 6.8 kg/d of the nutrient. Under the medium flow regime, loadings increase from Wilson to Cleveland and then decrease from Cleveland to Garfield. Ammonia-N levels then increase again at the Mill station. As mentioned previously, this location contains a riverine wetland and may be a natural source of nutrients. The low flow conditions indicate a steady increase in loading to the Garfield site, followed by a decrease to Mill. The losses observed may be due to conversion to nitrate. The incremental increases between stations in Figure 5.4.2 show the greatest gains in Ammonia-N occur between Roosevelt and Cleveland (1.68 kg/d) and between Pin Oak and Garfield (2.38 kg/d) under high flow. Cleveland to Pin Oak also contributed significant incremental increases (1.45 kg/d). These results suggest that there are minor differences between loadings from urban and agricultural sources for this nutrient under high flow conditions. Since urban loadings of ammonia are negligible under medium flows, there may be a discharge threshold related to the export of this nutrient. The stream segment from Wilson to Cleveland accounts for a majority of the ammonia loading under medium flow. Low flow exhibited insignificant incremental changes in ammonia loadings (< 0.1 kg/d). Since ammonia is toxic to fish and aquatic life, the incremental loadings from Roosevelt-Cleveland and Pin Oak-Garfield need to be investigated in more detail to identify specific source areas.

Figure 5.4.1. Average Ammonia-N Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow (kg/d)	0.00	0.03	0.12	0.27	0.29	0.16
Medium Flow (kg/d)	0.01	0.31	1.41	0.90	0.76	2.45
High Flow (kg/d)	0.00	0.52	2.20	3.65	6.03	6.88

Figure 5.4.2. Cumulative Average Ammonia-N Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
Low Flow (kg/d)	0.02	0.09	0.15	0.02	-0.12
Medium Flow (kg/d)	0.30	1.10	-0.51	-0.14	1.69
High Flow (kg/d)	0.51	1.68	1.45	2.38	0.85

Ammonia-N yields shown in Figure 5.4.3 again indicate that the small subwatershed from Pin Oak to Garfield contributes the greatest amount of this nutrient per hectare (8.8 g/d/ha) under high flow conditions. Yields for the other segments were low (< 1 g/d/ha). The highest ammonia concentration (0.62 mg/l) was recorded at the Garfield site (Figure 4.3.5) during low flow conditions. Since ammonia is not a typical pollutant associated with urban runoff, the stretch of I-96 in the drainage area is probably not the source. Groundwater losses from the wastewater lagoons or the influx of landfill leachate would tend to be constant at base flow conditions and not result in a concentration spike. Since high *E. coli* concentrations were not present in the sample (Figure 4.3.9), an influx of animal wastes was probably not the cause. The only remaining source may have been an application of anhydrous ammonia to the soil as fertilizer that entered Deer Creek. In consideration of the small land area, high pollutant loadings, and the presence of multiple sources, the Pin Oak-Garfield segment of Deer Creek needs to be investigated to determine the origin of nutrient loading and evaluated for agricultural best management practices (BMPs) and storm water control.

5.5 Total Kjeldahl Nitrogen-N Loading

Average TKN-N loadings for each station during high, medium, and low flow regimes are shown in Figure 5.5.1. Under high flow conditions, TKN-N loadings steadily increase from 1.26 kg/d at Wilson to 112 kg/d at Mill. Under the medium flow regime, loadings increase from Wilson to Cleveland and then remain relatively constant for the remainder of the stream course. This was the same pattern observed for Nitrate-N (Figure 5.2.1) and Ammonia-N (5.4.1). The low flow conditions show a steady increase to the Pin Oak site, and then remain relatively constant to the Mill station. The incremental increases between stations in Figure 5.5.2 indicate that the greatest gains in TKN-N occur between Roosevelt and Cleveland (37.7 kg/d) under high flow. The Wilson-Roosevelt, Cleveland-Pin Oak, and Pin Oak-Garfield segments also contributed significant incremental increases (14.3, 13.0, and 28 kg/d, respectively). Results from the Cleveland-Pin Oak segment show that the city of Coopersville makes a moderate contribution to TKN-N loadings during high flow and adds limited incremental amounts during medium and low flow periods. The stream segment from Wilson to Cleveland accounts for a majority of the TKN-N loading under low and medium flow conditions. This pattern was again similar to the incremental loading trends observed for Nitrate-N. Based on these results, the Beaver Creek subwatershed appears to be the source area for TKN-N. The stream segment from Roosevelt to Cleveland on the main branch of Deer Creek passes through a wetland area with a wooded buffer (Figure 2.1). As previously mentioned, wetlands border the main branch of Deer Creek and Beaver Creek near the Cleveland station. Productivity and decomposition associated with these wetlands may account for a part of the observed loading during low and medium flow conditions. Additional sampling and analysis of the Beaver Creek tributary and Deer Creek above the confluence and wetlands would be required to determine the extent each segment and corresponding wetlands contribute to the loadings observed at Cleveland St.

TKN-N yields shown in Figure 5.5.3 again indicate that the small drainage basin from Pin Oak to Garfield contributes the greatest amount of this nutrient per hectare (67.7

Figure 5.4.3. Ammonia-N Yields for the Deer Creek Sampling Stations During High Flow (2003). (High Flow is based on 0.8 – 1.5 m^3/sec recorded at Mill St.)

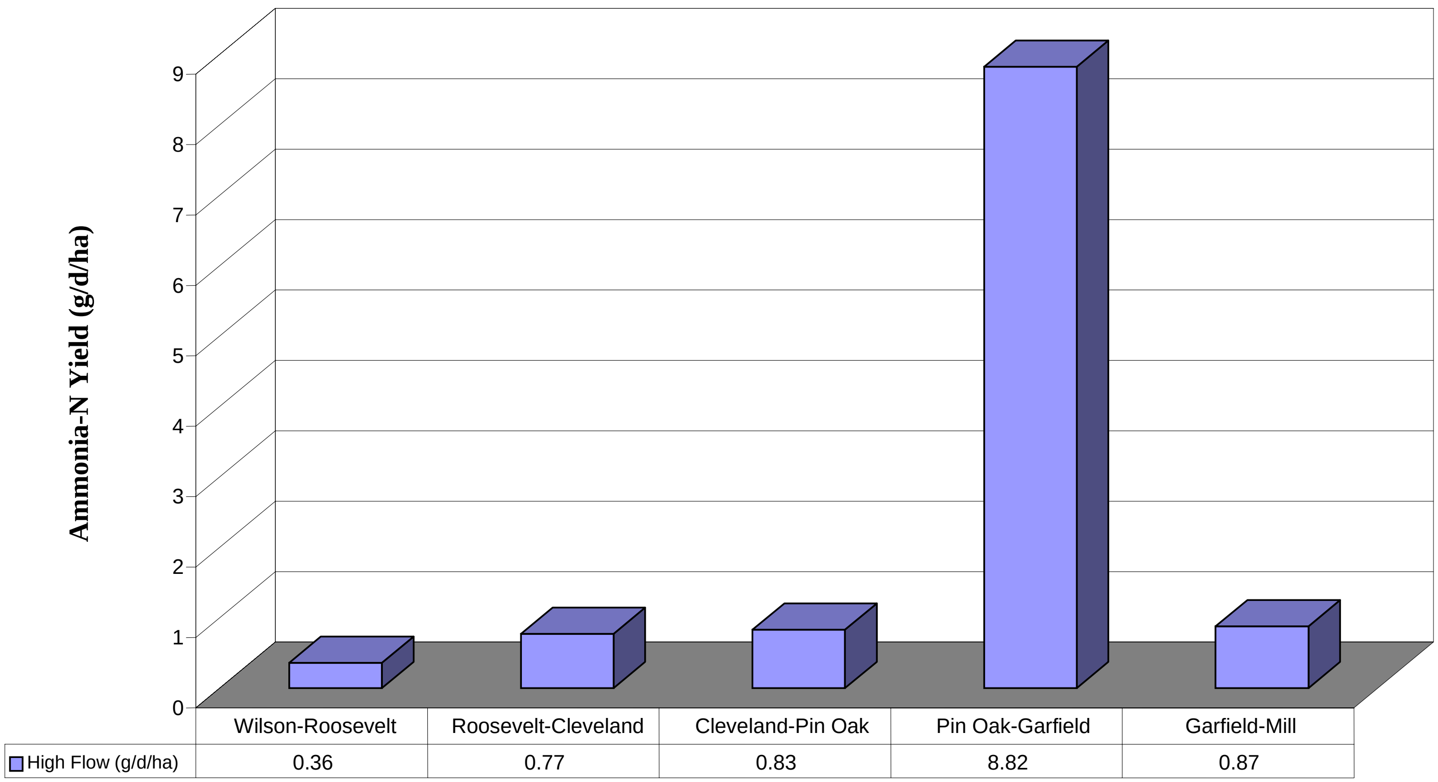
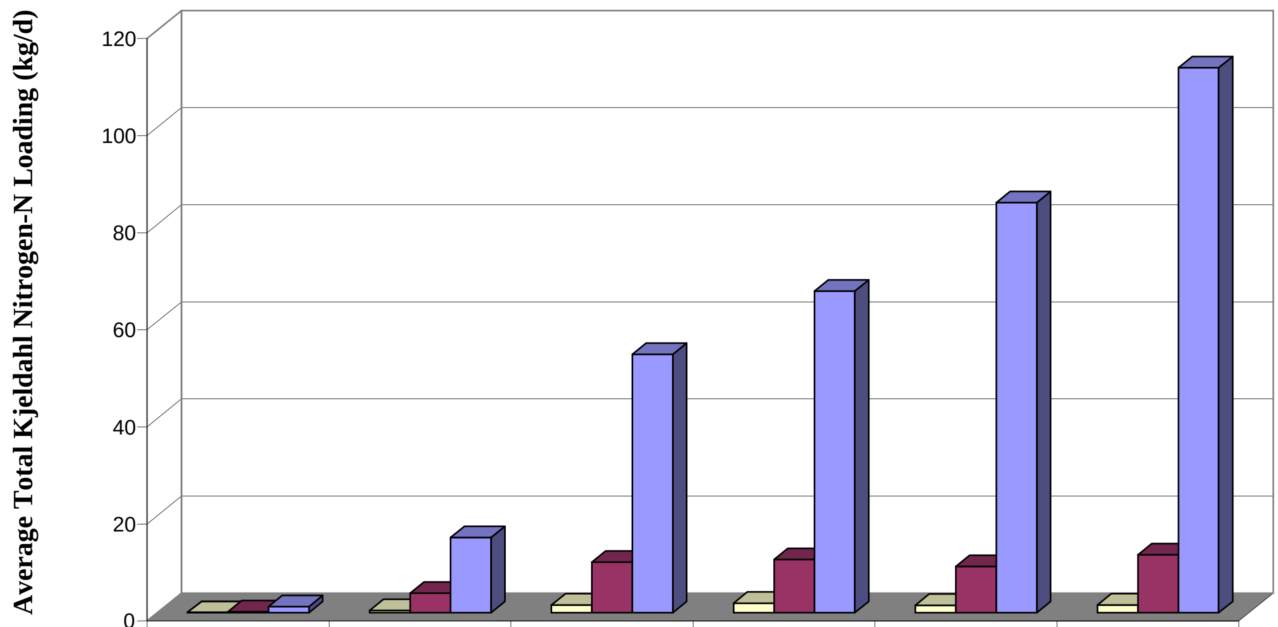
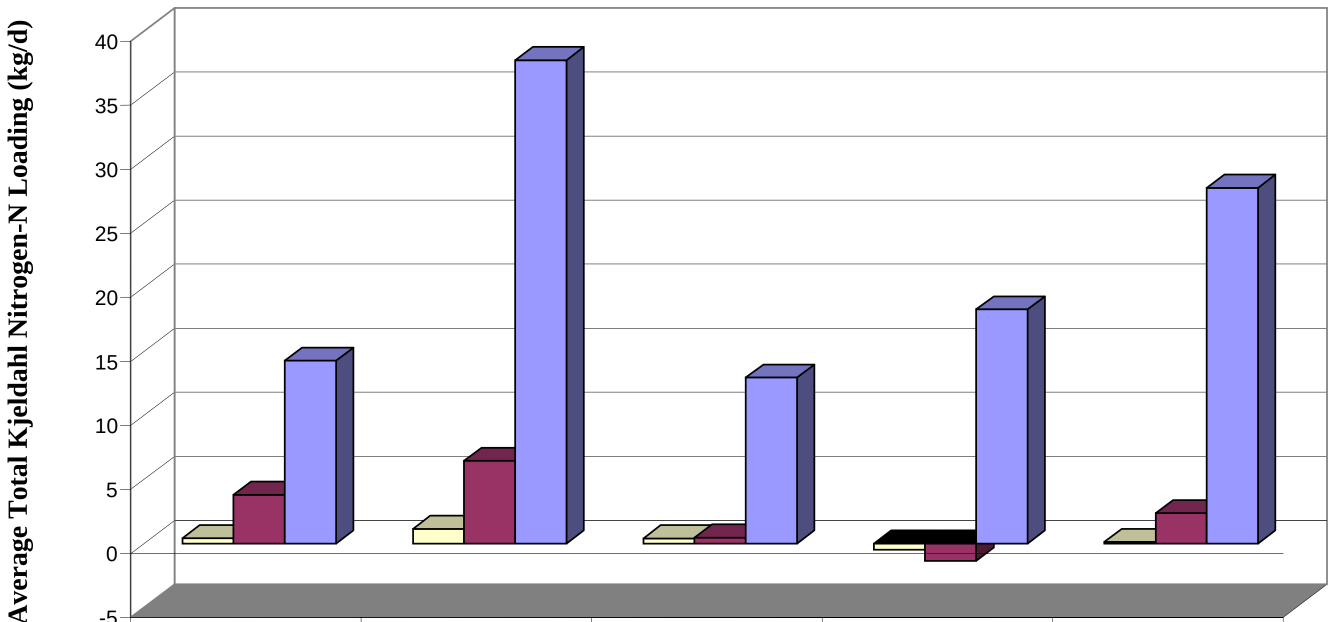


Figure 5.5.1. Average Total Kjeldahl Nitrogen-N Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



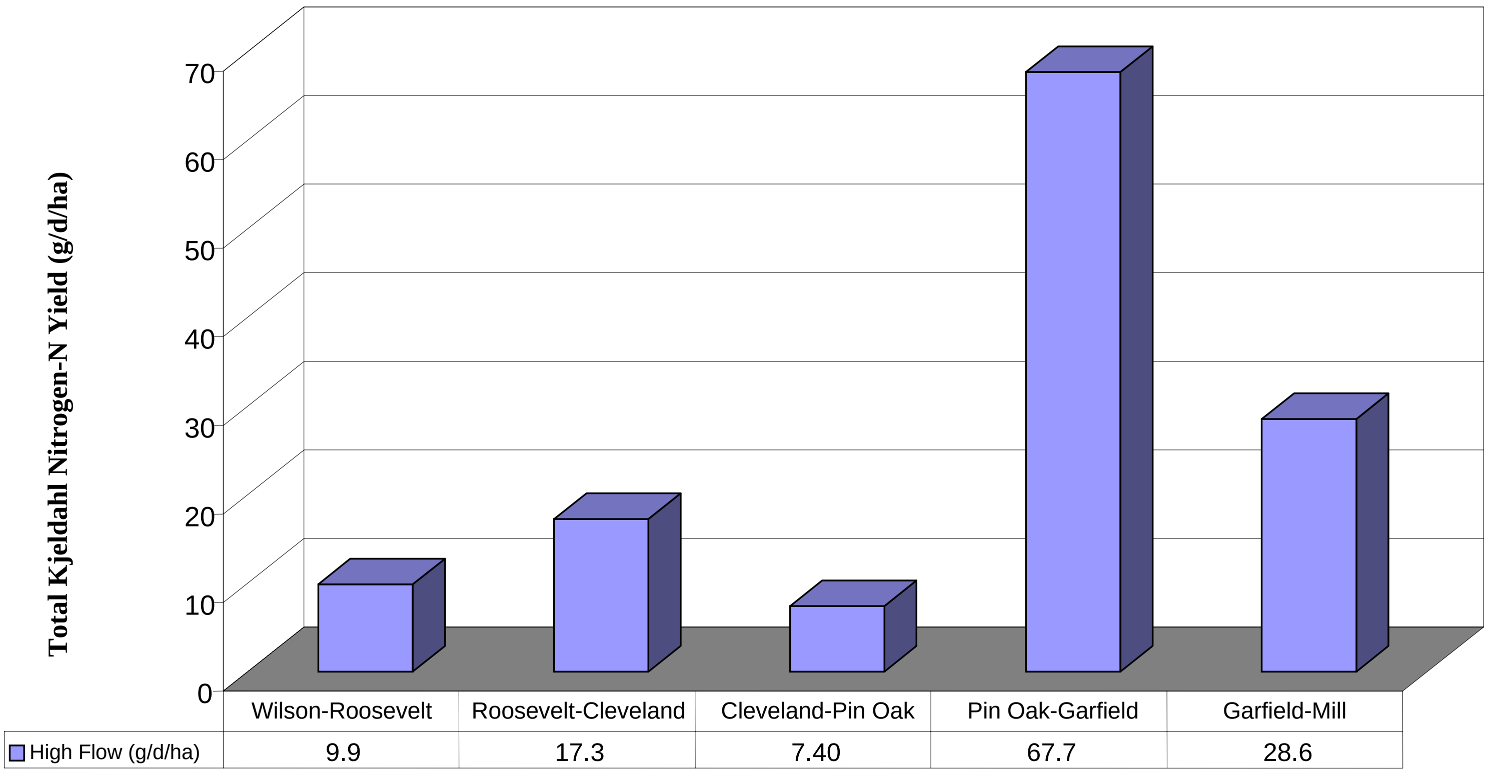
	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow (kg/d)	0.07	0.48	1.61	2.00	1.50	1.61
Medium Flow (kg/d)	0.22	4.02	10.5	10.9	9.58	11.9
High Flow (kg/d)	1.26	15.5	53.3	66.2	84.5	112

Figure 5.5.2. Cumulative Average Total Kjeldahl Nitrogen-N Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
Low Flow (kg/d)	0.41	1.13	0.38	-0.50	0.11
Medium Flow (kg/d)	3.80	6.4	0.5	-1.4	2.4
High Flow (kg/d)	14.3	37.7	13.0	18.3	28

Figure 5.5.3. Total Kjeldahl Nitrogen-N Yields for the Deer Creek Sampling Stations During High Flow (2003). (High Flow is based on 0.8 – 1.5 m^3/sec recorded at Mill St.)



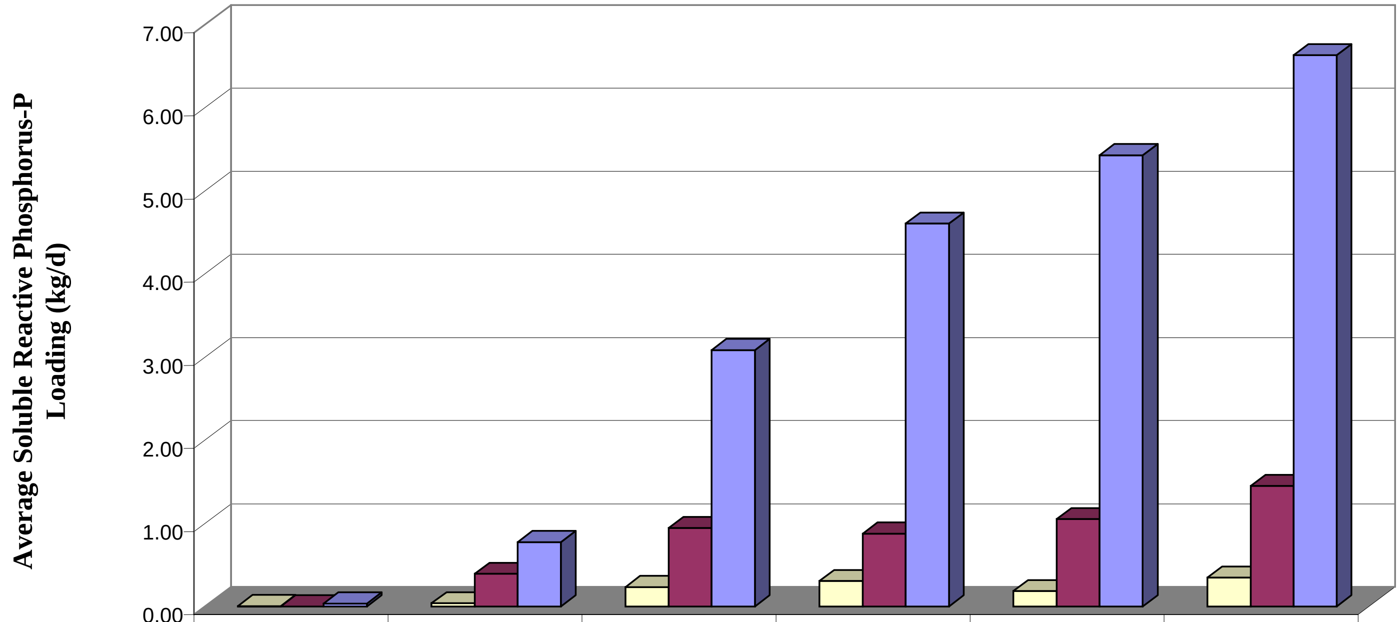
g/d/ha) under high flow conditions. The Roosevelt-Cleveland and Garfield-Mill segments also contribute moderate yields (17.3 g/d/ha and 28.6 g/ha/d, respectively). As with suspended solids, overland flow represents the most likely source of TKN export during and after rain events. Similar to ammonia loadings, the results show that urban runoff makes a minor contribution to the TKN-N budget for Deer Creek. The source of TKN-N in this watershed is agricultural nonpoint source pollution with a potential influence from the wetlands.

5.6 Soluble Reactive Phosphorus-P Loading

Average SRP-P loadings for each station during high, medium, and low flow regimes are shown in Figure 5.6.1. Under high flow conditions, SRP-P loadings steadily increase from 0.03 kg/d at Wilson to 6.6 kg/d at Mill. At the medium flow regime, loadings follow a similar pattern with an increasing trend with distance over the stream length. The low flow conditions show a steady increase to the Pin Oak site, a drop at Garfield, then an increase back to previous amounts at the Mill station. The incremental increases between stations in Figure 5.6.2 indicate that the greatest gains in SRP-P occur between Roosevelt and Cleveland (2.31 kg/d) under high flow. The Cleveland-Pin Oak and the Garfield-Mill segments contributed moderate incremental increases (1.52 and 1.20 kg/d, respectively). Results from the Cleveland-Pin Oak segment show that the city of Coopersville makes a moderate contribution to SRP-P loadings during high flow and adds very limited incremental amounts during medium and low flow periods. Consistent with the other nutrients, the stream segment from Wilson to Cleveland accounts for a majority of the SRP-P loading under low and medium flow conditions. Based on these results, this drainage area, including the Beaver Creek subwatershed, appears to be the major source area for SRP-P. Since SRP-P can be added by pollutant loading and decomposition and lost by biological uptake, precipitation, and adsorption, data interpretation is problematic. Since SRP is usually a limiting nutrient and found in very low concentrations in most Michigan soils, measurable loadings during base flow conditions suggest a groundwater source or the direct input of animal waste materials. Since spikes in concentration of *E. coli* bacteria were observed at base flow (Figure 4.3.9), there is a strong indication that animal wastes are directly entering Deer Creek.

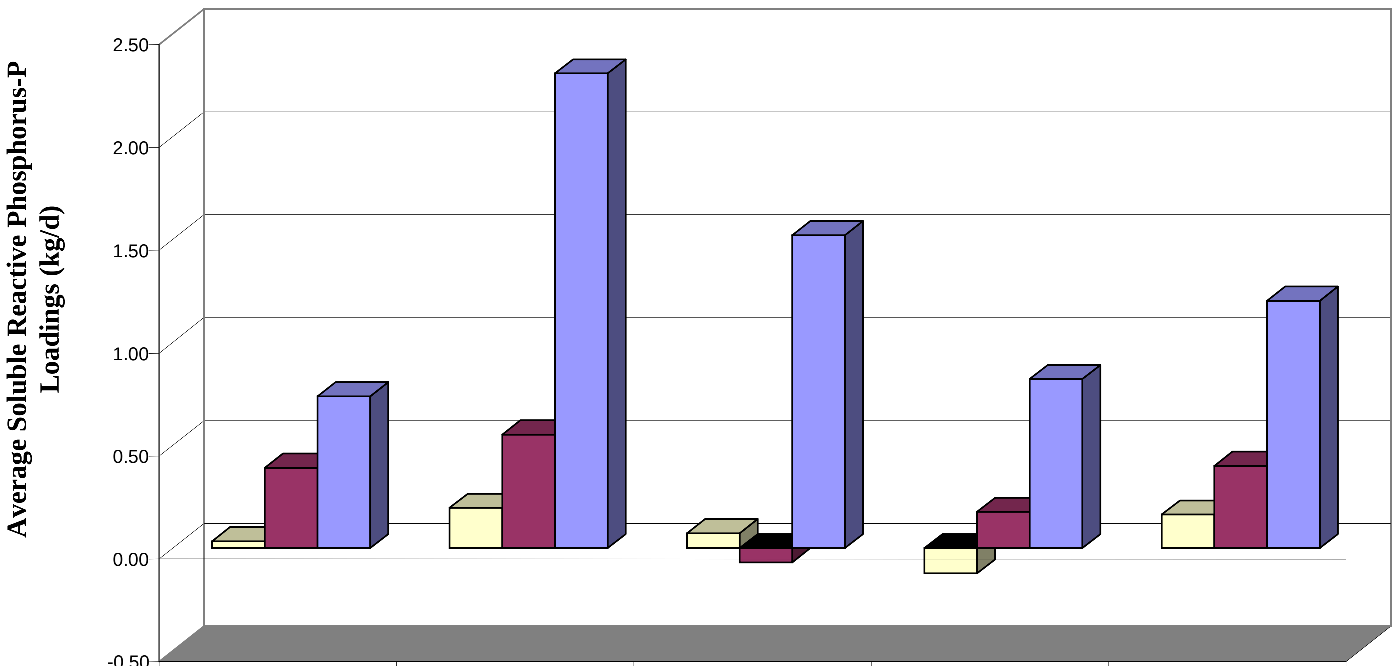
SRP-P yields shown in Figure 5.6.3 again show that the small subwatershed from Pin Oak to Garfield contributes the greatest amount of this nutrient per hectare (3.05 g/d/ha) under high flow conditions. The Roosevelt-Cleveland and Garfield to Mill segments also contribute moderate yields (1.06 g/d/ha and 1.24 g/ha/d, respectively). Using a drainage area of 6626 ha for Deer Creek at the Mill St site, the SRP-P yields for this part of the watershed for low, medium and high flow events are (0.40, 2.32, and 10.59 g/ha/d, respectively). As with suspended solids, Ammonia-N, and TKN-N, overland flow represents the most likely source of SRP-P export during and after rain events. In contrast to ammonia and TKN loadings, the results illustrate that urban runoff makes a moderate contribution to the SRP-P budget for Deer Creek under high flow conditions. The predominant source of SRP-P in this watershed appears to be agricultural nonpoint source pollution.

Figure 5.6.1. Average Soluble Reactive Phosphorus-P Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



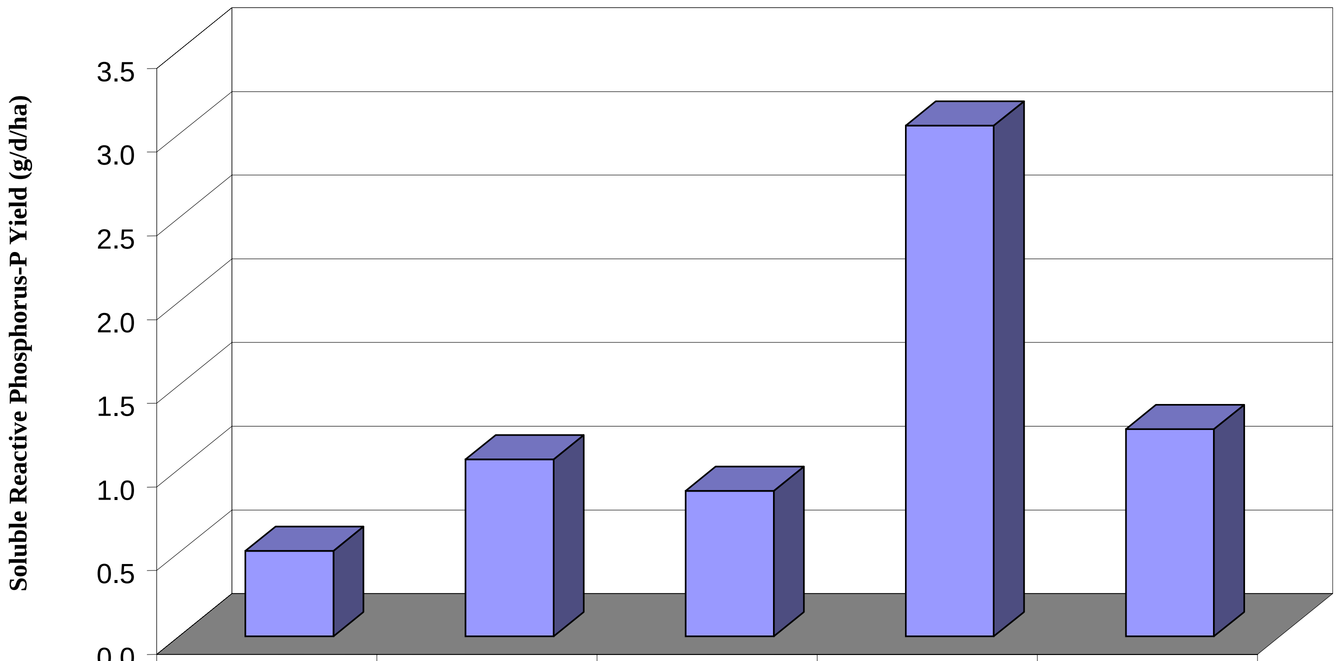
	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow (kg/d)	0.00	0.04	0.23	0.31	0.18	0.35
Medium Flow (kg/d)	0.00	0.39	0.94	0.87	1.05	1.45
High Flow (kg/d)	0.03	0.77	3.08	4.60	5.43	6.63

Figure 5.6.2. Cumulative Average Soluble Reactive Phosphorus-P Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
Low Flow (kg/d)	0.03	0.20	0.07	-0.12	0.16
Medium Flow (kg/d)	0.39	0.55	-0.07	0.18	0.40
High Flow (kg/d)	0.74	2.31	1.52	0.82	1.20

Figure 5.6.3. Soluble Reactive Phosphorus Yields for the Deer Creek Sampling Stations During High Flow (2003). (High Flow is based on 0.8 – 1.5 m^3/sec recorded at Mill St.)



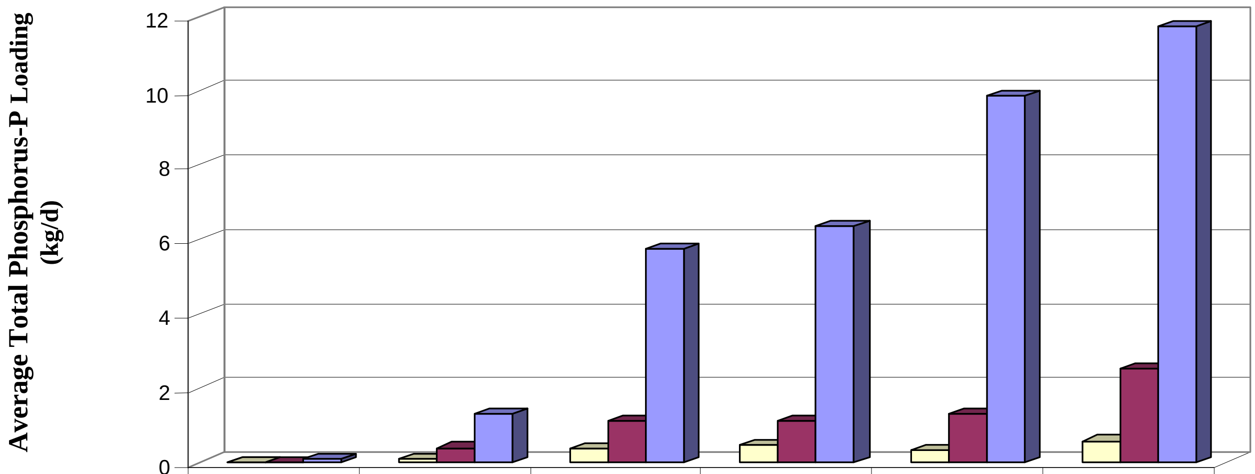
	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
High Flow (g/d/ha)	0.51	1.06	0.87	3.05	1.24

5.7 Total Phosphorus-P Loading

Average TP-P loadings for each station during high, medium, and low flow regimes are shown in Figure 5.7.1. Under high flow conditions, TP-P loadings steadily increase from 0.08 kg/d at Wilson to 11.7 kg/d at Mill. Under the medium flow regime, loadings increase from Wilson to Mill in a similar manner with a range between the upper and lower watershed of 0.01 kg/d to 2.51 kg/d. The low flow conditions also show an increasing trend, with a slight dip in loading at the Garfield site. The incremental increases between stations in Figure 5.7.2 present a different pattern. The greatest gains in TP-P occur between Roosevelt-Cleveland (4.42 kg/d) and Pin Oak-Garfield (3.50 kg/d) under high flow. The Wilson-Roosevelt, Cleveland-Pin Oak, and Garfield-Mill segments also contributed significant incremental increases (1.22, 0.63, and 1.9 kg/d, respectively). Results from the Cleveland-Pin Oak segment show that the city of Coopersville makes a small contribution to TP-P loadings during high flow and adds limited incremental amounts during medium and low flow periods. The stream segments from Wilson to Cleveland and Garfield to Mill have similar incremental contributions to the loading of TP-P. These reaches also accounted for a majority of the TP-P inputs during medium flow. While loadings for nitrate, ammonia, TKN, and SRP illustrate that the Roosevelt-Cleveland reach (including the Beaver Creek subwatershed) contributes the greatest mass of these nutrients, TP-P contributions are equally split between the upper and lower watersheds. This pattern also was noted for TSS (Figure 5.2.2) and links erosional losses with TP-P export. Over 50% of the TP-P loading consists of soluble reactive phosphorus compounds. The mean SRP-P/TP-P ratios for high, medium and low flows were 57%, 80%, and 60%, respectively. The presence of a high mean SRP-P/TP-P ratio during low flow indicates that groundwater plays a significant role in phosphorus export. High SRP-P/TP-P ratios during medium and high flows indicate that regional soils are saturated with phosphorus to the point that soluble and adsorbed fractions are mobilized during precipitation events that produce runoff. The high mean SRP-P/TP-P ratio that was present during medium flow was related to data recorded during the August rain event (Figures 4.3.7 and 4.3.8). These results suggest that soluble phosphorus from summer fertilizer applications may have been released to the watershed during this rain event. Since high SRP-P concentrations stimulate primary productivity and accelerate eutrophication, it is critical that farm management plans be developed to ensure that fertilizer is applied at rates that do not exceed available nutrients currently in the soil.

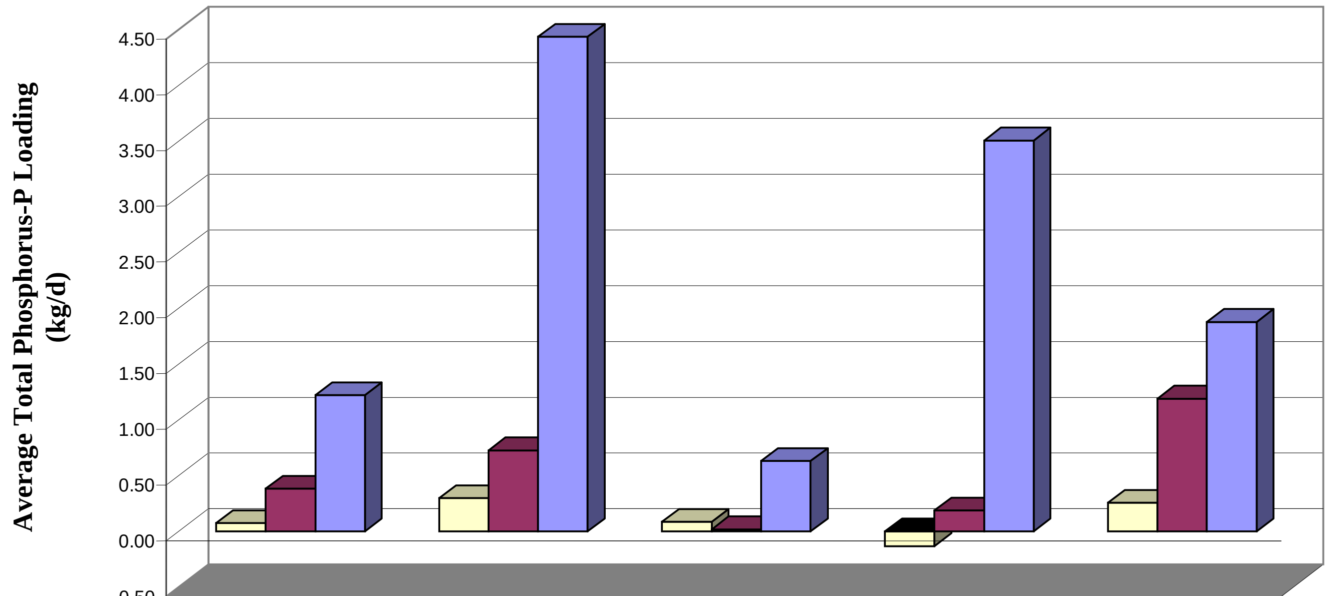
Similar to the other nutrients and TSS, TP-P yields in Figure 5.7.3 again indicate that the small subwatershed from Pin Oak to Garfield contributes the greatest loading per hectare (12.99 g/d/ha) under high flow conditions. The Roosevelt-Cleveland and Garfield-Mill segments contribute minor yields (2.03 g/d/ha and 1.93 g/ha/d, respectively). The absence of significant loadings and yields of TP-P at the Cleveland-Pin Oak segment indicates that urban runoff does not make a significant contribution to the loading of this nutrient. The predominant source of TP-P in this watershed again appears to agricultural nonpoint source pollution.

Figure 5.7.1. Average Total Phosphorus-P Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



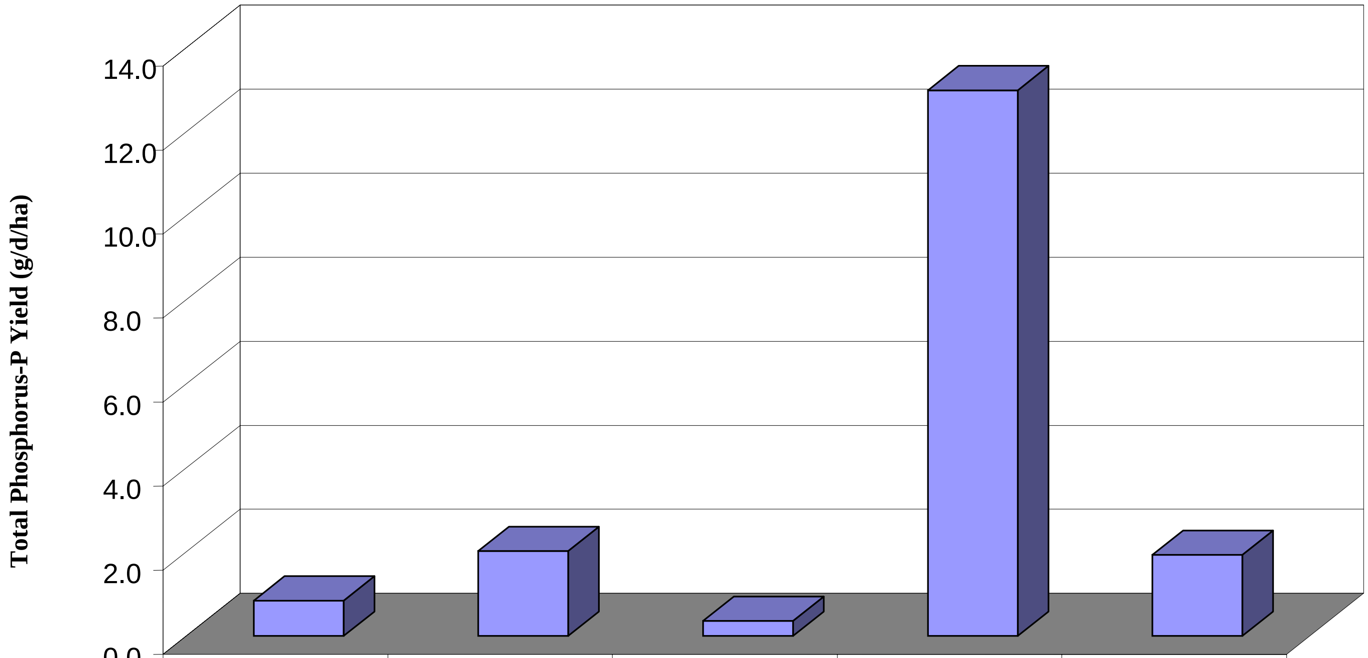
	Wilson	Roosevelt	Cleveland	Pin Oak	Garfield	Mill
Low Flow (kg/d)	0.00	0.08	0.37	0.46	0.32	0.58
Medium Flow (kg/d)	0.01	0.39	1.11	1.13	1.32	2.51
High Flow (kg/d)	0.08	1.30	5.73	6.36	9.87	11.7

Figure 5.7.2. Cumulative Average Total Phosphorus-P Loading During High, Medium, and Low Flow Periods Recorded at the Deer Creek Sampling Stations (2003). (Flow Periods Based in Mill St: High 0.8 – 1.5 m^3/sec, Medium 0.12-0.26 m^3/sec, Low 0.00-0.53 m^3/sec.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
Low Flow (kg/d)	0.07	0.30	0.08	-0.13	0.25
Medium Flow (kg/d)	0.38	0.73	0.02	0.19	1.19
High Flow (kg/d)	1.22	4.43	0.63	3.50	1.9

Figure 5.7.3. Total Phosphorus Yields for the Deer Creek Sampling Stations During High Flow (2003). (High Flow is based on 0.8 – 1.5 m^3/sec recorded at Mill St.)



	Wilson-Roosevelt	Roosevelt-Cleveland	Cleveland-Pin Oak	Pin Oak-Garfield	Garfield-Mill
High Flow (g/d/ha)	0.84	2.03	0.36	12.99	1.93

5.8 Summary

The nutrient and suspended solids loading and yield data for Deer Creek provided important information related to pollutant sources and their significance in the watershed. Three major problem areas were identified:

- Agricultural nonpoint source pollution is the major contributor of nutrients and suspended solids in the watershed. The city of Coopersville has a very limited effect on the stream with respect to the addition of these materials.
- The watershed area drained by Deer Creek from Roosevelt St to Cleveland St (including Beaver Creek) produces the largest load of most nutrients and suspended solids during high, medium, and low flow regimes,
- The watershed area drained by Deer Creek from Pin Oak to Garfield yields the largest nutrient and suspended solids loading per hectare during high stream flows. The drainage area is only 272 ha yet it is capable of producing loadings equivalent to other drainage areas in excess of 1,000 ha.

These issues form the basis for future investigations and remediation projects that are focused improving land use practices in critical areas that reduce nutrient export and stabilize the hydrology of the system.

It must be emphasized that these data represent preliminary estimates of nutrient loading and yields. This investigation was conducted over a 6-month time frame and did not include measurements during storm events and critical periods of high loading such as the spring thaw and late fall. In consideration of the high degree of flashiness and wide range of nutrient export rates observed, a sampling design with greater frequency and duration would be necessary to provide sufficient temporal resolution to develop an accurate estimate of annual loadings. Because of these uncertainties, the data from this project may underestimate the magnitude of peak loading and lack the temporal resolution to develop an annual estimate of nutrient and sediment loads. Additional data collection should be conducted in conjunction with the development of a hydrologic model that considers precipitation and flow relationships for the individual subwatersheds and the system as a whole. In addition, future investigations should focus on loading determinations within selected stream segments. Additional locations such as tributaries, sites above and below areas of suspected nonpoint source pollution, and zones of significant groundwater influx need to be sampled to identify and rank specific sources with respect to contribution. It is important from a management standpoint to know whether regional nutrient loading originates from diffuse sources, or as in the case of the Pin Oak-Garfield segment, can be attributed to large contributions from a relatively small area. Since agricultural nonpoint source pollution was identified as a problem throughout the watershed, it is important to obtain loading information with greater spatial and temporal resolution to develop cost effective and efficient management solutions.

6.0 Conclusions and Recommendations

The Deer Creek watershed is a small catchment that faces a number of environmental challenges. Historic and current land use practices have resulted in a watershed severely impacted by agricultural nonpoint source pollution from excess nutrients and suspended solids. Mean TP-P concentrations observed during this investigation ranged from 0.14 – 0.19 mg/l in the watershed area downstream of the Cleveland St site. These levels exceed mean concentrations reported by Omerink (1977) for North American agricultural watersheds (0.03-0.06 mg/l). The removal of riparian vegetation and the expansive proliferation of agricultural land use have created a fragile watershed that exports large amounts of nutrients and sediment into Deer Creek and its tributaries. Export yields for SRP-P in the Deer Creek watershed at the Mill St station (70% of the watershed area) under low, medium, and high flow conditions were 0.40, 2.32, and 10.59 g/d/ha, respectively. Omerink (1977) reported average annual SRP-P yields for North American watersheds to range from 0.25 -0.32 g/ha/d. MacDonald et al. 2001 estimated annual SRP-P yields from a highly impacted agricultural watershed in west Michigan, the Pigeon River, to range from 0.60 - 0.65 g/ha/d. Even though the study duration was insufficient to calculate mean annual yields, this value can be estimated to be within the range of the low and medium flow averages for Deer Creek. Using the mid point of the range as an initial estimate, the average annual yield for Deer Creek would be approximately 1.4 g/ha/d. This value is considerably higher that the yield reported for the Pigeon River and indicates a high level of nutrient export from agricultural land in the watershed.

Comment [s1]: Do you mean TP-P?

Deer Creek has a thermal regime capable of supporting a cool water fishery and wetlands that can be restored to function as natural filters and processing areas for nutrient reduction. It is critical that a watershed management plan be developed that identifies areas where the implementation of best management practices will improve water quality and recommend additional investigations that provide the information necessary to identify and remediate pollutant sources. The major issues facing Deer Creek are summarized below and recommendations for remediation and/or investigation are identified.

Issue 1: Improving Land Use to Enhance Water Quality

The Deer Creek watershed contains valuable agricultural lands that are important to the local and regional economy. Land cover analysis shows that a majority of the riparian vegetation has been removed and the water quality data from this investigation demonstrate that the uncontrolled runoff of fertilizer and animal waste is prevalent throughout the watershed. It is imperative that BMPs and farm management plans be developed and implemented to stabilize hydrology and reduce the loss of sediment and nutrients to the stream. A variety of cost share and assistance programs are available to support these activities. Since 85% of the watershed is agricultural, BMPs need to be implemented throughout the watershed. The reconstruction of effective riparian zones is essential to erosional losses of sediment and nutrients. Riparian habitat can function as a ‘sponge’, greatly reducing nutrient and sediment runoff into streams (Peterjohn and Correll 1984, Cooper et al.1987). In addition, critical areas of wetlands are located in the upper and lower watershed. Wetlands play an important role in reducing nutrient loads to surface waters (Weller et al. 1996). The function of these wetlands can be enhanced to provide additional filtering capacity for nutrient and sediment removal in combination with improving the diversity and quality of the aquatic habitat in the watershed. Isolated improvements in the watershed will have limited effectiveness so a comprehensive strategy must be developed.

Issue 2: Nutrient Loading within the Deer Creek Watershed

Excessive nutrient loads entering Deer Creek have been identified. While this is a watershed wide problem, two specific areas make significant contributions to the problem. The small drainage area from Pin Oak to Garfield contributes substantial loads of nutrients to Deer Creek in terms of total mass and mass per unit of land area. A number of potential sources exist in the stream segment including Ottawa Farms Landfill, the Coopersville wastewater lagoons, drainage from I-96, and local farming operations. The contribution of these sources to the total loading in this investigation has not been evaluated. It is critical to investigate the magnitude of each source and implement a strategy to reduce nutrient loading. In addition, the watershed area drained by Deer Creek from Roosevelt St to Cleveland St (including Beaver Creek) produces the largest load of most nutrients. The specific sources in this area have not been established. Further investigation is required to identify the nature of these sources so that an effective remediation plan can be developed and implemented.

Issue 3: Sediment Loading within the Deer Creek Watershed

Erosion and sedimentation are critical problems that must be addressed to improve water and habitat quality in Deer Creek. A hydrological model of the drainage basin needs to be developed in order to understand the dynamics of water flow and the influence of rain events on stream discharge. Suspended sediment loadings result from erosion of surface soils and channel cutting. The physical effects on the landscape and their impacts to water quality are evident in the loading data and the appearance of the stream channel. The stream segments from Garfield to Mill, Pin Oak to Garfield and Roosevelt to Cleveland (including Beaver Creek) produce the largest loads of suspended sediment. In terms of land area, the Pin Oak to Garfield and Garfield to Mill segments exhibit the greatest yields. The specific sources of sediment export in these stream segments have not been identified. Source control measures that limit erosional losses are necessary to reduce suspended sediment loading. In addition, a fundamental understanding of the hydrology of the system is required to develop efficient management strategies that reduce nutrient loading and enhance the effectiveness of landscape improvements.

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Appendices

Appendix A

Daily Water Temperature Data for the Deer Creek Sampling Locations (2003)

Figure A.1. Daily Water Temperature Data for Deer Creek Sampling Locations (2003).

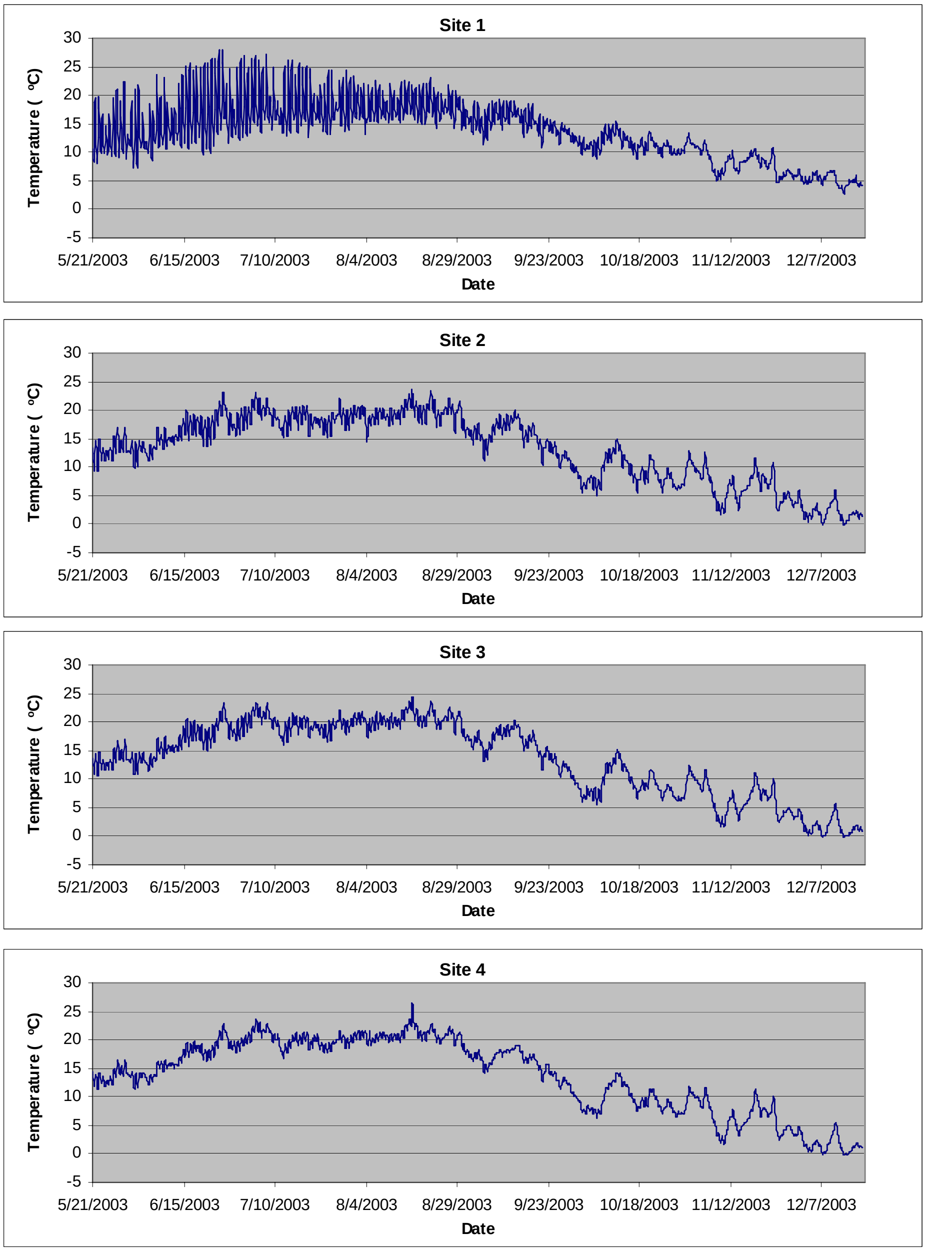
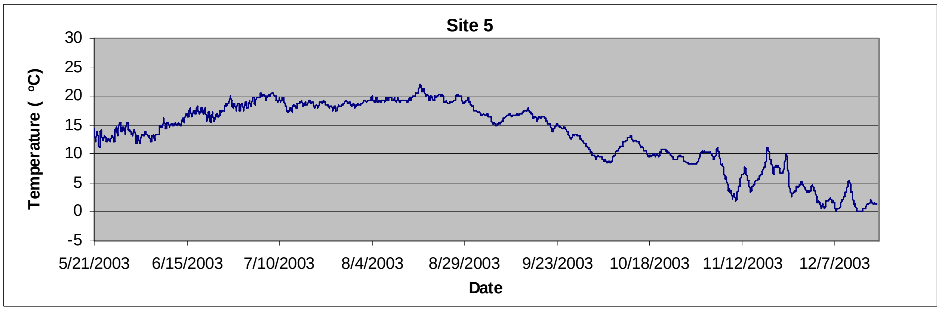
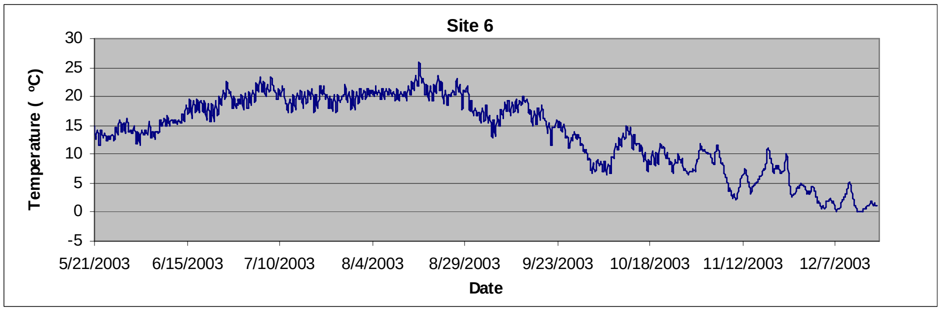
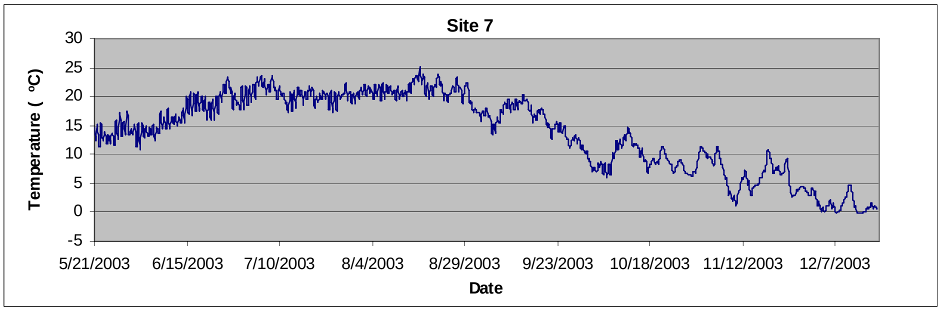


Figure A.1 (continued). Daily Water Temperature Data for the Deer Creek Sampling Locations (2003).







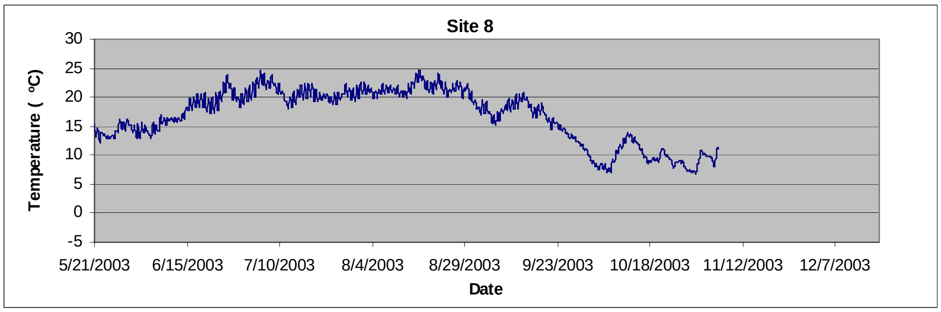
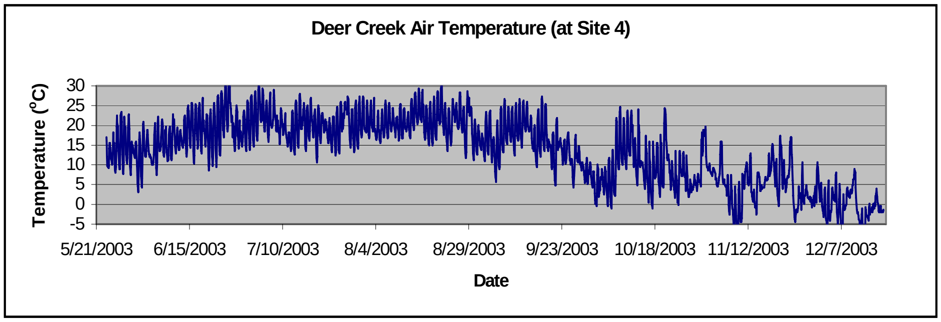


Figure A.2. Daily Air Temperature Data for the Deer Creek Sampling Locations (2003).



Appendix B

Precipitation Data for the Deer Creek Rain Gauges (2003)

Figure B.1. Cumulative Precipitation Data for the Deer Creek Rain Gauges (2003).

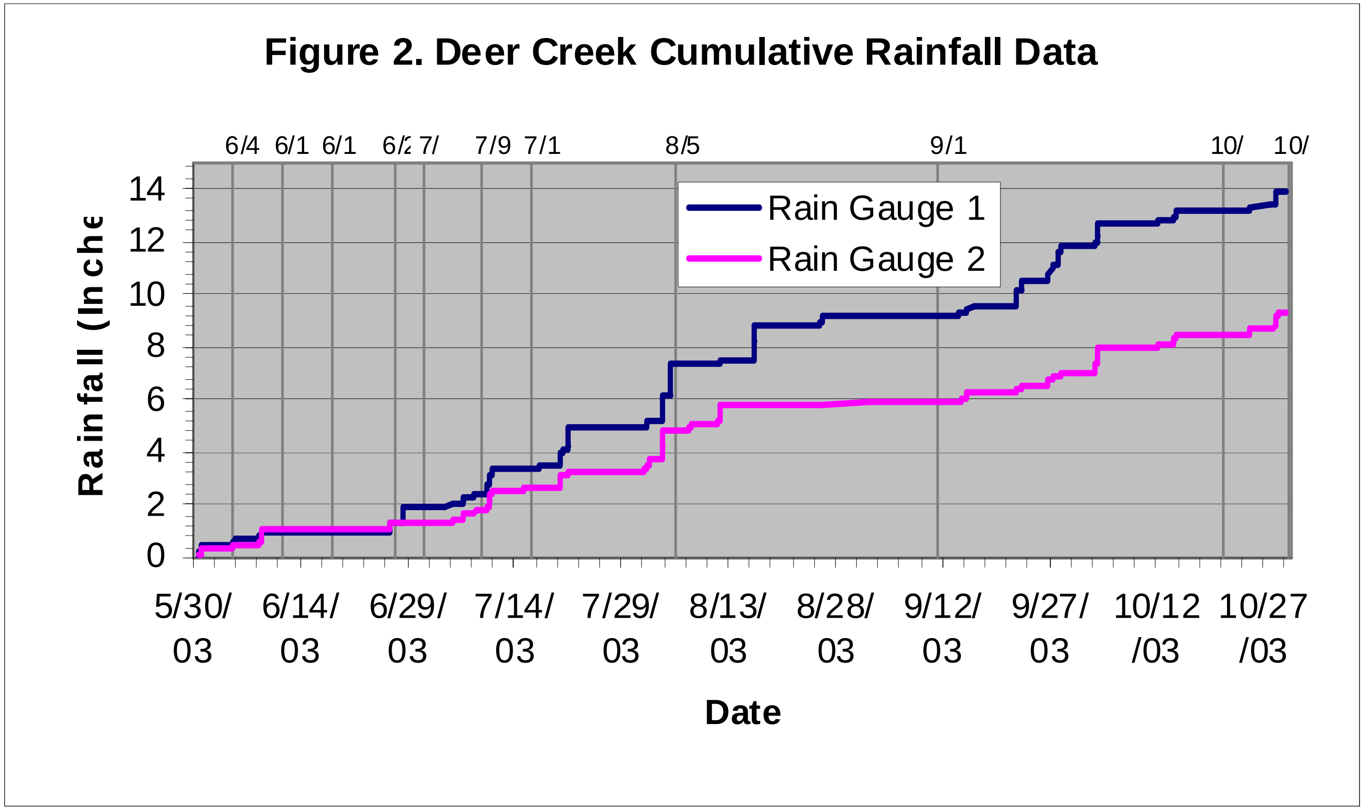
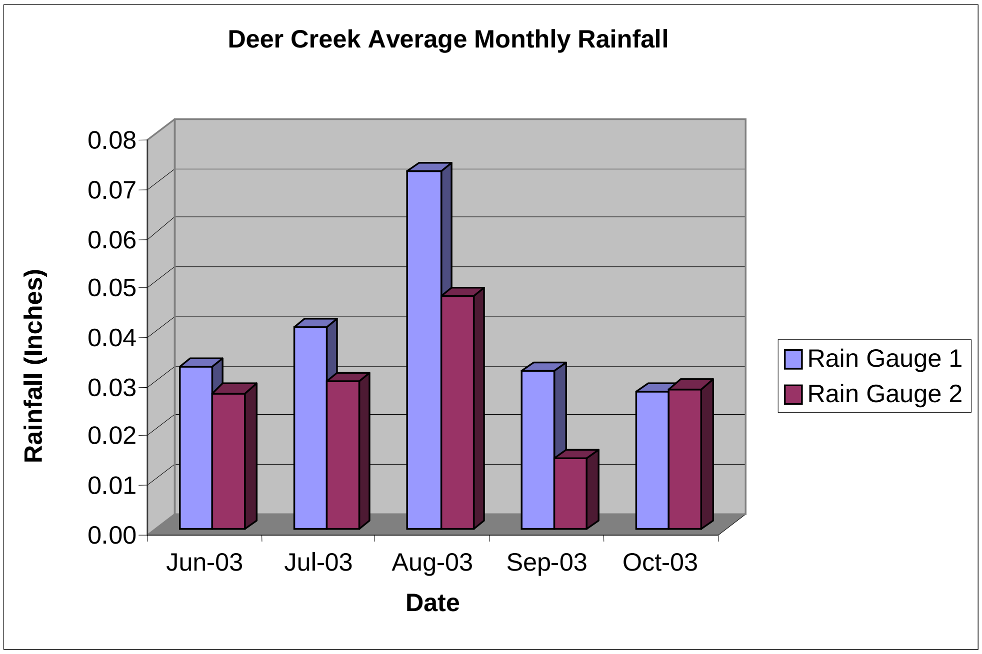


Figure B.2. Monthly Average Precipitation Data for the Deer Creek Rain Gauges (2003).



Appendix C

Analytical Results for the Deer Creek Sampling Locations (2003)

Table C.1. Analytical Results for the Deer Creek Sampling Locations (2003).

Sampling Date	Site	NO_3 mg/L	SO_4 mg/L	Cl mg/L	NH_3-N mg/L	SRP-P mg/L	TP-P mg/L	TKN-N mg/L	TSS mg/L	*E.coli* # per 100ml	Flow (cfs)	Flow (cms)
8-May	Wilson	3.35	37.0	29.0	0.01	0.07	0.11	1.47	13	2000	0.72	0.02
	Roosevelt	5.17	42.0	31.0	0.02	0.07	0.12	1.38	4	2000	9.68	0.27
	Cleveland	4.94	42.0	31.0	0.05	0.08	0.16	1.76	10	2000	26.5	0.75
	PinOak	4.10	40.0	38.0	0.05	0.09	0.10	1.20	15	2000	35.6	1.01
	Garfield	4.36	43.0	44.0	0.09	0.08	0.15	1.43	11	2000	44.7	1.27
	Mill	4.60	45.0	44.0	0.08	0.06	0.13	1.59	11	2000	51.7	1.47
	Leonard	4.04	49.0	47.9	0.08	0.07	0.11	1.47	9	2000	NS	NS
14-May	Wilson	3.57	30.0	23.0	0.01	0.01	0.06	0.94	12	33	0.65	0.02
	Roosevelt	6.21	40.0	24.0	0.05	0.05	0.08	1.09	3	167	7.06	0.20
	Cleveland	5.41	42.0	27.0	0.06	0.08	0.14	1.14	12	216	22.0	0.62
	PinOak	4.80	40.0	35.0	0.07	0.09	0.14	1.21	7	129	28.8	0.82
	Garfield	4.87	43.0	39.0	0.09	0.08	0.14	1.12	12	224	40.8	1.16
	Mill	5.07	43.0	37.0	0.08	0.09	0.16	1.28	13	200	47.9	1.36
	Leonard	4.15	40.8	36.5	0.08	0.02	0.17	1.17	12	383	NS	NS
21-May	Wilson	3.41	30.0	25.0	0.01	0.01	0.04	0.89	9	6000	0.36	0.01
	Roosevelt	5.08	40.0	27.0	0.06	0.05	0.08	0.86	1	183	4.08	0.12
	Cleveland	4.21	39.0	29.0	0.07	0.09	0.15	1.03	5	6000	11.8	0.33
	PinOak	3.23	36.0	38.0	0.09	0.08	0.12	1.37	5	6000	19.7	0.56
	Garfield	3.68	40.0	42.0	0.08	0.08	0.14	1.09	12	6000	23.7	0.67
	Mill	3.79	42.0	42.0	0.10	0.11	0.14	1.15	19	6000	29.7	0.84
	Leonard	2.73	39.3	44.0	0.14	0.08	0.16	1.30	22	200	NS	NS
4-Jun	Wilson	4.02	37.0	36.0	0.04	0.01	0.02	0.72	5	163	0.10	0.00
	Roosevelt	3.62	37.0	23.0	0.06	0.03	0.08	0.85	2	100	0.96	0.03
	Cleveland	3.76	43.0	38.0	0.04	0.03	0.09	1.02	5	33	3.17	0.09
	PinOak	2.32	35.0	41.0	0.08	0.03	0.09	0.74	3	17	4.86	0.14
	Garfield	2.71	44.0	49.0	0.06	0.03	0.09	0.61	5	33	4.28	0.12
	Mill	1.85	34.0	41.0	0.06	0.03	0.13	1.16	19	17	4.91	0.14
	Leonard	1.29	35	61	0.08	0.05	0.12	0.95	14	50	NS	NS
11-Jun	Wilson	4.00	37.0	37.0	0.01	0.01	0.02	0.65	5	327	0.10	0.00
	Roosevelt	3.85	40.0	23.0	0.05	0.06	0.09	0.73	4	412	0.13	0.00
	Cleveland	3.66	44.0	27.0	0.04	0.07	0.10	0.66	5	353	3.05	0.09
	PinOak	2.53	43.0	42.0	0.06	0.07	0.10	0.80	3	305	3.77	0.11
	Garfield	2.35	43.0	49.0	0.05	0.07	0.11	0.75	6	121	5.04	0.14
	Mill	2.36	44.0	49.0	0.05	0.09	0.14	0.82	14	443	4.46	0.13
	Leonard	1.61	44.3	56.9	0.09	0.09	0.15	1.06	18	933	NS	NS
18-Jun	Wilson	4.40	39.0	83.0	0.03	0.01	0.02	0.81	21	235	0.12	0.00
	Roosevelt	4.30	44.0	97.0	0.03	0.05	0.09	1.03	6	428	0.71	0.02
	Cleveland	3.70	44.0	55.0	0.04	0.05	0.13	1.08	8	773	1.48	0.04
	PinOak	1.90	41.0	91.0	0.08	0.04	0.12	1.03	4	292	2.14	0.06
	Garfield	2.10	46.0	95.0	0.07	0.15	0.11	1.10	9	103	1.79	0.05
	Mill	1.40	41.0	97.0	0.10	0.03	0.14	1.16	13	400	1.86	0.05
	Leonard	1.3	50.1	98.3	0.11	0.03	0.15	1.27	26	141	NS	NS
27-Jun	Wilson	4.08	32.0	39.0	0.07	0.01	0.03	0.39	6	NS	0.06	0.00
	Roosevelt	3.77	40.0	52.0	0.05	0.05	0.10	0.71	7	NS	0.45	0.01
	Cleveland	3.09	42.0	44.0	0.08	0.09	0.17	0.87	10	NS	1.32	0.04
	PinOak	0.75	32.0	67.0	0.17	0.10	0.18	0.72	6	NS	1.67	0.05
	Garfield	0.75	35.0	70.0	0.2	0.1	0.2	0.8	10	NS	1.16	0.03
	Mill	0.98	42.0	57.0	0.12	0.10	0.21	0.54	20	NS	0.71	0.02
	Leonard	0.49	47.3	71.2	0.15	0.12	0.22	0.75	19	NS	NS	NS
1-Jul	Wilson	4.78	38.0	55.0	0.05	0.01	0.05	0.44	18	680	0.02	0.00
	Roosevelt	4.28	44.0	56.0	0.04	0.06	0.11	0.56	9	1800	0.41	0.01
	Cleveland	3.19	42.0	56.0	0.06	0.11	0.18	0.69	11	2233	1.34	0.04
	PinOak	1.79	41.0	73.0	0.10	0.11	0.19	0.90	7	864	1.75	0.05

Table C.1 (continued). Analytical Results for the Deer Creek Sampling Locations (2003).

Sampling Date	Site	NO_3 mg/L	SO_4 mg/L	Cl mg/L	NH_3-N mg/L	SRP-P mg/L	TP-P mg/L	TKN-N mg/L	TSS mg/L	*E.coli* # per 100ml	Flow (cfs)	Flow (cms)
1-Jul	Garfield	1.68	40.0	69.0	0.08	0.10	0.19	0.62	10	207	1.07	0.03
	Mill	1.28	36.0	75.0	0.14	0.16	0.25	0.78	17	159	1.31	0.04
	Leonard	0.55	30.5	76.4	0.14	0.16	0.23	0.63	12	105	NS	NS
9-Jul	Wilson	4.70	36.0	57.0	0.02	0.01	0.01	0.48	7	134	0.07	0.00
	Roosevelt	3.10	35.0	56.0	0.05	0.08	0.11	0.58	5	133	0.31	0.01
	Cleveland	2.30	38.0	53.0	0.06	0.15	0.20	0.60	12	66	0.95	0.03
	PinOak	0.98	34.0	40.0	0.11	0.14	0.19	0.65	5	130	1.03	0.03
	Garfield	0.65	30.0	75.0	0.62	0.16	0.22	0.59	9	52	0.52	0.01
	Mill	0.59	33.0	69.0	0.01	0.24	0.37	0.83	20	415	1.09	0.03
	Leonard	0.34	38.6	71.8	0.16	0.15	0.32	0.65	10	45	NS	NS
16-Jul	Wilson	5.00	42.0	62.0	0.02	0.10	0.00	0.39	3	114	0.07	0.00
	Roosevelt	3.50	40.0	51.0	0.02	0.05	0.10	0.54	7	800	0.31	0.01
	Cleveland	2.80	42.0	42.0	0.04	0.11	0.17	0.52	12	490	0.95	0.03
	PinOak	1.50	41.0	45.0	0.06	0.17	0.17	0.53	8	768	1.03	0.03
	Garfield	1.00	30.0	52.0	0.05	0.14	0.17	0.57	9	400	0.52	0.01
	Mill	0.20	37.4	61.6	0.06	0.15	0.27	0.31	14	619	1.09	0.03
	Leonard	0.93	43.4	72.9	0.14	0.14	0.24	1.86	13	187	NS	NS
5-Aug	Wilson	3.11	36.4	128.4	0.03	0.01	0.02	0.45	0	585	0.24	0.01
	Roosevelt	2.89	37.8	42.1	0.19	0.23	0.21	2.16	15	6000	1.90	0.05
	Cleveland	3.34	36.2	35.2	0.35	0.20	0.20	2.10	28	6000	4.39	0.12
	PinOak	2.15	23.3	42.1	0.11	0.11	0.12	1.25	84	6000	6.55	0.19
	Garfield	1.24	22.8	62.1	0.10	0.13	0.16	1.13	80	6000	5.30	0.15
	Mill	1.30	24.1	42.5	0.28	0.14	0.24	0.96	29	6000	9.19	0.26
	Leonard	0.78	17.1	32.5	0.19	0.10	0.16	0.85	35	6000	NS	NS
11-Sep	Wilson	5.72	34.7	53.3	0.01	0.01	0.01	0.26	1	633	*	*
	Roosevelt	3.20	39.1	44.5	0.04	0.06	0.10	0.39	5	1327	*	*
	Cleveland	2.30	38.7	50.6	0.05	0.01	0.12	0.25	5	82	*	*
	PinOak	0.69	38.9	54.5	0.07	0.01	0.12	0.45	5	116	*	*
	Garfield	0.61	35.2	49.4	0.06	0.01	0.13	0.50	3	153	*	*
	Mill	0.22	37.6	85.4	0.10	0.01	0.20	0.33	9	231	*	*
	Leonard	0.17	34.2	67.8	0.09	0.01	0.22	0.33	2	17	NS	NS
16-Sep	Wilson	5.2	37	55	0.01	0.01	0.01	0.93	1	466	*	*
	Roosevelt	3.6	39	33	0.04	0.05	0.11	0.46	5	2337	*	*
	Cleveland	2.3	37	30	0.04	0.09	0.14	0.20	4	224	*	*
	PinOak	0.54	36	68	0.10	0.13	0.21	0.45	22	82	*	*
	Garfield	0.52	31	87	0.06	0.13	0.18	0.42	6	993	*	*
	Mill	0.20	37	62	0.06	0.15	0.27	0.31	19	619	*	*
	Leonard	0.20	49	59	0.15	0.16	0.30	0.32	18	554	NS	NS
23-Oct	Wilson	4.75	44.1	49.4	0.01	0.01	0.01	0.24	1	67	0.12	0.00
	Roosevelt	2.40	39.9	46.2	0.01	0.01	0.05	0.25	2	33	0.22	0.01
	Cleveland	1.63	53.7	1293**	0.01	0.04	0.05	0.26	3	33	0.89	0.03
	PinOak	0.84	48.0	80.3	0.04	0.01	0.06	0.27	0	33	0.33	0.01
	Garfield	0.58	46.9	65.7	0.01	0.04	0.07	0.36	2	100	1.00	0.03
	Mill	0.28	46.2	69.3	0.01	0.06	0.09	0.42	1	342	1.23	0.03
	Leonard	0.06	46.9	69.1	0.03	0.11	0.20	0.58	2	82	NS	NS
30-Oct	Wilson	4.29	43.9	46.8	0.01	0.01	0.02	0.32	2	33	0.12	0.00
	Roosevelt	2.73	40.8	27.2	0.01	0.01	0.05	0.54	0	33	0.41	0.01
	Cleveland	2.90	51.2	30.0	0.01	0.02	0.04	0.44	0	17	1.33	0.04
	PinOak	1.19	43.9	66.7	0.01	0.04	0.06	0.51	1	153	1.60	0.05
	Garfield	0.96	45.2	58.8	0.03	0.03	0.07	0.58	1	200	2.03	0.06
	Mill	0.63	44.5	54.8	0.03	0.04	0.07	0.43	3	100	1.87	0.05
	Leonard	0.21	47.7	47.1	0.01	0.04	0.09	0.35	2	50	NS	NS

NS-Not Sampled * Below Detection Limits **Abnormally High Observation