2007

Hydrology and dissolved organic carbon dynamics of a temperate peatland

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September 2007

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by

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A Thesis
Presented to the Graduate and Research Committee
of Lehigh University
in Candidacy for the Degree of
Master of Science

in
Earth and Environmental Sciences

Lehigh University

September 2007

This thesis is accepted and approved in partial fulfillment of the requirements for the Masters of Science.

July 13, 2007

Date

Thesis Advisor: Dr. Bruce R. Hargreaves

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Acknowledgements

This research was completed with funding from a Palmer Grant from Lehigh University's Earth and Environmental Sciences department and from an EPA Star Grant (# R829642). Support was also received from the Earth Environmental Sciences Department and the Lehigh Earth Observatory. I would like to thank my advisor, Dr. Bruce R. Hargreaves, for his enthusiasm, insight, and assistance. I am also appreciative of the guidance from Dr. Robert K. Booth, Dr. Steve C. Peters, Dr. Joan M. Ramage, and Dr. Zicheng Yu in their participation on my advisory committee. Dr. Don Morris and Dr. Jason Porter deserve thanks for their assistance in sample analysis. I am grateful for access to the study area from The Nature Conservancy, Birchwood Resort, Mr. Mike Taylor, and Kathy from Chester's Hair Salon. Also, thanks to my friends and parents, John and Cynthia Luebbe, for their support and encouragement, and to George Yasko, Dr. Lisa Windham, Dr. Ken Kodama, and Dr. Don Morris for getting me involved in scientific research of the earth sciences.

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Abstract

Storage and flux of water and dissolved organic carbon (DOC) in wetlands are ecologically important processes potentially sensitive to climate change. Around 27 percent of the Cranberry Creek watershed in Eastern Pennsylvania includes Tannersville Bog wetland, a mid-latitude peatland that could serve as an important model of boreal peatlands under climate change scenarios. Automated measurements and samples from 6 sites along Cranberry Creek provided chemical, physical, optical, and flow data as the creek passed through Tannersville Bog from February 2006 to April 2007. The wetland reduced peak storm discharge and delayed discharge downstream following precipitation. The storage capacity of the wetland served to continually supply water for discharge downstream during dry conditions. Through the wetland area, specific conductance of Cranberry Creek water decreased, implying groundwater had little influence on hydrology or DOC dynamics and the system was fed mainly through precipitation and surface water. DOC in Cranberry Creek was predominantly soil-derived as the stream water gained DOC mainly from decaying plant matter in the watershed soils, especially through the peatland. The stream DOC concentration and flux were greatest from the summer into early-fall and DOC generally varied with average temperature. Because DOC concentration changed little with discharge, DOC flux strongly correlated with discharge, except for a slight reduction in DOC concentration at the highest rates of discharge. The estimated annual DOC flux, scaled per unit of watershed area, was similar to that of the literature for the percentage of peatland area (Dillon and Molot 1997) and the annual precipitation of the system (Mulholland 2003). However,

variability in DOC concentration and flux among different catchments may result from differences in precipitation and discharge, temperature, percentage of peatland area, or landcover type. Cranberry Creek watershed may serve as a valuable model for hydrological and DOC dynamics because seasonal variations in DOC concentration and flux and the response of stream DOC concentration and flux to storm discharge appear to correlate with temperature. If these relationships can be confirmed with continued monitoring, a testable prediction can be made for other sites after accounting for wetland area, storm runoff, and temperature of the other sites.

Introduction

In forecasting future climate change, the stability of global soil carbon is a major uncertainty. A carbon pool of 455 Pg has accumulated in boreal and subarctic peatlands during the postglacial period (Gorham, 1991). Peatlands currently cover about 15% of boreal and subarctic regions and store 20-30% of the world's soil carbon (Freeman et al. 2001). It was suggested that peatlands influence glacial and interglacial cycles (Franzen 1994; Franzen et al. 1996, Klinger et al. 1996) and the most influential factors affecting peatland carbon dynamics seem to be temperature, water fluxes, soil moisture, and the balance between decomposition and biological productivity (Freeman et al. 2004; Tranvik et al. 2002; Freeman et al. 2001). Therefore, it is important to understand the dynamics of carbon storage and flux in peatland ecosystems. Figure 2 shows the major components of the carbon cycle in peatlands and the primary controls on the fluxes of carbon. Several studies have been carried out to estimate methane and carbon dioxide fluxes for peatlands (Charman, Aravena, and Warner 1994; Moore, Roulet, and Waddington 1998; Gorham 1991). The dissolved organic carbon (DOC) component, defined as carbon-containing molecules in an aqueous solution that can pass through a filter of 0.7 micrometer pore size (Aitkenhead-Peterson et al. 2003), is not fully understood. A strong relationship has been shown between DOC concentration and soil carbon pools, which are large in peatlands (Aitkenhead et al. 1999), as well as between DOC flux and percentage of peatland area in catchments as seen in Figure 1 (Dillon and Molot 1997; Mulholland 2003). Therefore, peatland DOC storage and flux are important components of the carbon cycle and potentially sensitive to environmental controls such as temperature and precipitation (Mulholland 1997; Moore et al. 1998).

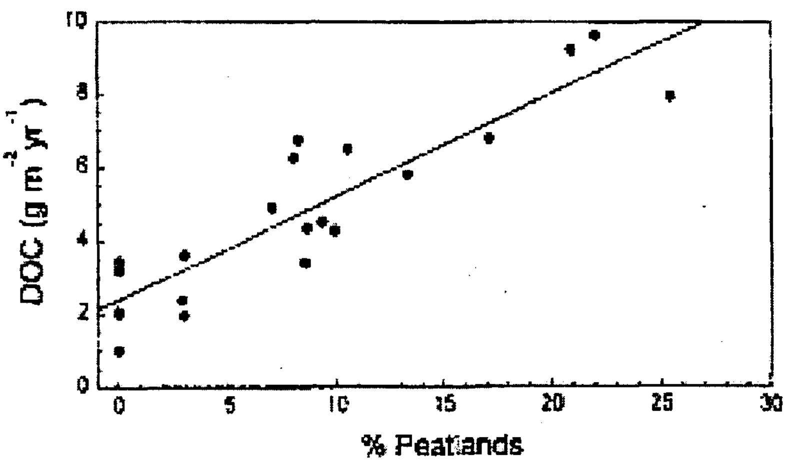

Figure 1: Relationship between mean annual DOC flux from 1980 to 1992 and percentage of peat cover in catchments from central Ontario (from Dillon and Molot 1997).

Many studies have measured DOC concentration, flux, or export for watersheds throughout the world (Dillon and Molot 1997; Mulholland 1997; McDowell and Likens 1988; Mulholland and Kuenzler 1979; Tate and Meyer 1983; Cory et al. 2004; Meybeck 1981; Schlesinger and Melack 1981). Levels of DOC streams and lakes have risen recently, reducing the soil carbon pool (Roulet and Moore 2006; Frey and Smith 2005; Evans et al. 2006; Evans et al. 2007). These changes may be attributed to destabilization of the carbon budget due to climate change. However, some recent studies consider the reduction of acid rain (sulfate deposition) with clean-air legislation taking effect as a

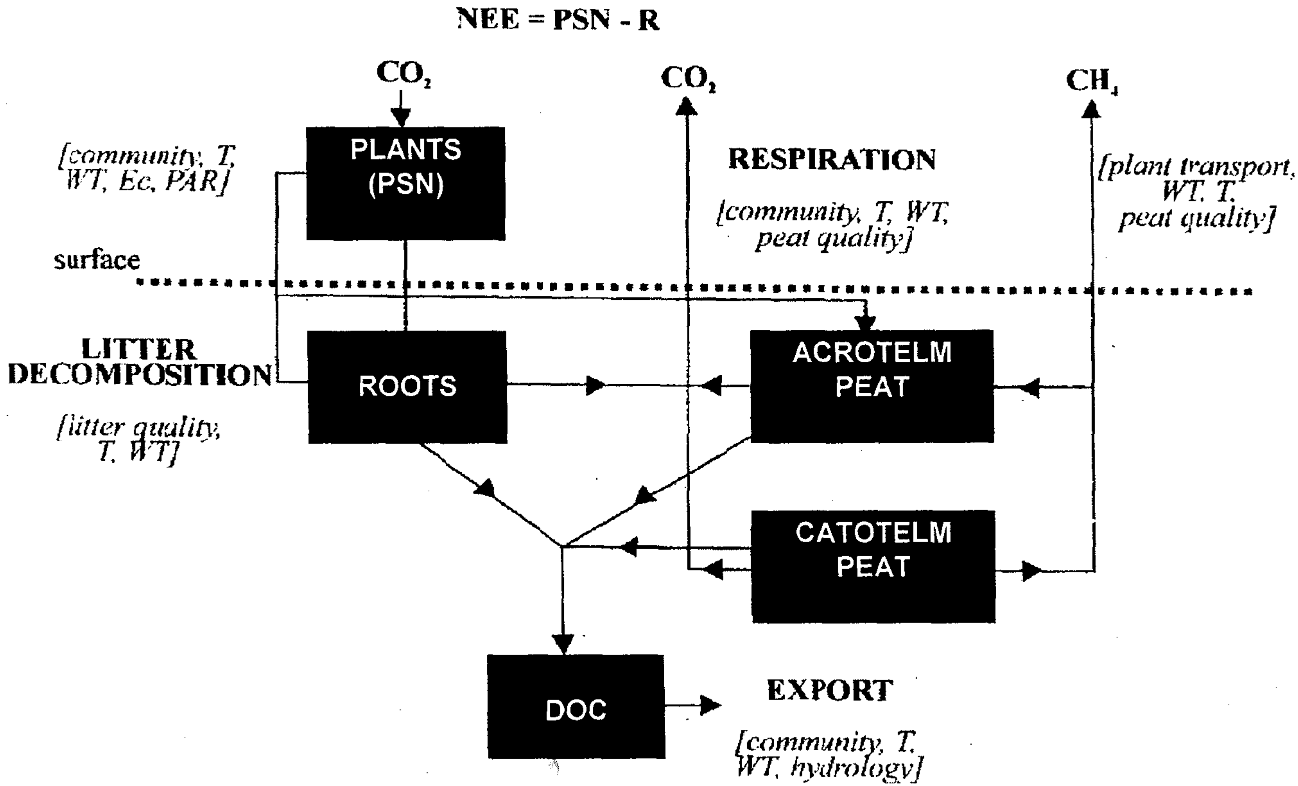

Figure 2: Major components of the carbon cycle in peatlands and the primary controls on the fluxes of carbon (in *italics*). NEE: net ecosystem exchange of CO_2; PSN: photosynthesis; R: respiration; T: temperature; WT: water table position; E_c: porewater electrical conductivity; PAR: photosynthetically active radiation (from Moore et al. 1998).

possible cause of increased DOC concentrations and fluxes in watersheds since experimental studies have shown increased sulphate concentrations and the corresponding raised pH in soil pore water decreases the mobilization of DOC in soils (Roulet and Moore 2006; Evans et al. 2007; Evans et al. 2006). The recent rise in DOC levels may actually be a process of recovery from acidification. It is important to understand how hydrology and climate affect peatland DOC dynamics to predict if possible climate change may effect carbon cycling, especially because the greatest amount of climatic warming is expected to occur in high latitudes over the next several decades (Pastor et al. 2003).

Present-day temperate peatlands, such as that investigated in this study (Tannersville Bog, a *Sphagnum*-dominated, oligotrophic peatland in the Cranberry Creek watershed of Northeastern, Pennsylvania), may serve as an excellent model for boreal and subarctic peatlands in a warmer future. Table 1 lists values obtained from some studies for DOC export from different terrestrial ecosystems to the ocean. A lot of variability in DOC concentration and export exists with watershed characteristics, climate, and season. The calculation of DOC export is an attempt to generalize DOC function in ecosystems by scaling DOC flux by area. Scaling to account for variability in wetland area and climate may be possible as well. It is valuable to understand variations in DOC concentration and flux to accurately account for the important DOC component of the carbon cycle. Few studies account for stream discharge, weather, and DOC concentration and flux at the high resolution of this study.

Table 1: Comparison of DOC flux and export from different studies, including those estimated in Meybeck, 1981, Schlesinger and Melack, 1981, and those using a global C:N model from the study (from Aitkenhead and McDowell, 2000).

	Aitkenhead & McDowell 2000		Meybeck 1981		Schlesinger & Melack 1981			Aitkenhead & McDowell 2000
Biome	Flux (kg ha^{-1} yr^{-1})	Area (x10^8 ha)	Flux (kg ha^{-1} yr^{-1})	Export (x10^{14} g)	Area (x10^8 ha)	Flux (kg ha^{-1} yr^{-1})	Export (x10^{14} g)	Export (x10^{14} g)
Taiga	6.2	15.90	24.9	0.40	-	-	-	-
Tundra	26.4	7.55	6.0	0.04	8.0	10.0	0.08	0.21
Temperate	42.7	22.00	42.3	0.93	12.0	40.0	0.48	0.51
Wet Tropical	60.5	37.30	64.6	2.41	24.5	50.0	1.23	1.48
Semi arid/Desert	6.7	17.20	2.7	0.05	8.0	5.0	0.04	0.05
Boreal	64.3	-	-	-	12.0	50.0	0.60	0.77
Wood & Shrub	26.7	-	-	-	8.5	40.0	0.34	0.23
Tropical Grass	5.1	-	-	-	15.0	10.0	0.15	0.08
Temperate Grass	4.9	-	-	-	9.0	10.0	0.09	0.04
Cultivated	5.3	-	-	-	14.0	50.0	0.70	0.07
Swamp/Marsh	96.7	-	-	-	2.0	200.0	0.40	0.19
Total	-	99.95	-	3.83	113.0	-	4.11	3.63
Rest of Earth	-	29.05	-	-	16.0	-	-	0.55

Dissolved Organic Carbon (DOC) Sources

DOC may come from atmospheric deposition, canopy throughfall, decaying plants, or microbial photosynthesis in the water-column or on streambed or wetland surfaces (Aitkenhead-Peterson et al. 2003). Allocthonous (soil-derived; outside of an aquatic environment) DOC is that which comes from decaying terrestrial plant matter while autocthonous (water-column-derived; within an aquatic environment) DOC comes from organic production within a water-column. A fluorescence index using the ratio of the fluorescence of the water at 450 nm to that at 500 nm can be used to detect the source of DOC (McKnight et al. 2001). Values of the fluorescence index range from 1.2 to 1.9, with higher values signifying more-allocthonous DOC and lower values more-autocthonous DOC. The source of DOC should vary depending on the characteristics of the watershed, amount of precipitation, and season.

a. Precipitation and Throughfall

Precipitation falling directly onto a watershed surface contributes DOC (Willey et al. 2000). The likely source of DOC in precipitation is from pollen and organic dust particles in the atmosphere. The flux and concentration of DOC from this source is minimal compared to the magnitude of other sources. Yet, with greater precipitation, more DOC is input to the system. As precipitation passes through the canopy and lower layers of vegetation its DOC concentration increases (Aitkenhead-Peterson et al. 2003). The enrichment is probably due to dry organic materials (pollen, dust, aphid honeydew, and insect exudates) from the vegetation surface along with leaching of organic molecules from inside the plants. However, the frequency of precipitation and type of vegetation may influence the amount and quality of DOC available from the vegetation surface for input to the soil. DOC concentration in throughfall and stemflow is usually an order of magnitude higher than precipitation DOC, but still minute compared to other sources (Aitkenhead-Peterson et al. 2003). Still, peatland vegetation is often unique and could influence DOC inputs from throughfall and stemflow differently spatially and temporally than for other non-peatland systems.

b. Soil-Derived DOC

The amount of DOC in soils is related to the magnitude of soil organic carbon pools. The size of these pools in forest soils depends on the rate of litter incorporation into the forest floor and the degradation of litter into products of varying degrees of humification. The time of maximum litterfall and peak DOC leaching in soils do not coincide, but the DOC dynamics are probably related to the amount of recent litter and organic matter in soils (Kalbitz et al. 2000). Higher concentration and flux of DOC in forest soils has been observed during litterfall, but it could be related to other factors such as high temperature (Kalbitz et al. 2000). Peatlands usually have a large amount of recent litter and organic matter to supply soil organic carbon pools for degradation to DOC. But I expect that peatland organic content is not primarily from litter fall even when trees are present; rather it accumulates from upward growth of nonvascular plants with dead plant matter remaining in the water-saturated soil.

DOC dynamics are related to the type of organic carbon in soils. The carbon input is determined greatly by the dominant vegetation at the site. Table 2 shows the release of DOC from different substrates incubated in a laboratory at 22 degrees Celsius and 4 degrees Celsius in oxic and anoxic conditions. *Sphagnum* is common in bog peatlands and showed a moderate release of DOC in the incubation experiment while the greatest release of DOC was from maple leaves (Moore and Dalva 2001). Still, peatland vegetation is unique and variable, which makes it difficult to characterize the influence of substrate quality on DOC dynamics. DOC concentration decreases with soil depth largely due to adsorption in mineral soil horizons. Adsorption is more important than decomposition in mineral soils in accounting for DOC loss (Brady and Weil 2002). Yet, few soil horizons containing minerals are found in peatlands.

Decomposition of the large peatland organic matter pool is typically more influential on DOC dynamics than adsorption. Decomposition is related to the bioavailable portion of DOC (labile fraction) in a soil horizon. This bioavailable portion depends greatly on the type of microbial community supported and the type of organic inputs. Fresh DOC input or production in soil has a high substrate value for microbes. The dominant vegetation and its chemical properties as discussed above affect the rate of decomposition by microbes. Hydrophilic molecules are more labile than hydrophobic molecules because hydrophobic molecules commonly adsorb to soil particles. Once organic carbon is adsorbed, it is difficult to remove the molecules from the soil surface to be dissolved as DOC (Kalbitz et al. 2000). The depth within the soil also influences decomposition since it is more efficient in the upper horizons where aerobic microbes and other decomposers commonly function (Boyer and Groffman 1996). Therefore, upper, aerobic peat supports greater decomposition and DOC production than lower, anaerobic peat. Still, pore water transport can move younger DOC downward (Charman et al. 1994).

Table 2: Release of DOC (mg g^{-1}) from samples over 60 days of incubation under oxic and anoxic conditions at 4 and 22 degrees Celsius. Figures in parentheses indicate the standard deviation of the triplicate samples used in each treatment (from Moore and Dalva 2001).

Sample	Treatment				Mean
	22 °C		4 °C		
	Oxic	Anoxic	Oxic	Anoxic	
Fresh maple leaves	260.0	195.2	153.7	148.2	189.3
	(17.4)	(16.5)	(13.9)	(15.1)	
Old maple leaves	21.1	21.4	7.7	11.7	15.5
	(4.1)	(3.8)	(1.2)	(3.1)	
Inceptisol A	0.35	0.69	0.25	0.16	0.4
	(0.09)	(0.03)	(0.07)	(0.10)	
Hemic peat	2.24	1.89	0.62	0.60	1.3
	(0.16)	(0.23)	(0.03)	(0.08)	
Sphagnum	5.59	4.79	1.93	2.25	3.6
	(0.28)	(0.46)	(0.48)	(0.42)	
Fibric peat	2.86	2.76	1.13	1.07	2.0
	(0.25)	(0.22)	(0.26)	(0.06)	
Sapric peat	1.79	1.69	0.69	0.93	1.3
	(0.19)	(0.18)	(0.07)	(0.18)	

c. Water-Column-Derived DOC

In aquatic systems, DOC is also produced within the water-column due to actions of aquatic algae and macrophytes (predatory grazing, cell death and senescence, viral lysis, and extracellular release) (Bertilsson and Jones 2003). Standing water often occurs in peatlands. Therefore, DOC input to the system from the wetland water-column is possible as well as from other deeper bodies of water in a watershed.

DOC Aquatic Ecosystem Functions

DOC molecules serve valuable functions in aquatic ecosystems. Trophic interactions depend on DOC as a source of food for microbes (Meyer 1994). Water-column-derived DOC is typically more-liable (more-easily consumed) than soil-derived DOC molecules (Bertilsson and Jones 2003; Aitkenhead-Peterson et al. 2003). DOC also attenuates harmful UV-B radiation in aqueous environments, which protects biota. In soils, DOC affects complexation, solubility, and mobility of metals (Mulholland 2003). It is important to understand factors controlling the concentration and flux of DOC to be able to predict DOC dynamics that may affect these functions.

Temperature Control of DOC Dynamics

Soil temperature is important since it can regulate both plant and microbial processes. The balance between plant production and microbial oxidation of organic matter determines the effect temperature has on organic matter accumulation in soils (Fig. 3). Globally and locally, less soil organic matter exists in soils with warmer climates, which is why peatlands are common in cooler, high-latitude climates.

Temperature also affects the transformation of soil organic matter (particulate) to DOC. A higher concentration of soil DOC occurs in warm, summer months than for other periods. Yet, the seasonal variation in DOC may also be related to increased inputs during the growing season or low water fluxes (still indirectly related to temperature with evapotranspiration) in the summer leading to elevated DOC production. Other factors controlling soil DOC may modify or mask the effect of temperature such as litterfall and litter quality, soil texture and other soil properties, and hydrodynamics (aerobic or anaerobic conditions as seen in Figure 3). In poorly drained areas, which include peatlands, DOC concentrations in surface horizons are usually high regardless of the climate (Kalbitz et al. 2000).

Soil Moisture Control of DOC Dynamics

Higher DOC concentrations are found in waterlogged soils than in better-aerated soils since anaerobic conditions are often created and anaerobic decomposition is less efficient than aerobic decomposition (occurring in better-aerated soils), leaving a larger soil organic carbon pool surrounded by water for DOC production (Kalbitz et al. 2000; Charman et al. 1994) as seen above in Figure 3 and above in Table 2. Peatland soils are typically water-logged for some portion of the year and, therefore, tend to produce more DOC than in other environments per square meter.

Precipitation and Water Flux Control of DOC Dynamics

More precipitation on a watershed typically results in higher DOC flux (Fig. 4). Yet, the DOC flux varies with landcover and climate as seen in with the different slopes from various studies shown in Figure 4.

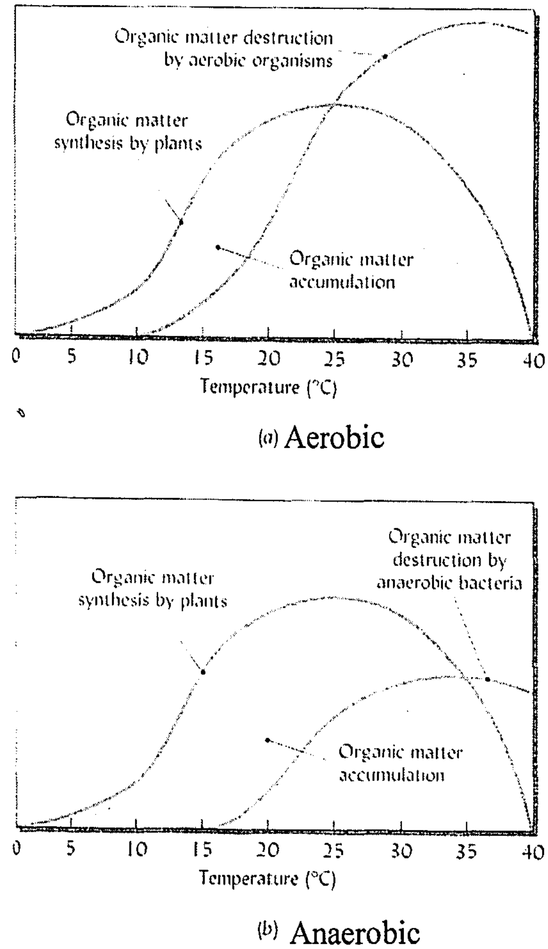

Figure 3: The balance between plant production and biological oxidation of organic matter determines the effect that temperature has on organic matter accumulation in soils. The shaded areas indicate organic matter accumulation under (a) aerobic and (b) anaerobic conditions (from Brady and Weil, 2002). In this conceptual model the synthesis of organic matter by plants is the same in aerobic and anaerobic conditions, but the decomposition by microbes (bacteria and fungi) is reduced under anaerobic compared to aerobic conditions. Not indicated are the multiple steps by which particulate organic matter is converted first to DOC and then removed from the system by export or by respiration.

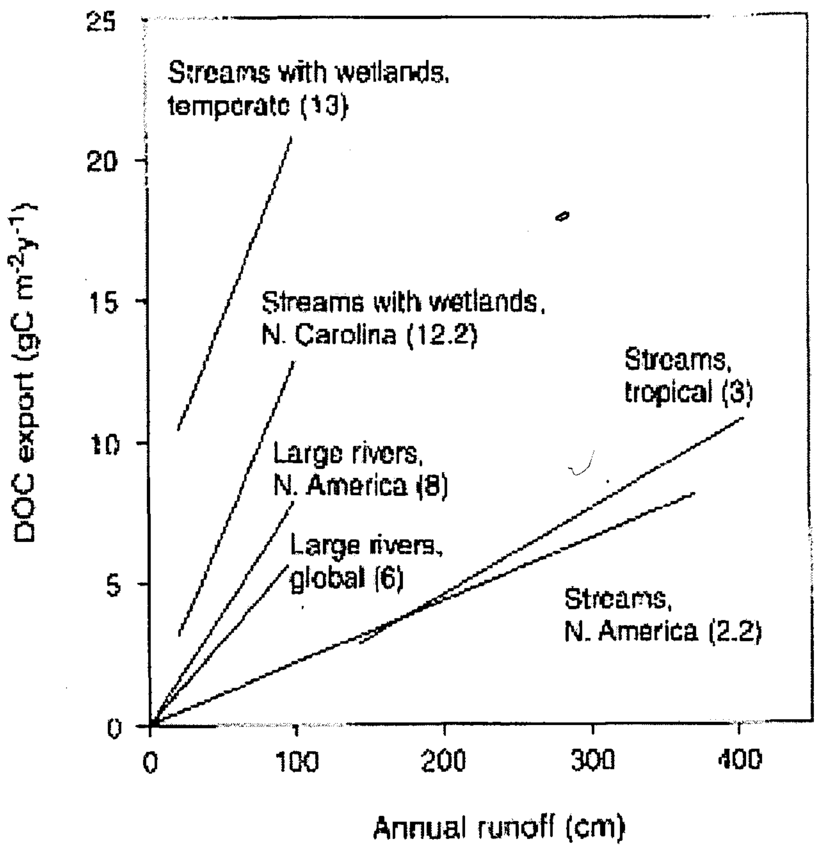

Figure 4: Relationships between annual runoff and watershed export of DOC in streams and rivers reported in the literature. The respective lines extend only over the range of runoff values included in the dataset. Sources for each relationship are as follows: streams with wetlands, temperate (Mulholland 1997); streams with wetlands, N. Carolina (Mulholland and Kuenzler 1979); large rivers, global (Spitzy and Leenheer 1991); large rivers, N. America (Mulholland and Watts 1992); streams, tropical (McDowell and Asbury 1994); streams, N. America (Mulholland 1997) (from Mulholland 2003). Note that the line for temperate wetlands is suspect because it implies a high rate of export for zero annual runoff.

With greater water fluxes in organic soil horizons there is lower soil DOC concentration. Low soil water content and flux allow longer contact times with organic carbon to produce higher soil DOC concentrations. These patterns may explain some of the seasonal changes in surface DOC concentrations with leaching. The highest DOC concentration and fluxes in soils typically occur in the early-fall with buildup of DOC in the summer and release with rewetting or water-table rise in the fall along with greater humification in the fall (Kalbitz et al. 2000; Worrall et al. 2002).

In well-drained soils precipitation should cause shorter contact times between organic matter and water with more water passing through the forest floor to dissolve more organic carbon. During precipitation events, dilution of DOC occurs in O horizons. Storm events alter DOC concentration and fluxes by shifting the dominant flowpaths throughout the soil toward preferred flow through macropores, runoff, and lateral flow. DOC builds up in periods of low flow and is transported in high flow (Kalbitz et al. 2000). During a storm event, the highest DOC concentration is observed in initial transportation of the soil solution and it decreases quickly to a baseline level as flow continues (Easthouse et al. 1992). In peatlands, DOC export has been reported to rise during precipitation events (Aitkenhead et al. 1999; Urban et al. 1989). Yet, the variability in DOC flux with storm magnitude, climate, and landcover is not fully understood.

Wetland Hydrology

Water may enter a stream from upstream discharge, groundwater, precipitation, and inflow from lateral surface storage. Losses of water might include downstream discharge, groundwater recharge, evapotranspiration, and outflow to lateral surface storage. A water budget for areas of a watershed can be created by determining how the components interact. Wetlands in watersheds are valuable for stream flood mitigation as shown in Figure 5 where the wetland intercepts storm runoff and stores water to change the sharp runoff peaks to slower discharges over longer periods of time. The extent of the water storage during storm or baseflow conditions may depend on the size or type of the wetland, location of the wetland in the watershed, size of storms, season, or other watershed characteristics such as options for other storage areas (e.g. ponds) (Mitsch and Gosselink 2000). Different wetland types have water contribution from different components. For example, *Sphagnum*-dominated, oligotrophic peatlands should have

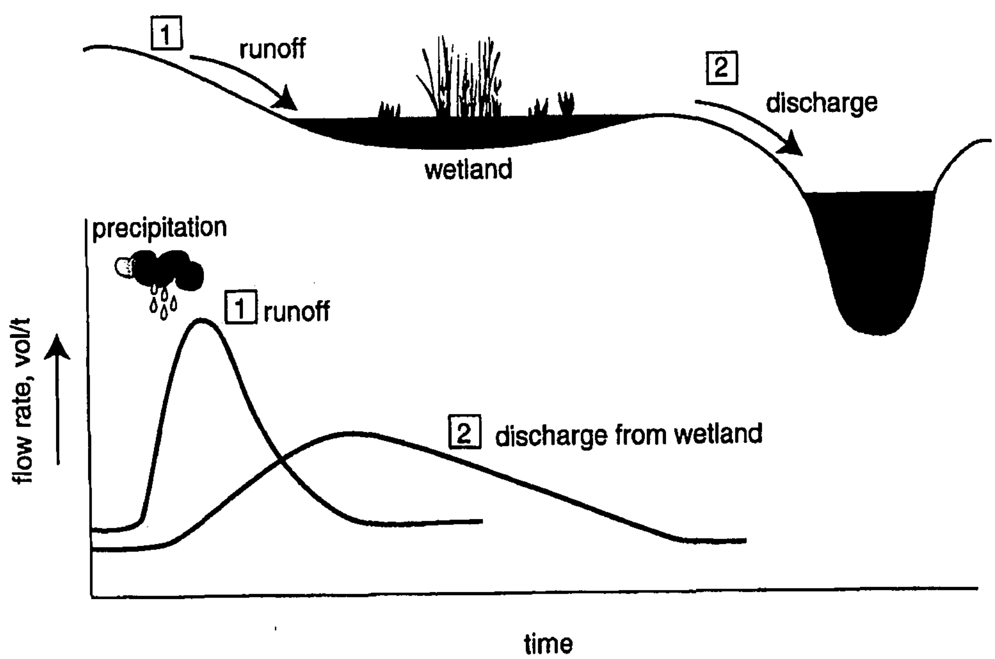

Figure 5: Wetland interception of storm runoff and storage to change the sharp runoff peaks to slower discharges over longer periods of time (from Mitsch and Gosselink 2000)

little groundwater influencing the hydrology of the system since they are fed mainly by surface water and precipitation.

Wetlands have been known to be vital in controlling water quality and quantity within a watershed as they mediate water level fluctuations and contribute greatly to DOC export (Mitsch and Gosselink 2000). Hydrology is a key factor regulating DOC flux. However, not all wetlands are alike and we do not fully understand their ecologic and hydraulic functions, especially under the dynamic conditions of storm runoff. With the greatest amount of climatic warming expected to occur in high latitudes over the next several decades, large scale DOC storage in and export from peatlands could be affected (Pastor et al. 2003). Present-day temperate peatlands, such as Tannersville Bog, a *Sphagnum*-dominated, oligotrophic peatland, may serve as an excellent model for boreal peatlands in the future. Understanding the dynamics of DOC concentration and flux in peatlands is important to predict their responses to climate change.

Approach and Hypotheses

Approach

The goal of this research is to understand peatland functions with respect to water and DOC concentration and flux at temperate latitudes, specifically the characterization of the dynamic response of a *Sphagnum*-dominated, oligotrophic peatland during wet and dry conditions from the Spring of 2006 to the Fall of 2006. Cranberry Creek will be used as a sampling conduit to determine the spatial and temporal effects from the wetland area at high-resolution. Water quality parameters and stream flow will be measured at sites upstream and downstream from the wetland area and changes between the upstream and downstream sites can be attributed to groundwater and stored surface water entering from the wetland, precipitation and runoff in the bog catchment, and wetland processes adding or removing materials from the water. The impact of bog processes can be verified by modeling loading from the wetland from calculation of the downstream increase in stream discharge and measurements of concentrations of water quality parameters in water sampled at several locations along the stream. From this kind of study, I will test the following hypotheses.

Hypotheses

a. Wetlands Delay Runoff

Since wetlands influence storm-water discharge by allowing water to spread out and by slowing the movement of water through the drainage area, we expect storm hydrograph peaks to be of lower magnitude and longer period at sampling sites within and downstream from the wetland area than for sites above the wetland even though total discharge should increase downstream. Due to water storage within the wetland and delayed discharge, there should be a continuous supply of water to be discharged in the stream through the wetland to downstream sites during baseflow conditions while above the wetland, the discharge will be diminished.

b. Limited Groundwater Influence on DOC Dynamics

I predict groundwater contribution to the system does not greatly affect the variability in water or DOC concentration, flux, or quality throughout the stream stretch since bog wetlands typically have little groundwater input and are mainly affected by precipitation and surface water either stored or discharged from upstream.

c. Consistent Soil-Derived DOC Source

The DOC throughout the stream stretch is expected to be mostly from allocthonous (soil-derived) sources since the water containing the DOC that typically contributes to bog wetland systems is typically from surface runoff, upstream discharge, and precipitation. water entering the stream via the peatland, regardless of whether it is from precipitation or local surface and shallow lateral flow (typical hydrology for a *Sphagnum*-dominated, oligotrophic peatland), should displace pore water from the peat, which is expected to be very high in DOC. The water should gain DOC mainly from decaying plant matter in the forest or peatland soils of the watershed. If there is some contribution of soil-derived DOC from standing water during baseflow periods, then during storm events, I predict the quality of DOC throughout the sampling sites along the stream to become even more soil-derived with greater surface runoff contributing DOC to the system.

d. DOC Concentration and Flux Peaks With Peatland Drainage and Decomposition Rates

I expect DOC concentration will be greatest for sampling sites along the section of the stream that flows through the wetland due to the peat material acting as a nearly infinite source of DOC. The DOC concentration should have a similar relationship to the percentage of peatland area as for peatlands in Ontario shown in Figure 2. DOC flux should vary spatially along Cranberry Creek in response to changes in discharge with

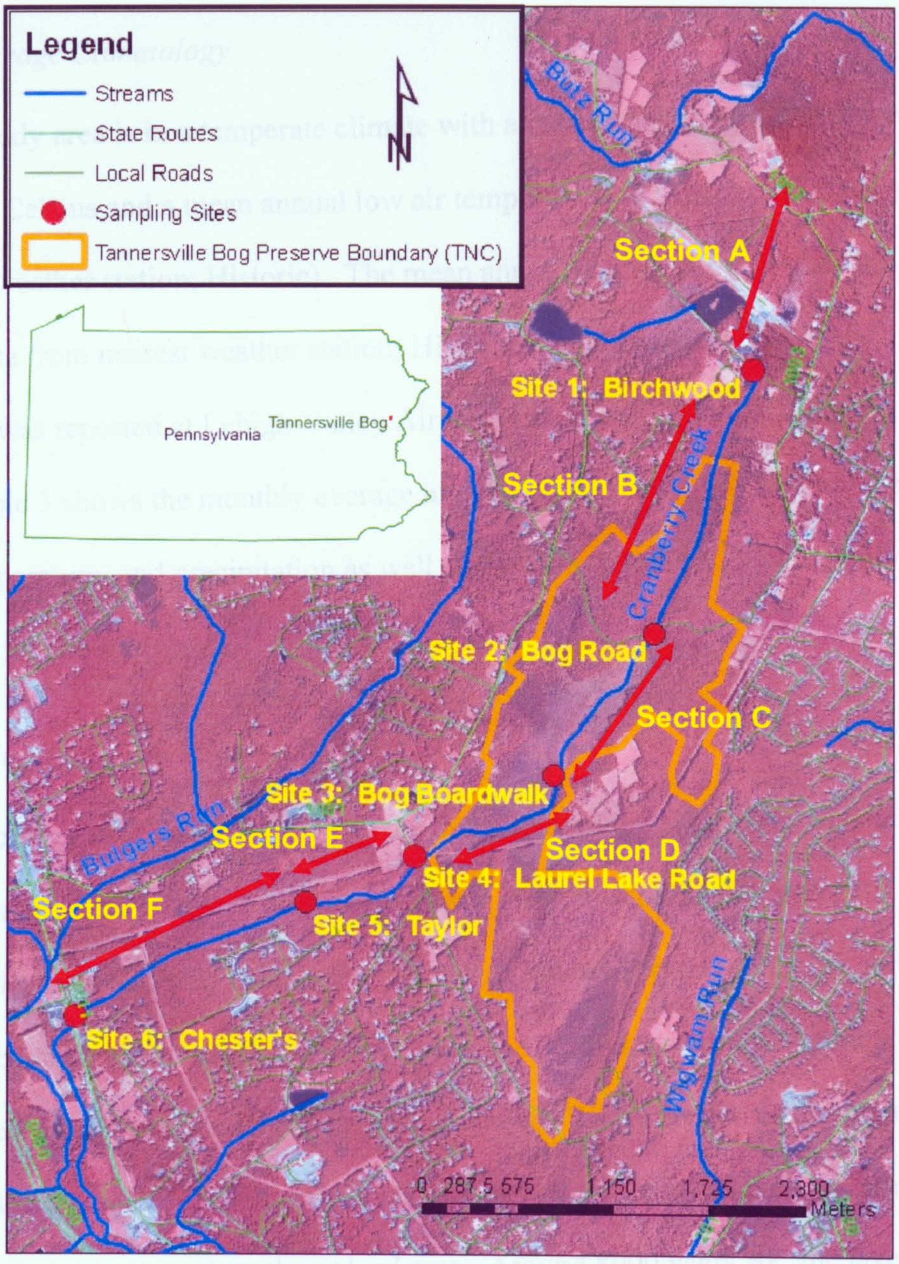

Figure 6: Sampling sites 1 through 6 and watershed sections A through F are shown along with the path of Cranberry Creek, the Tannersville Bog Preserve boundary, and nearby roads in Eastern Pennsylvania.

precipitation. I also expect DOC flux to vary seasonally due to higher temperatures during summer months causing higher DOC flux than during cooler periods, such as in the late-fall.

Methods

Study Area

a. Location

A watershed drained by a first-order stream, Cranberry Creek, in Eastern Pennsylvania (longitude 75.26° W, latitude 41.04° N, and elevation 277 meters) was chosen as the study area (Fig. 6). Cranberry Creek (6 km long) flows through Tannersville Bog, a *Sphagnum*-dominated, oligotrophic peatland. The Nature Conservancy owns a large portion of the peatland area where the organization maintains Cranberry Preserve, outlined in orange in Figure 6. The rest of the watershed is privately owned, but it is not highly developed.

b. Average Climatology

The study area is in a temperate climate with a mean annual high air temperature of 16 degrees Celsius and a mean annual low air temperature of 3 degrees Celsius (data from nearest weather station; Historic). The mean annual precipitation for the area is 1270 mm (data from nearest weather station; Historic). In 2006, 1252 mm of precipitation was reported at Lehigh Valley Airport, 45 km away (Lehigh Valley Airport). Table 3 shows the monthly average high air temperature, low air temperature, mean air temperature, and precipitation as well as the record high and low monthly air temperatures for the study area.

c. Site History and Vegetation

Cranberry Creek watershed lies on the outer edge of the Wisconsin Glaciation terminal moraine. The land was therefore exposed early, around 14,000 years BP. Pioneer species such as *Salix,* Gramineae, *Artemisia, Rumex/Oxyria,* and other herbs colonized the area with *Pinus*, *Picea*, and Cyperaceae species becoming dominant shortly after. A lake formed with glacial retreat where banded silts were deposited until around 13,300 years BP. Sedge species dominated the area surrounding the lake and forest vegetation began to migrate into the upland area. Around 8000 years BP, the lake became overgrown at the margins and by 4000 years BP the modern conifer bog vegetation was established. Presently, around 11 meters of peat has accumulated in the glacial basin (Watts 1979). Figure 7 is a pollen diagram for Tannersville Bog from Watts (1979) showing the vegetation history.

Table 3: Monthly average climatology for Tannersville, PA (30-year; data from nearest weather station; Historic)

Month	Average High Air Temperature	Average Low Air Temperature	Mean Air Temperature	Average Precipitation	Record High Air Temperature	Record Low Air Temperature
January	2°C	-9°C	-3°C	101.1 mm	22°C (1932)	-32°C (1961)
February	4°C	-8°C	-2°C	76.5 mm	23°C (1954)	-29°C (1943)
March	9°C	-3°C	3°C	97.5 mm	31°C (1977)	-26°C (1934)
April	16°C	2°C	9°C	101.6 mm	36°C (1976)	-12°C (1965)
May	22°C	8°C	15°C	127.3 mm	36°C (1996)	-4°C (1956)
June	27°C	13°C	19°C	115.8 mm	43°C (1933)	0°C (1964)
July	29°C	15°C	22°C	112.3 mm	40°C (1953)	2°C (1963)
August	28°C	14°C	21°C	108.7 mm	39°C (1955)	0°C (1965)
September	24°C	10°C	17°C	124.2 mm	41°C (1953)	-7°C (1957)
October	18°C	3°C	11°C	96.8 mm	35°C (1941)	-10°C (1936)
November	11°C	-1°C	4°C	108.2 mm	37°C (1947)	-17°C (1938)
December	4°C	-6°C	-1°C	99.6 mm	22°C (1984)	-26°C (1963)

The current peatland vegetation is *Sphagnum*-dominated. Within the peatland area, stands of *Larix laricina* (tamarack) and *Picea mariana* (black spruce) are also common. The canopy opens up a little more in the middle of the peatland to support *Chamaedaphne* and other low-growing ericaceous shrubs. Near the edges of the peatland, *Alnus, Rhododendron, Tsuga,* and *Pinus strobus* grow. The upland vegetation is mainly secondary oak forest with *Pinus rigida, Fagus, Carya*, *Castanea*, *Tsuga*, *Acer saccharum*, *Betula alleghaniensis*, and *Pinus strobes* (Fig. 7) (Watts 1979).

d. Stream Monitoring and Sampling Sites and Watershed Sections

Six sites (Fig. 6), along a 6 km stretch of Cranberry Creek were chosen for monitoring and sampling. The headwaters drain a pond surrounding an abandoned resort (Birchwood Resort). Site 1 is just below the outflow of this pond. Downstream, Cranberry Creek flows under Bog Road, where site 2 is located. Then, the stream flows through Tannersville Bog. Site 3 is located along Cranberry Creek, in the middle of Tannersville Bog at the end of a boardwalk. Site 4 is located near the lowest extent of the wetland area where Cranberry Creek flows under Laurel Lake Road. Site 5 is located further downstream at the end of the wetland area, around 1 km above a small, man-made pond. Below the pond is site 6, just before the stream flows under State Rt. 611 (Fig. 6).

Segments of the watershed and wetland area were separated in-between sites (Fig. 6). Section A includes the area above site 1, section B is the area between sites 1 and 2, section C occurs between sites 2 and 3, section D is between sites 3 and 4, section E contains the area between sites 4 and 5, and section F includes the area between sites 5 and 6 (Fig. 6).

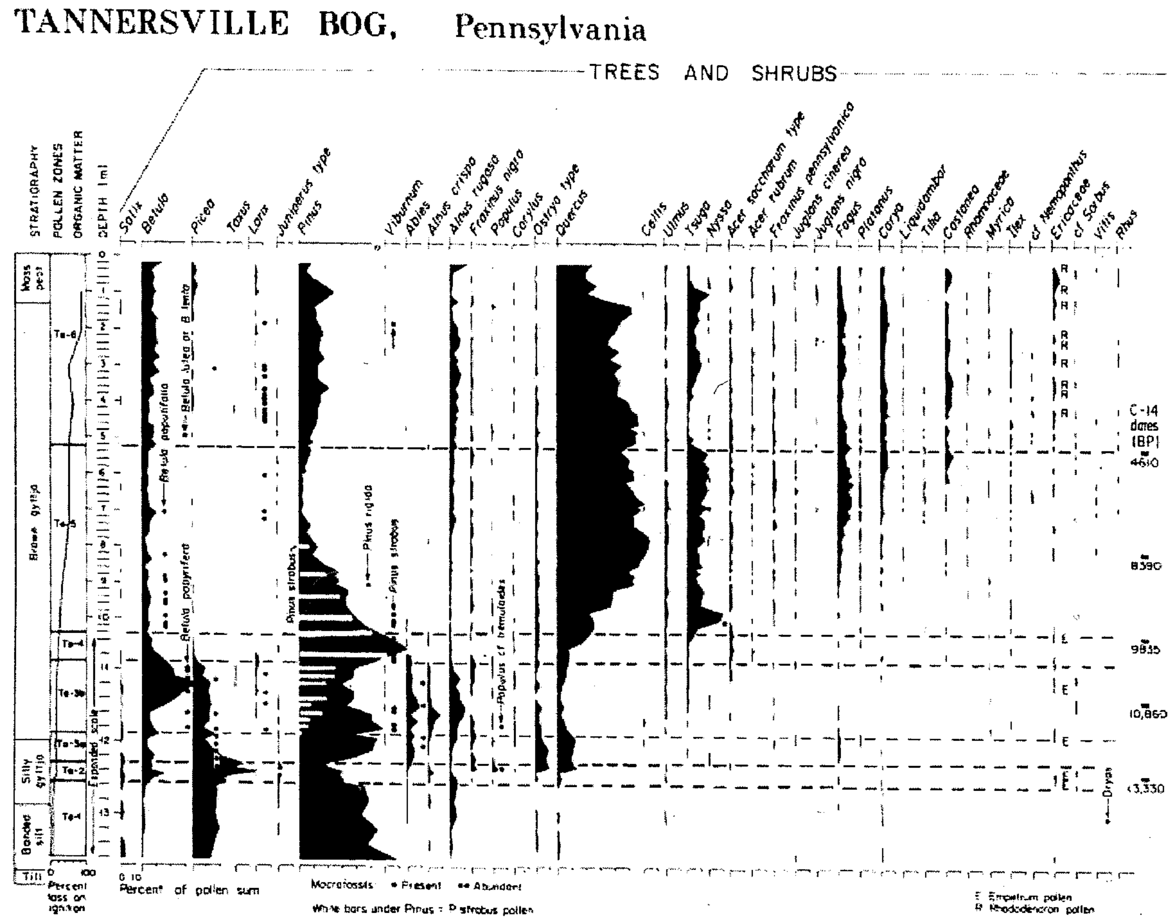

Figure 7: Pollen diagram for Tannersville Bog, northeastern Pennsylvania (from Watts 1979).

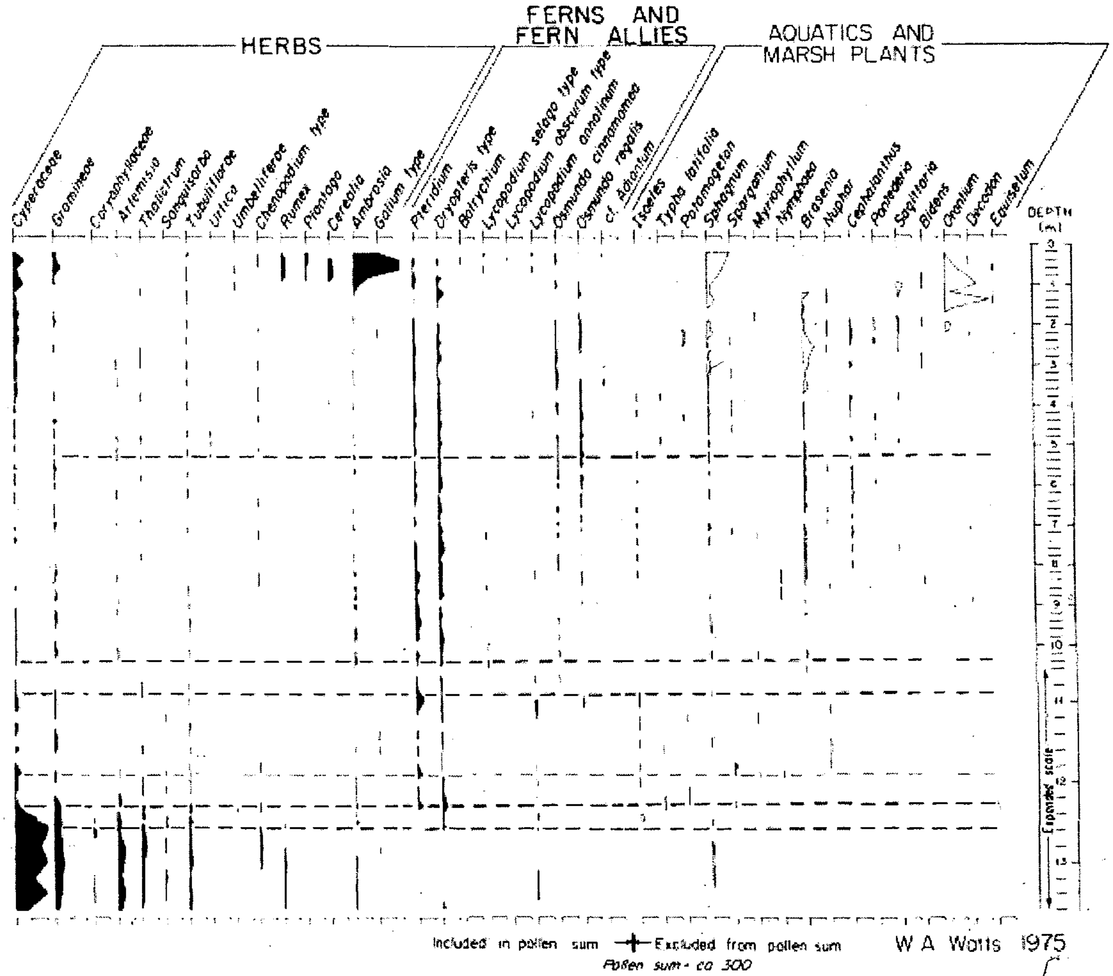

Figure 7 Continued: Pollen diagram for Tannersville Bog, northeastern Pennsylvania (from Watts 1979).

e. Watershed Area Determination

The watershed area was determined by delineating the Cranberry Creek catchment using elevation observed in a USGS Digital Elevation Model (DEM) (10 meter resolution) in the ENVI computer program (Digital). Both shaded relief and aspect images were created and used to distinguish the watershed divide. The method used is similar to that explained in Kost and Kelly (2006). A watershed vector was created and the watershed area calculated (7,604,325 square meters).

f. Wetland Area Determination

Most of the wetland is included in Tannersville Bog Preserve, but some wetland area lies outside the preserve boundaries. In order to delineate the wetland area the DEM (Digital) was used in the ENVI computer program to determine the area of low and uniform elevation for standing water to persist and support a characteristic wetland environment. The use of a DEM image is beneficial for accuracy of the delineation (Stefanov et al. 2001). Furthermore, ASTER (15 meter resolution) bands 3 (near infrared; 0.760 to 0.860 μm spectral range), 2 (visible red; 0.630 to 0.690 μm spectral range), and 1 (visible green; 0.520 to 0.600 μm spectral range) (ASTER) were displayed respectively in an image using the ENVI computer program, which are useful to distinguish differences in vegetation and soil (Yamaguchi et al. 1998). The spectral characteristics were observed to distinguish wetland vegetation/soil from upland vegetation/soil. Both methods of delineation were considered in the creation of a wetland vector and the wetland area was calculated (1,879,200 square meters).

g. Watershed Remote Sensing Spectral Characteristics and Wetland Landcover

In order to better-understand the ecology of the study area, remote sensing was used to spectrally characterize the watershed and wetland areas and distinguish land cover types. To characterize the watershed spectrally, the 3,2,1 ASTER Image (ASTER) was cropped using the ENVI computer program to the area of the watershed using the watershed vector. Six arbitrary profiles along Cranberry Creek were created perpendicular to the streamflow. The digital numbers from each ASTER band for each profile were exported and graphed in Microsoft Excel to observe the spectral characteristics of the land cover in the watershed. Within the wetland area, the landcover variability was distinguished using remote sensing, considering the differences in spectral characteristics. Water and wetland areas appear low in bands 3, 2, and 1 (lower for more water). Upland areas typically appear higher in each band than wetland areas, especially for band the near infrared, band 3. Residential or clear-cut areas should appear the highest in all three bands.

The 3,2,1 ASTER Image (ASTER) was cropped using the ENVI computer program to the wetland area using the wetland vector. Four regions of different spectral characteristics within the wetland region were chosen and used to create a parallelepiped, supervised, classified image. This was performed similar to the methods explained in Jensen (2007).

Monitoring Data

a. Weather

A weather station and water level monitor (Fig. 8) was set up at site 3, in the middle of the peatland, to determine a representation of the weather for the whole watershed system. Data were logged in 15-minute intervals from June 20, 2006 to the April 27, 2007. Air and water temperature, wind speed, relative humidity, photosynthetically active radiation (PAR), and precipitation were recorded (sensors and CR10 datalogger from Campbell Scientific, Inc., http://www.campbellsci.com; vented H310 pressure sensor with 0.1 mm resolution for water level from Environmental Analysis Associates, http://www.waterlog.com/). Plastic rain gages were mounted at sites 2 and 6 for rain collection and comparison to the precipitation measured with the automated gage at site 3. Precipitation at site 3 was compared to that of the region (using data from the Lehigh Valley Airport) to determine the approximate annual precipitation for the watershed.

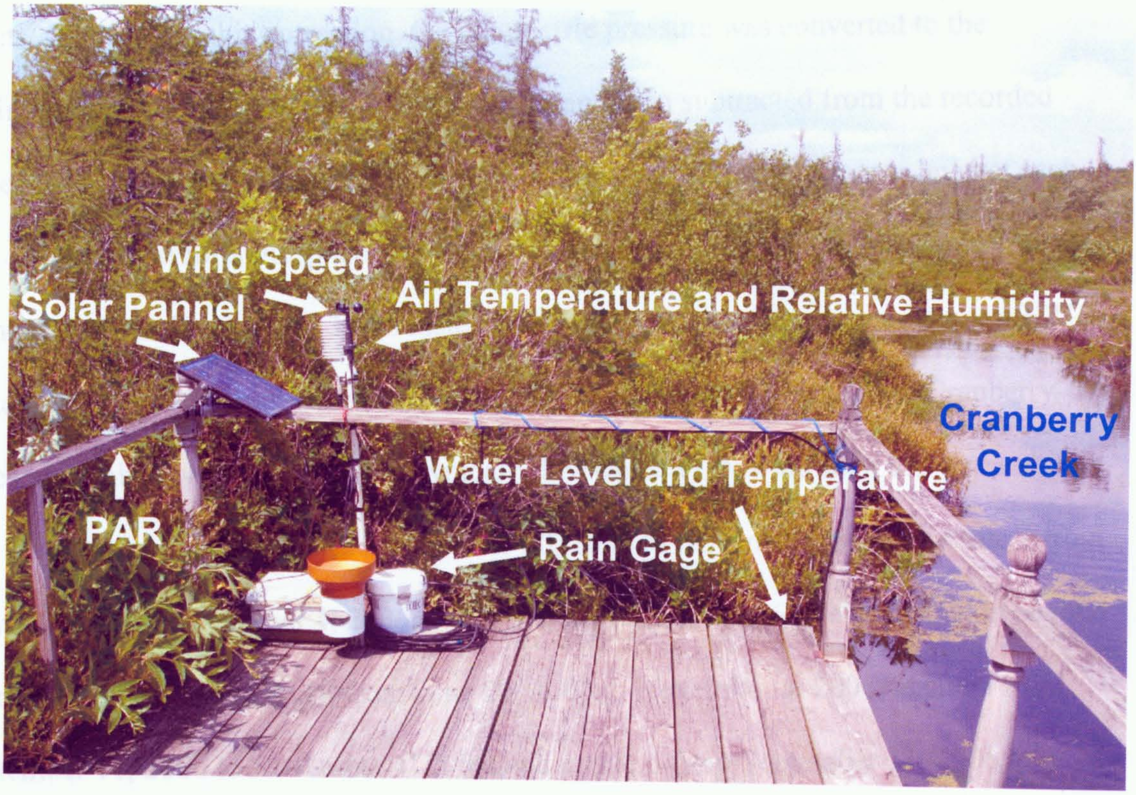

Figure 8: A photograph depicting the weather station set-up at site 3 in the middle of the peatland.

b. Stream Level

Stream depth, at 15-minute intervals, was calculated from pressure sensors (SOLINST Leveloggers and Onset HOBO Water Level Loggers, corrected for atmospheric pressure using local and regional atmospheric pressure records) placed on the stream bottom at sites 1, 2, 4, 5, and 6 (weighted by attachment to salvaged disc brake rotors as seen in Figure 9). The positioning of the sensors in the center recess of the disc brake rotors served as a replacement for a stilling well to minimize flow artifacts. An outdoor local barometer and a SOLINST barologger were considered for use to correct for atmospheric pressure of the pressure sensors deployed in the stream but an indoor barometer located 40 miles away was used for the correction to minimize temperature effects. To perform this correction, the barometric pressure was converted to the centimeters of water equivalent to that pressure and then subtracted from the recorded values from pressure sensors deployed in the stream. The result was water level at each site. A correction for atmospheric pressure was not needed for the pressure sensor at site 3 since the water level at site 3 was instead monitored by a vented pressure sensor (H310 vented pressure sensor described earlier) and weighted by a cinder block to Cranberry Creek streambed within a section of typically low-velocity flow through the wetland area. The level was monitored at site 1 from June 20, 2006 to November 4, 2006, at site 2 from May 29, 2006 to November 4, 2006, at site 3 from June 18, 2006 to continuing on beyond the data in this thesis, at site 4 from June 20, 2006 to November 4, 2006, at site 5 from September 11, 2006 to November 4, 2006, and at site 6 from September 11, 2006 to November 4, 2006 (Fig. 5).

Figure 9: A photograph of a pressure sensor attached in the center recess of a disc brake rotor on the Cranberry Creek stream bottom at site 1.

c. Stream Velocity and Channel Cross-Sectional Area

Periodically (when available; see table 4), during storm and baseflow conditions, from June to November of 2006, the stream velocity (at 1/3 of the distance from the surface to the streambed) and channel cross-sectional area (at regular intervals) were measured at all sites except site 3 where accessing the stream channel on the peat substrate was not feasible. A Marsh- McBirney Model Flomate 2000 Magnetic Flow Meter was used to measure the stream velocity.

d. Monitored Water Quality (datasondes)

Two submersible data loggers (*YSI* EDS datasondes) measured and recorded pH, specific conductance, dissolved oxygen, and turbidity in 15-minute intervals during several periods from June to November of 2006. From May 11, 2006 to May 15, 2006, May 26, 2006 to May 29, 2006, June 2, 2006 to June 5, 2006, June 22, 2006 to July 10, 2006, and September 1, 2006 to September 11, 2006. They were deployed at sites 2 and 5 from October 1, 2006 to October 2, 2006 and October 14, 2006 to November 2, 2006. (Data not included in this study)

Water Sampling

Two automated samplers (*ISCO* 6712c) were used upstream and downstream from Tannersville Bog, during mainly storm periods, at sites 2 and 6 from April 29, 2006 to September 11, 2006 and at sites 2 and 5 from September 11, 2006 to November 4, 2006 (Fig. 10). The samplers collected samples from Cranberry Creek periodically at increasing intervals (6 at 1hours, 6 at 2 hours, 6 at 4 hours, 6 at 8 hours) during storm events once triggered by rain measured in a rain gage (0.07 inches of rain within an hour) at each site. Some sampling was carried out at six-hour intervals and was time-triggered instead of rain-triggered. The field set-up is shown in Figure 11.

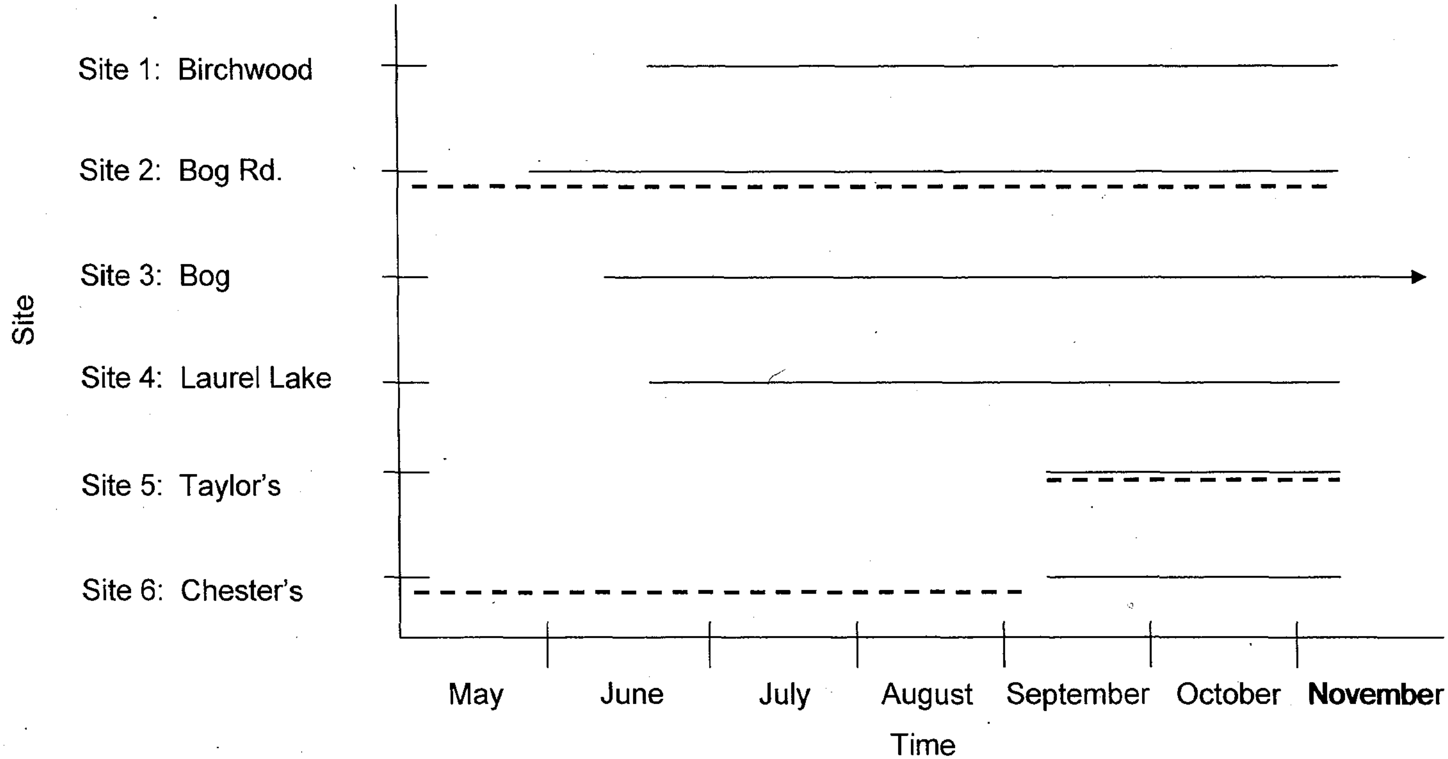

Figure 10: Stream level monitoring (lines) and ISCO automated sampling (dashes) periods at each site in 2006.

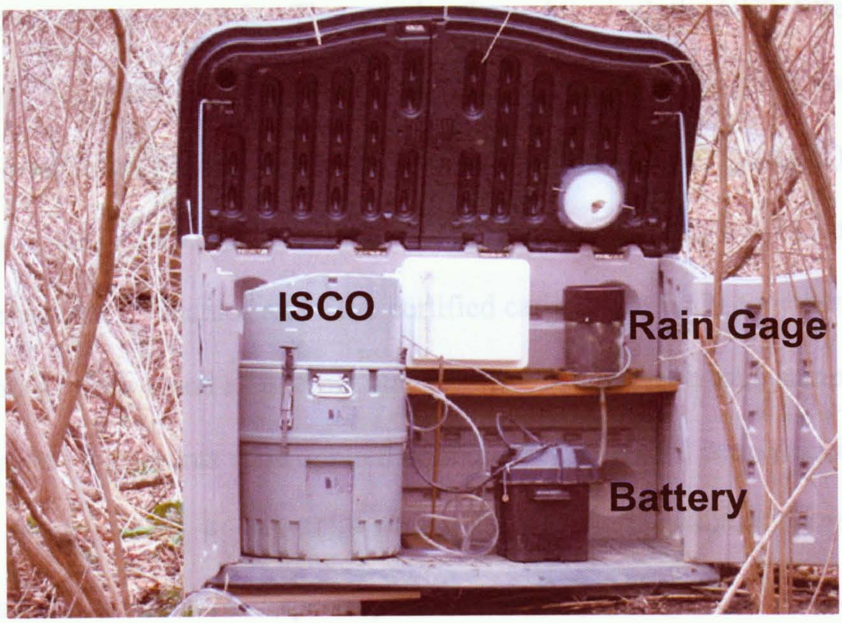

Figure 11: A photograph of one of the garden-shed enclosures containing an ISCO automated sampler, the rain gage for triggering storm sampling, and a battery to power the system.

In addition to automated stream sampling, stream water grab samples at all sites were collected using *Nalgene* bottles periodically from February 2006 to March of 2007. At these times, water from an artesian well near Cranberry Creek at site 6 was also collected.

Water Sample Analysis

All water samples were analyzed in the laboratory after warming to room temperature for pH (*Orion model 330* meter, Ross electrode with automatic temperature correction) and specific conductance (*Orion model 105* meter, readings adjusted to 25°C). A subset of the samples was filtered using Whatman, GF/F, 25 mm filters and 25 mm

Nylon filters. The portion of samples filtered through the Nylon filters were saved for analysis in a 60 mL, *Nalgene* bottle. The samples filtered through the GF/F filters were split into 125 mL *Nalgene* bottles and 40 mL glass archive vials. Using the samples of GF/F filtrate stored in the 40 mL glass archive vials, DOC concentration (mg/L) was measured using a *Shimadzu TOC-VCPH 5000* analyzer using an ultra-low carbon deionized water source for blanks, and EPA-certified carbon standards, together used to create the calibration curve and as internal blanks and standards with each sample run, from which further adjustments were applied to obtain sample DOC concentration in mg/L. For the same samples, scans of CDOM optical density from 800 to 200 nm were performed on a *Shimadzu UV-1601* spectrophotometer in a 1 cm or 10 cm quartz cuvette referenced to air after warming to room temperature. The absorption coefficient at 320 nm (m^{-1}) was calculated after subtracting the optical density of low-carbon deionized water measured at the same time and temperature in the same cuvette, and also subtracting the average absorption coefficient for 775-800 nm from all wavelengths to adjust for any baseline errors not corrected by the instrument baseline correction procedure. Scans of CDOM fluorescence (emission from 400 to 700 nm) were also measured in these samples (warmed to room temperature in a water bath) on a *Shimadzu RF-551* fluorometer (excited at 370 nm) in a 1 cm quartz cuvette (clear on 4 sides). Emission spectra were corrected for Raman scattering in water by subtracting the scan for low-carbon deionized water carefully adjusted to the same temperature as the samples, and for baseline errors by subtracting from all wavelengths the average emission near 700 nm. The sample portions stored in the 60 mL bottles were analyzed for dissolved cations (using a *Thermo* inductively coupled plasma mass spectrometer). These data appear in

Appendix I. The samples exist for future analysis for dissolved anions (using a *Dionex series 4500* ion chromatograph). While the 125 mL sample portions were intended to be analyzed for dissolved nutrients (nitrate and phosphate, using a *QuickChem 8000 series* analyzer) this was not completed due to instrument problems.

Data Analysis

a. Stream Water Discharge Calculation

Rating curves were developed for all sites except site 3 (where only water depth was recorded) using the velocity and cross-sectional area measurements. Power functions fitted to each rating curve were used to calculate discharge from the 15-minute stream depth data at each site throughout the sampling period. The average monthly discharge from June to November of 2006 was calculated for each site to observe possible spatial and temporal variability. The difference between discharge downstream and upstream for each section of the watershed was calculated ($Q_{downstream} - Q_{upstream} = \Delta Q_{section}$) throughout the monitoring period as well to determine the response of the wetland area with respect to water storage. A general approach of looking for errors and inconsistencies in the data was taken to validate the stream discharge calculations.

b. Groundwater Contribution Detection Using Specific Conductance

Specific conductance measurements from all water samples were averaged monthly from June to November of 2006 for each site to observe spatial and temporal variations possibly linked to groundwater contribution. Changes in specific ions and ion ratios over time and space and at different discharge levels were also considered as tracers to give clues about groundwater contributions (data were not used in this study, but are included in Appendix I).

c. DOC Source Using Fluorescence Index

The fluorescence index, calculated as the ratio of the fluorescence at 450 nm to that of 500 nm was calculated from each fluorescence emission spectrum (described above) to determine the source of DOC for each sample (McKnight et al., 2001; Cory and McKnight, 2005). The fluorescence index of each water sample collected was averaged monthly from June to November of 2006 for each site to determine possible spatial or temporal variations in DOC source.

d. DOC Concentration and Flux Calculation

DOC concentration from each sample was averaged monthly from February to November of 2006 for each site to observe spatial and temporal differences. The difference between the monthly average DOC concentration at site 1 and the monthly average DOC concentration at site 5 was taken for months monitored in 2006 to determine DOC contribution from sections B, C, D, and E (watershed area containing peatland). For months without monitoring, the values were estimated by interpolation.

The difference between storm peak DOC concentration and DOC concentration in baseflow before the storm was calculated for four storm periods (6/24/06 to 6/26/06, 8/11/06 to 8/29/06, 9/11/06 to 9/17/06, and 10/26/06 to 11/1/06) at all sites and compared to the average air temperature and total precipitation over each storm period. Then, for each storm period, these values from site 1 were subtracted from those of site 4 to determine the segment (combined segments B, C, and D) DOC concentration difference for each storm period for comparison to the average air temperature for each period.

To model how DOC concentration changed over time and with variations in flow, DOC flux was graphed against discharge for each site. Power function regressions were then applied to the data. Separate power regression equations were developed by separating data collected during large storms as well as for data during late-fall. The appropriate regression equations were then applied to the 15-minute interval discharge data throughout the monitoring period to account for spatial and temporal variability in DOC flux and create a continuous record at each site throughout the monitoring period.

Another method was used to calculate monthly average DOC flux from the peatland for comparison to monthly precipitation and monthly average air temperature in 2006 (historical averages were used for weather data when not monitored). To calculate monthly average DOC flux, the monthly average DOC concentration from the peatland was multiplied by the monthly average discharge below the peatland and divided by the watershed area containing peatland. The monthly average DOC concentration from the peatland was found by subtracting the monthly average DOC concentration at site 1 from the monthly average DOC concentration below the peatland. The average monthly DOC concentration at site 5 was used when available. Otherwise, the average monthly DOC concentration was taken from site 4. When neither value was available, interpolation from sampled dates was used to estimate the monthly average DOC concentration. To determine the monthly average discharge from the peatland, monthly average discharge from site 1 was subtracted from monthly average discharge from below the peatland. The discharge at site 5 was used for the monthly average discharge below the peatland when available. During this period, a regression between the discharge at site 4 and the discharge at site 5 was carried out to determine a polynomial equation that was used to estimate the monthly average discharge at site 5 from the discharge at site 4 during the rest of the monitoring period when the discharge at site 5 was not available. Monthly average discharge was estimated by interpolation for months when no measurements were taken.

Results

Watershed Area

The Cranberry Creek watershed area, determined using a DEM as explained above, is 7,604,325 square meters as shown in Figure 12. The peatland area in the middle of the watershed is fairly even in elevation. The upland area has varying terrain with few steep slopes. Still, all water within the watershed drains down slope to Cranberry Creek.

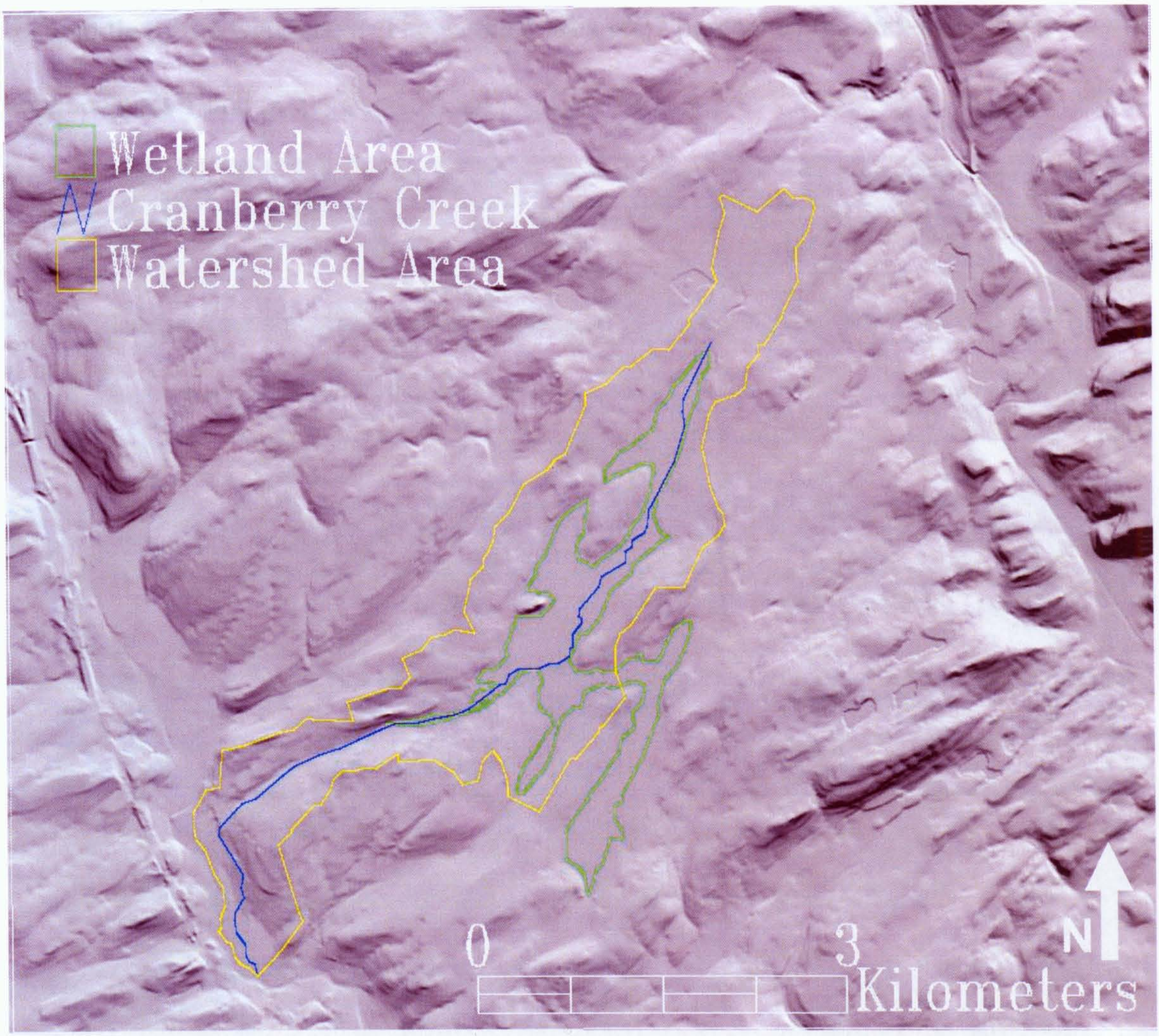

Figure 12: The watershed area (7,604,325 square meters) and wetland area (1,766,025 square meters) created using the DEM image are overlaid on a shaded relief image created from the DEM data. The approximate elevation near the center of the wetland is 277 meters above sea level.

Wetland Area

The wetland area (1,766,025 square meters), determined using a 3,2,1 ASTER image and a DEM as explained above, is shown in Figure 13 as the darker vegetation in the middle of the watershed. The wetland area is 27 percent of the watershed area between sites 1 and 5.

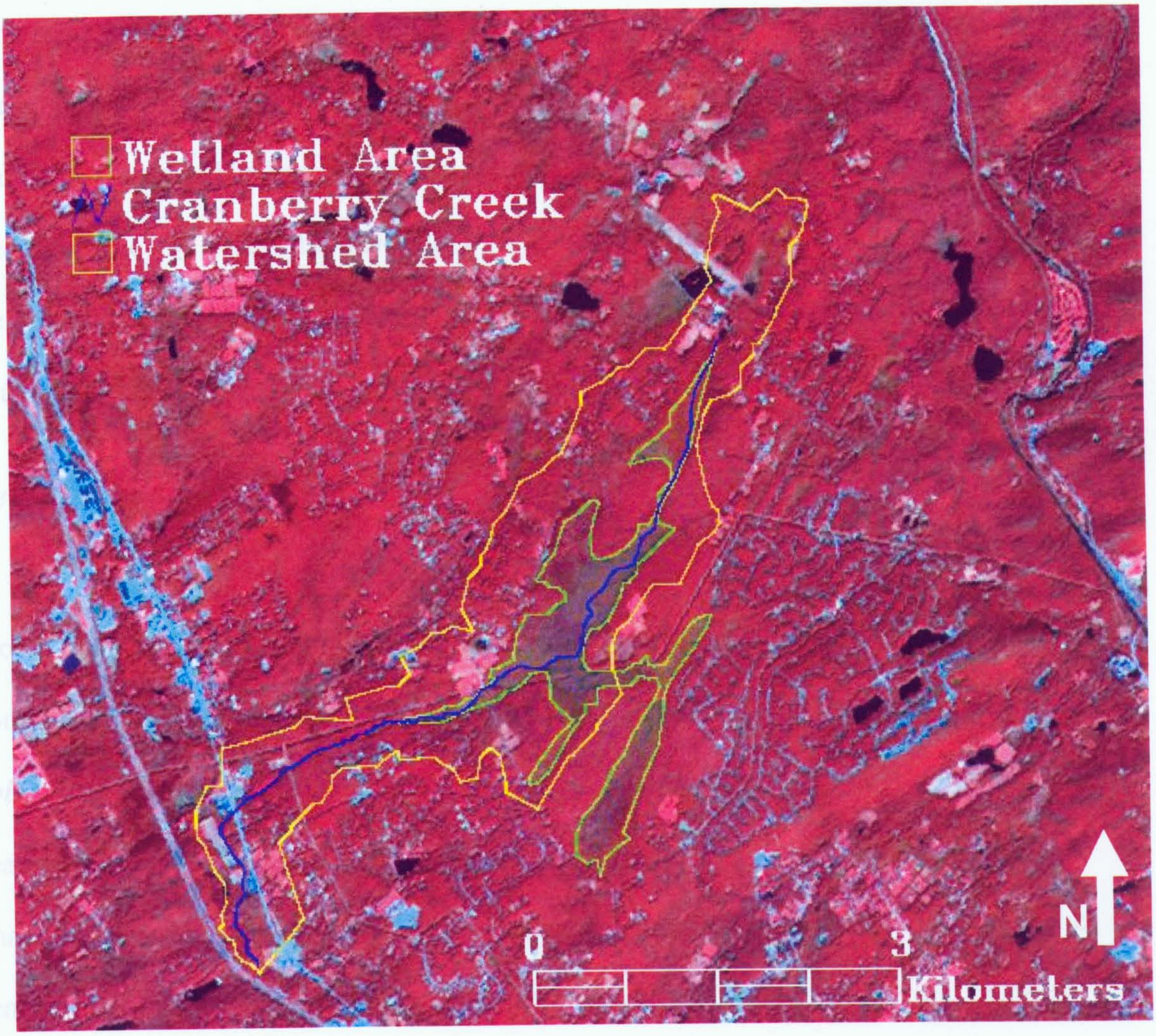

Figure 13: The wetland area (1,766,025 square meters; 27 percent of the watershed area) and Cranberry Creek stream channel, created using the 3,2,1 ASTER image, are overlaid on the 3,2,1 ASTER image along with the watershed area, delineated using the DEM image. The vegetation of the wetland area appears as the darker region in the middle of the watershed.

Watershed Remote Sensing Spectral Characteristics

Environmental spectral characteristics of the 3,2,1 Aster bands along six transects perpendicular to Cranberry Creek streamflow are displayed in Figures 14a to 14g. Wetland areas in profiles #1, #2, #3, and #4 appeared lower in the near infrared (NIR) than upland areas. The lowest wetland NIR values were from the middle of the wetland area in profile #3. The limited amount of residential areas, roads, and clear-cut areas in the upland portion of the watershed appeared higher in the visible bands than other areas in the watershed (Figs. 14b to 14g).

Wetland Land Cover

A parallelepiped, supervised, classified image of four wetland land cover types is shown in Figure 15. Within the wetland area, spectral characteristics of *Sphagnum*-dominated, peatland vegetation were detected in the middle of the bog surrounded by *Sphagnum*-dominated, fringe vegetation with more trees. The *Sphagnum*-dominated, peatland vegetation appeared darker than its surrounding vegetation in the 3,2,1 Aster image and was lower in the near infrared. Spectral characteristics (still fairly low in the near infrared) of shrubby swamp vegetation were detected in downstream and upstream portions of the wetland. Areas upstream and along edges of the wetland area showed spectral characteristics of a forested swamp environment (still somewhat low in the near infrared compared to the upland forested area). Each spectrally classified land cover was verified in the field.

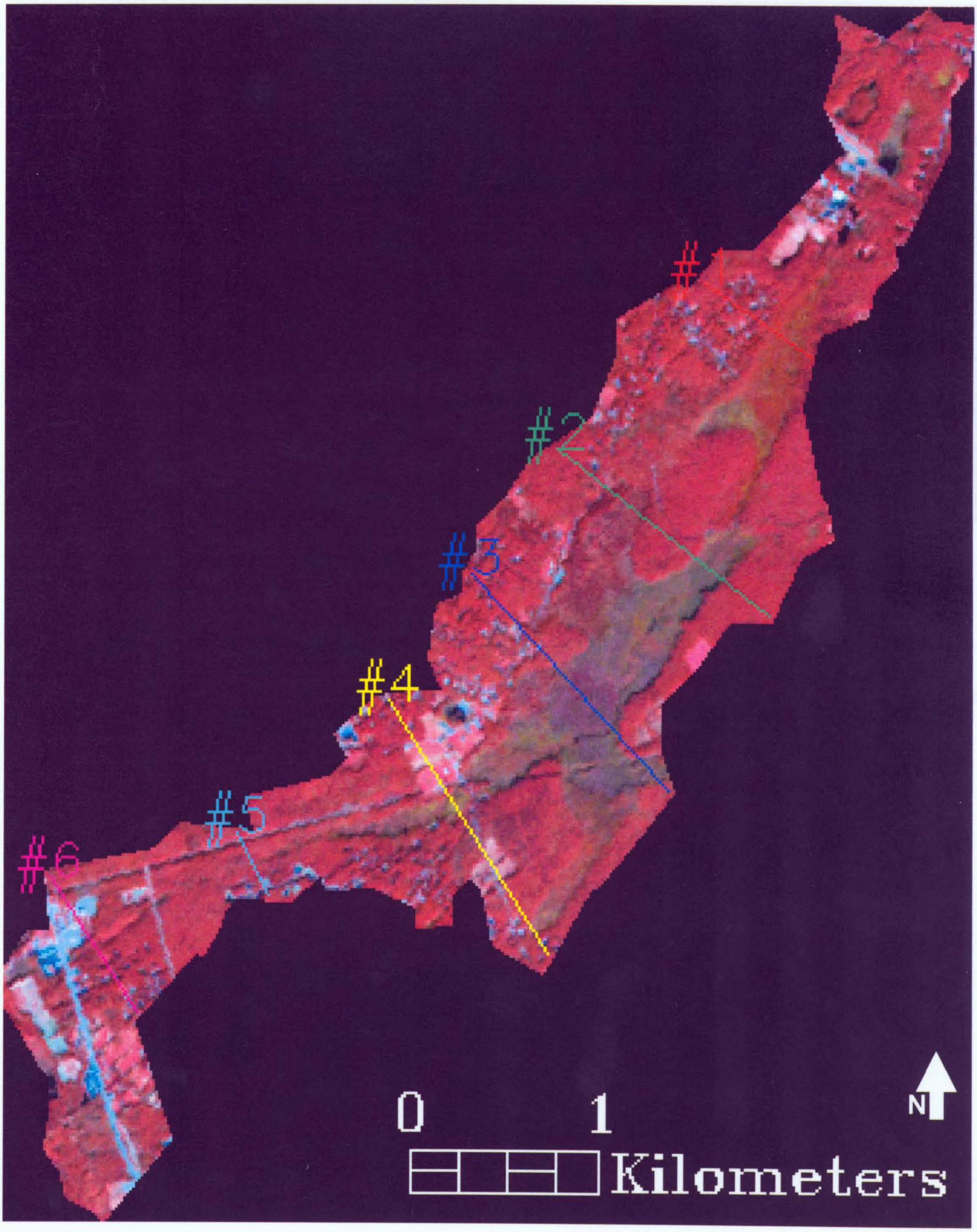

Figure 14a: Cranberry Creek watershed cropped from the 3,2,1 Aster image with the location of six transects perpendicular to Cranberry Creek streamflow are shown.

Figure 14b: Environmental spectral characteristics of the 3,2,1 Aster bands (3: near infrared, 2: visible red, and 1: visible green; spectral characteristics are relative using a digital number scheme) along transect #1 (profile values start at the transect number) where the residential area is detected as high in the visible bands and the wetland area is low in the near infrared .

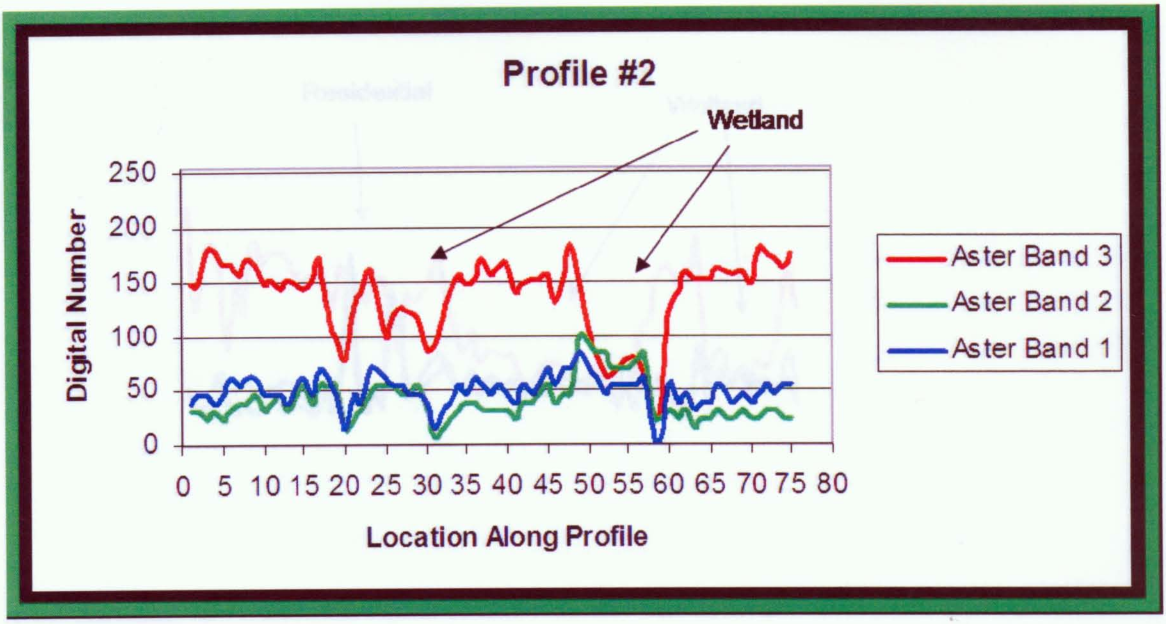

Figure 14c: Environmental spectral characteristics of the 3,2,1 Aster bands (3: near infrared, 2: visible red, and 1: visible green; spectral characteristics are relative using a digital number scheme) along transect #2 (profile values start at the transect number) where the two wetland areas are low in the near infrared .

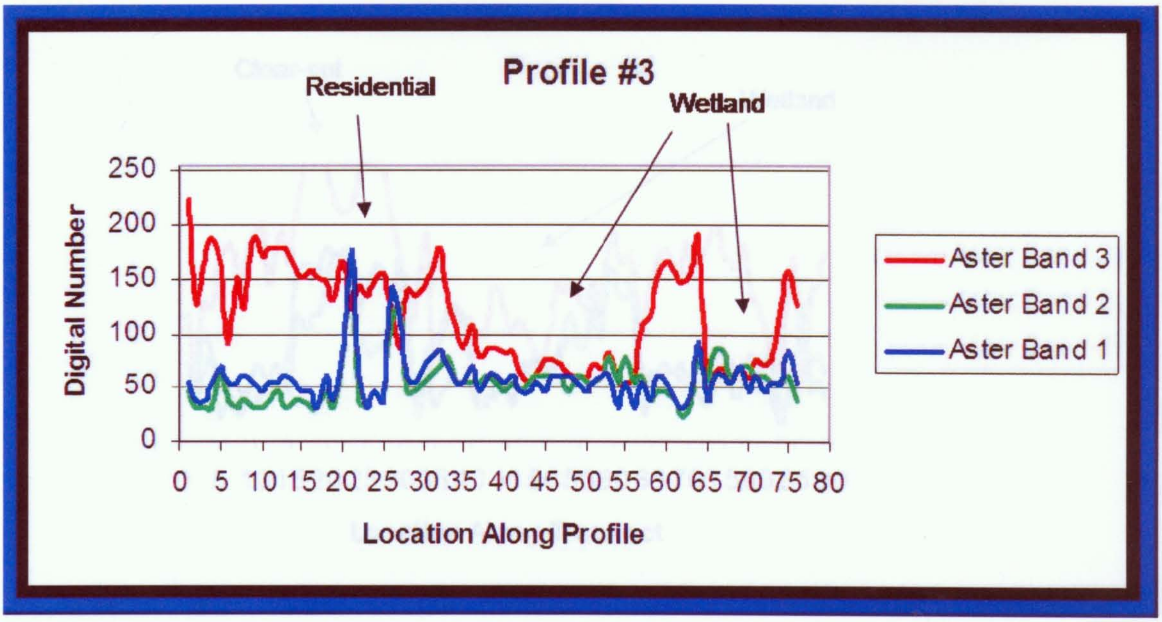

Figure 14d: Environmental spectral characteristics of the 3,2,1 Aster bands (3: near infrared, 2: visible red, and 1: visible green; spectral characteristics are relative using a digital number scheme) along transect #3 (profile values start at the transect number) where the residential areas are detected as high in the visible bands and the wetland areas are low in the near infrared .

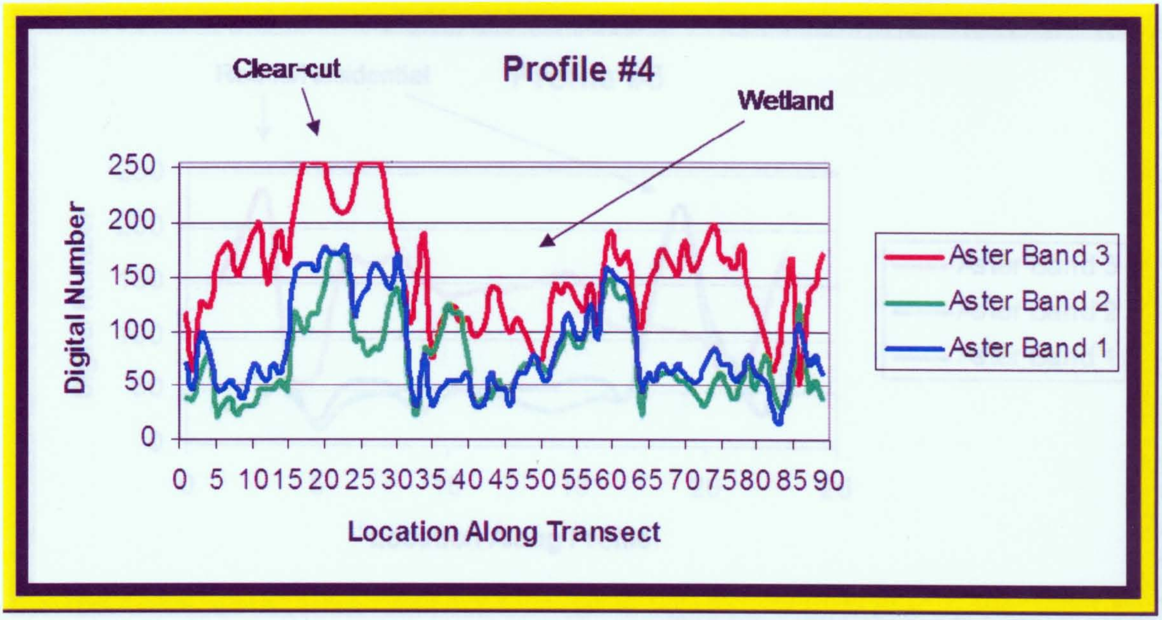

Figure 14e: Environmental spectral characteristics of the 3,2,1 Aster bands (3: near infrared, 2: visible red, and 1: visible green; spectral characteristics are relative using a digital number scheme) along transect #4 (profile values start at the transect number) where the clear-cut area is detected as high in the near infrared and visible bands and the wetland area is low in the near infrared .

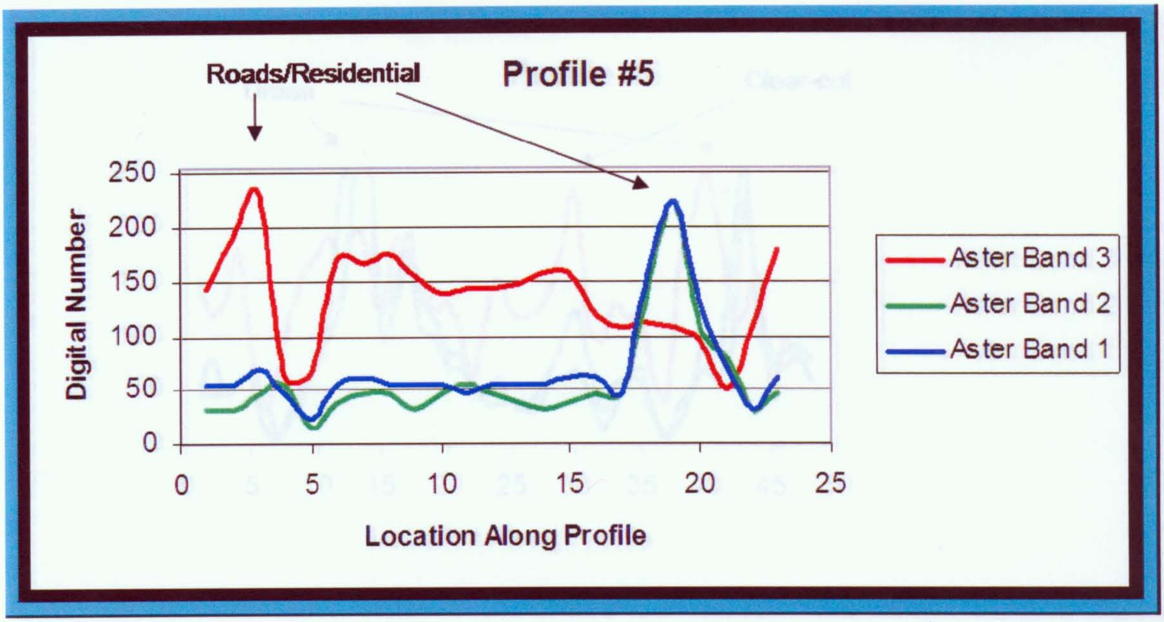

Figure 14f: Environmental spectral characteristics of the 3,2,1 Aster bands (3: near infrared, 2: visible red, and 1: visible green; spectral characteristics are relative using a digital number scheme) along transect #5 (profile values start at the transect number) where the roads and residential areas are detected as high in the visible bands.

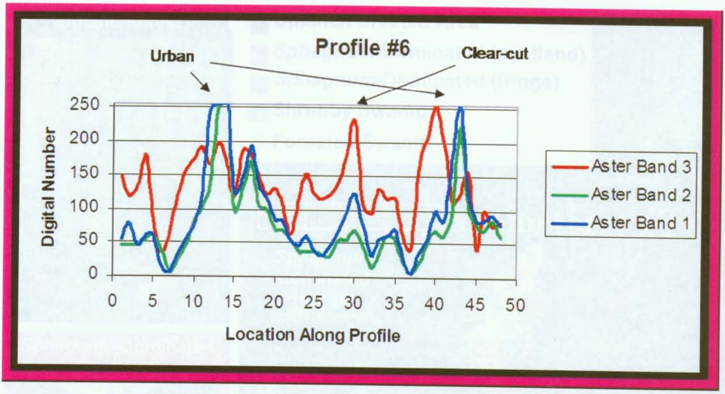

Figure 14g: Environmental spectral characteristics of the 3,2,1 Aster bands (3: near infrared, 2: visible red, and 1: visible green; spectral characteristics are relative using a digital number scheme) along transect #6 (profile values start at the transect number) where the urban areas are detected as high in the visible bands and the clear-cut area is high in the visible and near infrared bands.

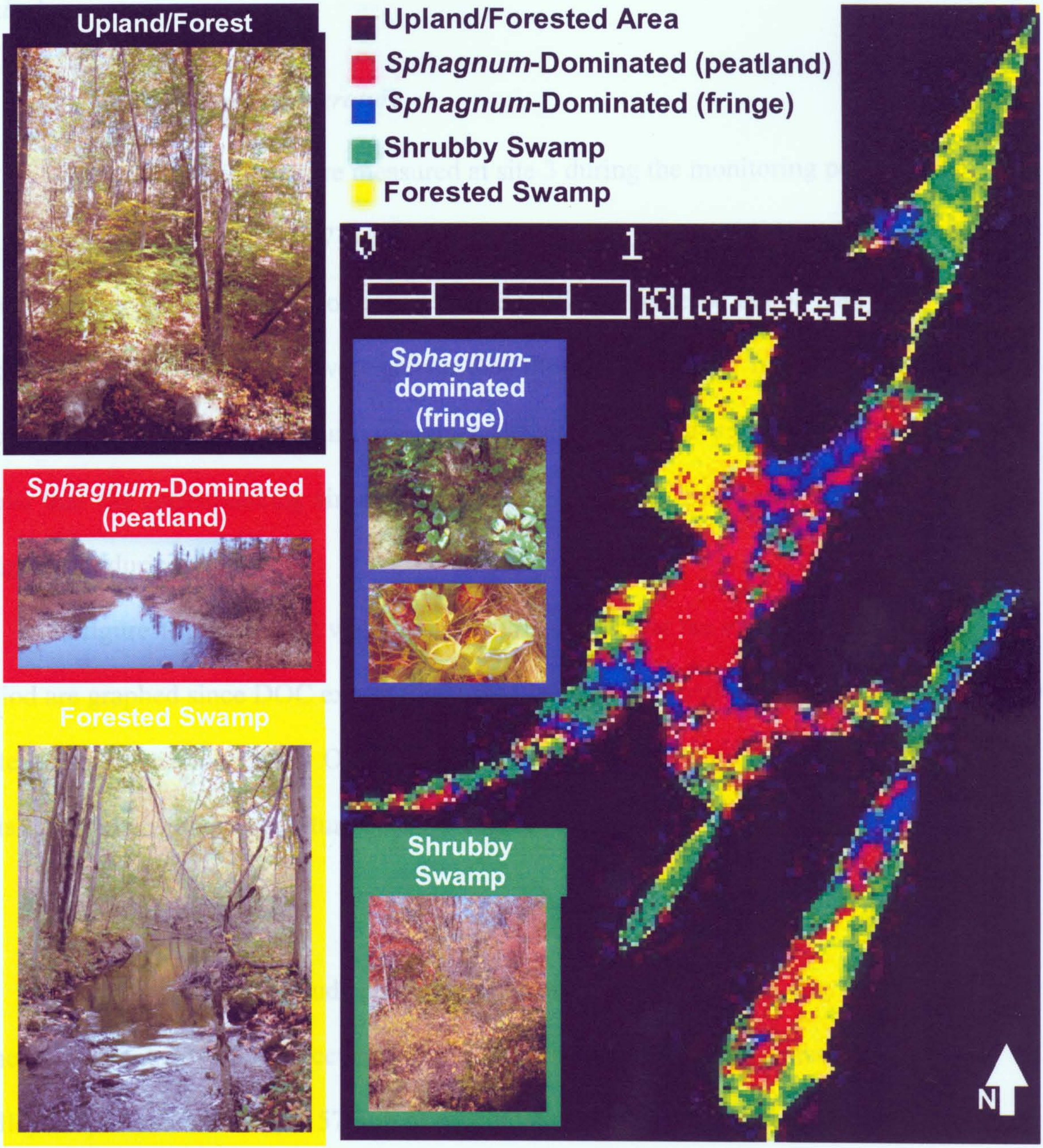

Figure 15: A parallelepiped, supervised, classified image of four wetland land cover types within the Cranberry Creek watershed is displayed along with photographic examples of each land cover type.

Hydrology

a. Air and Water Temperature

The mean air temperature measured at site 3 during the monitoring period (June 20, 2006 through April 27, 2007) was 9.1 degrees Celsius. Figure 16 shows air and water temperature at site 3 over the monitoring period until November 4, 2006. Daily fluctuations in air temperature were greater than those of the water. In addition to the expected rise in temperatures during summer, the stream daily average temperature was cooler than the corresponding air temperature during summer, but was warmer than air temperature during fall.

In figure 17, the air and water temperature recorded at the end of the monitoring period are graphed since DOC export (discussed later) may be reduced by cooler air and water temperatures in the fall. On October 27th, the air temperature fell below -5 degrees Celsius and the water temperature below 5 degrees Celsius.

b. Precipitation

One very large-magnitude precipitation event (298 mm measured at site 3 from June 24th to June 30th, 2006) occurred during the monitoring period. At the Lehigh Valley Airport, 45 km away, 157 mm of precipitation was recorded for the same storm. A smaller large event of 109 mm, recorded at site 3, occurred in mid-September. For this storm, 57 mm of precipitation was recorded at the Lehigh Valley Airport. A few smaller-magnitude precipitation events occurred in the fall and precipitation in August was minimal. The Lehigh Valley Airport reported 1252 mm of precipitation for 2006.

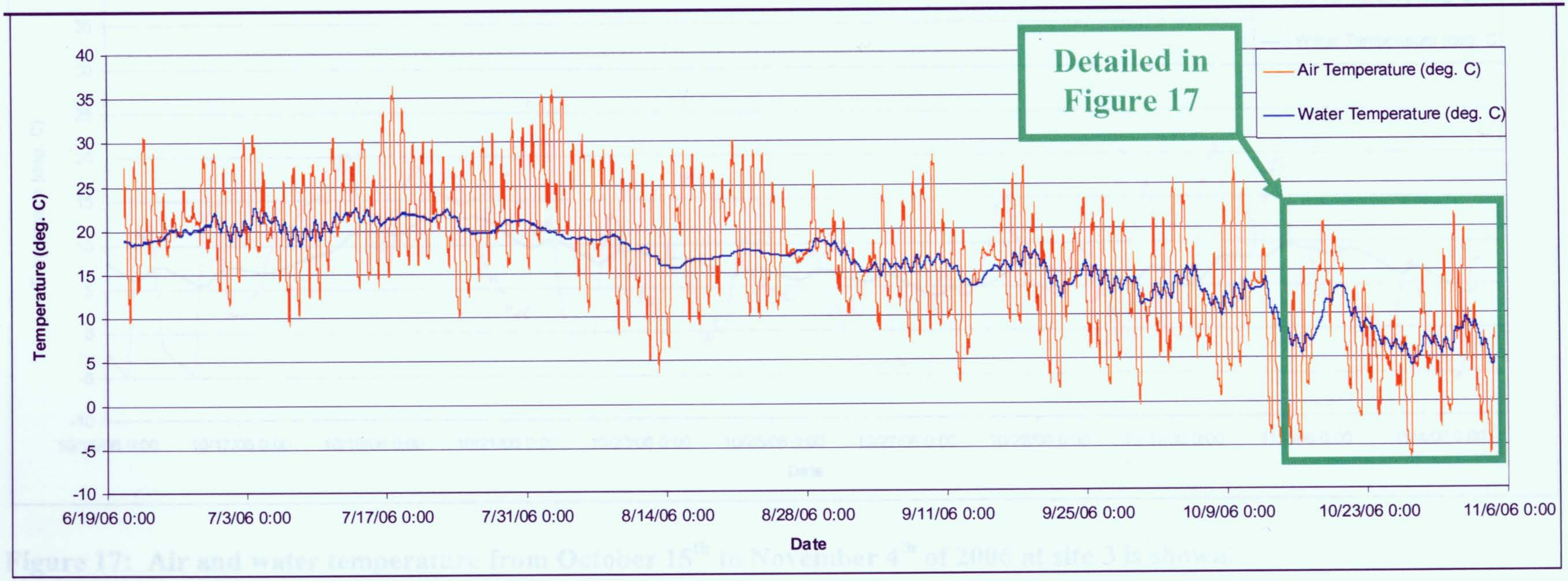

Figure 16: Air and water temperature from June to November of 2006 at site 3 is plotted.

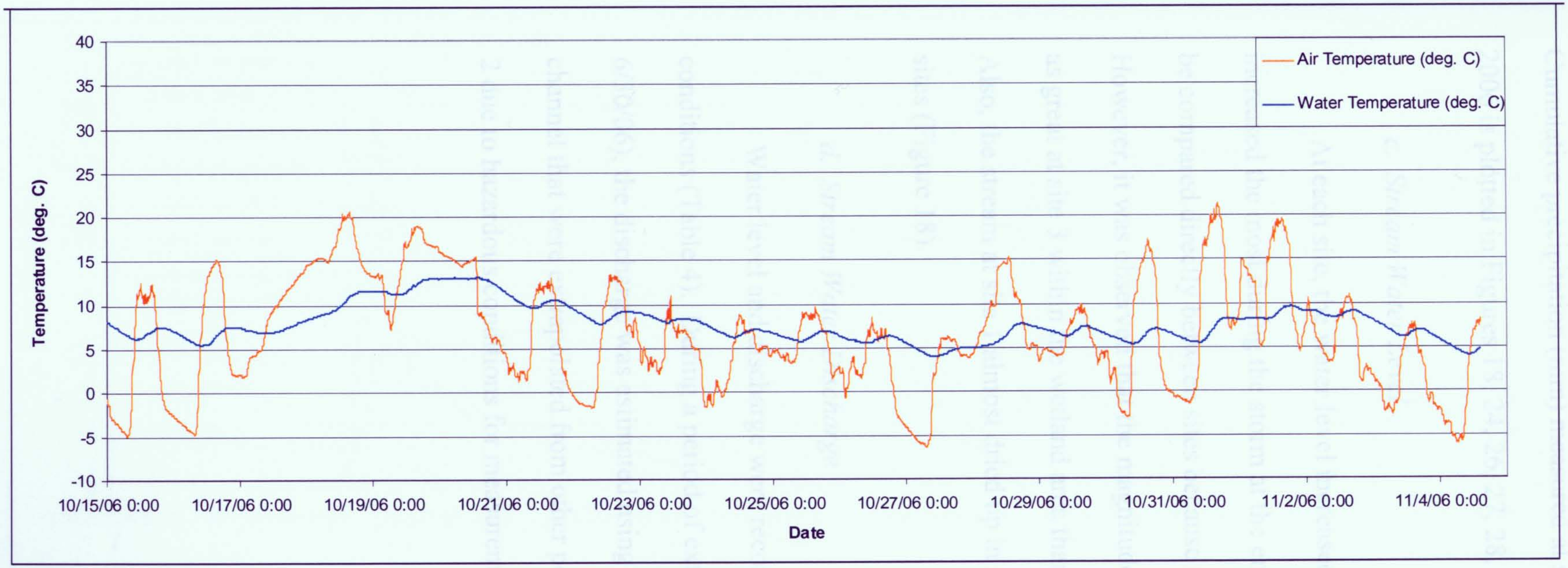

Figure 17: Air and water temperature from October 15th to November 4th of 2006 at site 3 is shown.

Cumulative precipitation (mm) measured at site 3 from June 20th to November 4th of 2006 is plotted in Figures 18, 24, 26, 27, 28, 30, 32, 33, and 42.

c. Stream Water Level

At each site, the water level increased with precipitation. The water level increased the most during the storm at the end of June into early-July. Water level cannot be compared directly between sites because the stream channel is different at each site. However, it was observed that the magnitude of level increase with precipitation was not as great at site 3 within the wetland area than the levels at the other monitoring sites. Also, the stream at site 1 almost dried up in August while higher levels persisted at other sites (Figure 18).

d. Stream Water Discharge

Water level and discharge were recorded during stormflow and baseflow conditions (Table 4). During a period of extremely high flow (measurements on 6/30/06), the discharge was estimated using measurements from half of the stream channel that were extrapolated from other periods for site 4 and not included for sites 1 or 2 due to hazardous conditions for measurement.

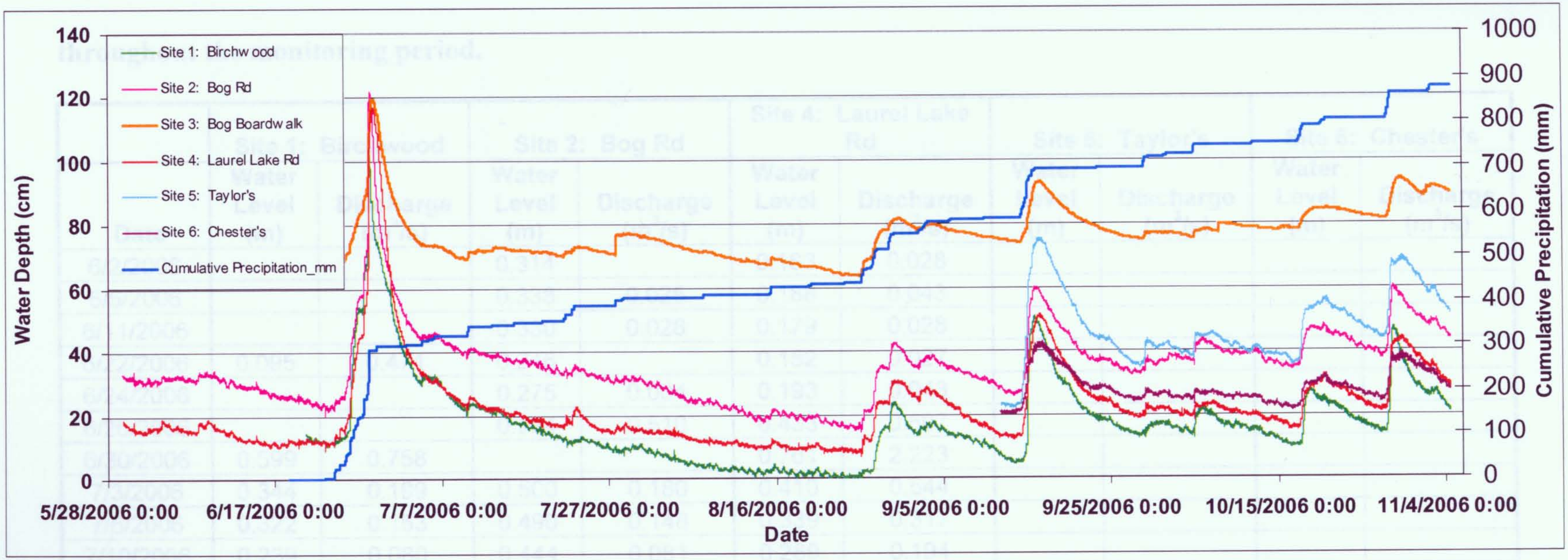

Figure 18: Water level at each site along Cranberry Creek during the monitoring period is plotted with cumulative precipitation (starting June 20, 2006 and ending November 4, 2006).

Table 4: Periodic measurements of Cranberry Creek water level and discharge are shown for sites 1, 2, 4, 5, and 6 throughout the monitoring period.

	Site 1: Birchwood		Site 2: Bog Rd		Site 4: Laurel Lake Rd		Site 5: Taylor's		Site 6: Chester's	
Date	Water Level (m)	Discharge (m^3/s)	Water Level (m)	Discharge (m^3/s)	Water Level (m)	Discharge (m^3/s)	Water Level (m)	Discharge (m^3/s)	Water Level (m)	Discharge (m^3/s)
6/2/2006			0.314		0.163	0.028				
6/5/2006			0.338	0.025	0.188	0.043				
6/11/2006			0.330	0.028	0.179	0.028				
6/22/2006	0.095	0.471	0.246		0.152	0.027				
6/24/2006			0.275	0.004	0.193	0.043				
6/26/2006			0.534	0.510	0.433	0.607				
6/30/2006	0.599	0.758			0.761	2.223				
7/3/2006	0.344	0.199	0.500	0.180	0.410	0.544				
7/6/2006	0.322	0.153	0.490	0.148	0.339	0.317				
7/10/2006	0.239	0.080	0.444	0.081	0.289	0.194				
7/18/2006	0.147	0.015	0.383	0.008	0.212	0.050				
7/21/2006	0.120	0.009	0.363		0.185					
9/11/2006	0.098	0.028	0.328	0.003	0.237	0.024	0.259	0.031	20.744	0.207
9/19/2006	0.322	0.155	0.503	0.175	0.447	0.483	0.591	0.497	35.543	0.355
10/1/2006	0.207	0.053	0.429	0.058	0.332	0.110	0.445	0.166	29.050	0.291
10/10/2006	0.185	0.064	0.436	0.043	0.290	0.068	0.410	0.114	26.829	0.268
11/4/2006	0.278	0.204	0.500	0.228	0.396	0.396	0.554	0.562	34.500	0.345

The rating curve and power function relating stream level to discharge at site 1 is shown in Figure 19. At site 1, the shape of the channel changed and became irregular for periods of high flow when the discharge overflowed the normal stream banks.

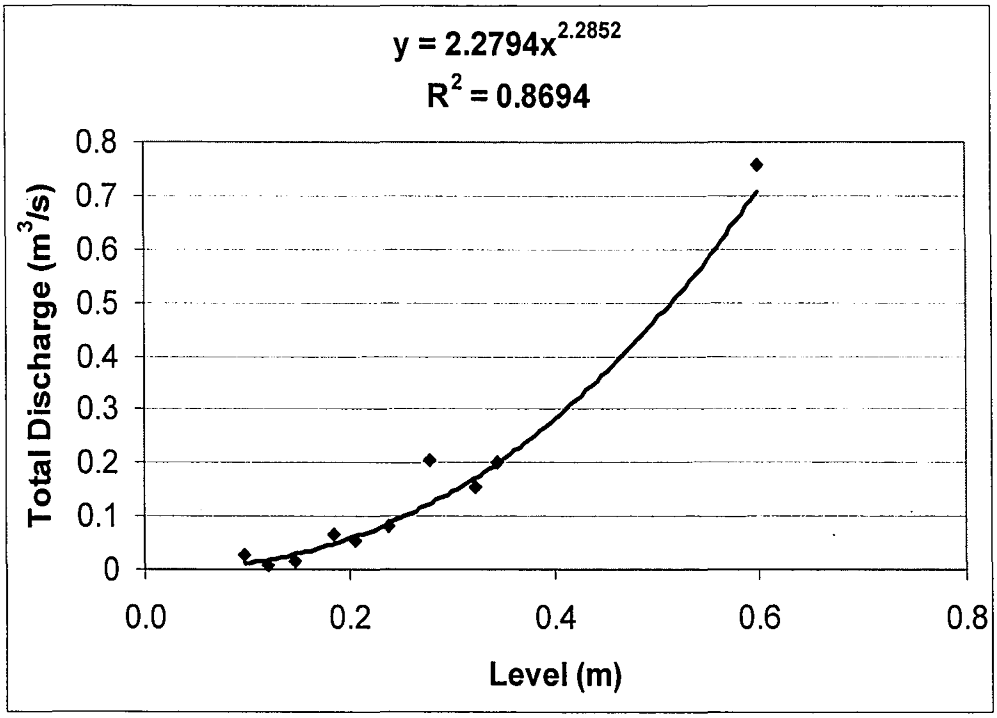

Figure 19: The rating curve and power function relating stream level to discharge at site 1 is displayed. The lowest water level measured during the study period was 0.005 meters and the highest was 102.053 meters.

The rating curve and power function relating stream level to discharge at site 2 is shown in Figure 20. The channel at site 2 was regular for periods of stormflow and baseflow.

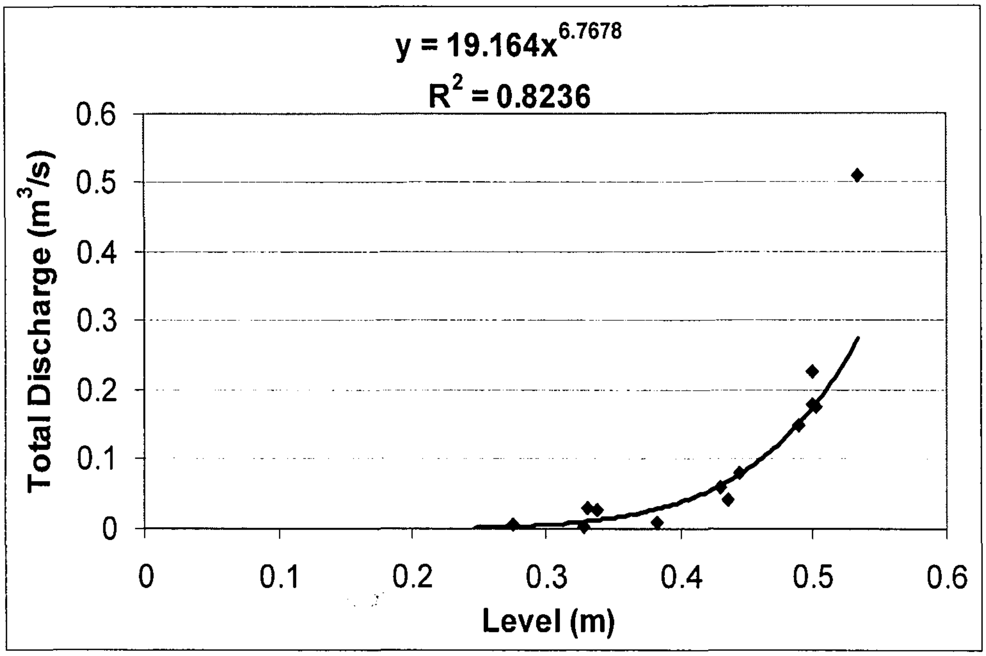

Figure 20: The rating curve and power function relating stream level to discharge at site 2 is displayed. The lowest water level measured during the study period was 14.446 meters and the highest was 121.600 meters.

The rating curve and power function relating stream level to discharge at site 4 is shown in Figure 21. The channel at site 4 was also regular for periods of stormflow and baseflow.

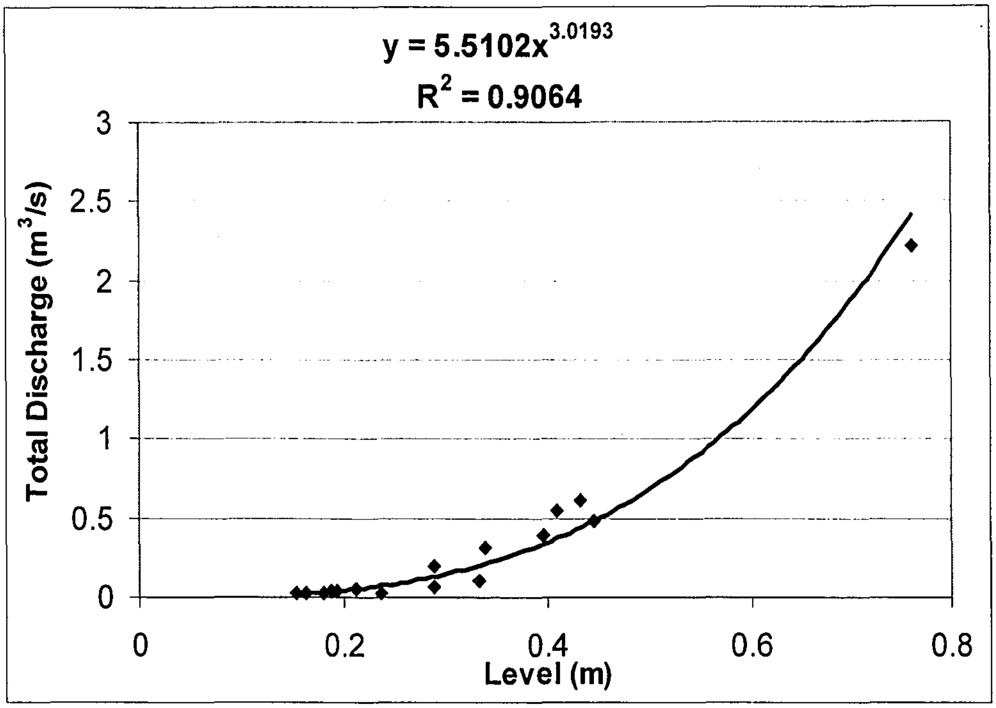

Figure 21: The rating curve and power function relating stream level to discharge at site 4 is displayed. The lowest water level measured during the study period was 6.730 meters and the highest was 116.957 meters.

The rating curve and power function relating stream level to discharge at site 5 is shown in Figure 22. During periods of high flow, the discharge overflowed the banks of the channel at site 5. Measurements of extremely high flow in late-June and early-July were not taken for inclusion in the rating curve creation.

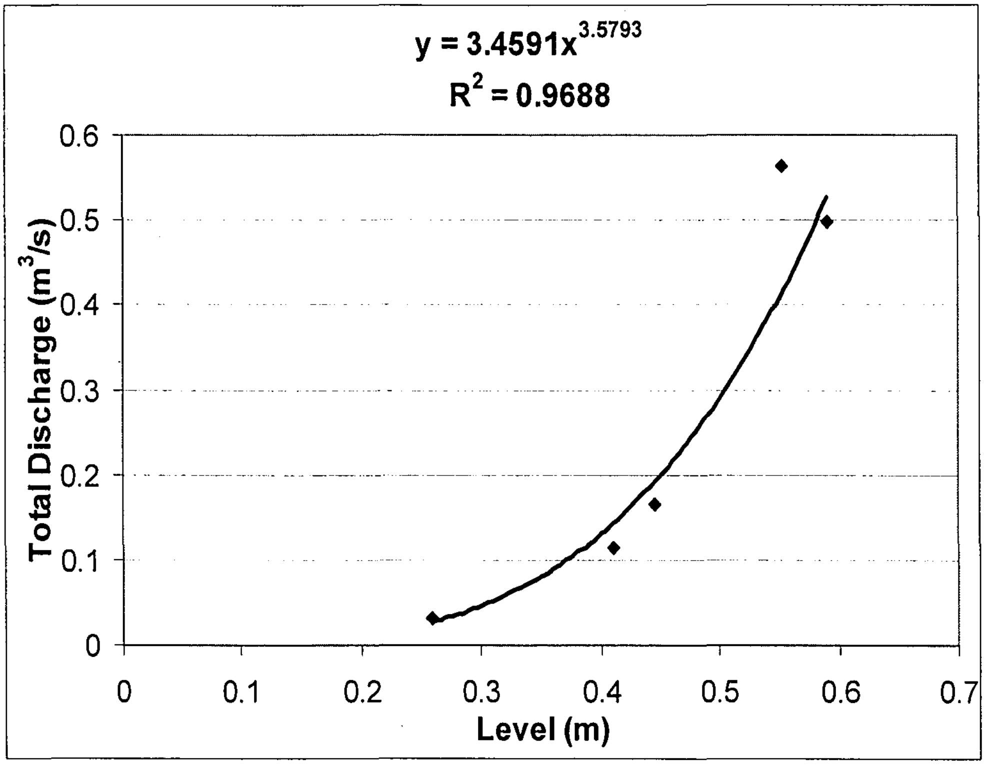

Figure 22: The rating curve and power function relating stream level to discharge at site 5 is displayed. The lowest water level measured during the study period was 22.081 meters and the highest was 75.268 meters.

The rating curve and power function relating stream level to discharge at site 6 is shown in figure 23. At site 6, the profile and width of the channel changed between low and high flow, especially when the discharge overflowed the normal stream banks. Measurements to accurately take into account the extremely high flow in late-June and early-July did not exist.

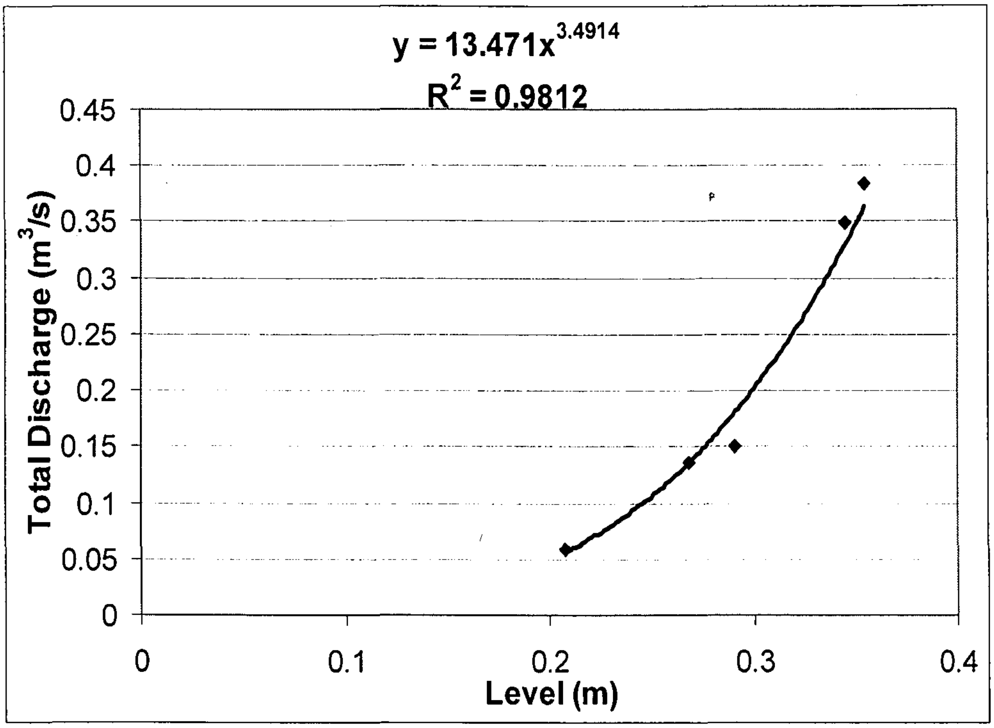

Figure 23: The rating curve and power function relating stream level to discharge at site 6 is displayed. The lowest water level measured during the study period was 20.042 meters and the highest was 42.941 meters.

Figure 24 depicts discharge at each site throughout the monitoring period. For the most part, discharge increased downstream. However, during most dry periods, discharge at site 2 was lower than at site 1 and discharge at site 6 was lower than at site 5. During a long dry period in August, stream discharge decreased nearly to zero at sites 1 and 2, above the peatland, while discharge at site 4, below the peatland, did not decrease as much. Discharge increased at each site when precipitation occurred. Greater discharge resulted during the storm period at the end of June into early-July than for other storms during the monitoring period.

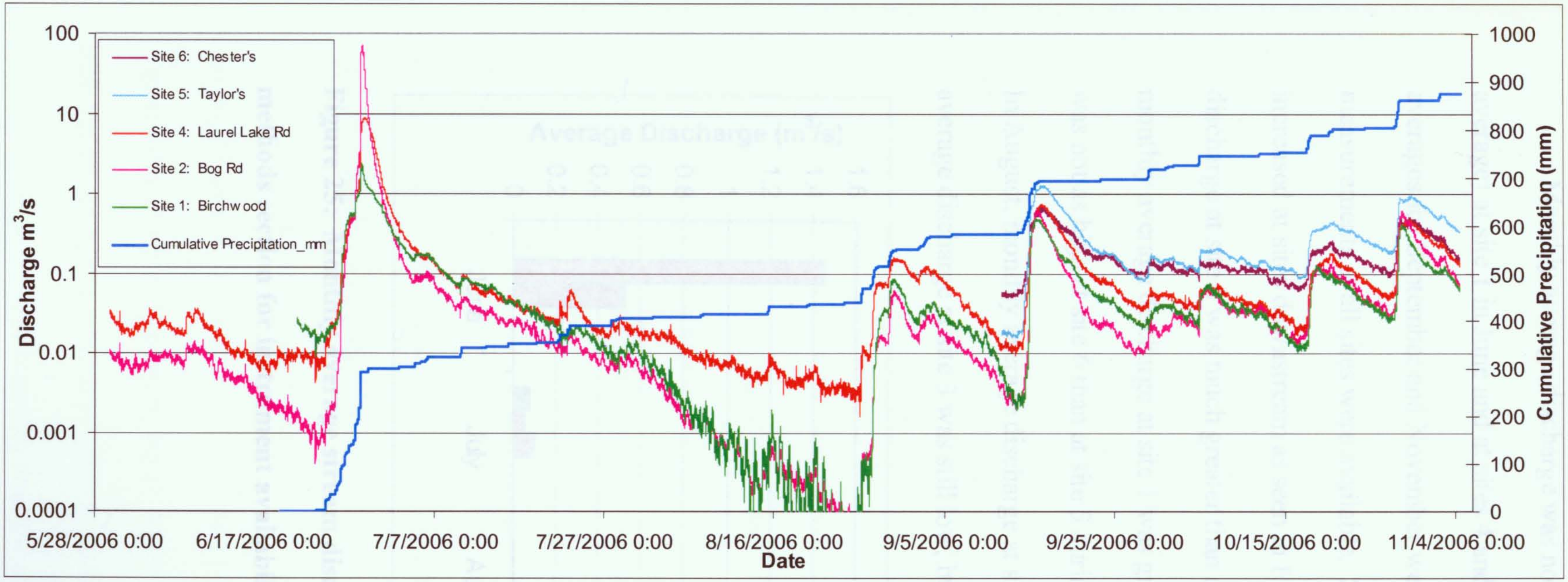

Figure 24: Stream discharge at sites 1, 2, 4, 5, and 6 is plotted throughout the monitoring period along with cumulative precipitation from June 20, 2006 to November 4, 2006 determined by 15-minute interval stream level measurements and rating curves for each site.

Monthly average discharge was not recorded (full period of data not available to average) at site 1 in June and at sites 4 and 5 in June, July, and August. The monthly averages for September and November were taken for the period when discharge measurements at all sites were available. Still, monthly average discharge typically increased at sites downstream as seen in Figure 25. However, in June, monthly average discharge at site 2 was much greater than at site 4. In July and September (11th to 30th), monthly average discharge at site 1 was greater than at site 2. Monthly average discharge was not as high at site 6 than at site 5 during the whole monitoring period for those sites. In August, monthly average discharge at sites 1 and 2 was nearly zero while the monthly average discharge at site 3 was still low, but slightly higher (Fig. 25).

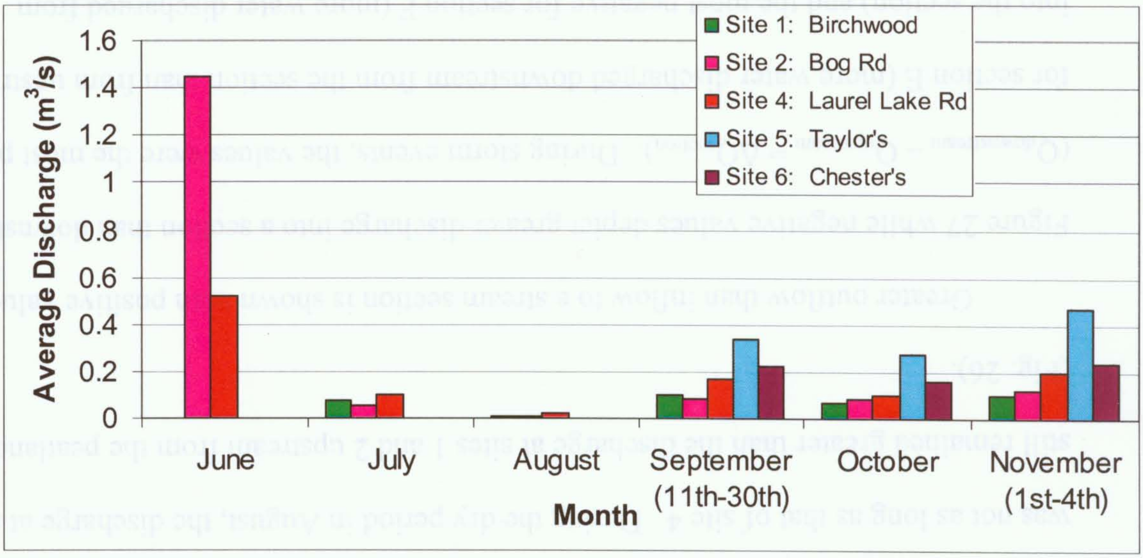

Figure 25: Monthly average stream discharge for sites 1, 2, 4, 5, and 6 (refer to methods section for instrument availability).

The storm hydrograph peak for the storm in late-June in to early-July was lowest and shortest for discharge at site 1. The peak at site 1 occurred slightly before the peak discharge at other sites. Near the lower portion of the wetland area at site 4, the peak discharge was greater than at site 1, started later, and occurred over a longer period of time. The storm discharge near the upper portion of the peatland area at site 2 had the largest peak discharge that began at about the same time as for site 4, but the peak period was not as long as that of site 4. During the dry period in August, the discharge at site 4 still remained greater than the discharge at sites 1 and 2 upstream from the peatland area (Fig. 26).

Greater outflow than inflow to a stream section is shown with positive values in Figure 27 while negative values depict greater discharge into a section than downstream ($Q_{downstream} - Q_{upstream} = \Delta Q_{section}$). During storm events, the values were the most positive for section E (more water discharged downstream from the section than from upstream into the section) and the most negative for section F (more water discharged from upstream into the section than discharged downstream from the section). The values ($\Delta Q_{section}$) for sections C and D were negative at the beginning of a storm, but they became positive later during the storm period (more water was entering the section than leaving during the first part of the storm, but later more water was leaving than was entering the section (Fig. 27).

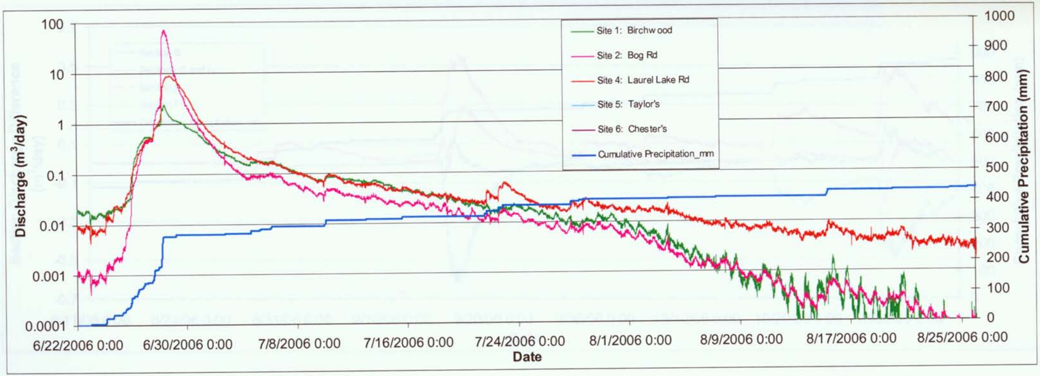

Figure 26: Stream discharge at sites 1, 2, 4, 5, and 6 is plotted from June 22, 2006 to August 25, 2006 along with cumulative precipitation starting June 20, 2006.

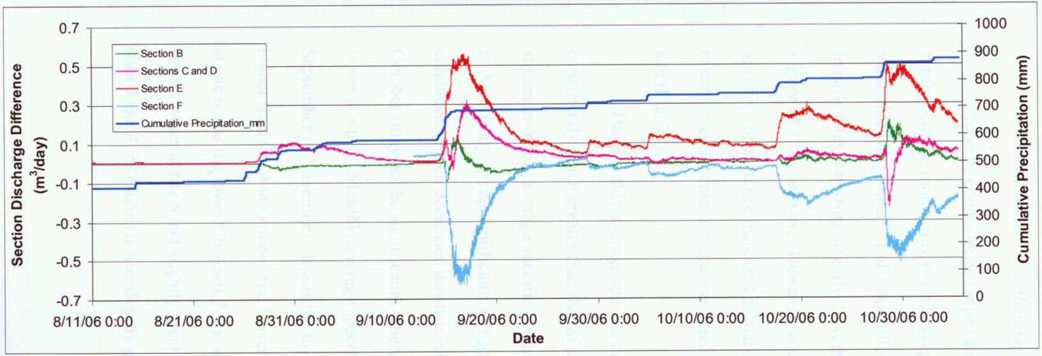

Figure 27: The difference between downstream and upstream discharge ($Q_{downstream} - Q_{upstream} = \Delta Q_{section}$)for each section of Cranberry Creek is plotted from August 21, 2006 to November 4, 2006 along with cumulative precipitation. A rise in the section discharge difference indicates more water is entering the section than leaving and water is being stored while a fall in the section discharge difference indicates more water is leaving the section than entering and water is being released downstream.

e. Groundwater Contribution: Specific Conductance

Specific conductance ranged from 70 to 140 μS/cm in Cranberry Creek throughout the monitoring period except during storm events. It was reduced to a lower value that was similar for all sites following extremely large precipitation events as seen in early-May, late-June to early-July, mid-September, and early-November of 2006 in Figure 28 (blue arrows). However, at the onset of precipitation following a dry period, specific conductance increased as marked by red arrows in Figure 28. After storm events, specific conductance recovered to values similar to those before the storm at each site (Fig. 28).

The monthly average specific conductance of the well water near site 6 was consistently much greater than that of all stream sites as seen in Figure 29. Within the stream, monthly average specific conductance was typically the highest at site 1, except in April (may not be significant) and July where site 2 was the highest. Specific conductance then decreased downstream at sites 3 and 4 respectively, except in May and October (may not be significant), where the monthly average specific conductance was lower at site 2. Monthly average specific conductance at site 5 was only available from September to November. It was the lowest of all sites in September and only slightly higher than site 4 in October and November. The average monthly specific conductance at site 6 was the lowest in April, May, and July (may not be significant), but in June the stream water at site 6 had slightly greater average monthly specific conductance than at sites 3 and 4, in August it was slightly greater than at site 4, in September it was slightly

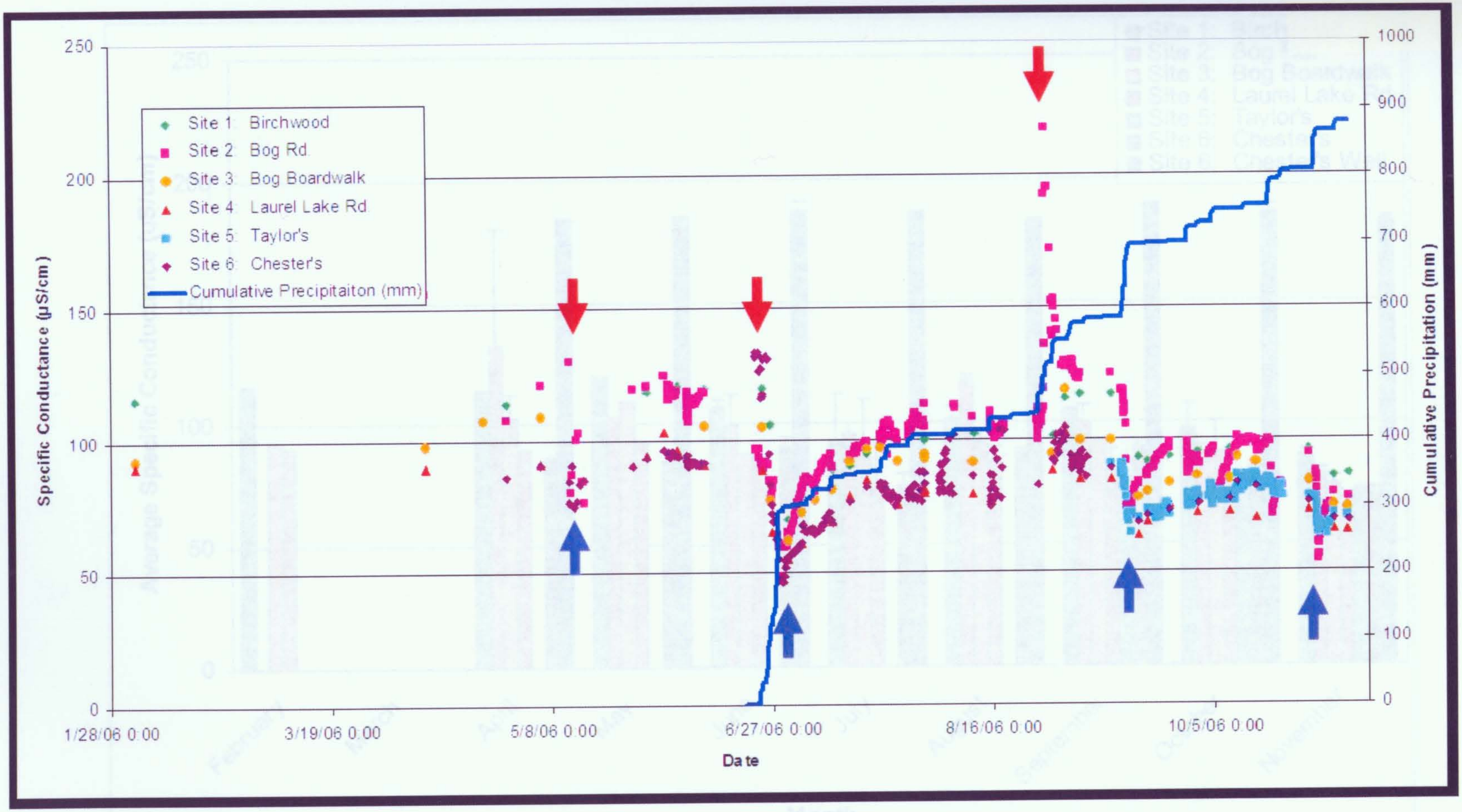

Figure 28: Specific conductance measured periodically for each site from May to September of 2006 is plotted along with cumulative precipitation starting June 20, 2006 (red arrows indicate increased specific conductance and blue arrows indicate reduced specific conductance).

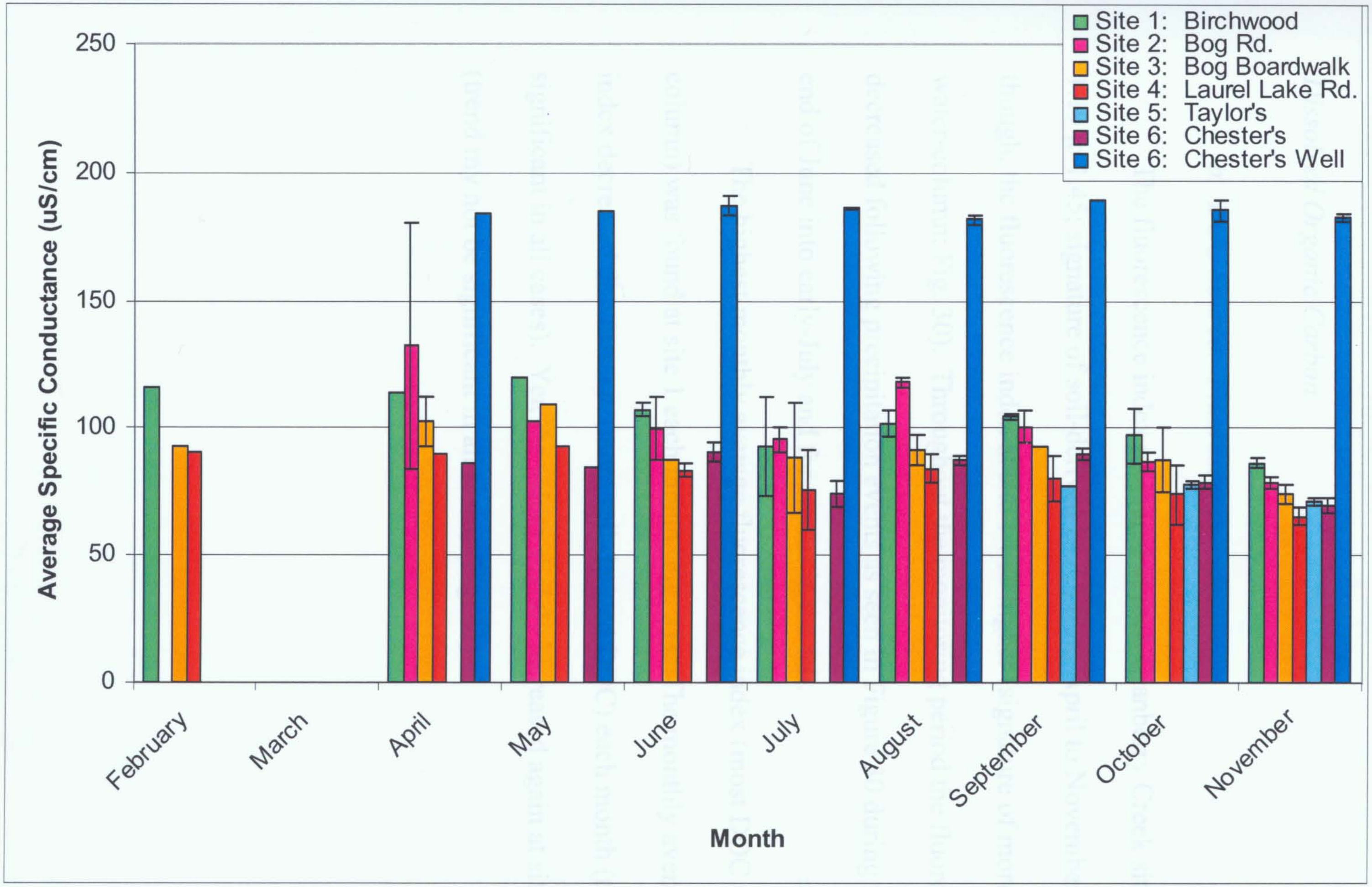

Figure 29: Monthly average specific conductance at each sampling site along Cranberry Creek and for the well water near the stream at site 6 is graphed.

greater than sites 4 and 5, and in October and November it was slightly greater than site 4, but still a little lower than at site 5 (Fig. 29).

Dissolved Organic Carbon

a. DOC Source: Fluorescence Index

The fluorescence index measured at each Cranberry Creek site was low (from 1.19 to 1.45; signature of soil-derived DOC) from April to November. In February, though, the fluorescence index at site 1 was higher (signature of more DOC from the water-column; Fig. 30). Throughout the monitoring period the fluorescence index decreased following precipitation events as seen in Figure 30 during the storm from the end of June into early-July and for storms in the fall.

The highest monthly average fluorescence index (most DOC from the water-column) was found at site 1 each month (Fig. 31). The monthly average fluorescence index decreased downstream (more soil-derived DOC) each month (trend may not be significant in all cases). Yet, the values slightly increased again at site 6 each month (trend my not be significant in all cases) (Fig. 31).

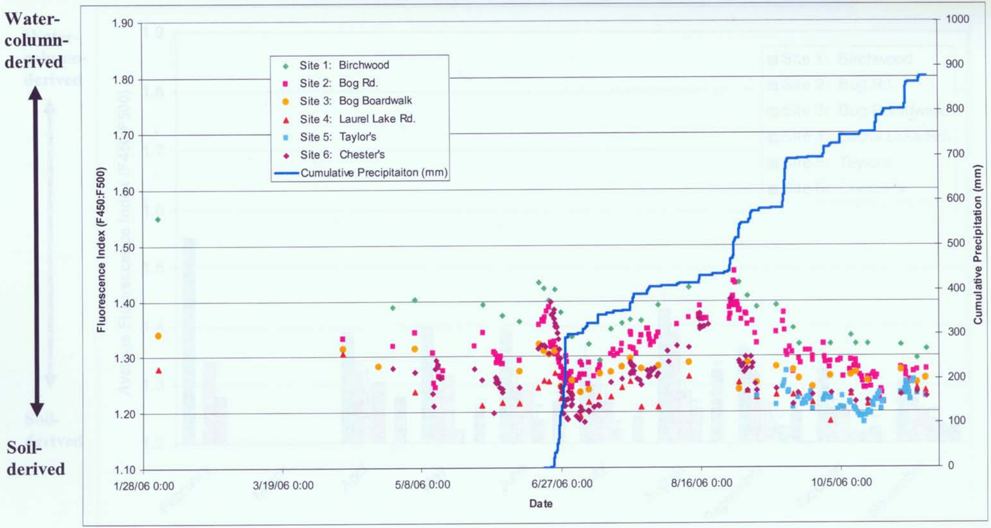

Figure 30: Fluorescence index, calculated periodically from May to November of 2006, is plotted for each Cranberry Creek site along with cumulative precipitation starting June 20, 2006.

Figure 31: Monthly average fluorescence index at each sampling site along Cranberry Creek is graphed.

b. DOC Concentration and Flux

DOC concentration ranged from 3 to 23 mg/L within Cranberry Creek. The concentration was highest as it increased following storm events as seen for the end of June into early-July and in mid-September (Fig. 32). Fairly high DOC concentration was recorded into the fall with continued periodic precipitation events (Fig. 32). However, in the late fall, DOC concentration decreased at all sites while air temperature also decreased (Fig. 33).

The lowest monthly average DOC concentration in Cranberry Creek was calculated for site 1. The DOC concentration increased progressively at sites downstream with the greatest DOC concentration at site 4. Sites 5 and 6 still had high monthly average DOC concentration, but it still was lower than that at site 4. The monthly average DOC concentration was greatest for late-summer and early-fall months and lowest when measured in February at all sites (Fig. 34). Little DOC was found in the well water at site 6. The DOC concentration contributed from sections B, C, D, and E was greatest in summer months and lowest in the winter as graphed (monthly average DOC concentration; measured or estimated by interpolation) in Figure 35.

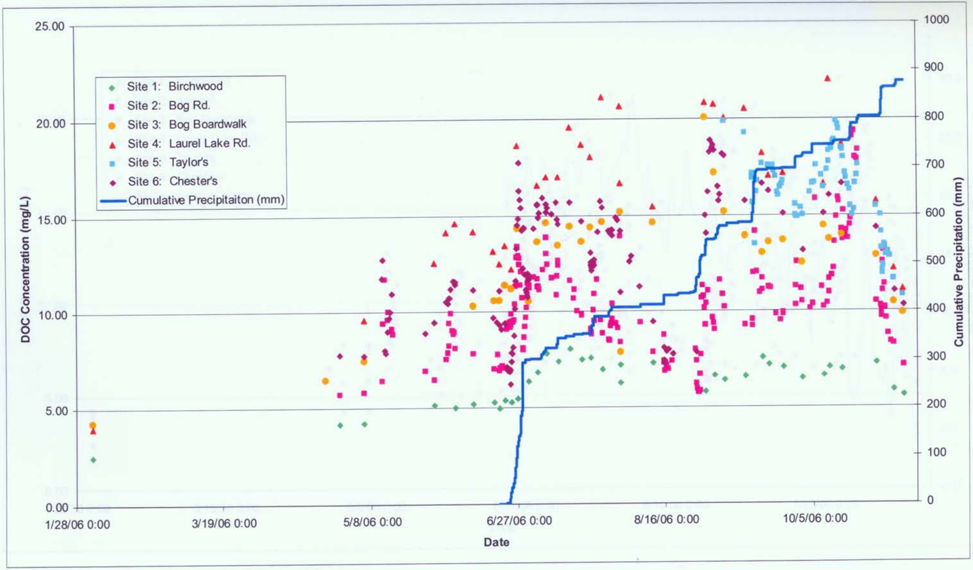

Figure 32: DOC concentration measured periodically at each site throughout the sampling period is plotted along with cumulative precipitation (starting June 20, 2006).

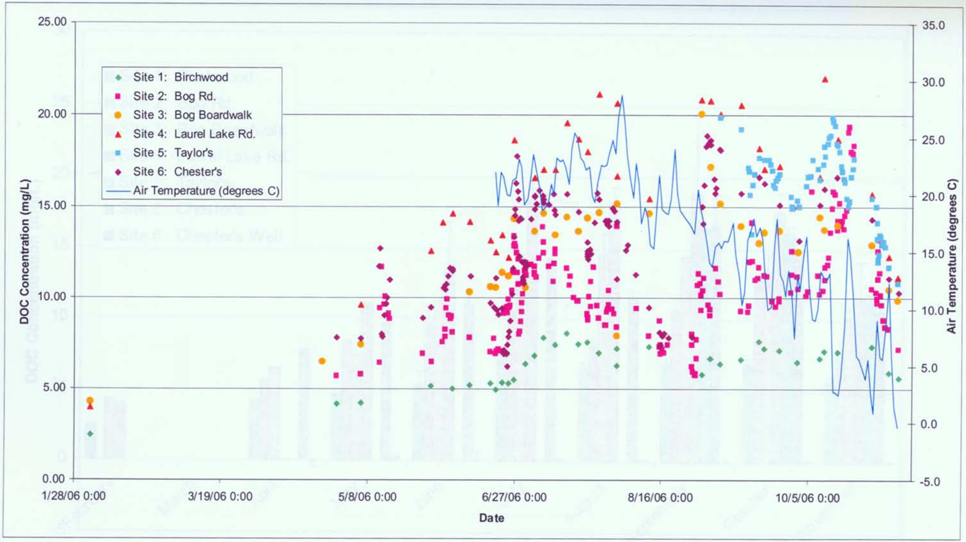

Figure 33: DOC concentration measured periodically at each site throughout the sampling period is plotted along with daily average air temperature (starting June 20, 2006).

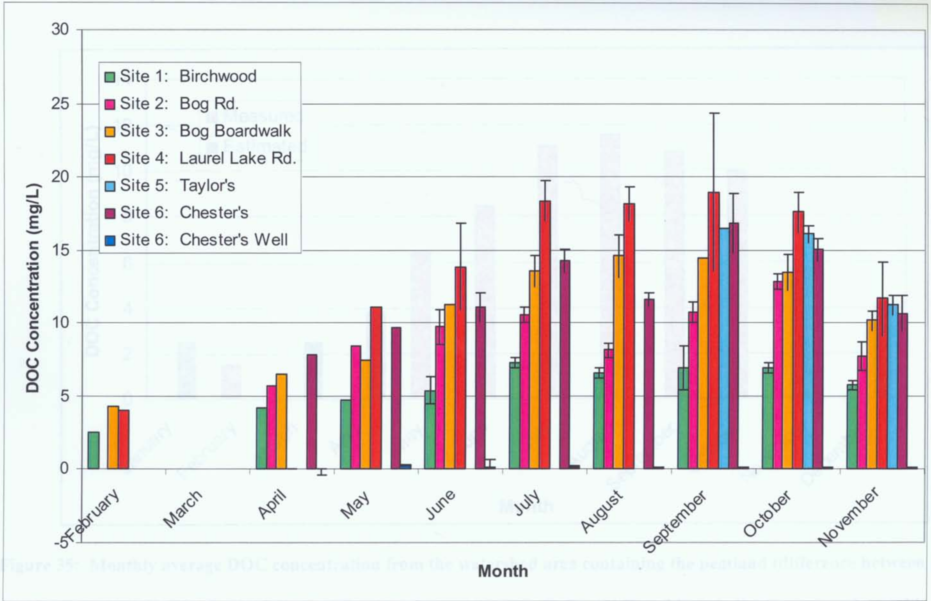

Figure 34: Monthly average DOC concentration is graphed for each Cranberry Creek site and the well water at site 6.

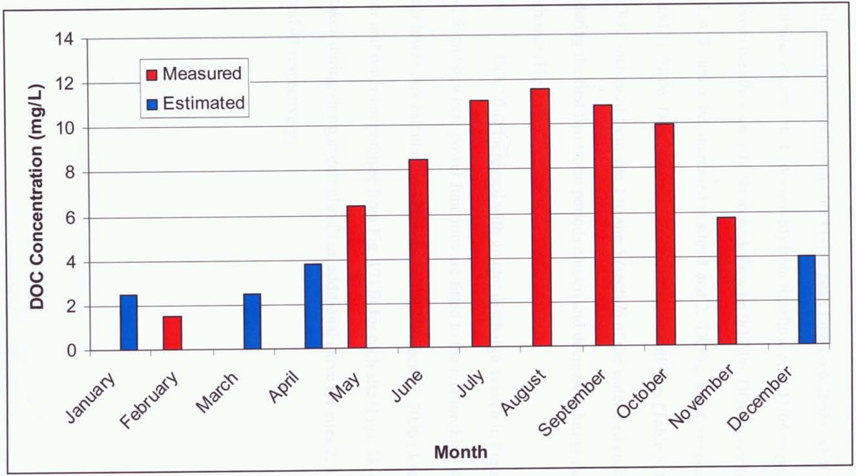

Figure 35: Monthly average DOC concentration from the watershed area containing the peatland (difference between [DOC] at site 1 and [DOC] at site 5 to include contributions from sections B, C, D, and E; red bars indicate measured monthly averages and blue bars indicate estimated (by interpolation) monthly averages).

The DOC concentration responded differently between peak flow and baseflow of Cranberry Creek during the four chosen storm periods. The DOC concentration rose at all sites from baseflow on 6/24/06 to peak flow on 6/26/06. DOC concentration rose at all sites except site 1 (decreased) from baseflow on 8/11/06 to peak flow on 8/29/07. From baseflow on 9/11/06 to peak flow on 9/17/06, DOC concentration decreased at sites 3, 4, 5, and 6, but increased at sites 1 and 2. During the storm period between 10/26/06 and 11/01/06, DOC concentration decreased at all sites (Table 5; Fig. 36). Therefore, DOC increased from site 1 to site 5 (section of the watershed containing peatland area) during the first two storm periods chosen and decreased during the last two storm periods chosen (Fig. 37).

DOC flux increased with greater discharge as seen in Figures 38-42 for sites 1, 2, 4, 5, and 6, where power functions are fitted to the relationship. Separate power curves for lower flux calculations taken following October 27, 2006 (determined by minimum air and water temperature from Fig. 17) fit for each site (Figs. 38-42). Measurements taken during storm events also fit an additional curve for sites 2, 4, and 5 (Figures 39, 40, and 41 respectively).

Table 5: DOC concentration at baseflow before four storms, at the peak of the storms, and the difference between the peak and baseflow DOC concentration for each storm when measured at all sites along with the average air temperature and total precipitation over each storm period.

	Peak 6/24/ 2006	Baseflow 6/26/ 2006	Peak-Baseflow	Peak 8/11/ 2006	Baseflow 8/29/ 2006	Peak-Baseflow	Peak 9/11/ 2006	Baseflow 9/17/ 2006	Peak-Baseflow	Peak 10/26/ 2006	Baseflow 11/1/ 2006	Peak-Baseflow
Site 1: Birchwood [DOC] (mg/L)	5.31	5.49	0.18	7.31	5.8	-1.51	6.62	7.58	0.96	7.29	5.88	-1.41
Site 2: Bog Rd. [DOC] (mg/L)	9.88	13.37	3.49	7.89	9.29	1.4	9.26	11.68	2.42	10.48	8.28	-2.2
Site 3: Bog Boardwalk [DOC] (mg/L)	11.19	14.33	3.14	14.6	20.06	5.46	13.91	12.99	-0.92	12.87	10.45	-2.42
Site 4: Laurel Lake Rd. [DOC] (mg/L)	12.21	18.64	6.43	15.4	20.84	5.44	20.52	18.21	-2.31	15.71	12.24	-3.47
Site 5: Taylor's [DOC] (mg/L)							19.23	17.64	-1.59	15.43	11.66	-3.77
Site 6: Chester's [DOC] (mg/L)	7.84	14.51	6.67	9.44	14.99	5.55	18.21	16.64	-1.57	14.33	11.06	-3.27
Average Air Temperature (°C)			20.4			18.7			14.6			6.4
Precipitation (mm)			135.6			133.6			109			58.8

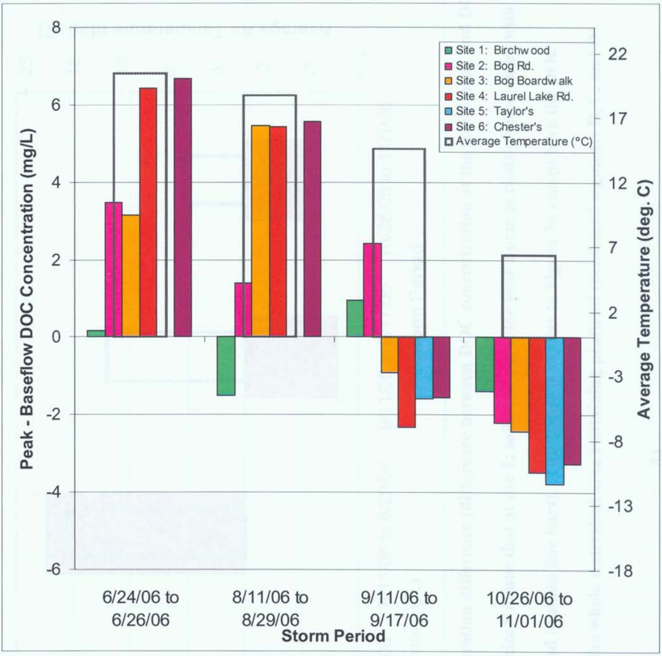

Figure 36: The difference between storm peak DOC concentration and DOC concentration during baseflow before the storm for storms at all sites (solid bars) plotted along with average air temperature over the storm period (dashed line bars).

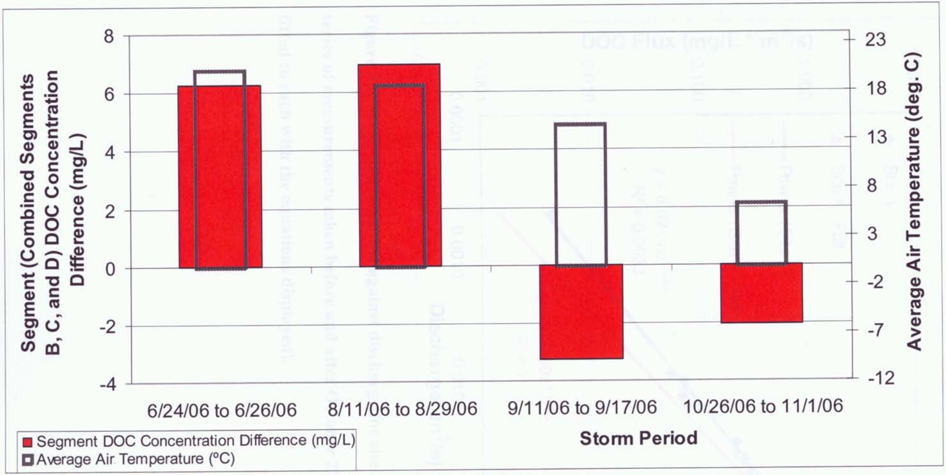

Figure 37: The segment DOC concentration difference (difference between DOC concentration at the storm peak and DOC concentration before a storm event at site 5 minus that at site 1; solid red bars) for four storm periods plotted along with average air temperature for each period (dashed line bars). This figure is similar to Figure 36 except here the DOC concentration difference is shown for the whole watershed area containing peatland (combined segments B, C, and D).

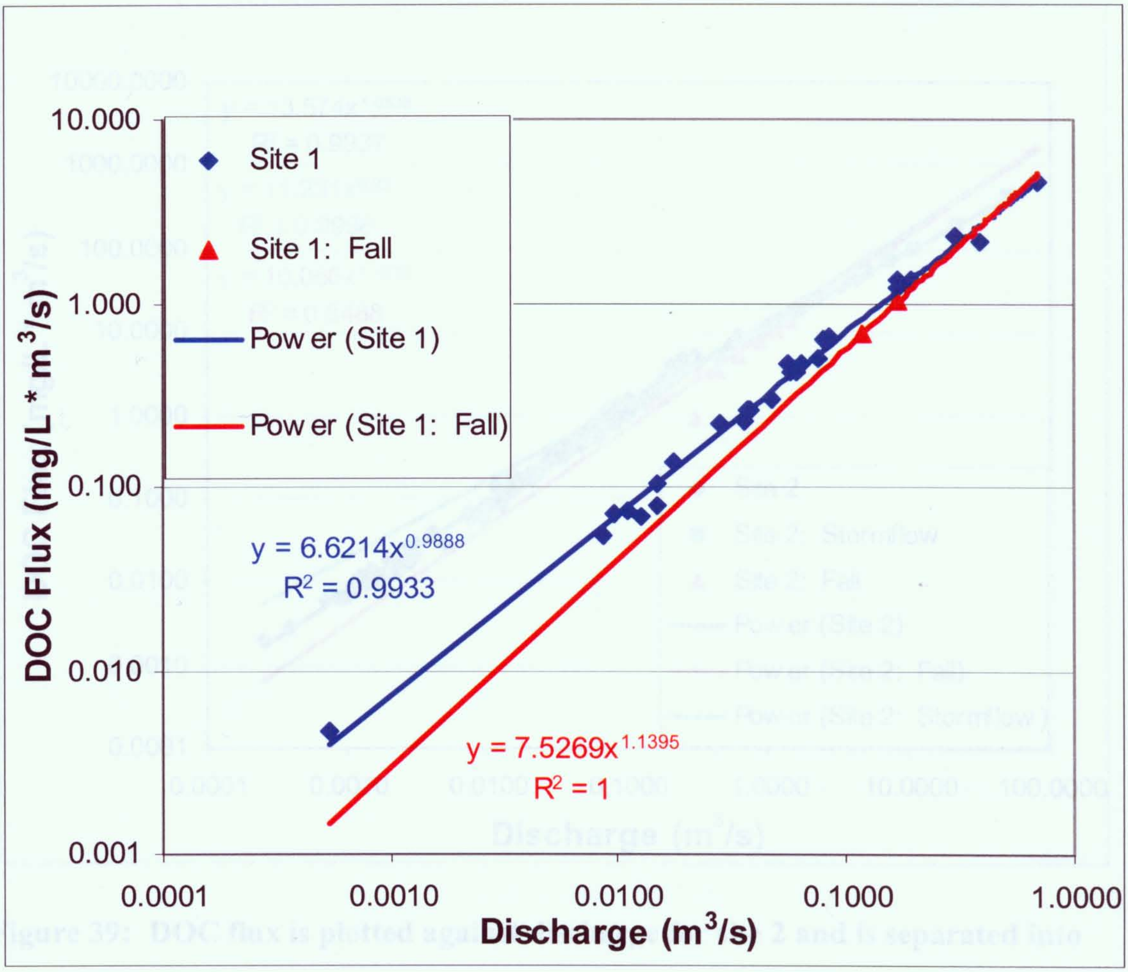

Figure 38: DOC flux is plotted against discharge for site 1 and is separated into series of measurements taken before and after October 27th, 2006 (power curves are fitted to each with the equations displayed).

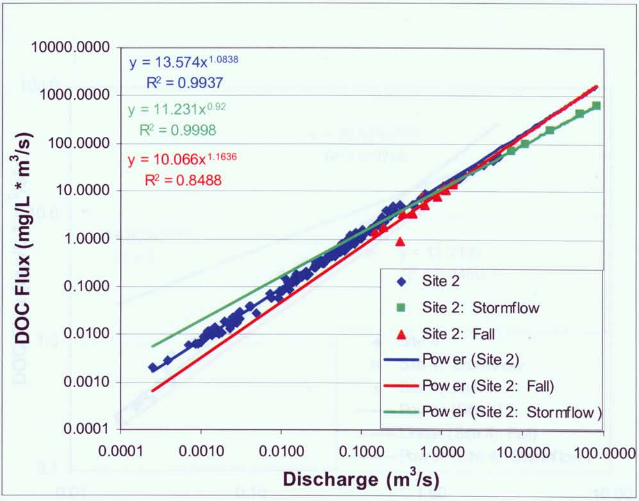

Figure 39: DOC flux is plotted against discharge for site 2 and is separated into series of measurements taken before and after October 27th, 2006 with another division of measurements taken during high flow conditions (power curves are fitted to each with the equations displayed).

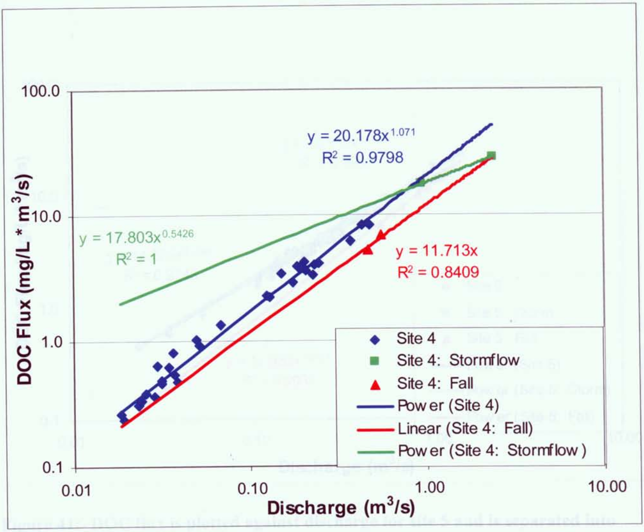

Figure 40: DOC flux is plotted against discharge for site 4 and is separated into series of measurements taken before and after October 27th, 2006 with another division of measurements taken during high flow conditions (power or linear curves are fitted to each with the equations displayed).

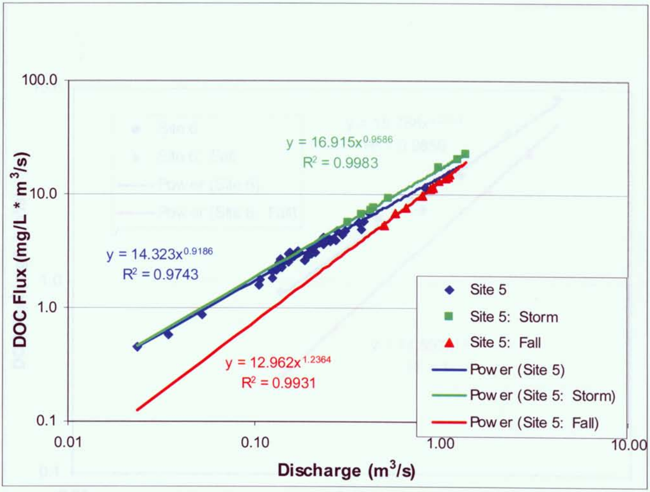

Figure 41: DOC flux is plotted against discharge for site 5 and is separated into series of measurements taken before and after October 27th, 2006 with another division of measurements taken during high flow conditions (power curves are fitted to each with the equations displayed).

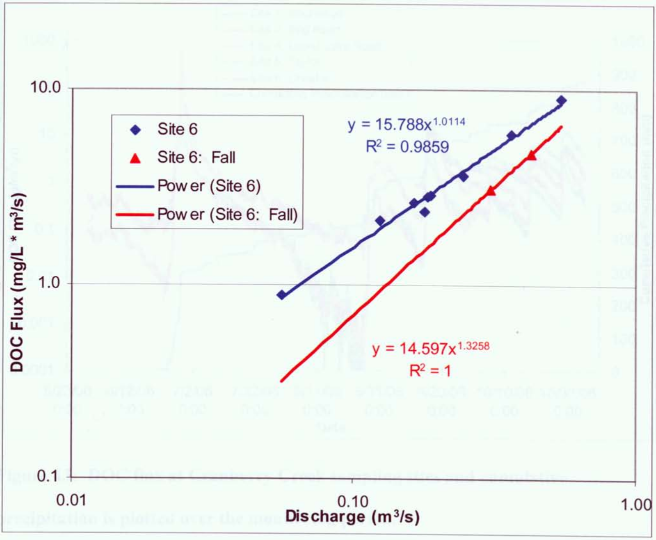

Figure 42: DOC flux is plotted against discharge for site 6 and is separated into series of measurements taken before and after October 27th, 2006 (power curves are fitted to each with the equations displayed).

DOC flux, calculated using the equations from Figures 38 to 42 multiplied by stream discharge at each site, increased following storm events as seen in Figure 42. The DOC flux also increased progressively at sites downstream except greater DOC flux was found at site 5 than site 6 (Fig. 42).

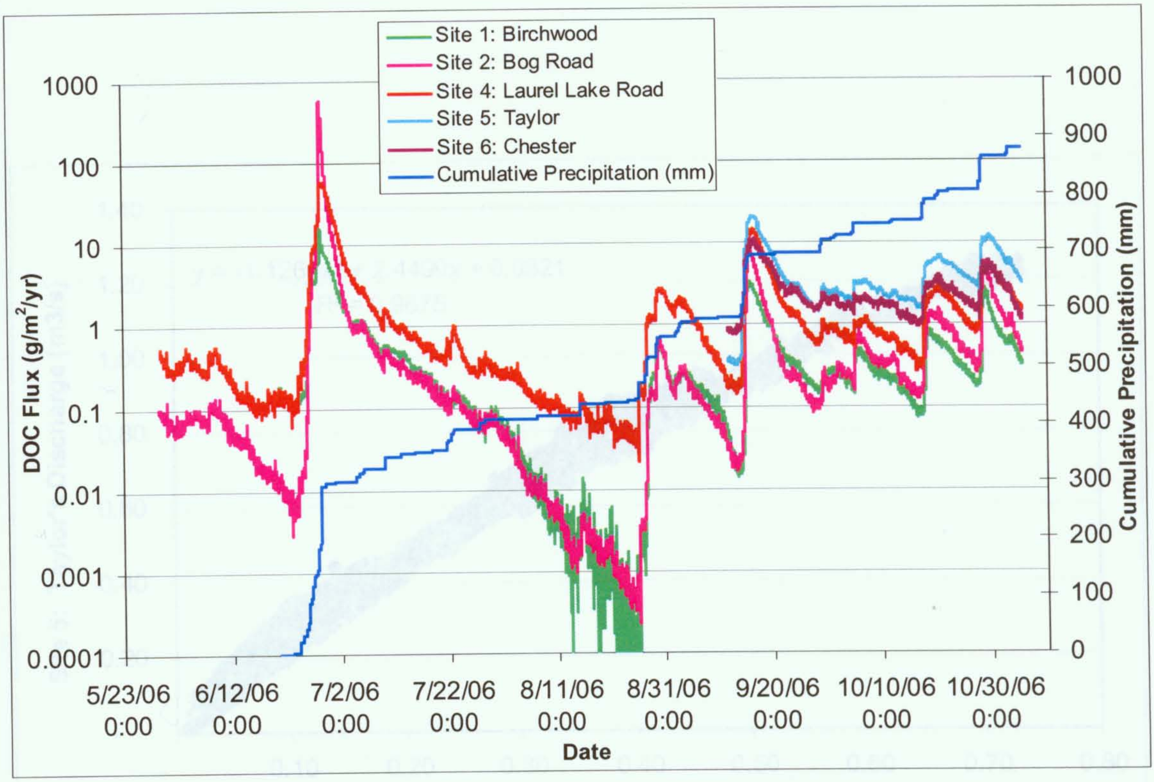

Figure 43: DOC flux at Cranberry Creek sampling sites and cumulative precipitation is plotted over the monitoring period.

The polynomial equation fitted to the relationship between discharge at site 4 and discharge at site 5, from September 11 to November 4, 2006, is displayed in Figure 44. This relationship was used to extrapolate the DOC discharge at site 5 for the rest of the monitoring period, for site 5, below the wetland area. When multiplied by the DOC concentration from the peatland (difference between DOC concentration at site 5 and DOC concentration at site 1; measured or estimated using interpolation (Figures 36 and 37 and Table 6)) and scaled for the area of the watershed, the resulting DOC flux was greatest in June, remained fairly high through the Fall, and was lowest in the winter (Table 6). The annual DOC flux estimated for 2006 was 12.18 $g/m^2/yr$ (121.8 kg/ha/yr).

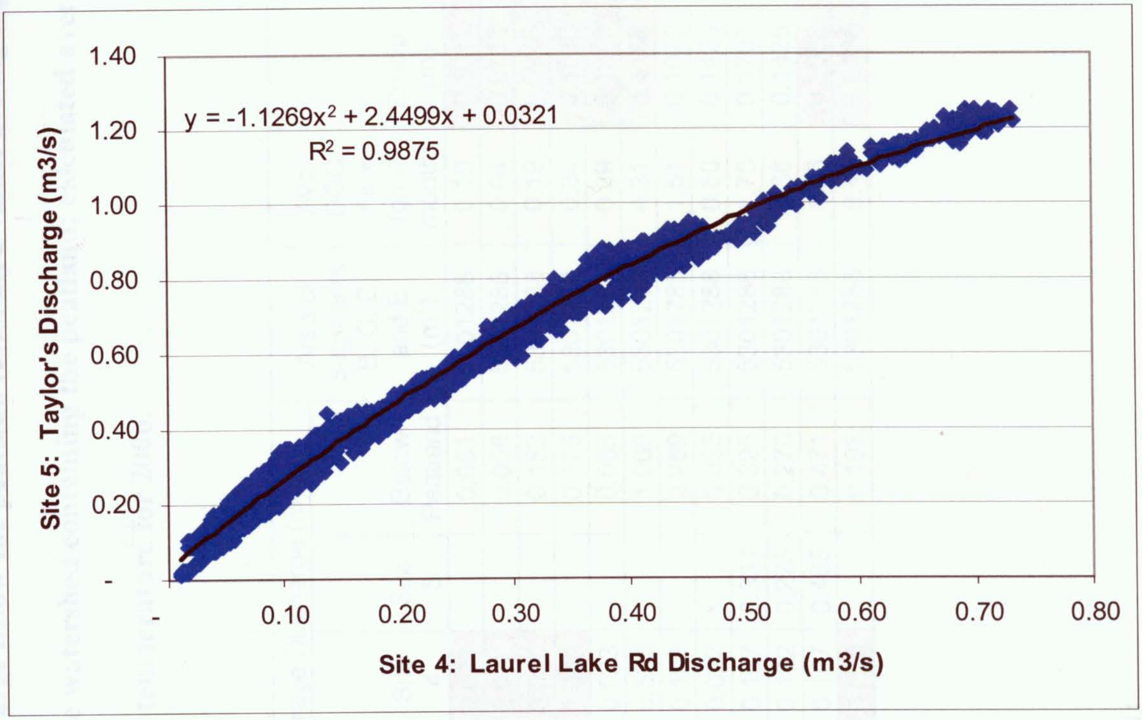

Figure 44: A polynomial trendline fitted to the relationship between discharge at site 4 and discharge at site 5 used to estimate a continuous function for discharge at site 5 (Taylor's).

Table 6: Average monthly DOC concentration and discharge for sites 1, 4, and 5 used to determine the monthly average DOC concentration from the peatland and the monthly average discharge below the peatland (estimated values are highlighted orange and calculated values are highlighted yellow); area of the watershed containing the peatland; calculated average monthly DOC flux; monthly precipitation; monthly average air temperature for 2006.

Month	Average DOC Concentration (mg/L)					Average Discharge (m^3/s)				Area of Segments B, C, D, and E (m^2)	Avg. DOC Flux (g/m^2/ month)	Precip. (m)	Avg. Air Temp. (° C)
	Site 1	Site 4	Site 5	Below Peatland	[DOC] from Peatland (mg/L)	Site 1	Site 4	Site 5	Below Peatland				
January	3.00	5.50		5.50	2.50	0.007	0.020		0.081	5301288	0.10	0.1011	-3
February	2.47	3.98		3.98	1.51	0.005	0.010		0.056	5301288	0.04	0.0765	-2
March	3.00	5.50		5.50	2.50	0.020	0.050		0.152	5301288	0.19	0.0975	3
April	4.19	8.00		8.00	3.81	0.040	0.060		0.175	5301288	0.34	0.1016	9
May	4.68	11.08		11.08	6.40	0.010	0.023		0.088	5301288	0.29	0.1273	15
June	5.37	13.86		13.86	8.49	0.436	0.523		1.006	5301288	4.31	0.1158	19.0
July	7.28	18.37		18.37	11.08	0.077	0.101		0.269	5301288	1.51	0.1070	22.0
August	6.55	18.14		18.14	11.59	0.007	0.022		0.085	5301288	0.50	0.1420	19.9
September	6.92	18.96	16.51	17.74	10.82	0.072	0.127	0.334	0.325	5301288	1.78	0.1703	14.2
October	6.90	17.60	16.11	16.85	9.95	0.066	0.102	0.275	0.270	5301288	1.36	0.1425	8.7
November	5.74	11.69	11.23	11.46	5.72	0.098	0.197	0.465	0.471	5301288	1.36	0.1082	4.0
December	4.00	8.00		8.00	4.00	0.030	0.070		0.198	5301288	0.40	0.0996	-1

Discussion

Wetland Hydrology

As expected, stream discharge increased with precipitation and at successive sites downstream until site 6, with site 6 appearing to be an outlier with lower discharge than expected. This variation may be due to storage in a small pond just upstream from site 6 causing an underestimate of discharge, but it is most likely our measurements of discharge caused an underestimate because the regressions used to calculate discharge from 15-minute records of stream level may not be as accurate as desired. There was variability in the stream channel at site 6 as well as inaccurate or missing measurements at high flow. Similar errors may have occurred at sites 1 and 5, too, where the stream discharge was not restricted to flow under a bridge as for sites 2 and 4. Yet, it still was evident the wetland area affected storm-water discharge by allowing water to spread out and by slowing the movement of water through the drainage area. This was evident in hydrograph peaks from site 1 that were smaller and shorter while the hydrograph peaks within or below the wetland area (e.g. site 4) were greater and longer. The discharge difference curve (Fig. 27) for sections C and D that include the wetland area showed negative values, signifying the filling up of the area, initially with storm run-off. Several days after the large storms, the discharge difference curve in watershed sections C and D became positive with greater export of water at successive downstream sites. The storage was also evident in the smaller magnitude of fluctuation in stream level at site 3 than for the other sites as the water from storm runoff most-likely flows into the bog and spreads out to later be discharged downstream, eliminating a sharp peak in discharge following a storm event. Since this storage of storm water occurs within the wetland area, water was continually discharged downstream from the wetland area between storms. Upstream from the wetland, the flow diminished greatly during dry periods. Most of the study area watershed land cover was forest or wetland, but if the land use were to change in the future with development, the hydrology of the system may be altered. Therefore, continued monitoring of the area through remote sensing may be beneficial to detect changes.

Groundwater Contribution

As predicted, groundwater contribution to the system did not greatly affect the variability in water flow or DOC quantity or quality throughout Cranberry Creek since the specific conductivity for all sites was greatly lower than that of the well water near site 6. Slightly more groundwater may influence the system above and below the wetland area than within the wetland area since the water from these sites had slightly higher specific conductance than that of sites within the wetland area. This is probably due to the main sources of water in bog wetlands, like that of Tannersville Bog in the study watershed, being from precipitation and surface water either stored or discharged from upstream. Groundwater most-likely became somewhat more important with the reduction of stream flow during dry periods, especially that in August, since the specific conductance increased at each site with precipitation at the onset of storm discharge, in contrast to the normal pattern of decreased specific conductance as storm discharge increases. Yet, the contribution to the system was still probably minimal. During most other storm events, the specific conductance of stream water decreased at all sites for a period, most-likely due to dilution with precipitation, even following the rise in specific conductance with precipitation onset after dry periods.

DOC Source

As expected, DOC with a low fluorescence index was found throughout Cranberry Creek, indicating DOC was mainly soil-derived. This is likely related to the water sources in this system and other bog wetland systems typically being surface runoff, upstream discharge, and precipitation. Cranberry Creek water should gain DOC mainly from decaying plant matter in the forest or peatland soils of the Cranberry Creek watershed. The different wetland landcover types classified did not seem to significantly influence the DOC concentration in Cranberry Creek. Still, the fluorescence index decreased at downstream sites, signifying the DOC input from each section downstream through the Cranberry Creek watershed was more-soil-derived. During storm events, DOC throughout the sampling sites along Cranberry Creek developed DOC with a fluorescence index of more-soil-derived DOC than the water entering from the headwater pond with greater surface runoff contributing DOC to the system than from other possible sources. It may be important to determine the concentration and fluorescence index of soil DOC to look for an effect from the unique peatland vegetation or the upland forest vegetation. During baseflow, the fluorescence index upstream may have been slightly more-autocthonous than sites downstream with DOC production in the water-column of the pond. The fluorescence index was slightly higher again at site 6, too, probably due to autocthonous DOC production in the small pond just upstream from site 6. Yet, the DOC at these sites still had a low fluorescence index and therefore was mostly soil-derived.

DOC Concentration and Flux

DOC concentration and flux was greatest for sampling sites along the section of Cranberry Creek that flows through the wetland as expected. This is likely due to the peat material acting as a strong source of DOC. The water-logged environment is valuable to create conditions for DOC production and contribution to the system. The percentage of peat cover in the Cranberry Creek watershed was around 27% from site 1 to site 5 and the annual DOC flux from that area of the watershed was 12.18 $g/m^2/yr$ (121.8 kg/ha/yr). These values are plotted over Figure 1 in Figure 45. If the trendline fitted to the points from the percentage of peatland area and DOC flux measurements from central Ontario was extended, the values from this study fall near the line. Although the relationship between the DOC flux and percentage of peatland area in this study does follow a similar relationship as that of catchments with peat cover in central Ontario, variability in climate (temperature and precipitation), land cover, or other factors besides the percentage of peatland area that affect DOC flux may need to be accounted for in the system from this study or in other systems. The mean annual temperature from this study site (average throughout the monitoring period 9.1 degrees Celsius) was higher than that from the central Ontario study (5.0 +/- 0.8 degrees Celsius; Dillon and Molot 1997), possibly allowing for greater biomass production and partial (anaerobe) decomposition to create a larger supply of DOC to the Cranberry Creek system than for central Ontario peatlands in a cooler climate. The warmer climate from this study may be related to why the plot for Cranberry Creek watershed on Figure 45 is above the trendline. Because of the temperate climate and weather data available for this study, Cranberry Creek watershed may serve as a valuable model for other temperate peatland systems or boreal peatlands under climate change scenarios.

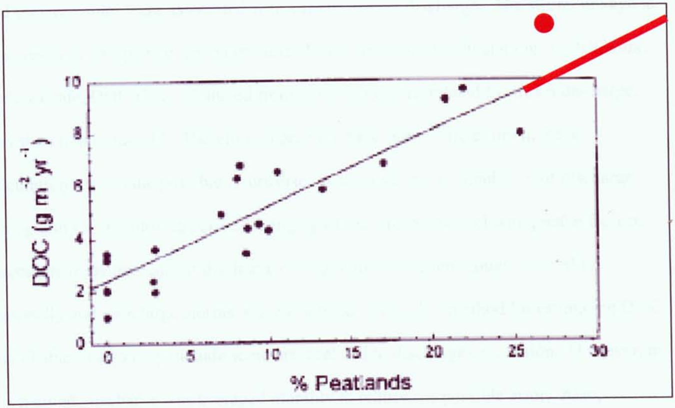

Figure 45: Percentage of peatland area in the Cranberry Creek watershed (27%) as well as the estimated annual DOC flux (12.18 g/m^2/yr) is plotted as a red dot overlain on a plot of the relationship mean annual DOC flux from 1980 to 1992 and percentage of peat cover in catchments from central Ontario (Dillon and Molot 1997). The trendline from the relationship plotted from central Ontario data is extended as a red line. Mean annual temperature from the study of central Ontario peatlands was 5.0 +/- 0.8 degrees Celsius (Dillon and Molot) and the mean annual temperature from this study was 9.1 degrees Celsius (June 20, 2006 to April 27, 2007).

The DOC concentration and flux was also greatly affected by precipitation and the associated stream discharge at all sites. DOC concentration and flux increased to its highest values during the monitoring period following warm-weather precipitation events and greater values were associated with sites of greater discharge. The strong linkage to changes in discharge may have contributed some error to the calculations of DOC flux. For each site, DOC flux, calculated from power equations related to stream discharge, was shown in Figure 43. Therefore, there may have been some errors in these calculations due to the possible errors discussed above in the calculation of discharge throughout the monitoring period (changing of the stream channel with greater flow or inaccurate measurements of discharge during high flow) even though variability seasonally and with large storms was considered. The other method for estimating DOC flux (Table 6) also may include some error related to discharge calculation. However, in this method, discharge was averaged monthly to reduce the possible error. Also, discharge below the wetland was estimated from discharge at site 4 (Figure 44), which had a uniform stream channel under a bridge, most-likely reducing errors in the discharge calculation.

There was no consistent pattern for the amount of DOC released (change in DOC concentration) from the onset of precipitation to peak flow for the four storms analyzed. A lot of DOC was released during the first two storms, but not as much DOC was released during the second two storms as shown in Figures 36 and 37. This variability may be related to the magnitude of the storm as the first storm analyzed in late-June was very large (298 mm). However, the second storm in late-August that resulted in a large amount of DOC released was not as large. Instead, the large release of DOC during the first two storms analyzed probably is related to the fact that the area had little precipitation before these storms that allowed for DOC to accumulate in the soil for flushing and release with the storm onset. The two storms analyzed in the fall with little DOC release occurred following periods with some precipitation. So, with these storms, there probably was not as much DOC available for release from the soil into Cranberry Creek and with the onset of precipitation, DOC concentration decreased (dilution of DOC concentration in Cranberry Creek). Also, the air and water temperature decreased in the late-fall for the last storm, possibly leading to less soil DOC available for release into Cranberry Creek with precipitation. More monitoring is needed to determine the seasonality of DOC source and seasonal variations in DOC concentration per unit of storm discharge. Knowing these functions is important to predict possible implications for the carbon cycle with climate change.

When the values from this study of annual regional precipitation around 1252 mm (Lehigh Valley Airport) and annual DOC flux of 12.18 $g/m^2/yr$ (80 kg/ha/yr) are plotted as a red dot over Figure 4 in Figure 46, the point falls just below the "Streams with wetlands, N. Carolina" dataset from swamp catchments in North Carolina. The data from Tannersville Bog may fall below the data from North Carolina swamp watersheds because the North Carolina climate is warmer, allowing for greater DOC concentration (associated with the balance between biological production and decomposition). The swamp vegetation also might function differently than the peatland vegetation for DOC production. The data from this study do not fit the "Streams with wetlands, temperate" dataset in Figure 46 (also seen in Fig. 4). The accuracy of the "Streams with wetlands, temperate" dataset is questionable, though, since it does not extrapolate to zero as one would expect (no DOC flux with no annual precipitation). Also, temperate wetlands may be quite variable in their contribution to DOC flux of a watershed with wetland type, percentage of wetland area, and region or climate. The range of DOC flux in central Ontario peatlands for the annual regional precipitation of the boreal climate in the region (Dillon and Molot) is plotted (green dots connected by a green line) in Figure 46. These peatlands have much lower DOC flux for the annual precipitation in central Ontario than for studies of wetlands in temperate regions. Further comparison of DOC concentration and flux in temperate and boreal wetlands, especially peatlands, is clearly necessary to better-understand the variability with wetland type, precipitation and discharge, and region or climate. Also, it is important to determine how rates of DOC production and breakdown vary by site, vegetation type, climate, and season.

Variability in DOC concentration and flux at each Cranberry Creek monitoring site was observed during periods of extremely high flow and in the fall. In periods of extremely high flow, the DOC concentration and flux was lower than expected for sites near the wetland area as seen with the DOC flux measurements during these periods that fell below the curves fitted to the relationship between DOC flux and discharge values during other conditions. Dilution of stream-water by the large amount of precipitation likely caused the DOC concentration and flux reduction. Seasonal variation in DOC concentration and export was also observed since temperature affects the balance between plant production and biological oxidation of organic matter and organic matter accumulation in soils. Availability of DOC in the soils and for export into Cranberry Creek was likely reduced with cooler air and water temperatures in the late-fall (after October 27^{th}). Either a reduced concentration of DOC in soil water or a change of flow

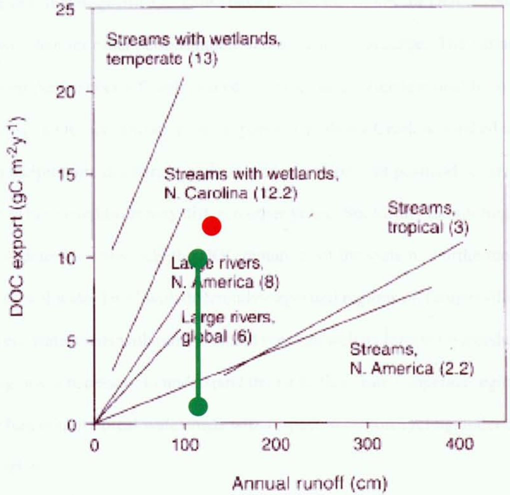

Figure 46: The annual regional precipitation and DOC flux (export) from this study is plotted as a red dot and the range of the DOC flux for the annual regional precipitation and for central Ontario peatlands (Dillon and Molot) is plotted as green dots connected by a green line. Each overlay plots of relationships between annual runoff and watershed export of DOC in streams and rivers reported in the literature. The respective lines extend only over the range of runoff values included in the dataset. Sources for each relationship are as follows: streams with wetlands, temperate (Mulholland 1997); streams with wetlands, N. Carolina (Mulholland and Kuenzler 1979); large rivers, global (Spitzy and Leenheer 1991); large rivers, N. America (Mulholland and Watts 1992); streams, tropical (McDowell and Asbury 1994); streams, N. America (Mulholland 1997) (Mulholland 2003).

path relative to soil storage of DOC could have caused the values for DOC export in late-fall to be lower than for other periods monitored of similar discharge. The variability in DOC flux from the Cranberry Creek watershed serves as a valuable model for other similar systems. DOC concentration and export in Cranberry Creek watershed is a function of precipitation, discharge, wetland land cover (percent peatland cover), and temperature. These conditions may differ in other years. So, further monitoring would be valuable to determine precisely the DOC dynamics of the system. Furthermore, comparison of soil water DOC with differently-vegetated regions of Tannersville Bog, and in different watersheds with other wetland types as well as forested watersheds in temperate regions is necessary to understand the DOC flux from temperate regions and the possible function of boreal watersheds with respect to carbon cycling under climate change scenarios.

Conclusion

Tannersville Bog wetland reduced peak storm discharge and delayed discharge downstream following precipitation as storm runoff spread out into the wetland area. This storage served as a continuous supply of water to be discharged downstream during baseflow conditions, even when discharge upstream was diminished greatly.

There was little groundwater contribution in the Cranberry Creek watershed to influence water flow or DOC concentration, flux, or quality since the system is fed mainly through precipitation and surface water – either stored, through runoff, or discharged from upstream.

The source of DOC contributed to Cranberry Creek as it passed through Tannersville Bog was predominantly from decaying plant matter (soil-derived) as the stream water gained DOC mainly from decaying plant matter in the forest or peatland soils of the watershed.

DOC concentration and flux in Cranberry Creek was greatest through the wetland area where the peat material supplies a large pool of particulate organic matter and where water-logged conditions prevent aerobic decomposition of DOC to carbon dioxide to provide a highly available source of DOC. Yet, the DOC concentration and its response to increased storm runoff was reduced when temperatures were low and water levels were high in the late-fall and winter because reduced DOC concentration was observed then. This seasonal effect on DOC concentration resulted in lower export of DOC during late fall and winter. The estimated annual DOC flux (scaled to the watershed area) was similar to that of the literature for the percentage of peatland area (Dillon and Molot 1997) and the annual precipitation (Muholland 2003) of the system. However, with large precipitation events, DOC concentration in Cranberry Creek was diluted and runoff-specific DOC flux were somewhat reduced. Therefore, variability in DOC concentration and runoff-specific DOC flux or area-specific DOC flux may result from differences in precipitation and discharge, temperature, and percentage of peatland area.

Because of our success in quantifying runoff-specific and area-specific DOC flux from Tannersville Bog wetlands at different time scales ranging from hourly to annually, this site could be used as a model for the response of high latitude wetlands to climate change. Continued monitoring under different weather conditions is necessary to better-understand this variability and the overall function of the system, especially because of the appearance of strong seasonal patterns for DOC concentration under baseflow and storm runoff conditions. Furthermore, comparison of soil water between differently-vegetated sections of Tannersville Bog, and among different temperate and high latitude wetlands, taking into account differences in temperature and precipitation, would help determine the effect the percentage of peatland area or different landcover has on hydrology and DOC dynamics throughout the temperate region to model the potential function of boreal watersheds with respect to water flow and carbon cycling under climate change scenarios.

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Appendix I

The following pages show tables of dissolved cation concentrations (A.) and the standard deviation of each concentration (B.) measured in samples from this study area using a *Thermo* inductively coupled plasma mass spectrometer. The sample codes indicate the study area, sample bottle number, sample site, and collection date. Each code starts with "TB_" to signify the sample was from the Tannersville Bog study area. The next one or two digits indicate the sample bottle number if the sample was collected using the ISCO automated sampler. No numbers are shown if the sample was a grab sample. The next one or two letters tell the sample site. "BW" stands for "site 1: Birchwood." "BR" stands for "site 2: Bog Rd." "BS" also stands for site 2: Bog Rd," but for samples collected using the ISCO automated sampler. "BB" stands for "site 3: Bog Boardwalk." "LL" stands for "site 4: Laurel Lake Rd." "T" stands for "site 5: Taylor's." "TS" also stands for "site 5: Taylor's," but for samples collected using the ISCO automated sampler. "CS" also stands for "site 6: Chester's Stream." "RS" stands for "site 6: Chester's Stream," but for samples collected using the ISCO automated sampler. "CW" stands for site 6: Chester's Well. The final six digits of each sample code indicate the date the sample was collected (MMDDYY). The data were not analyzed in this study.

A. Dissolved cation concentrations in Cranberry Creek water samples (ppb).

Sample	Be	B	Na	Mg	Al	Si	K	Ca
TB_BW062206	0.043	11.25	11450	1917	16.46	1460	615.6	8467
TB_BR062206	0.045	12.55	11580	2147	17.99	2254	845.3	9130
TB_BB062206	0.034	8.909	11020	1827	13.82	3098	424.8	7976
TB_LL062206	0.038	7.867	9419	1504	33.15	3068	513	6107
TB_CS062206	0.043	8.814	8811	1764	32.07	3847	6705	6719
TB_15BS062406	0.031	9.013	8417	1673	28.62	3495	840.3	6308
TB_15RS062406	0.017	11.92	11150	2153	21.29	2369	962.4	9482
TB_21BS062506	0.022	9.005	8002	1572	32.51	4133	633.7	6268
TB_21RS062506	0.031	12.02	10180	2156	50.59	4321	697.4	9879
TB_BW062606	0.034	10.95	9831	1582	22.68	1667	561	7621
TB_BR062606	0.061	10.8	6700	1164	173.3	2566	612.8	5594
TB_BB062606	0.033	7.579	6529	1320	53.51	2462	553.3	5673
TB_LL062606	0.038	8.099	6047	1027	110.3	2753	533.6	4550
TB_CS062606	0.036	8.992	6608	1296	98.85	2877	572.7	5265
TB_7BS062806	0.049	10.93	5864	732.2	127.4	1654	512	3496
TB_7RS062806	0.04	9.906	4924	868.6	104.5	2174	1959	3957
TB_8BS062806	0.033	11.42	4312	587.9	89.77	1370	662.9	2993
TB_8RS062806	0.043	11.84	4052	710	117.2	1727	1219	3416
TB_11BS062906	0.047	11.74	5885	748.3	88.08	1507	665.5	3609
TB_11RS062906	0.039	10.69	4536	628.5	107.3	1687	605.3	2866
TB_BW063006	0.033	12.14	5436	919.6	61.12	1954	1003	5895
TB_BR063006	0.06	11.95	5897	908.1	160.3	2045	851.5	4662
TB_BB063006	0.029	11.31	5859	833.3	82.37	2019	13610	3779
TB_LL063006	0.04	9.526	5110	775.9	120.7	2107	1216	3192
TB_CS063006	0.026	10.19	5443	752.2	105.3	2026	1211	3318
TB_CW063006	0.014	7.155	8449	5776	2.002	6908	654.3	22180
TB_BW070306	0.027	13.26	6311	1084	41.79	1986	1638	6546
TB_BR070306	0.062	11.75	6612	1290	114.4	2714	820.2	6792
TB_BB070306	0.039	9.759	6471	1104	89.89	2613	976.7	5278
TB_LL070306	0.043	9.251	5695	960.1	135.5	2820	881.6	4366
TB_CS070306	0.044	9.77	5958	963	126.9	2864	996.6	4250
TB_BW081106	0.021	12.95	8152	1622	6.979	2081	678.6	7833
TB_BR081106	0.029	11.61	9156	2073	34.41	2001	720.4	9787
TB_BB081106	0.038	8.644	7989	1558	39.36	5658	388.6	6566
TB_LL081106	0.025	8.844	7400	1378	50.55	5023	290.5	5771
TB_CS081106	0.029	8.322	7300	1740	26.79	5697	664.3	6912
TB_CW081106	0.021	9.047	9882	5618	0.957	7169	481.3	21410
TB_BW091106	0.039	13.41	9675	2000	16.81	2512	491.5	10020
TB_BR091106	0.035	13.03	10040	2042	47.58	3158	672.2	9839
TB_BB091106	0.025	10.79	9144	1734	49.8	4084	630.1	7871
TB_LL091106	0.029	8.822	7652	1413	123.9	4634	483.7	5657

Sample	Be	B	Na	Mg	Al	Si	K	Ca
TB_CS091106	0.03	8.606	7210	1530	80.36	4869	514.1	6253
TB_CW091106	0.016	8.557	9469	5941	0.786	7719	360.8	22210
TB_1BS091406	0.026	13.49	9779	2084	38.72	3228	673.3	10040
TB_4TS091406	0.036	8.771	8147	1583	95.94	5056	514.2	6054
TB_15BS091506	0.065	9.911	6034	1202	165.6	3062	394.2	5913
TB_16TS091506	0.036	10.31	6267	1138	96.48	3486	637.1	5394
TB_BW091706	0.023	11.85	8448	1443	42.66	2394	678.3	7247
TB_BR091706	0.06	11.41	8132	1282	138.1	2840	525.2	5956
TB_BB091706	0.045	10.38	7047	1161	98.87	3179	441.4	5074
TB_LL091706	0.042	9.221	5663	994.9	157.6	3168	422.9	4267
TB_T091706	0.056	9.947	6439	1061	137.1	3293	447	4776
TB_CS091706	0.052	9.797	6234	1049	131.8	3318	444.9	4883
TB_CW091706	0.02	8.324	8942	6037	2.544	7795	363.9	22850
TB_BR091906	0.052	11.42	7964	1377	123	2932	550.5	6553
TB_T091906	0.025	9.695	6797	1113	137.9	3417	479.2	4742
TB_BW092406	0.04	11.31	8251	1396	35.63	2339	546.9	6939
TB_BR092406	0.048	11.21	8472	1636	76.89	3188	699.7	7790
TB_BB092406	0.034	9.329	7998	1342	73.53	3776	615.1	5608
TB_LL092406	0.052	8.988	6572	1102	110.4	3363	588.9	4368
TB_T092406	0.036	10.1	7585	1196	120.6	4118	574.1	4790
TB_CS092406	0.035	8.662	6967	1190	100	3942	520.3	4843
TB_CW092406	0.02	8.213	8886	6130	1.264	7672	399.4	22450
TB_19BS101306	0.044	10.94	8056	1950	129.2	3627	779.5	8213
TB_19TS101306	0.033	9.687	7797	1703	120.7	4886	1069	6076
TB_21BS101306	0.045	10.07	8150	1819	96.28	3565	721.5	7722
TB_21TS101306	0.04	9.047	7250	1659	118.7	4798	1087	5246
TB_1BS101406	0.04	10.02	8228	1889	96.39	3642	683.3	7925
TB_1TS101406	0.036	8.833	7844	1633	97.49	4899	1054	5649
TB_3BS101506	0.031	9.543	7998	1842	92.1	3395	633.2	7726
TB_3TS101506	0.03	8.254	7762	1667	93.15	4695	975.7	5856
TB_5BS101506	0.038	9.598	8216	1890	94.24	3558	677.3	7993
TB_5TS101506	0.029	9.567	7865	1566	100.2	4720	1009	5223
TB_7BS101606	0.035	8.882	8426	1927	94.7	3684	642.9	7899
TB_7TS101606	0.039	8.315	7629	1607	85.02	4517	900.7	5539
TB_9BS101606	0.038	8.853	8091	1887	86.3	3506	637.9	8065
TB_9TS101606	0.029	8.986	7788	1582	90.84	4757	948.1	5203
TB_BW102606	0.034	12.12	8399	1673	60.43	2191	694.9	6680
TB_BR102606	0.052	9.854	8396	1638	90.8	3104	659.1	6784
TB_BB102606	0.026	8.384	7612	1394	81.56	3403	604.8	5178
TB_LL102606	0.034	8.529	6776	1285	100.3	3909	691.9	4453
TB_T102606	0.025	8.902	7074	1351	95.05	4117	728.6	4766
TB_CS102606	0.039	8.872	6648	1384	88.92	4118	746.7	4871
TB_1BS102706	0.047	9.368	7826	1455	68.93	2907	593.2	5919
TB_1TS102706	0.025	8.452	7067	1355	86.43	4114	742.6	4860
TB_5BS102806	0.035	8.651	7594	1454	68.47	2869	621	5713
TB_5TS102806	0.026	7.782	7142	1341	85.43	3971	799.8	4694

Sample	Be	B	Na	Mg	Al	Si	K	Ca
TB_13TS102806	0.029	9.153	5697	1128	88.14	3103	796	4008
TB_17BS101906	0.031	9.129	6018	1032	105.8	2410	503.5	4064
TB_17TS101906	0.035	9.146	6105	1166	86	3152	619.9	4118
TB_BW110106	0.04	8.57	7663	1381	48.71	2134	591.6	5732
TB_BR110106	0.029	10.07	7120	1192	85.29	2522	486.1	4840
TB_BB110106	0.023	9.227	6836	1159	66.8	2857	405.2	4274
TB_LL110106	0.025	9.091	5761	1051	91.76	3094	382.3	3723
TB_T110106	0.03	9.603	6245	1154	81.66	3222	412.1	4319
TB_CS110106	0.036	9.712	6216	1142	77.16	3340	450.9	4443

Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As
TB_BW062206	0.386	0.526	229.4	1238	0.177	1.517	3.055	4.041	1.115
TB_BR062206	0.366	0.492	974.5	356.1	0.941	19.68	17.35	9.249	0.902
TB_BB062206	0.124	0.809	28.93	186.1	0.335	31.67	3.909	6.6	0.706
TB_LL062206	0.158	0.019	125.6	339.9	0.176	30.97	3.976	8.514	0.741
TB_CS062206	0.257	-0.823	5.459	181.4	0.125	2.336	6.309	9.727	0.72
TB_15BS062406	0.212	0.222	1.259	110	0.103	2.896	5.887	9.844	0.635
TB_15RS062406	0.378	0.481	3.29	437.9	0.141	1.144	1.705	3.729	0.949
TB_21BS062506	0.218	-0.469	2.217	167.8	0.123	1.289	1.376	7.378	0.656
TB_21RS062506	0.368	-0.709	16.44	389.1	0.12	1.357	4.196	7.336	0.772
TB_BW062606	0.164	0.465	36.66	164.9	0.098	1.313	8.06	6.356	0.853
TB_BR062606	0.576	-0.942	78.12	374.9	0.126	1.577	2.376	18.43	0.737
TB_BB062606	0.236	-0.724	102.1	424.8	0.157	1.187	0.934	6.461	0.696
TB_LL062606	0.409	-0.833	74.99	452	0.26	1.369	2.193	13.33	0.645
TB_CS062606	0.342	-0.961	1.141	308	0.178	1.389	1.945	13.61	0.635
TB_7BS062806	0.479	-0.896	1.412	225.6	0.087	1.253	2.106	15.51	0.627
TB_7RS062806	0.302	-0.886	2.528	210.8	0.088	1.224	1.769	10.55	0.536
TB_8BS062806	0.302	-0.57	0.401	109.4	0.073	1.125	8.131	8.961	0.572
TB_8RS062806	0.462	-1.037	1.249	231	0.072	1.44	2.476	14.76	0.645
TB_11BS062906	0.253	-0.68	-0.172	109.4	0.079	1.078	2.16	9.709	0.642
TB_11RS062906	0.422	-1.159	5.889	215.6	0.075	0.99	2.214	13.97	0.568
TB_BW063006	0.232	-0.524	2.941	131.6	0.061	1.061	2.322	6.318	0.711
TB_BR063006	0.42	-0.768	21.82	313	0.103	1.643	1.79	14.32	0.956
TB_BB063006	0.272	-1.548	1.465	203.4	0.073	1.492	2.545	8.986	0.831
TB_LL063006	0.423	-1.746	225.2	580.9	1.071	1.293	1.296	11.82	1.003
TB_CS063006	0.342	-1.685	48	342.1	0.201	1.172	1.924	12.67	0.682
TB_CW063006	0.169	1.413	0.568	10.26	0.044	0.506	0.566	1.846	2.534
TB_BW070306	0.167	0.197	3.378	176	0.065	1.254	1.726	5.3	0.883
TB_BR070306	0.366	-0.501	98.35	368.2	0.257	2.033	2.966	12.61	1.424
TB_BB070306	0.215	-0.616	28.64	421.6	0.11	1.814	2.216	9.657	1.188
TB_LL070306	0.324	-1.067	146	675.6	0.74	2.521	6.603	17.58	1.379
TB_CS070306	0.382	-1.127	56.96	489.1	0.234	2.148	9.935	16.25	1.172
TB_BW081106	0.145	-0.338	3.697	122	0.198	2.486	4.425	5.87	0.994
TB_BR081106	0.335	0.754	17.6	378.3	0.203	1.244	7.813	4.202	0.885
TB_BB081106	0.097	-0.732	44.3	311	0.173	0.981	1.348	5.756	0.64

Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As
TB_CS081106	0.272	-0.73	5.958	173.3	0.105	1.188	2.066	6.654	0.824
TB_CW081106	0.185	2.06	4.037	12.52	0.058	0.753	1.648	3.06	2.848
TB_BW091106	0.269	0.677	1.651	458.3	0.083	1.003	2.476	3.579	0.917
TB_BR091106	0.331	0.315	4.086	380	0.101	1.238	6.268	7.372	0.991
TB_BB091106	0.153	-0.211	5.456	296	0.108	2.173	2.136	4.701	1.045
TB_LL091106	0.36	-1.008	169.5	753	0.588	1.301	2.518	8.858	0.703
TB_T091106	0.344	-0.874	71.19	547.9	0.26	2.123	1.479	12.49	0.725
TB_CS091106	0.301	-0.756	12.36	293.9	0.132	1.184	1.946	10.77	0.687
TB_CW091106	0.182	2.073	-0.308	16.12	0.048	0.407	0.4	2.12	2.87
TB_1BS091406	0.341	1.07	2.386	332.3	0.111	1.885	3.547	12.66	0.828
TB_4TS091406	0.294	-0.751	0.706	401	0.097	1.847	2.65	10.33	0.566
TB_15BS091506	0.394	-0.559	6.16	288.8	0.111	1.975	2.331	22.65	0.665
TB_16TS091506	0.347	-0.612	0.266	250.9	0.079	2.415	1.588	11.12	0.5
TB_BW091706	0.212	0.048	1.97	288.5	0.069	0.876	1.231	5.393	0.721
TB_BR091706	0.457	-0.62	2.639	327.6	0.089	1.676	3.682	19.94	0.799
TB_BB091706	0.332	-0.656	59.64	370.1	0.12	1.241	1.43	9.234	0.645
TB_LL091706	0.461	-1.082	11.15	501.8	0.156	1.474	1.266	12.4	0.642
TB_T091706	0.462	-0.997	15.13	409.5	0.11	1.298	2.181	14.08	0.679
TB_CS091706	0.374	-1.199	2.356	319	0.082	1.438	1.622	14.57	0.586
TB_CW091706	0.175	2.01	3.013	15.1	0.053	0.394	0.904	2.02	2.632
TB_BR091906	0.442	0.087	11.03	341.6	0.105	2.285	2.248	13.17	0.997
TB_T091906	0.45	-0.834	59.04	557.2	0.261	1.272	1.155	11.79	0.755
TB_BW092406	0.208	-0.273	1.847	365.6	0.078	1.484	1.724	6.757	0.758
TB_BR092406	0.336	0.121	4.56	376	0.102	1.642	2.085	10.28	0.897
TB_BB092406	0.202	-0.394	26.04	390.6	0.122	1.304	1.557	6.938	0.647
TB_LL092406	0.276	-2.081	14.94	480.6	0.122	2.353	1.674	12.7	0.632
TB_T092406	0.356	-2.218	1.529	472.4	0.083	1.182	1.393	9.852	0.651
TB_CS092406	0.313	-1.258	3.912	329.9	0.091	1.84	1.883	11.6	0.67
TB_CW092406	0.172	2.14	-0.341	11.08	0.045	0.473	1.061	1.61	2.758
TB_19BS101306	0.333	0.366	2.187	451.7	0.11	2.459	2.219	14.46	1.164
TB_19TS101306	0.283	-0.163	6.408	604.4	0.12	2.328	1.489	15.46	0.733
TB_21BS101306	0.237	-0.21	2.361	289.8	0.091	2.404	2.634	16.07	1.05
TB_21TS101306	0.221	-0.488	50.07	547.8	0.115	2.042	4.501	21.94	0.712
TB_1BS101406	0.293	-0.317	6.137	388.8	0.103	2.036	1.704	17.71	0.972
TB_1TS101406	0.278	-0.6	3.902	455.6	0.1	1.436	1.091	12.75	0.644
TB_3BS101506	0.291	-0.208	2.649	410.6	0.106	1.986	1.415	19.01	0.936
TB_3TS101506	0.23	-0.351	1.079	416	0.095	1.86	0.99	14.67	0.661
TB_5BS101506	0.299	-0.141	7.052	435	0.118	1.998	1.638	11.04	1
TB_5TS101506	0.241	0.957	3.993	381.8	0.102	5.8	1.866	16.55	0.635
TB_7BS101606	0.3	-0.261	6.647	465.6	0.129	1.972	1.391	16.4	1.072
TB_7TS101606	0.204	-0.546	1.249	369.3	0.09	1.613	1.031	14.59	0.669
TB_9BS101606	0.252	0.02	5.61	357.6	0.105	2.295	1.454	13.45	0.959
TB_9TS101606	0.224	-1.395	2.39	373.7	0.097	1.914	1.279	13.8	0.545
TB_BW102606	0.225	-2.07	11.27	340	0.083	1.153	2.743	13.55	0.536
TB_BR102606	0.217	-0.632	70.38	219.6	0.183	1.531	3.14	12.41	0.793
TB_BB102606	0.216	-1.104	15.54	294.9	0.112	1.178	2.101	7.045	0.455

Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As
TB_T102606	0.232	-1.222	76.24	394.8	0.29	1.589	2.117	10.68	0.423
TB_CS102606	0.212	-0.883	5.817	276.1	0.082	1.142	2.154	9.167	0.457
TB_1BS102706	0.219	-0.549	1.879	230	0.078	1.236	0.974	10.47	0.542
TB_1TS102706	0.213	-0.898	5.486	375.8	0.101	1.647	0.621	12.18	0.477
TB_5BS102806	0.186	-0.508	3.321	213.6	0.079	2.665	0.995	13.03	0.634
TB_5TS102806	0.204	-0.847	9.237	332.5	0.087	1.697	0.665	11.47	0.441
TB_13BS102806	0.256	-0.973	1.742	311.2	0.07	1.265	0.974	18.13	0.6
TB_13TS102806	0.239	-1.01	6.486	300.9	0.069	1.161	0.755	14.56	0.376
TB_17BS101906	0.266	-1.836	2.025	253.4	0.068	0.994	1.004	17.05	0.526
TB_17TS101906	0.242	-2.178	12.72	375.7	0.075	1.143	0.635	11.68	0.396
TB_BW110106	0.168	-0.825	28.34	146.7	0.078	1.058	1.975	8.037	0.489
TB_BR110106	0.27	-0.821	16.43	177.6	0.088	1.164	2.539	13.34	0.562
TB_BB110106	0.268	-1.015	28.68	220.9	0.119	0.747	1.407	7.769	0.478
TB_LL110106	0.32	-1.033	56.91	383.7	0.363	0.775	1.053	7.506	0.434
TB_T110106	0.27	-1.13	36.31	282.2	0.16	0.831	1.311	8.168	0.452
TB_CS110106	0.217	-0.894	1.08	189.7	0.089	0.89	1.674	8.478	0.454

Sample	Se	Sr	Ag	Cd	Sn	Sb	Ba	Tl	Pb
TB_BW062206	0.097	36.43	0.023	0.062	0.444	0.19	14.31	0.021	0.513
TB_BR062206	0.212	43.92	0.024	0.062	0.201	0.161	35.77	0.015	0.518
TB_BB062206	0.163	36.86	0.016	0.053	0.125	0.163	21.05	0.015	0.135
TB_LL062206	0.131	29.97	0.016	0.052	0.097	0.083	25.57	0.014	0.154
TB_CS062206	0.147	31.04	0.022	0.06	0.09	0.152	39.83	0.015	0.366
TB_15BS062406	0.147	27.52	0.02	0.057	0.137	0.086	28.36	0.013	0.223
TB_15RS062406	0.222	43.79	0.015	0.044	0.08	0.12	16.23	0.011	0.407
TB_21BS062506	0.268	27.21	0.015	0.053	0.137	0.097	12.96	0.014	0.281
TB_21RS062506	0.27	47.22	0.02	0.05	0.083	0.205	24.81	0.012	0.333
TB_BW062606	0.115	33.25	0.014	0.052	0.066	0.182	27.11	0.012	0.191
TB_BR062606	0.149	26.44	0.015	0.084	0.091	0.21	30.44	0.014	0.454
TB_BB062606	0.114	29	0.013	0.044	0.075	0.138	23.77	0.013	0.235
TB_LL062606	0.105	21.84	0.014	0.061	0.103	0.1	17.39	0.014	0.666
TB_CS062606	0.178	24.47	0.014	0.063	0.085	0.138	21.69	0.015	0.289
TB_7BS062806	0.126	16.27	0.014	0.067	0.078	0.117	14.92	0.013	0.309
TB_7RS062806	0.132	17.86	0.014	0.06	0.086	0.221	21.64	0.014	0.206
TB_8BS062806	0.078	14.16	0.013	0.054	0.067	0.11	10.55	0.012	0.214
TB_8RS062806	0.21	14.7	0.013	0.062	0.082	0.125	13.98	0.016	0.322
TB_11BS062906	0.192	16.98	0.013	0.053	0.063	0.338	22.9	0.012	0.165
TB_11RS062906	0.068	12.94	0.013	0.061	0.084	0.112	11.35	0.018	0.396
TB_BW063006	0.178	26.74	0.012	0.052	0.045	0.177	12.93	0.013	0.148
TB_BR063006	0.168	21.98	0.017	0.079	0.069	0.158	17.95	0.014	0.548
TB_BB063006	0.322	18.21	0.019	0.045	0.055	0.143	15.28	0.015	0.15
TB_LL063006	0.097	14.84	0.016	0.089	0.076	0.125	15.05	0.018	2.251
TB_CS063006	-0.056	15.17	0.016	0.076	0.067	0.141	15.31	0.017	0.671
TB_CW063006	0.534	179.8	0.011	0.042	0.034	0.073	23.82	0.01	0.073
TB_BW070306	0.183	28.98	0.012	0.043	0.041	0.277	23.79	0.013	0.117

Sample	Se	Sr	Ag	Cd	Sn	Sb	Ba	Tl	Pb
TB_BB070306	0.192	25	0.014	0.057	0.072	0.322	24.8	0.014	0.174
TB_LL070306	0.176	21.65	0.018	0.065	0.082	0.182	18.21	0.015	0.912
TB_CS070306	0.222	19.84	0.015	0.073	0.081	0.594	26.67	0.017	0.662
TB_BW081106	0.153	34.55	0.012	0.041	0.058	0.379	16.68	0.01	0.144
TB_BR081106	0.144	44.81	0.013	0.041	0.051	0.118	13.51	0.011	0.421
TB_BB081106	0.281	32.06	0.012	0.046	0.06	0.144	21.65	0.012	0.121
TB_LL081106	0.114	26.65	0.013	0.046	0.063	0.134	24.36	0.012	0.178
TB_CS081106	0.208	30.27	0.013	0.052	0.061	0.061	11.87	0.014	0.223
TB_CW081106	0.549	215.7	0.011	0.054	0.042	0.105	19.95	0.01	0.073
TB_BW091106	0.198	41.96	0.013	0.043	0.062	0.121	17.94	0.011	0.3
TB_BR091106	0.202	42.32	0.016	0.044	0.068	0.109	21.98	0.011	0.35
TB_BB091106	0.139	35.68	0.013	0.05	0.061	0.08	22.54	0.012	0.172
TB_LL091106	0.205	26.14	0.015	0.051	0.111	0.077	23.9	0.013	1.307
TB_T091106	0.263	27.66	0.015	0.061	0.096	0.133	24.42	0.013	0.59
TB_CS091106	0.119	26.51	0.014	0.052	0.074	0.085	19.56	0.012	0.274
TB_CW091106	0.471	213.6	0.011	0.046	0.035	0.07	19.93	0.01	0.075
TB_1BS091406	0.202	44.32	0.016	0.063	0.228	0.147	17.74	0.011	0.365
TB_4TS091406	0.063	25.66	0.015	0.068	0.111	0.1	21.77	0.012	0.313
TB_15BS091506	0.207	26.84	0.016	0.094	0.096	0.175	22.05	0.011	0.234
TB_16TS091506	0.178	22.94	0.016	0.073	0.11	0.116	21.01	0.012	0.243
TB_BW091706	0.129	30.96	0.017	0.049	0.061	0.156	16.5	0.011	0.235
TB_BR091706	0.192	28.23	0.016	0.094	0.072	0.158	20.24	0.012	0.419
TB_BB091706	0.095	23.75	0.017	0.05	0.074	0.131	19.38	0.013	0.471
TB_LL091706	0.068	19.45	0.014	0.064	0.084	0.183	16.2	0.014	0.404
TB_T091706	0.134	21.15	0.013	0.07	0.135	0.109	20.9	0.013	0.573
TB_CS091706	0.185	21.2	0.014	0.081	0.075	0.123	20.49	0.012	0.293
TB_CW091706	0.574	192	0.011	0.048	0.044	0.079	19.94	0.01	0.08
TB_BR091906	0.258	28.72	0.016	0.069	0.064	0.153	20.24	0.012	0.422
TB_T091906	0.137	21.13	0.014	0.077	0.082	0.099	22.14	0.015	0.884
TB_BW092406	0.249	29.56	0.015	0.05	0.332	0.153	16.84	0.011	0.275
TB_BR092406	0.154	35.29	0.02	0.075	0.1	0.136	19.37	0.011	0.332
TB_BB092406	0.176	25.69	0.155	0.055	0.083	0.084	19.14	0.012	0.287
TB_LL092406	0.165	20.16	0.015	0.056	0.077	0.089	18.02	0.013	0.523
TB_T092406	0.222	21.13	0.016	0.058	0.084	0.078	15.46	0.013	0.416
TB_CS092406	0.242	21.14	0.015	0.057	0.071	0.08	18.25	0.012	0.486
TB_CW092406	0.544	199.7	0.014	0.047	0.034	0.068	20.01	0.01	0.12
TB_19BS101306	0.207	35.33	0.015	0.06	0.077	0.27	18.62	0.011	0.327
TB_19TS101306	0.137	25.39	0.013	0.048	0.095	0.282	19.57	0.013	0.583
TB_21BS101306	0.242	33.13	0.014	0.053	0.082	0.99	18.02	0.011	0.229
TB_21TS101306	0.236	22.48	0.016	0.057	0.096	0.36	14.65	0.014	0.338
TB_1BS101406	0.259	33.58	0.017	0.075	0.074	0.514	17.16	0.011	0.284
TB_1TS101406	0.263	23.64	0.016	0.059	0.082	0.091	14.97	0.013	0.355
TB_3BS101506	0.153	33.22	0.014	0.058	0.064	0.262	21.99	0.011	0.265
TB_3TS101506	0.217	23.94	0.014	0.051	0.071	0.106	14.38	0.012	0.32
TB_5BS101506	0.107	33.91	0.016	0.056	0.064	0.227	15.65	0.011	0.286
TB_5TS101506	0.205	22.82	0.014	0.063	0.091	0.134	47.51	0.012	0.348

Sample	Se	Sr	Ag	Cd	Sn	Sb	Ba	Tl	Pb
TB_7TS101606	0.303	23.53	0.013	0.049	0.064	0.091	13.23	0.012	0.289
TB_9BS101606	0.275	33.92	0.014	0.056	0.06	0.208	15.35	0.011	0.225
TB_9TS101606	0.136	22.13	0.014	0.052	0.074	0.107	16.19	0.012	0.307
TB_BW102606	0.127	27.72	0.014	0.199	0.07	39.02	15.89	0.011	0.357
TB_BR102606	0.251	31.88	0.014	0.081	0.055	5.645	20.49	0.011	0.226
TB_BB102606	0.12	22.85	0.014	0.064	0.07	3.367	15.32	0.011	0.256
TB_LL102606	0.093	19.36	0.014	0.059	0.067	0.931	13.88	0.012	0.707
TB_T102606	0.085	20.71	0.014	0.065	0.084	1.809	17.56	0.011	0.672
TB_CS102606	0.17	20.14	0.013	0.056	0.07	0.194	22.3	0.012	0.301
TB_1BS102706	0.132	25.69	0.014	0.043	0.096	0.107	11.22	0.011	0.193
TB_1TS102706	0.188	20.62	0.012	0.047	0.084	0.08	17.66	0.012	0.227
TB_5BS102806	0.249	24.61	0.012	0.044	0.045	0.113	13.87	0.01	0.168
TB_5TS102806	0.114	19.98	0.012	0.044	0.054	0.081	11.87	0.012	0.283
TB_13BS102806	0.188	16.46	0.013	0.059	0.063	0.085	15.83	0.011	0.227
TB_13TS102806	0.103	17.05	0.012	0.047	0.052	0.083	15.44	0.011	0.302
TB_17BS101906	0.234	17.77	0.013	0.051	0.045	0.103	14.14	0.011	0.222
TB_17TS101906	0.08	17.29	0.012	0.049	0.057	0.085	11.91	0.012	0.34
TB_BW110106	0.21	24.18	0.014	0.054	0.048	0.591	14.53	0.011	0.25
TB_BR110106	0.317	22.01	0.012	0.056	0.051	0.317	21.01	0.011	0.28
TB_BB110106	0.188	19.15	0.012	0.044	0.049	0.167	14.84	0.012	0.338
TB_LL110106	0.141	16.8	0.013	0.048	0.078	0.387	13.34	0.012	0.715
TB_T110106	0.158	18.47	0.013	0.048	0.06	0.678	13.7	0.012	0.475
TB_CS110106	0.195	18.57	0.021	0.053	0.063	0.149	14.45	0.011	0.222

B. Standard deviation of dissolved cation concentrations (Appendix I: A) in Cranberry Creek water samples (ppb).

Sample	Be	B	Na	Mg	Al	Si	K	Ca
TB_BW062206	0.002	0.198	1133	150.3	0.501	125.5	20.73	49.66
TB_BR062206	0.01	0.801	330.2	20.22	1.005	169.1	10.51	282.8
TB_BB062206	0.014	0.495	408.8	28.1	0.063	85.78	5.901	24.32
TB_LL062206	0.019	0.322	507.7	72.34	1.548	139.3	14.01	71.97
TB_CS062206	0.016	0.466	536.4	107.4	1.988	163	87.27	62.83
TB_15BS062406	0.01	0.834	181.8	74.47	0.393	409.5	32.51	72.71
TB_15RS062406	0.006	0.701	525.1	62.51	0.765	174	25.93	130.9
TB_21BS062506	0.004	0.141	299.8	99.01	0.818	319.8	8.354	50.65
TB_21RS062506	0.008	1.456	375.5	26.59	1.916	331.1	34.23	52.58
TB_BW062606	0.01	0.94	253.7	50.13	1.575	150.2	23.77	32.86
TB_BR062606	0.004	0.351	277.9	50.47	11.62	195.9	24.34	154.7
TB_BB062606	0.012	0.282	236.5	54.07	1.648	84.97	39.34	60.94
TB_LL062606	0.004	0.421	209.3	15.08	1.362	97.31	16.79	105.2
TB_CS062606	0.006	0.865	582.5	25.42	3.345	79.62	5.462	232.1
TB_7BS062806	0.014	0.308	156.4	20.09	6.059	230.6	31.22	85.36
TB_7RS062806	0.02	0.16	69.66	8.95	1.972	170.9	79.46	30.33

Sample	Be	B	Na	Mg	Al	Si	K	Ca
TB_8RS062806	0.012	0.889	207.8	17.82	1.405	83.37	27.91	17.12
TB_11BS062906	0.01	0.856	76.77	20.6	2.642	89	28.24	85.57
TB_11RS062906	0.016	0.15	311.7	31.94	0.607	88.17	8.523	45.89
TB_BW063006	0.016	0.512	217.9	37.21	1.593	387.9	26.34	74.05
TB_BR063006	0.018	1.279	196.7	13.75	5.068	186.5	14.09	96.18
TB_BB063006	0.012	0.362	262.9	46.69	1.668	177	464.7	35.75
TB_LL063006	0.021	0.772	119.9	38.39	7.71	241.7	16.79	79.19
TB_CS063006	0.004	0.523	283	41.3	2.571	160.8	17.05	34.6
TB_CW063006	0.004	0.14	321.7	101.4	0.203	58.35	12.71	519.8
TB_BW070306	0.008	0.644	145.2	51.56	2.985	207.7	25.45	95.94
TB_BR070306	0.012	0.438	257	58.89	2.136	133.8	35.4	135.9
TB_BB070306	0.006	0.567	227.9	55.61	4.552	191.5	34	38.94
TB_LL070306	0.011	0.434	87.06	60.59	0.884	315.3	35.22	113.2
TB_CS070306	0.008	0.418	214.6	47.19	2.373	103.3	77.75	70.26
TB_BW081106	0.014	0.938	434.9	120.4	0.249	163.2	2.569	160.8
TB_BR081106	0.004	0.393	542.5	85.23	0.691	109.7	23.37	240.9
TB_BB081106	0.007	0.532	280.9	16.51	1.6	54.1	16.02	29.13
TB_LL081106	0.01	0.291	549.8	53.35	1.152	190.7	8.795	181.7
TB_CS081106	0.006	0.43	257	89.19	2.173	339.4	29.62	55.06
TB_CW081106	0.012	0.299	830.5	214.5	0.101	162.4	22.59	463.2
TB_BW091106	0.006	0.531	609.2	83.79	0.674	138.5	15.35	201.9
TB_BR091106	0.009	0.906	293.4	28.64	0.573	83.11	18.49	232.2
TB_BB091106	0.002	0.436	295.6	48.49	1.162	123.4	31.5	104
TB_LL091106	0.004	0.71	232.6	39.12	2.967	220.8	2.624	63.64
TB_T091106	0.008	0.617	180.5	12.43	1.847	58.55	15.63	131.4
TB_CS091106	0.004	0.803	609	24.28	5.07	37.14	22.57	99.94
TB_CW091106	0.008	0.226	261.3	172.7	0.161	341.1	11	488.4
TB_1BS091406	0.014	0.268	311.8	45.07	1.364	70.08	10.43	173.4
TB_4TS091406	0.012	0.088	289.9	51.92	1.744	272.6	16.76	16.86
TB_15BS091506	0.008	0.39	188.5	48.8	8.676	147.5	2.243	224.1
TB_16TS091506	0.01	0.674	202.6	49.15	4.211	409.6	17.63	89.67
TB_BW091706	0.009	0.472	188.9	21.85	3.268	187.1	18.85	167.4
TB_BR091706	0.002	0.94	402.8	49.06	2.772	64.61	16.37	83.47
TB_BB091706	0.013	0.887	105.1	20.46	3.312	180.8	15.34	18.71
TB_LL091706	0.004	0.364	33.76	17.54	2.162	245.1	8.144	73.51
TB_T091706	0.01	0.969	36.68	35.94	1.618	209.9	12.71	68.36
TB_CS091706	0.006	0.576	267.8	26.42	6.407	126.2	13.1	28.83
TB_CW091706	0.016	0.334	291.3	4.817	0.157	247.3	8.519	624.4
TB_BR091906	0.006	0.763	296	52.61	5.722	145.6	9.755	194.3
TB_T091906	0.015	0.61	228	59.21	2.685	63.95	21.02	47.35
TB_BW092406	0.014	0.352	279.8	24.65	0.667	110.9	12.19	193.5
TB_BR092406	0.004	0.166	196.7	37.23	1.839	178.6	28.25	218.7
TB_BB092406	0.01	1.117	192.6	35.38	2.204	72.49	27.55	42.04
TB_LL092406	0.004	0.426	353.3	20.95	2.46	257.9	14.99	22.2
TB_T092406	0.008	0.156	134.3	45.82	7.402	240.6	5.714	72.25
TB_CS092406	0.01	0.396	285.1	21.25	2.581	153.1	21.46	76.79

Sample	Be	B	Na	Mg	Al	Si	K	Ca
TB_19BS101306	0.002	0.432	155.3	56.84	4.415	133.4	5.95	78.04
TB_19TS101306	0.008	0.288	128.8	91.9	4.082	266.8	52.7	30.37
TB_21BS101306	0.014	0.795	203.3	10.5	4.194	305.4	13.48	26.41
TB_21TS101306	0.008	0.412	169.4	33.44	5.367	188.7	37.46	36.62
TB_1BS101406	0.019	0.648	376.4	81.75	1.265	118.9	16.88	138.4
TB_1TS101406	0.008	0.113	154.9	35.87	4.029	334.4	16.37	73.22
TB_3BS101506	0.006	0.347	299.3	40.51	2.696	268.3	15.61	88.98
TB_3TS101506	0.012	0.27	331.5	97.22	3.34	99.93	24.64	187.2
TB_5BS101506	0.012	0.41	335.3	78.93	0.47	401.3	7.937	99.81
TB_5TS101506	0.012	0.297	438	70.03	3.717	247.1	31.41	149.6
TB_7BS101606	0.006	0.342	382.5	53.07	3.223	294.9	25.53	119
TB_7TS101606	0.008	0.426	292.7	13.1	0.727	360.8	28.44	83.66
TB_9BS101606	0.004	0.446	434.7	60.84	2.925	212.9	5.571	58.84
TB_9TS101606	0.006	0.648	512.9	74.79	5.231	222.7	25.4	122.6
TB_BW102606	0.02	0.393	137.9	57.39	2.641	138.1	32.38	57.34
TB_BR102606	0.015	0.632	313.3	34.73	0.817	144.1	16.72	41.04
TB_BB102606	0.014	0.104	136.8	15.7	2.758	61.3	2.02	58.22
TB_LL102606	0.008	0.275	316.7	34.67	2.175	282.6	17.25	98.23
TB_T102606	0.008	0.399	284.9	44.7	5.968	108.8	20.03	25.84
TB_CS102606	0.014	0.421	130.1	35.8	0.485	73.72	17.74	69.63
TB_1BS102706	0.006	0.498	160.7	27.58	1.776	214.3	20.05	42.82
TB_1TS102706	0.004	0.676	306.4	30.84	3.9	76.96	15.08	26.04
TB_5BS102806	0.016	0.95	22.26	50.62	3.08	131	12.82	55.9
TB_5TS102806	0.014	0.363	255.6	28.32	0.952	206.6	27.04	16.14
TB_13BS102806	0.008	0.788	249.3	13.78	3.771	308.6	19.22	85.32
TB_13TS102806	0.011	0.42	217.2	28.63	1.953	96.07	5.92	29.85
TB_17BS101906	0.019	0.327	147.6	9.232	0.612	220.7	5.008	37.88
TB_17TS101906	0.011	0.705	93.26	11.14	1.721	101.4	14.49	15
TB_BW110106	0.006	0.866	276.5	14.67	2.772	169.7	0.999	106.6
TB_BR110106	0.012	0.227	132.2	36.65	1.593	113.7	12.75	24.96
TB_BB110106	0.004	0.539	108.3	13.19	1.351	278	18.42	68.95
TB_LL110106	0.004	0.221	162.2	8.091	3.614	221.4	8.434	36.58
TB_T110106	0.007	0.323	206.8	41.36	3.557	114.3	13.28	76.29
TB_CS110106	0.011	0.107	104.5	24.08	1.418	292.8	11.37	103

Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As
TB_BW062206	0.03	0.295	1.827	12.64	0.003	0.015	0.102	0.096	0.06
TB_BR062206	0.004	0.227	34.64	15.01	0.06	0.581	0.396	0.056	0.039
TB_BB062206	0.002	0.301	1.439	11.61	0.019	0.554	0.047	0.117	0.022
TB_LL062206	0.008	0.168	4.521	17.2	0.013	0.581	0.109	0.133	0.032
TB_CS062206	0.01	0.379	0.068	4.368	0.004	0.085	0.036	0.169	0.023
TB_15BS062406	0.003	0.138	0.025	9.937	0.001	0.025	0.184	0.089	0.074
TB_15RS062406	0.019	0.195	0.105	12.87	0.003	0.062	0.033	0.037	0.132
TB_21BS062506	0.004	0.077	0.045	4.152	0.002	0.03	0.032	0.072	0.052
TB_21RS062506	0.01	0.242	1.549	6.319	0.006	0.026	0.11	0.171	0.021

Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As
TB_BR062606	0.02	0.214	0.808	2.13	0.006	0.025	0.067	0.454	0.032
TB_BB062606	0.01	0.164	0.24	9.686	0.003	0.003	0.018	0.27	0.03
TB_LL062606	0.014	0.099	24.2	24.06	0.058	0.005	0.114	0.328	0.044
TB_CS062606	0.019	0.198	0.098	10.86	0.009	0.055	0.023	0.231	0.056
TB_7BS062806	0.009	0.231	0.18	5.056	0.004	0.02	0.027	0.057	0.081
TB_7RS062806	0.003	0.198	0.34	3.167	0.002	0.021	0.018	0.029	0.038
TB_8BS062806	0.015	0.371	0.069	6.749	0.002	0.023	0.159	0.149	0.007
TB_8RS062806	0.008	0.113	0.065	5.997	0.001	0.037	0.018	0.139	0.045
TB_11BS062906	0.011	0.208	0.008	5.519	0.004	0.037	0.02	0.185	0.018
TB_11RS062906	0.004	0.372	0.087	3.397	0.003	0.02	0.102	0.335	0.06
TB_BW063006	0.01	0.085	0.272	3.015	0.002	0.031	0.05	0.125	0.016
TB_BR063006	0.012	0.156	1.163	5.282	0.004	0.034	0.007	0.212	0.067
TB_BB063006	0.014	0.298	0.182	14.92	0.001	0.073	0.078	0.252	0.055
TB_LL063006	0.036	0.116	66.81	56.62	0.267	0.037	0.029	0.607	0.033
TB_CS063006	0.012	0.076	2.26	5.459	0.018	0.03	0.041	0.151	0.036
TB_CW063006	0.005	0.308	0.021	3.733	0.002	0.015	0.028	0.021	0.058
TB_BW070306	0.004	0.03	0.062	1.911	0.001	0.019	0.017	0.036	0.017
TB_BR070306	0.006	0.19	3.915	11.14	0.012	0.052	0.074	0.328	0.095
TB_BB070306	0.005	0.064	0.38	7.498	0.003	0.021	0.019	0.212	0.005
TB_LL070306	0.004	0.293	1.036	11.31	0.017	0.094	0.088	0.46	0.056
TB_CS070306	0.011	0.275	2.876	6.559	0.006	0.056	3.26	0.123	0.031
TB_BW081106	0.003	0.1	0.103	6.506	0.004	0.013	0.032	0.186	0.059
TB_BR081106	0.003	0.09	1.667	7.204	0.004	0.018	0.079	0.039	0.083
TB_BB081106	0.003	0.472	0.237	2.884	0.005	0.045	0.044	0.167	0.077
TB_LL081106	0.006	0.153	0.919	12.08	0.005	0.07	0.056	0.101	0.044
TB_CS081106	0.006	0.075	0.34	8.797	0.003	0.018	0.047	0.129	0.081
TB_CW081106	0.011	0.248	0.027	3.769	0.001	0.022	0.02	0.07	0.035
TB_BW091106	0.006	0.253	0.071	4.083	0.004	0.027	0.02	0.062	0.023
TB_BR091106	0.012	0.221	0.495	22.51	0.003	0.026	0.173	0.079	0.099
TB_BB091106	0.004	0.431	0.666	6.462	0.004	0.093	0.045	0.059	0.014
TB_LL091106	0.014	0.071	40.08	27.8	0.095	0.029	0.053	0.294	0.062
TB_T091106	0.006	0.154	14.38	28.14	0.027	0.066	0.027	0.038	0.072
TB_CS091106	0.012	0.178	3.169	5.523	0.012	0.034	0.022	0.043	0.013
TB_CW091106	0.011	0.219	0.027	3.56	0.003	0.025	0.019	0.055	0.092
TB_1BS091406	0.002	0.292	0.111	6.756	0.003	0.041	0.056	0.127	0.048
TB_4TS091406	0.005	0.385	0.046	3.085	0.004	0.044	0.016	0.058	0.04
TB_15BS091506	0.029	0.482	0.624	16.4	0.006	0.06	0.056	0.185	0.063
TB_16TS091506	0.003	0.169	0.121	2.127	0.001	0.046	0.053	0.375	0.055
TB_BW091706	0.007	0.234	0.079	4.257	0.002	0.013	0.012	0.098	0.065
TB_BR091706	0.005	0.118	0.011	3.763	0.003	0.015	0.087	0.232	0.01
TB_BB091706	0.007	0.061	11.71	19.42	0.01	0.002	0.014	0.156	0.029
TB_LL091706	0.008	0.109	1.569	15.65	0.02	0.028	0.06	0.17	0.07
TB_T091706	0.006	0.158	5.248	6.731	0.009	0.02	0.019	0.03	0.022
TB_CS091706	0.004	0.15	0.398	3.196	0.002	0.038	0.014	0.117	0.071
TB_CW091706	0.005	0.32	0.103	7.592	0.003	0.029	0.037	0.004	0.032
TB_BR091906	0.008	0.283	0.77	13.71	0.007	0.055	0.045	0.203	0.03

Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As
TB_BW092406	0.014	0.366	0.311	15.15	0.004	0.066	0.083	0.08	0.04
TB_BR092406	0.01	0.219	0.47	23.76	0.005	0.037	0.03	0.2	0.053
TB_BB092406	0.005	0.24	4.486	14.4	0.005	0.029	0.004	0.103	0.065
TB_LL092406	0.006	0.079	0.877	8.594	0.002	0.052	0.058	0.096	0.027
TB_T092406	0.009	0.084	0.036	10.09	0.001	0.019	0.02	0.148	0.023
TB_CS092406	0.003	0.074	0.656	1.462	0.002	0.013	0.021	0.261	0.045
TB_CW092406	0.001	0.192	0.002	0.58	0.003	0.018	0.017	0.024	0.086
TB_19BS101306	0.01	0.125	0.015	8.521	0.005	0.081	0.022	0.041	0.034
TB_19TS101306	0.009	0.142	0.102	12.08	0.001	0.009	0.018	0.21	0.038
TB_21BS101306	0.008	0.319	0.138	3.746	0.004	0.042	0.097	0.271	0.02
TB_21TS101306	0.005	0.201	0.398	3.984	0.003	0.042	0.128	0.224	0.05
TB_1BS101406	0.011	0.201	0.113	6.971	0.003	0.03	0.037	0.303	0.02
TB_1TS101406	0.009	0.106	0.32	2.04	0.005	0.038	0.007	0.106	0.013
TB_3BS101506	0.016	0.183	0.06	8.002	0.004	0.019	0.04	0.188	0.043
TB_3TS101506	0.005	0.245	0.032	12.73	0.002	0.053	0.022	0.272	0.009
TB_5BS101506	0.009	0.062	0.663	4.069	0.008	0.057	0.041	0.081	0.128
TB_5TS101506	0.005	0.041	0.193	11.61	0.004	0.079	0.018	0.465	0.03
TB_7BS101606	0.002	0.171	0.287	2.597	0.006	0.027	0.053	0.075	0.053
TB_7TS101606	0.001	0.088	0.105	1.333	0.001	0.046	0.024	0.026	0.042
TB_9BS101606	0.009	0.232	0.705	6.038	0.007	0.056	0.04	0.236	0.043
TB_9TS101606	0.007	0.474	0.407	4.386	0.005	0.023	0.049	0.136	0.054
TB_BW102606	0.001	0.279	0.207	9.305	0.004	0.046	0.025	0.045	0.054
TB_BR102606	0.009	0.13	1.524	3.709	0.006	0.048	0.044	0.062	0.023
TB_BB102606	0.005	0.348	1.662	6.67	0.004	0.014	0.062	0.031	0.037
TB_LL102606	0.013	0.124	4.193	8.266	0.02	0.049	0.036	0.123	0.034
TB_T102606	0.009	0.157	12.06	20.64	0.05	0.009	0.008	0.023	0.022
TB_CS102606	0.001	0.09	0.554	0.395	0.003	0.034	0.016	0.078	0.042
TB_1BS102706	0.006	0.28	0.024	2.288	0.003	0.016	0.02	0.27	0.049
TB_1TS102706	0.001	0.16	0.552	13.89	0.005	0.036	0.015	0.083	0.016
TB_5BS102806	0.002	0.027	0.55	9.567	0.005	0.068	0.008	0.095	0.049
TB_5TS102806	0.006	0.204	0.651	14.67	0.009	0.065	0.011	0.151	0.055
TB_13BS102806	0.02	0.148	0.183	6.054	0.003	0.028	0.014	0.198	0.031
TB_13TS102806	0.01	0.11	1.096	3.314	0.003	0.019	0.013	0.399	0.029
TB_17BS101906	0.004	0.289	0.025	5.737	0.004	0.046	0.011	0.228	0.029
TB_17TS101906	0.009	0.037	0.294	8.365	0.001	0.024	0.018	0.145	0.014
TB_BW110106	0.009	0.19	7.008	8.822	0.005	0.01	0.038	0.079	0.07
TB_BR110106	0.006	0.076	2.534	4.243	0.006	0.007	0.054	0.34	0.013
TB_BB110106	0.003	0.244	0.392	4.097	0.003	0.025	0.061	0.05	0.044
TB_LL110106	0.008	0.228	3.038	3.71	0.044	0.03	0.013	0.138	0.119
TB_T110106	0.002	0.057	1.1	3.033	0.004	0.018	0.061	0.12	0.012
TB_CS110106	0.009	0.008	0.164	3.304	0.003	0.028	0.034	0.031	0.073

Sample	Se	Sr	Ag	Cd	Sn	Sb	Ba	Tl	Pb
TB_BW062206	0.13	0.239	0.003	0.005	0.112	0.025	0.126	0.002	0.059
TB_BR062206	0.134	0.169	0.003	0.007	0.02	0.007	0.385	0	0.007

Sample	Se	Sr	Ag	Cd	Sn	Sb	Ba	Tl	Pb
TB_LL062206	0.074	0.165	0.001	0.003	0.006	0.005	0.127	0.001	0.004
TB_CS062206	0.032	0.244	0.001	0.007	0.003	0.006	0.138	0.001	0.003
TB_15BS062406	0.145	0.204	0.001	0.002	0.004	0.008	0.143	0.001	0.004
TB_15RS062406	0.254	0.392	0.001	0.005	0.005	0.009	0.146	0.001	0.007
TB_21BS062506	0.031	0.172	0.001	0.003	0.012	0.003	0.054	0.001	0.005
TB_21RS062506	0.057	0.709	0.001	0.001	0.001	0.003	0.083	0.001	0.009
TB_BW062606	0.181	0.128	0	0.006	0.002	0.007	0.069	0	0.014
TB_BR062606	0.013	0.089	0.001	0.003	0.004	0.006	0.17	0	0.007
TB_BB062606	0.125	0.346	0	0.001	0.004	0.003	0.22	0	0.006
TB_LL062606	0.107	0.152	0.001	0.006	0.005	0.005	0.348	0	0.174
TB_CS062606	0.109	0.34	0	0.006	0.004	0.002	0.392	0	0.001
TB_7BS062806	0.164	0.152	0	0.009	0.008	0.004	0.059	0	0.01
TB_7RS062806	0.102	0.131	0.001	0.001	0.001	0.005	0.027	0	0.006
TB_8BS062806	0.021	0.153	0.001	0.006	0.003	0.004	0.03	0	0.002
TB_8RS062806	0.127	0.153	0.001	0.004	0	0.005	0.197	0.001	0.006
TB_11BS062906	0.075	0.168	0	0.004	0.001	0.011	0.147	0.001	0.001
TB_11RS062906	0.114	0.164	0	0.003	0.006	0.004	0.073	0.001	0.003
TB_BW063006	0.157	0.202	0	0.005	0.001	0.011	0.171	0	0.001
TB_BR063006	0.047	0.207	0	0.005	0.001	0.002	0.196	0.001	0.017
TB_BB063006	0.034	0.254	0.001	0.002	0.003	0.007	0.095	0.001	0.002
TB_LL063006	0.108	0.101	0	0.004	0.002	0.005	0.591	0.001	0.575
TB_CS063006	0.077	0.213	0.001	0.003	0.004	0.006	0.083	0.001	0.043
TB_CW063006	0.16	2.554	0	0.003	0.006	0.006	0.098	0	0
TB_BW070306	0.028	0.167	0.001	0.002	0.005	0.016	0.181	0.001	0.002
TB_BR070306	0.143	0.218	0.002	0.005	0.001	0.005	0.166	0	0.016
TB_BB070306	0.019	0.126	0.001	0.004	0.004	0.013	0.074	0.001	0.003
TB_LL070306	0.074	0.335	0.002	0.004	0.005	0.004	0.154	0	0.01
TB_CS070306	0.101	0.055	0	0.005	0.002	0.004	0.092	0.001	0.041
TB_BW081106	0.156	0.699	0.001	0.005	0.006	0.015	0.092	0	0.005
TB_BR081106	0.166	0.371	0	0.002	0.001	0.005	0.019	0	0.005
TB_BB081106	0.105	0.123	0	0.002	0	0.005	0.171	0	0.001
TB_LL081106	0.125	0.326	0.001	0.002	0.003	0.012	0.085	0	0.002
TB_CS081106	0.186	0.643	0	0.002	0.003	0.003	0.121	0	0.011
TB_CW081106	0.04	1.899	0	0.002	0.002	0.006	0.037	0.001	0.001
TB_BW091106	0.056	0.389	0	0.001	0.001	0.003	0.106	0	0.008
TB_BR091106	0.215	0.184	0.001	0.001	0.005	0.002	0.206	0	0.004
TB_BB091106	0.064	0.199	0	0.005	0.003	0.002	0.173	0.001	0.008
TB_LL091106	0.016	0.23	0	0.005	0.009	0.005	0.248	0	0.26
TB_T091106	0.11	0.098	0	0.005	0.004	0.01	0.097	0	0.065
TB_CS091106	0.064	0.208	0.001	0.003	0.008	0.002	0.028	0	0.023
TB_CW091106	0.169	2.984	0	0.003	0.002	0.005	0.114	0	0.001
TB_1BS091406	0.065	0.298	0.001	0.001	0.013	0.007	0.08	0	0.006
TB_4TS091406	0.156	0.149	0	0.003	0.002	0.003	0.079	0	0.003
TB_15BS091506	0.108	0.161	0	0.006	0.005	0.012	0.47	0	0.008
TB_16TS091506	0.142	0.226	0.004	0.003	0.004	0.004	0.212	0	0.008

Sample	Se	Sr	Ag	Cd	Sn	Sb	Ba	Tl	Pb
TB_BR091706	0.115	0.491	0.001	0.005	0.002	0.008	0.158	0.001	0.001
TB_BB091706	0.091	0.294	0.001	0.002	0.002	0.002	0.212	0.001	0.065
TB_LL091706	0.087	0.233	0.001	0.006	0.004	0.007	0.108	0	0.009
TB_T091706	0.08	0.184	0.001	0.005	0.005	0.006	0.282	0	0.075
TB_CS091706	0.092	0.206	0	0.01	0.006	0.005	0.103	0	0.005
TB_CW091706	0.072	2.365	0.001	0.004	0.001	0.006	0.082	0	0.002
TB_BR091906	0.068	0.161	0.001	0.006	0.002	0.008	0.323	0	0.012
TB_T091906	0.165	0.181	0.001	0.001	0.004	0.004	0.132	0.001	0.043
TB_BW092406	0.166	0.079	0	0.004	0.007	0.008	0.207	0	0.013
TB_BR092406	0.081	0.261	0.001	0.002	0.004	0.007	0.117	0.001	0.009
TB_BB092406	0.021	0.064	0.004	0.005	0.002	0.007	0.239	0	0.025
TB_LL092406	0.082	0.078	0.001	0.002	0.007	0.005	0.18	0.001	0.035
TB_T092406	0.043	0.201	0.001	0.004	0.004	0.006	0.048	0	0.002
TB_CS092406	0.106	0.283	0.001	0.006	0.003	0.001	0.127	0	0.015
TB_CW092406	0.181	0.578	0	0.003	0.002	0.001	0.123	0	0.002
TB_19BS101306	0.097	0.248	0	0.003	0.001	0.009	0.071	0	0.009
TB_19TS101306	0.112	0.21	0	0.004	0.009	0.015	0.178	0.001	0.004
TB_21BS101306	0.081	0.387	0.001	0.003	0.003	0.012	0.125	0	0.003
TB_21TS101306	0.131	0.088	0.001	0.007	0.001	0.017	0.081	0.001	0.007
TB_1BS101406	0.049	0.398	0	0.004	0.004	0.007	0.192	0	0.003
TB_1TS101406	0.06	0.205	0.001	0.004	0.002	0.006	0.041	0.001	0.002
TB_3BS101506	0.057	0.411	0.001	0.002	0.003	0.008	0.181	0	0.003
TB_3TS101506	0.06	0.282	0.001	0	0.003	0.004	0.034	0.001	0.004
TB_5BS101506	0.199	0.242	0.001	0.003	0.003	0.007	0.138	0	0.005
TB_5TS101506	0.034	0.282	0.001	0.005	0.003	0.007	0.198	0	0.011
TB_7BS101606	0.06	0.163	0.001	0.003	0.001	0.004	0.084	0	0.006
TB_7TS101606	0.041	0.175	0.001	0.003	0.004	0.004	0.131	0.001	0.002
TB_9BS101606	0.049	0.435	0.001	0.001	0.001	0.009	0.051	0	0.002
TB_9TS101606	0.097	0.321	0.001	0.003	0.004	0.003	0.059	0	0.002
TB_BW102606	0.143	0.248	0.001	0.003	0.004	0.464	0.271	0	0.011
TB_BR102606	0.072	0.697	0.001	0.002	0.003	0.036	0.124	0	0.006
TB_BB102606	0.143	0.043	0	0.002	0.004	0.058	0.016	0	0.014
TB_LL102606	0.058	0.219	0.001	0.004	0.003	0.016	0.088	0	0.083
TB_T102606	0.081	0.076	0.001	0	0.005	0.223	0.127	0	0.097
TB_CS102606	0.166	0.017	0.001	0.006	0.007	0.006	0.155	0	0.014
TB_1BS102706	0.17	0.212	0.001	0.004	0.009	0.006	0.039	0	0.007
TB_1TS102706	0.028	0.046	0.001	0.003	0.004	0.002	0.008	0	0.008
TB_5BS102806	0.013	0.233	0	0.001	0.005	0.003	0.126	0	0.002
TB_5TS102806	0.21	0.198	0.001	0.003	0.002	0.007	0.195	0	0.01
TB_13BS102806	0.168	0.269	0	0.004	0.003	0.002	0.074	0	0.005
TB_13TS102806	0.065	0.062	0.001	0.001	0.005	0.002	0.146	0	0.01
TB_17BS101906	0.043	0.018	0	0.002	0.002	0.004	0.138	0	0.006
TB_17TS101906	0.043	0.095	0.001	0.005	0.003	0.002	0.086	0	0.002
TB_BW110106	0.112	0.297	0	0.004	0.002	0.019	0.085	0	0.013
TB_BR110106	0.041	0.113	0.001	0.002	0.006	0.004	0.229	0	0.009

Sample	Se	Sr	Ag	Cd	Sn	Sb	Ba	Tl	Pb
TB_LL110106	0.24	0.195	0	0.004	0.003	0.011	0.169	0	0.032
TB_T110106	0.104	0.057	0.001	0.005	0.004	0.025	0.079	0	0.02
TB_CS110106	0.22	0.032	0.001	0.002	0.006	0.004	0.125	0	0.003

Andrea Luebbe

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Parents: John and Cynthia Luebbe
Birth: Bozeman, MT, May 17, 1983

EDUCATION: **Lehigh University**, Bethlehem, PA
B.S. in Ecology, May 23, 2005
GPA Overall: 3.66

HONORS: Poster Presentation Winner at Lehigh Valley Ecology and Evolution Symposium; Track and Field/Cross Country Individual Academic All-American 2nd Team 2005-06; USAT All-American Triathlete 2006; 2007 Ryan Collegiate All-Star Cycling Team member; Track and Field/Cross Country Individual Academic All-District 1st Team 2005-06; Two-Time First Team All-Patriot League Cross Country; 2003 Athlete of the Year Cross Country; 2005 Cornerstone Award Cross Country; Four-Year Team Academic All-American and Letter Winner Cross Country and Track; Indoor Track Patriot League Runner of the Week; Cross Country Patriot League Runner of the Week; Indoor Track ECAC Runner of the Week; Dean's List; Sigma Xi Student Member; Phi Sigma Pi; Phi Eta Sigma Honor Fraternity; National Society of Collegiate Scholars.

RESEARCH AND RELATED EXPERIENCE:

Teaching Assistant, Lehigh University
Bethlehem, PA — Fall 2005 – Present
Supervised Mount Bethel Fens, South Mountain groundwater, and Lehigh River water quality data collection and computer analysis by undergraduate interns.

Teaching Assistant, Lehigh University
Bethlehem, PA — Spring 2007 – Present
Prepared lectures, graded assignments, and taught the course, "Science of Environmental Issues."

Presenter and Planning Committee Member, Invasive Species Training and Demonstration Project
Emmaus, PA — Spring 2006
Presented to area land managers GIS applications toward invasive species extent mapping and monitoring. Designed three-session program with NPO and NGO supervisors in area.

Intern, Lehigh Earth Observatory and The Nature Conservancy
Bethlehem, PA Summer 2003 – Summer 2005
Monitored water amount, quality, and chemical composition in Mount Bethel Fens groundwater wells and Jacoby Creek. Sampled fens soil for alkalinity test. Monitored fens plants and created herbarium. Gathered weather data from fens stations with Hobo shuttle. Monitored Lehigh River water quality (measured conductivity, dissolved oxygen, pH, alkalinity, particulate matter, particulate phosphate, absorbance, fluorescence, and total organic carbon from samples). Collected *Hydrolab* datasonde from Lehigh River for calibration, cleaning, and re-deployment. Analyzed data and prepared written reports and presentations.

Undergraduate Research, Lehigh University
Bethlehem, PA Winter 2004 – Spring 2005
Honors thesis for forest vegetation restoration from agricultural use related to soil characteristics, herbivory, and seed supply.

Consulting Intern, Hill Environmental Group, Inc.
Pennington, NJ Summer 2004
Wrote part of environmental impact statement, collected vegetation analysis data, researched for reports, re-formatted procedures according to EPA guidelines, edited documents, performed office work, and carried out document collection and distribution.

Government Intern, Environment ACT
Canberra, Australia May and June 2004
Collected and analyzed stream water quality data from Australian Capital Territory. Produced graphical representation of data and written description for annual report – published for Australian government. Monitored trout-cod fish through surgically inserted tracking system. Collected fox scat data to analyze for effect on bandicoot ecology. Observed kangaroo control and well-water permit monitoring. Scuba dived on the Great Barrier Reef.

Extern, Hill Environmental Group, Inc.
Pennington, NJ January 5-7, 2004
Learned about environmental consulting through field work and reading. Shadowed senior project geologist, Andrea McGahan.

Extern, Friends of Peace Valley Nature Center
Doylestown, PA January 8-10, 13, 2004
Learned about environmental education. Shadowed center coordinator, Gail Hill. Nature walks, Alliance for New Jersey Environmental Education convention, and observed elementary level classes.

Laboratory Assistant, Plant Growth Center
Bozeman, MT Summers 2001 and 2002
Tested seed potato leaves for diseases. Prepared test results for report. Kept lab clean and organized.

SKILLS: Computer: ArcGIS, Microsoft Office Suite, ENVI, Omnion 3.0, Flowlink 4, TOC-Control V, EcoWatch, LoggerNet 2.1c, PC208W 2.0, Spectrum, Sigmaplot, Aabel, BoxCar Pro, Statistica, and Internet.
Languages: Basic Spanish

LEADERSHIP: **Department Co-Representative**

Graduate Student Senate — Fall 2006 – Present

Attend graduate student senate meetings, provide input, and report back to department.

Team Representative

COACH Program — Fall 2002 – Spring 2005

Organized events such as mentoring Broughal Middle School students and adopting a family for Christmas through Community Outreach by Athletes who Care about Helping.

Fundraising Committee Chair

Phi Sigma Pi — Fall 2002 – Spring 2004

Organized fundraising events such as selling t-shirts, Halloween grams, game night, raffle, and working Lehigh Bookstore booth at football games for Honor, Service, and Social Fraternity.

ACTIVITIES: SCUBA Diving (PADI Open Water Certified); GSA, SIL, Lehigh University Cycling Club; Lehigh University Philharmonic Orchestra; Lehigh University Wind Ensemble; Clarinet Ensemble; Hope Lutheran Church service and clarinet performances; Bozeman, MT City Band; outdoor activities; sports. Travel includes: South Africa; Zambia; Zimbabwe; Australia; St. Martin; St. Thomas; St. John; Grand Cayman; Hawaii; Alaska; South Florida for ecological activities.

END OF TITLE