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Water Quality Analysis of Black Creek Watershed: Identification of Point and Nonpoint Sources of Pollution and Loading Simulation Using the SWAT Model

by

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A thesis submitted to the Department of Environmental Science and Biology of the State University of New York College at Brockport in partial fulfillment of the requirements for the degree of

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Water Quality Analysis of Black Creek Watershed: Identification of Point and Nonpoint Sources of Pollution and Loading Simulation Using the SWAT Model

Date ______________________

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Abstract

Nearshore Lake Ontario suffers from several beneficial use impairments due to water quality issues from the Genesee River and its contributing tributaries. Segments of Black Creek located in the Lower Genesee River basin are listed as impacted on the New York State 303(d) list because of excess sediment, nutrient, and bacteria losses. Sources of these pollutants from the Black Creek watershed include improperly managed cropland and pastures, dairy manure application, and effluent discharges from wastewater treatment plants. An assessment of the Black Creek watershed was undertaken to determine the nutrient and sediment contribution of Black Creek to the Genesee River and to determine sources of nutrients and sediment loss geospatially within the watershed. To accomplish this task, a multifaceted, integrated approach was taken by combining stream monitoring, segment analysis, and hydrologic modeling [Soil and Water Assessment Tool (SWAT)]. The annual losses (June 2010 through May 2011) of total phosphorus (TP), total nitrogen (TN), and total coliform bacteria from the Black Creek watershed were 16.5 MT/yr, 349.4 MT/yr, and 7.0E15 CFU/yr, respectively, where most of the losses occurred in the upper portion of the watershed. Impacted tributaries (Bigelow Creek and Spring Creek) had the highest areal loads of nutrients and bacteria and were a focus for remediation. More than 70% of the TP load was found to be due to anthropogenic sources including but not limited to manure applications from Confined Animal Feeding operations, the Bergen wastewater treatment plant, and nonpoint agricultural practices throughout the watershed. Sediment loss, on the other hand, was the highest in the downstream reaches of Black Creek where 73% of the total sediment load (8,360.6 MT/yr) occurs due to excessive flooding and stream bank erosion during events. These findings were used to calibrate a SWAT model for Black Creek that simulated the impact of implementing several Best Management Practices (BMPs) to reduce phosphorus and sediment loads. Individual BMPs reduced TP loads from Black Creek at Lower BC anywhere from 0 to 28% and sediment 0 to 84%. A holistic approach to watershed remediation using a combination of several effective BMPs focusing on major contributors of phosphorus and sediment reduced TP 28% and total suspended solids (TSS) 73%. This remedial action plan, if implemented, can reach a water quality target of 65 µg P/L proposed by the Department of Environmental Conservation, which would reduce the annual TP concentration from 79.6 µg P/L to 38.3 µg P/L. This scenario can be used to determine an appropriate Total Maximum Daily Load for Black Creek that will help attain the ultimate goal of reducing the impairments of nearshore Lake Ontario.

Introduction

The United States Environmental Protection Agency has reported that nutrient enrichment from point and nonpoint sources is the largest contributor to the impairment of lakes and other water bodies within the United States (USEPA 1994). Thus, the mitigation of soil and nutrient loss is a major concern within watersheds in the US (Makarewicz and Lewis 2009). Under the Clean Water Act (CWA), states are required to periodically assess the quality of waters within their state and report on their findings. Section 303(d) requires states to identify impaired waters within the state where designated uses of the water body are not supported. Since its passage in 1972, the CWA has focused on reducing sources of nutrients from a single discharge point. One of the limitations of the CWA is the lack of control on nonpoint pollution sources that contribute pollutants to rivers and streams from numerous locations spread in a large area (Puckett 1994). States must also designate a Total Maximum Daily Load (TMDL) in order to reduce the input of pollutants that impair the waters. The TMDL determines the maximum amount of a pollutant that a certain water body can assimilate while maintaining adequate water quality to meet government standards (Cadmus Group 2007).

Sources, such as surface runoff of sediments and nutrients, animal and human wastes, agricultural chemicals, and industrial discharges, can all lead to water quality issues. Urban and agricultural runoff can produce undesirable effects to downstream ecosystems such as increased algae and bacteria, eutrophication, increased abundance of macrophytes, and generally reduced aesthetics (Makarewicz and Lewis 2009).

Bioavailable phosphorus (BAP) in agricultural runoff represents phosphorus that is potentially available for algal uptake, which can result in accelerated eutrophication of a water body that is receiving this input (Sharpley *et al*. 1992). In addition to BAP, particulate phosphorus, which is associated with sediment runoff, can serve as a long-term source of potentially bioavailable phosphorus in lakes (Sharpley *et al.* 1992). Commercial fertilizer and animal manure are both important nonpoint sources of phosphorus and nitrogen that are applied to agricultural land within the United States. Eutrophication from excessive algae growth may develop in nutrient-rich waters downstream from nonpoint sources of these nutrients. This is unattractive and causes damaging effects to the ecosystem (Puckett 1994).

Within the Great Lakes basin, urban runoff, contaminated sediments, sewage overflow, and animal and crop agriculture have been identified as major sources of nutrients, which impair the Great Lakes shoreline (USEPA 2002). It is well known that the Genesee River has a water quality problem; the main stem of the Genesee River is on the New York State 303(d) impaired waters list (He and Crowley 2007), and the Rochester Embayment is on the Area of Concern List (AOC), as defined by the U.S-Canada Great Lakes Water Quality Assessment. Point and nonpoint sources of nutrients and soil loss within the Genesee River watershed cause or have an effect on many beneficial use impairments in nearshore Lake Ontario such as eutrophication, nuisance algae, beach closings, and the degradation of fish habitat, aesthetics, benthos, and phytoplankton populations (Makarewicz 2010). Human activity within the Genesee River watershed can have a direct impact on land and water use patterns. If these activities are not monitored and managed, there can be large negative effects on water quality (GFLRPC 2006). The Genesee River basin drains a highly diverse land-use area, which includes urban and industrial impacts, residential communities, agricultural areas, and forested land (NYSDEC 2003).

Identification of Sources

Makarewicz and Howell (2007) have suggested that the drainage from Lake Ontario tributaries is impacting the nearshore waters of Lake Ontario. Nutrient loads from the Genesee River are second highest into Lake Ontario after the Niagara River (Booty *et al.* in press). In order to manage these problems and rehabilitate impaired waters in the Genesee River and the south shore of Lake Ontario, the sources of soil and nutrients need to be identified in the Genesee River watershed. Management of these problems, and rehabilitation of impaired waters, requires the identification and tracking of point and nonpoint sources of materials that are transported throughout the watershed (He and Crowley 2007).

Streams within a subwatershed can be used to monitor watershed health because nutrients are easily transported by water. Nutrients can then be traced back to the source by monitoring the stream geographically (Makarewicz and Lewis 2001). Segment analysis or stressed stream analysis is a useful method to identify point and nonpoint sources of nutrients, soils, salts, and metals within a watershed. This is a comprehensive approach that identifies impacted subwatersheds and associated streams within an entire watershed (Makarewicz and Lewis 2001). Stressed stream analysis determines the location of sources, the extent, and effects of pollution within a watershed. By dividing a subwatershed into small geographic units and by taking water samples for analysis at the beginning and end of each unit, sources of water quality problems within the subwatershed can be identified (Makarewicz and Lewis 2009). This approach combines aspects of many disciplines including limnology, hydrology, and ecology to look at the cause and effect of pollution in disturbed stream environments (Makarewicz and Lewis 1993).

Determination of sources and the extent of soil and nutrient loss from a watershed is the preliminary step for remedial action, which can then be used to make cost-effective land management decisions (Makarewicz *et al.* 2006). The basin characteristics, such as land-use and land cover, slope, and soil conditions, affect the quality of receiving waters through the regulation of sediment and chemical composition (Basnyat *et al*. 2000). Due to the correlation between pollution loading and land-use, there is the potential for water quality to be managed through proper land-use management (Basnyat *et al*. 2000). Once the sources are identified, Best Management Practices (BMPs) for land-use may be recommended and instituted to reduce or reverse Beneficial Use Impairments (BUIs) (Makarewicz 2010; Makarewicz and Lewis 2001).

Assessment Tools

Water quality models can help to organize and interpret data while providing continuous predictions of water quality quickly and efficiently (Spruill *et al.* 2000). Models are beneficial because they can help us understand hydrologic processes, evaluate the risks and benefits of land-use, and develop land-use management practices over varying periods of time (Spruill *et al*. 2000). Through the use of hydrologic modeling, TMDLs can be developed by simulating loads to water bodies while various potential BMPs are in place (Santhi *et al.* 2001). These models use a combination of observational data from historical and current monitoring which provide information for TMDL load allocations (Santhi *et al.* 2001). Although computer simulation models are useful tools for watershed science, they are not perfect in their ability to predict water quality from every watershed with complete accuracy. The ability of a model to fit observational data does not mean that the model setup and parameterization is adequate. There are many limitations to watershed models including the spatial and temporal variability within the natural watershed that is not completely inherent within watershed models (Harris and Heathwaite 2005). New technologies have been developed which have the ability to collect complete and representative datasets from watersheds. If watershed models are based on concrete data that better represents the links between land-use and water quality more effective policy decisions can be made (Harris and Heathwaite 2005).

The Soil and Water Assessment Tool (SWAT) is a basin-scale, continuous-time model that can be used to predict the impact of watershed management on water quality (Arnold *et al*. 1998, Gassman *et al.* 2007). It has proven effective for assessing water resources and nonpoint pollution issues for a large range of environmental conditions and scales around the world (Gassman *et al*. 2007). Once initial sampling is complete, the SWAT model may be used to determine the most effective BMPs to reduce sediment and nutrient load.

Background: Genesee River Basin

The Genesee River basin (Fig. 1) (Lat. 43°15 N; 77°36 W at the mouth) spreads over 6,423 km^2 in west-central New York and in north-central Pennsylvania (Eckhardt *et al*. 2007). The watershed is roughly rectangular in shape flowing from south to north; the main stem reaches about 247 km from its headwaters in the Alleghany plateau in Pennsylvania to drain into Lake Ontario at Charlotte, New York (NYSDEC 2010a; USEPA 1991a). The long-term mean flow of the Genesee River at Lake Ontario is 77 m^3/s. The mean annual temperatures of the Genesee River basin are 13ºC in the lower basin and 7ºC in upland areas (USEPA 1991a). Mean annual precipitation for the watershed, which is the primary source of water in the basin, is approximately 83.8 cm/yr (US Army Corps of Engineers 1967).

The Genesee River watershed encompasses much of Livingston, Allegany, Monroe, Genesee, and Wyoming Counties, as well as sections of western Ontario, Orleans, Steuben, and Cattaraugus Counties (NYSDEC 2010a). The basin contains four of the western most Finger Lakes (Conesus, Hemlock, Canadice, and Honeoye Lakes), and the New York State Barge Canal or Erie Canal near Rochester crosses the Genesee River (Eckhardt *et al*. 2007). Major tributary watersheds to the Genesee River within New York State include Canaseraga Creek, Honeoye Creek, Oatka Creek, and Black Creek (Eckhardt *et al*. 2007). The basin also includes 31 significant freshwater lakes, ponds, and reservoirs, which include Conesus Lake, Mount Morris Reservoir, Hemlock Lake, and Honeoye Lake (NYSDEC 2010a). The basin is divided into two primary drainage basins that contain a total of 24 separate watersheds, each with unique physical, environmental, and social characteristics (GFLRPC 2004).

The present state of the Genesee drainage system is a product of glacial succession during the Pleistocene period. This started with Wisconsinan Glaciation that formed the Olean terminal Moraine band running across southern New York and northern Pennsylvania (USEPA 1991b). During deglaciation of the basin, thick deposits of fluvial sand, gravel, clay, silt, and fine sand were left within the river valley. The most productive aquifers within the basin are the glacial and alluvial deposits of sand and gravel. Bedrock aquifers are used for water supply in areas where significant sources of sand and gravel are unavailable. These aquifers are made up of sedimentary units of shale, limestone, sandstone, and dolostone (Eckhardt *et al.* 2007).

The Genesee River basin drains a diverse area, which includes urbanized Rochester, commercial and industrial areas, residential communities, agricultural areas, and forested areas of low human population (NYSDEC 2003). The population of the entire Genesee River basin within New York State was totaled to be 401,000 people in 2000. The area with the largest population is within the city of Rochester with a considerable population in the suburban areas outside of the city (NYSDEC 2010a). The suburban regions give way to agricultural land in the fertile areas of the Genesee River Valley. Agriculture is the largest land-use in Livingston, Genesee, Wyoming, and Allegany Counties and forested land is the predominant land cover at the Genesee River headwaters in Pennsylvania (GFLRPC 2004). In the Genesee

River watershed approximately 52% of land is used for agriculture, 40% is forested, and 4.6% of land is developed (residential, commercial, industrial, utilities, or mixed urban) (GFLRPC 2004). The last two categories of land-use are wetlands and water, which comprise less than 2 percent of the total coverage area (GFLRPC 2004).

Sources of high impairment within the Genesee River basin include road bank erosion, stream bank erosion, habitat modification, hydrologic modification of the streambed, failing on-site systems, landfill/land disposition, resource extraction, urban runoff, agriculture, toxic/contaminated sediments, storm sewers, municipal drainage, and industrial discharges (GFLRPC 2004). Nonpoint urban runoff of the Lower Genesee River flushes many pollutants, nutrients, debris, and contaminated sediments into the river. Much of the silt and sediment load to the river is naturally occurring, but extensive agricultural activity and continued land development contribute to a high degree of loading. In addition to sediment load, nutrient loads from nonpoint sources impact the water quality of the basin. High nutrient concentrations can lead to excessive and uncontrollable weed and algae growth downstream that restricts many beneficial uses of the Genesee River and Lake Ontario. Agricultural activity, in addition to residential septic-systems and runoff is considered to be the largest source of nutrient load (NYSDEC 2003).

Within the Genesee River watershed, nine of the 31 large water bodies are listed on the US Department of Environmental Conservation’s Priority Waterbodies List (PWL). Six of these bodies of water require a TMDL. Of the river and stream miles within the Genesee River basin, 34% are included on the DEC’s PWL; 8% are listed as non-supportive of appropriate uses; 26% are listed as having minor impacts or threatened. Most of these segments are on the Genesee River, Black Creek, Oatka Creek, and Canaseraga Creek. Included among stream segments that are most heavily impaired from agricultural activities are Black Creek, Jaycox Creek, and Bigelow Creek (NYSDEC 2003). The focus of this study will be on the Black Creek watershed due to its high priority status as a threatened area.

Background: Black Creek Watershed

The Black Creek watershed (Fig. 2) (Lat 42° 27’ N; Long 78° 22’ W) comprises a large portion of the lower Genesee River drainage basin in New York (Autin *et al*. 2003), approximately 8% of the total Genesee River Basin. Black Creek flows from south to northeast from its headwaters in the Town of Middlebury, New York, and enters into the Genesee River in the Town of Chili, New York. The water from Black Creek flows through the City of Rochester via the Genesee River and eventually empties into the southern shore of Lake Ontario. The Black Creek drainage area is approximately 325.22 km^2 and covers 128,358 acres. The main stem of the river runs about 67.62 km. The total relief of the watershed is about 210 m with headwater elevations of 360 m and elevation of 153.6 m at the junction with the Genesee River (GFLRPC 2006).

The Black Creek watershed encompasses the counties of Genesee, Monroe, Orleans, and Wyoming and the towns of Middlebury in Wyoming; Bethany, Stafford, Batavia, Elba, Byron, Bergen, and LeRoy in Genesee County; Clarendon in Orleans County; and Sweden, Ogden, Riga, Chili, and Wheatland in Monroe County. Major tributaries within the watershed include Bigelow Creek, Spring Creek, North Branch Black Creek, Robin's Brook, Black Creek Tributary, Hotel Creek, and Mill Creek (Fig. 2). The largest wetland in the watershed is part of Bergen Swamp, which is a large mature swamp (Autin *et al*. 2003).

The land-use patterns in the Black Creek watershed are predominantly agricultural and rural with secondary uses of residential and commercial. There are also wetlands and forested areas that make up the rest of the land-use within the watershed (Autin *et al*. 2003). Human activity within the watershed has a direct impact on land-use and water-use patterns, which can negatively affect water quality if not managed (GFLRPC 2006). The human population in Black Creek watershed as of the year 2000 was estimated to be between 35,030 to 46,081. Most of the population resides in Chili and Churchville and in the southwest region of the city of Rochester. Agricultural use makes up the largest portion of land-use within the watershed at 78%. The primary agricultural activities in the area are vacant land, field and vegetable crops, dairy farming, and livestock operations (Autin *et al*. 2003). Residential land-uses are focused in Chili, Batavia, Bergen, Byron, and Stafford. The commercial land-uses are mainly in population centers near the city of Rochester, Batavia, and along roadways. Municipal and community service areas are also distributed throughout the watershed in a manner that correlates with the distribution of human population centers (Autin *et al*. 2003). Forested land makes up 8% of the land-use, and wetlands make up about 7% of the watershed area.

Black Creek has many risks that impair its water quality. The highest risks are from industrial point sources, agricultural nonpoint sources, and nonpoint sources from developed areas. Industrial and chemical activities in the watershed handle chemicals and hazardous materials, metal recovery, and food packaging which affect water quality from spills, solid and hazardous waste generation, and leaking underground storage tanks (Autin *et al*. 2003; GFLRPC 2006). Agricultural discharges are associated with the production of animal waste as well as the use of fertilizers, pesticides, and herbicides on farm fields. Nonpoint sources include transport of excess nutrients and pesticides applied to the land by runoff or groundwater, whereas point sources include discharges from small or confined areas such as a Confined Animal Feeding Operation (CAFO). There are eleven farms within the Black Creek Watershed defined as CAFOs that are all dairy farms. Wastewater treatment plants (WWTPs) are another point source that can discharge large quantities of nutrients into the water. The goal of a WWTP is to effectively remove physical (1° treatment), biological (2° treatment), and chemical (3° treatment) contaminants from human wastewater to be discharged into soil or water (USEPA 2000a). There are currently four active WWTPs in the Black Creek watershed and one closed WWTP. The State Pollutant Discharge Elimination System (SPDES) is a New York State program created by the DEC, which is used to control point sources of effluent by issuing permits to polluters (NYSDEC 2010b). This program limits the allowable amount of effluent that can be discharged into waterways, which can be decreased over time (NYS Department of State 2000). There are 31 registered

SPDES sites within the Black Creek watershed. The nonpoint sources of pollution discharge in the watershed emanate from developed areas, agricultural fertilizers and tillage, storm water runoff, sewer system discharge, and stream bank erosion (Autin *et al*. 2003).

Black Creek is currently designated as a Class C stream by the NYSDEC and has known impairments in the Upper and Lower reaches due to excessive nutrients from agricultural and municipal sources. The Bigelow Creek subwatershed of Black Creek is also known to have impairments to aquatic life from excess nutrients (NYS DEC 2003). A goal for water quality has been set to have "waterways in the Black Creek Watershed meet the best use classification goals set for them by the NYSDEC" (Autin *et al*. 2003). Tributaries of the Genesee River have been evaluated through the New York Statewide Waters Monitoring Program to determine segments within the drainage basin that need greater attention for study and remediation efforts. The Black Creek watershed has been designated by the GFLPC as "high priority; needs verification" by the PWL ranking system. The use impairments include stressed aquatic life and recreation as well as habitat and hydrology, which are suspect to stress. Major pollutants are suspected to include nutrients, pathogens, and depleted oxygen levels. Agriculture is also known to be a major source of pollution including many CAFOs of varying size classes (GFLRPC 2006). It is due to these known water quality issues that the Black Creek watershed is chosen to be the subject of this study.

Objectives and Goals

This study will assess the sources and sinks of sediment, nutrients, and bacteria in the Black Creek watershed and will evaluate its impact on the Genesee River. It will also determine what best management practices will be most effective at reducing the flux of sediments and phosphorus into the creek. Finally, it will identify a phosphorus concentration for Black Creek that is a reasonable water quality target from the point of view of watershed management. Specific objectives are listed as follows:

Objective 1: Determine the contribution of Black Creek and its tributaries to the watershed and to the Genesee River using discharge measurements and water quality monitoring.

Objective 2: Employ the stressed stream analysis approach to evaluate the relative impact that point sources such as wastewater treatment plants and the surrounding land uses have on water chemistry of stream segments throughout Black Creek.

Objective 3: Develop and calibrate a hydrological model (SWAT) to determine the allocation of pollution fluxes from different parts of the watershed, evaluate the role that point sources and septic fields have at the watershed scale, and determine which BMPs will be most effective at reducing the load of phosphorus to a reasonable level.

Methods

Study Site

The study area for this research was the Black Creek watershed (Lat 42° 27’ N; Long 78° 22’ W) (Fig. 2) located in the counties of Genesee, Monroe, Orleans, and Wyoming in New York State, USA. Within the watershed there are nine major tributaries and 23 minor tributaries that drain into the main stem of Black Creek. The major tributaries include Northeast Tributary, Black Creek Tributary, North Branch of Black Creek, Spring Creek, Bigelow Creek, Robin’s Brook, Bergen Swamp, Hotel Creek, Mill Creek, and Upper Black Creek (Fig. 2). Black Creek was divided into three major segments: Upper, Middle, and Lower Black Creek. Samples were taken at designated sites within the reaches of these segments (Table 1, Fig. 3).

Discharge

Discharge for Black Creek was obtained from the U.S. Geological Survey (http://waterdata.usgs.gov/ny/nwis/rt) station located in Churchville, NY in Monroe County (Lat. 43°06'02" N, long. 77°52'57" W) (hydrologic unit 04130003). In addition to the USGS discharge at the Middle Black Creek site in Churchville, rating curves at four other sites [Lower Black Creek (Fig. 4), Upper Black Creek (Fig. 5), Bigelow Creek (Figs. 6 and 7), and Spring Creek (Fig. 8)] were developed. Velocity was measured during low and high flow periods between June 2010 and March 2011 at 0.6 of the depth of the water column in increments specific to each site using a Gurley velocity meter. The number of dates in which velocity was measured at each site was dependent on the accessibility of the site and weather conditions. Velocity was measured on 14 dates at Lower Black Creek, 15 dates at Upper Black Creek, 18 dates at Bigelow Creek, and 17 dates at Spring Creek. Lower Black Creek water velocity was measured in horizontal 1.5-m increments, Upper Black Creek was measured in 1.2-m increments, Spring Creek was measured in 0.6-m increments, and Bigelow Creek was measured in 0.3-m increments. Cross-sectional areas were determined at each of these four sites by measuring an accurate drawing from precise initial measurements of each culvert using a planimeter. The regression lines for the rating curves were then determined using Microsoft Excel (Equation 1). Sites that had two culverts, such as the Bigelow Creek site, were measured separately, and two separate rating curves were created for each culvert.

Eq. 1. $\textit{Discharge, } Q\ (m^3/s) = \textit{Water Area}\ (m^2)\ X\ \textit{Velocity}\ (m/s)$

Water samples were taken on a weekly basis at these five locations (Lower, Middle, and Upper Black Creek, Spring Creek, and Bigelow Creek) over a period of 12 months. Weekly grab samples were analyzed and used to determine nutrient and sediment loading during ‘nonevent’ periods. Additional sampling occurred during rain and snowmelt events that were used to determine loading during ‘events’. Nutrient and sediment were calculated using the following equation:

Eq. 2. $\textit{Loading (mass/unit time)} = \textit{Discharge}\ (m^3/s)\ X\ \textit{Concentration}\ (mg/L \text{ or } \mu g/L)$

Loading was calculated at each site for the concentration of total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), nitrate, total suspended solids (TSS), and total coliform bacteria being discharged daily from the creek from nutrient data collected weekly. The loading from Bigelow Creek was calculated by adding the loadings from the east and west culverts. Annual loadings were estimated by expanding the observed daily nutrient loads half of a week before and after the sampling date for nonevents and extrapolated based on hydrograph attenuation for events. The discharge on days where samples and water depth measurements were not taken was estimated from the regression of measured discharge for a creek versus the discharge at the USGS site at Churchville (Middle BC). Predictive regressions for daily discharge were good with r^2 ranging from 0.64 to 0.89. The Lower Black Creek site was predicted without need for a lag time from the USGS station (Fig. 9). To improve regression predictions a lag time of one day for Upper BC and Spring Creek and lag time of two days for Bigelow Creek were employed (Fig. 9). The lag was calculated based on the average residence time in the main channel computed from water velocity data. The annual loading was also normalized for the area in hectares of each segment in the Black Creek watershed (Lower BC, Middle BC, Upper BC, Bigelow Creek, and Spring Creek). The drainage area of all five locations was determined using the United States Geological Survey StreamStats web-based GIS program. Monthly and seasonal loadings were also calculated to identify trends in the data.

Water Quality Analysis

Water samples were analyzed for TP, SRP, nitrate+nitrite (NO_3+ NO_2), TN, TSS, and total coliform bacteria (TC) weekly and after event water samples were taken throughout the study period. Water samples taken in the field were transported on ice and logged into the laboratory database upon arrival to the SUNY Brockport water quality laboratory. Water samples were analyzed for SRP (APHA Method 4500-P, 1999), TP (APHA Method 4500-P-F, 1999), TN (APHA Method 4500-N C), NO_3+ NO_2 (APHA Method 4500-NO3-F), TSS (APHA Method 2540D), and TC (3M Petrifilm^{TM} Coliform Plates (1-mL sample)). All analyses were performed on a Technicon AutoAnalyser II with the exception of TSS and Total Coliform. Method Detection limits were defined as: SRP (0.48 µg P/L), TP (0.38 µg P/L), NO_3+ NO_2 (0.005 mg N/L), TN (0.15 µg N/L), and TSS (0.2 mg/L). The water samples used for dissolved nutrient analysis (SRP, NO_3+ NO_2) were filtered on site with 0.45-µm MCI Magna Nylon 66 membrane filters and refrigerated at 4°C until sample analysis.

Quality Control

All water samples were analyzed at the State University of New York at Brockport Water Chemistry Laboratory. Soluble reactive phosphorous was analyzed within 24 hours after samples were taken. Nitrate, TP, TN, and TSS were analyzed within two days after sampling. The laboratory has a National Environmental Laboratory Accreditation Conference (NELAC) certification program, which includes proficiency audits and inspections that occur annually. Duplicate samples, laboratory quality control samples, matrix spikes, and method blanks were performed once for every 20 samples analyzed. Analytical data that fall within the control limits indicate that the method is in control. A quality control chart was created and used to ensure that data collected throughout this project was within control and is acceptable for documenting the quality of waters within the Black Creek watershed.

Stressed Stream Analysis

The process of segment analysis was used in this study to identify the point and nonpoint sources of nutrients, sediment, and bacteria in the watershed (Makarewicz and Lewis 1993, 2000, 2001; Makarewicz *et al.* 2006). This technique identifies the source, extent, and severity of sources of pollution in a watershed by breaking down and subdividing a watershed into small geographical units called stream segments. By taking samples at the beginning and end of each unit and analyzing each sample's water chemistry, sources of pollution can be determined within each reach of watershed subdivisions. Once a source is identified within a tributary, segments can be narrowed to pinpoint sources of nutrients and sediment. Samples were taken at a total of 14 sites throughout the Black Creek watershed at all nodes of major tributaries and at six mainstream sites initially. Following initial grab samples taken at the nodes of major tributaries, water grab samples were taken during or just after rainfall events systematically over the entire watershed, focusing on areas with high nutrient or sediment concentrations. Samples were treated in the same manner as discharge samples; samples used for dissolved nutrient analysis (SRP, NO_3+ NO_2) were filtered on site with 0.45-µm MCI Magna Nylon 66 membrane filters, stored in an ice filled cooler in the field, and refrigerated at 4°C until sample analysis in the lab. All water samples were analyzed for TP, SRP, NO_3+ NO_2, TN, TC, and TSS as discussed under water quality analysis.

Wastewater Treatment Plant (WWTP) Sampling

Sampling was done on segments of Black Creek and/or tributaries of Black Creek upstream and downstream of the Wastewater treatment plants (WWTPs) in Churchville, Bergen, Central Byron, North Byron, and South Byron. These WWTPs are all considered Class C or lower because they all discharge less than 1 million gallons of effluent per day (Table 2). At each location a total of five duplicate samples were taken upstream and downstream of the WWTP site. Wastewater treatment plant samples were analyzed for TP, nitrate, TSS, SRP, TN, and TC. A paired two-sample T-Test was employed to test whether contributions from wastewater treatment plants were significant at $\alpha=0.05$ with 95% confidence.

Limestone Quarry Sampling

Samples were collected for a period of seven weeks from a drainage ditch receiving waters from the Stafford-Hanson Limestone Quarry (Lat. 42.97793, Long. -78.08228) and the headwaters of Black Creek site (Fig. 3), just downstream of the quarry drainage. Samples collected from these two sites were analyzed for TP, SRP, TN, nitrate, TSS, TC, chloride (APHA Method 4500-Cl D), sulfate (APHA Method 4500E), potassium (APHA 3500-K B), alkalinity (APHA Method 2320B), sodium (APHA 3500-NaB), and calcium (APHA Method 3500-Ca B). A student's t-test was used to determine significance of the effect of quarry effluent on Black Creek.

Erosion Inventory

To assess the extent of erosion of stream banks within stream segments of interest, an erosion inventory was conducted via canoe or walking trips. Critically eroded areas were quantified by length and height of eroded stream bank using a Nikon Prostaff 550 laser rangefinder and visual observation. The location of eroded sites were logged on a handheld global positioning system (GPS), photographed, and classified using an erosion inventory checklist (Appendix A), which characterized the severity of impacted sites. The erosion inventory checklist and scoring system (Appendix A) were originally developed by LimnoTech. (2006) and were modified for the purposes of this project. Modifications included altering stream bank length and height to include more size classes, as well as adding a section to quantify erosion adjacent to agricultural fields. Areas where erosion is adjacent to agricultural fields were ranked the highest on the inventory checklist.

Soil and Water Assessment Tool (SWAT Model) Application

Model Setup

A Soil and Water Assessment Tool (SWAT) model was built for the Black Creek watershed using four core datasets as follows: land cover [National Land Cover Dataset (NLCD), (USGS-MRLC 2006)], soils [State Soil Geographic Database (SSTATSGO), (USDA-NRCS 2006)], topography [Digital Elevation Model (DEM) National Elevation Dataset (1/3 arc second, 10 meter resolution) (USGS 2010)], and weather [daily precipitation and temperature (NOAA-NWS 2011)]. The daily precipitation and temperature data for the study period (1 January 2008 through 31 May 2010) were obtained from a NWS station associated with subbasins in the eastern part of the watershed (Rochester station NWS COOP-ID 307167) and a NWS station associated with the subbasins in the western part of the watershed (Batavia station NWS COOP-ID 300443). The in-program climate generator for ArcSWAT estimated all other unspecified climate data using the Rochester airport climate station. Multiple hydrological response units were created for each subbasin using a 10/20/20 % overlap for land-use, soil type, and elevation, respectively.

Outlets for the model or pour points of a subwatershed drainage area within the watershed were placed at the location of the USGS monitoring station at Churchville (hydrologic unit 04231000) (Middle BC; Table 3) and at the routine monitoring sites for this project (Lower BC, Upper BC, Spring Creek, and Bigelow Creek (Fig. 3). Additionally, outlets were placed within subbasins containing point sources (Fig. 10). The whole watershed outlet was placed just above the juncture of Black Creek into the Genesee River. The model resulted in 33 subbasins and outlets (Fig. 10) and 833 hydrologic response units (HRUs). Table 3 details the subbasin-ID of the USGS site, which was used for calibration and quality control outlets.

Source Inputs

There are several sources within the watershed that heavily influence the quantity and timing of sediment and nutrient inputs to Black Creek. These include crop management practices, point sources of pollution, and confined animal feeding operations. To provide a more realistic prediction of sediment and TP output, these sources were incorporated into the BCSWAT model.

Crop Data

The percent crop distribution for the Black Creek watershed was determined using the New York State 2010 Crop Data Layer (USDA-NASS 2010). Within the watershed the crop distribution for the year 2010 was 37% corn, 20% alfalfa, 19% hay, 10% soybeans, 6% pasture, 3% winter wheat, 2% oats, 2% fruits, and 1% onion. This information was used to split the agricultural row crops land-use class into subclasses in order to account for the specific agricultural practices for the calibration period. Final HRU analysis once crop data was incorporated into the model resulted in 833 HRUs and 33 subbasins.

Crop rotation and fertilizer sequences were based on county data provided by the Soil and Water Conservation District (personal communication: George Squires, Genesee County SWCD) and the Cornell Guide for Integrated Field Crop Management (CCE 2010). The first year of each rotation where the cover crop coincided with the 2010 CDL was used to ensure that the crop cover during the calibration year was accurate. Spring tillage was assumed to occur in early to mid-May due to spring 2011 being a ‘wet season’ and fall tillage occurred in mid-October depending on the crop type. Additionally, a starter fertilizer high in nutrients was applied to agricultural fields in early May.

Point Sources

Several point sources exist in the Black Creek watershed that were used as inputs to the model as discharge and TP load. These include one WWTP, three municipal leachfields, and ten SPDES sites of interest (Table 4). Subbasin outlets were first defined to isolate point sources. A GIS layer defining the locations of point sources (WWTPs, Leachfields, and SPDES sites) within the watershed was used to locate where subbasins needed to be added. Smaller point sources were lumped (typically only SPDES sites) where output was not available on high resolution, and therefore only one subbasin was defined. Wastewater treatment plants and SPDES sites were all defined in subbasins based on their location (Fig. 10).

All discharge values for WWTPs and SPDES sites were acquired from the Environmental Protection Agency NPDES permit database and the New York State Department of Environmental Conservation web for Water Discharge Permits (WDP) (USEPA 2011). The average discharge data was used to calculate the P load from the point source and input into BCSWAT.

Nutrient concentration data were collected in one of two ways. If results from nutrient testing conducted on effluent were provided in the SPDES/NPDES permit, they were used as input for load calculations. If nutrient concentrations were not provided in the permit database, results from water samples taken in this study were used as inputs. Due to scarcity of information, the nutrient concentrations observed in one grab sample were used to calculate a constant annual load.

Point source inputs of P into the SWAT model need to be in the form of organic P and mineral P (Arnold *et al.* 2010). The SWAT model uses the Qual2E module to model nutrients within the watershed. Contrary to what is known by analytical chemists as the four fractions of phosphorus (soluble reactive, particulate, acid-hydrolyzable, and organic), this module assumes that mineral P is designated as inorganic P (SRP or orthophosphate) and organic P is designated as every other form of P other than soluble reactive (personal communication: Dr. James Almendinger, St. Croix Watershed Research Station, Science Museum of Minnesota). These two fractions (mineral P and organic P) can be summed to equal total P. Therefore results from SRP were used as mineral P inputs, and the organic P as defined by SWAT was the difference between TP and SRP. The mineral P and the organic P load from point sources were then calculated from concentration and discharge to be used as inputs to the SWAT model.

Confined Animal Feeding Operations

Confined animal feeding operations (CAFOs) are a nonpoint source of nutrients and sediments that were incorporated into BCSWAT. There are a total of ten CAFOs that were input into eight subbasins of BCSWAT. These were added to the model as the amount of manure spread on waste application fields (WAFs) as fertilizer. The amount of manure that was applied was dependent on the CAFO size (total number of cattle) for each farm. The number of cows each farm has and the WAFs were provided by the Genesee and Monroe County Soil and Water Conservation Districts (SWCD) (personal communication: George Squires, Genesee County SWCD; Tucker Kautz, Monroe County SWCD). The total amount of manure produced by each farm (kg manure/d) as viable dairy manure for fertilizer was calculated using the number of cows and the amount of manure produced per cow per day (ASAE, 1988).

The location and area of WAFs in the watershed were provided by the Genesee County SWCD. This data allowed us to determine where and how much manure (kg/ha/d) should be applied in BCSWAT. The manure application rate for each CAFO was calculated by dividing the total amount of manure produced by the CAFO by the total hectares of land area where manure is actually spread in the watershed. This application rate was then applied to specific HRUs within each subbasin. These HRUs within each subbasin where manure is spread were identified by overlaying the HRU map created by the model with the actual WAFs. The HRU areas where manure fertilization was applied was matched up with the real application area within the subbasin. This is consistent with the method used by Santhi *et al.* (2001) to simulate dairy operations in the Bosque River watershed. All of the WAFs in the Black Creek watershed coincided with HRUs with corn, hay, row crops, soybeans, or alfalfa land-uses. Manure application rates were applied as continuous fertilization applied to the surface soil layer with a frequency of 30 days. The manure application from CAFO operations was applied independently of row crop fertilizer practices. This was done to segregate the impact of routine fertilization practices to agricultural row crops from the impact that manure production from CAFOs has on water quality.

Septic Systems

When septic systems are activated in an HRU within SWAT, the entire HRU is considered as having septic systems (personal communication: Dr. Raghavan Srinivasan, Texas Agricultural Experiment Station, Blackland Research Center).

Knowing this, septic systems must be applied only to residential areas where septic systems are likely to occur. Active septic systems were applied to HRUs with the land-use designation Low Intensity Residential Developed Land which are areas with a mixture of constructed materials and vegetation, 20 to 49% imperviousness, and most commonly include single-family housing units (NLCD) (USGS-MRLC 2006). Low Intensity Residential Developed Land is approximately 5% of the land-use for the entire Black Creek watershed.

To correct for areas where sewer systems are located, the sanitary sewer pipe layer and a layer designated as homes serviced by sanitary sewers (2011 Monroe County Tax Parcel Layer, Monroe County) were clipped and overlayed with the SWAT HRU map. Subbasins where sewer districts overlap the residential HRUs were excluded from the septic system application. Sewered areas in the Black Creek watershed are in major towns such as Bergen, Churchville, Chili, Byron, and Batavia. The waste from the Bergen sewer district is routed to the Village of Bergen Wastewater Treatment Plant; the North Byron, Byron, and South Byron sewer districts use municipal leachfields within the Black Creek watershed. The Batavia sewer district goes to the Village of Batavia WWTP outside of the watershed, and the Churchville and Chili sewer districts go to the Van Lare WWTP in Rochester, NY, outside of the Black Creek watershed (Personal communication: Andy Sansone, Monroe County Water Authority).

An additional factor explored was how representative the residential HRUs are of all homes in the watershed. This issue applies to secluded single-family homes located between farm fields or within forested areas. To determine the number of homes not included in the residential land-use class, the HRU map was overlaid on orthoimagery or satellite photos (NYS GIS Clearinghouse High Resolution Imagery). This revealed approximately 185 homes that are not included in the residential land-use class and not within a sewer district out of the 5,700 homes on septic. Most of these homes are in new developments and do not show up as residential because of the lag time for the NLCD land-use layer (USGS-MRLC 2006). Because the number of houses outside of sewer districts that are not included in the residential land-use is low, their effect on phosphorus load was considered negligible.

Active septic systems were then applied to all HRUs with low intensity residential land-use with the exception of subbasins 7, 21, 28, 9, 27, and 12 to account for sewered regions in the Black Creek watershed. The septic system type used was ‘septic tank with conventional drainfield’ which is the most accurate for homes in western, NY.

Calibration and Verification

After the model was setup, the calibration and verification stage was initiated. The Black Creek SWAT model was calibrated for water balance, TSS load, and TP load at the Churchville monitoring station (Middle BC) and was verified at the other main stem sites (Upper BC and Lower BC). The calibration period that was used for this model was June 2010 through May 2011, and the verification year used for water balance was January 2001 through December 2001. Calibration criterion used included the Nash-Sutcliffe prediction efficiency, correlation coefficient (r^2), the percent bias (PBIAS) between observed values to SWAT output, and visual distribution of peaks (Moriasi *et al.* 2007). The Nash-Sutcliffe ranges from $-\infty$ to 1 and is a measure of the goodness of fit between values predicted by the model and the actual observed parameter in the watershed. A Nash Sutcliffe of $E > 0.7$ is considered a very good fit between modeled and actual values (Moriasi *et al.* 2007). The correlation coefficient ranges from -1 to 1 and was used to measure the strength of the linear dependence between observed and simulated variables in the watershed; an $r^2 > 0.7$ is considered very good (Moriasi *et al.* 2007). The PBIAS is a measure between the difference in magnitude of actual observed versus simulated peaks of discharge or nutrient load. A PBIAS of less than 10.0% was accepted with the ultimate goal to achieve a difference of 0.0% (Moriasi *et al.* 2007).

Water Balance

Initial calibration for water balance using the various evapotranspiration schemes available in SWAT determined that the existing model was grossly under-predicting the flow of water at the calibration site between February and April; that is, more water was actually leaving the basin than what was predicted by SWAT. The forcing climate data was checked and determined not to be a cause of the missing water. Previous studies and a calibrated SWAT model from a bordering watershed suggested that the Onondaga Escarpment, a limestone belt that crosses upstate New York State east to west (Baschnagel 1966), is the likely source of the water from outside the Black Creek watershed (Fig. 11). Large areas of the Onondaga Formation (FM) are thinly-soiled and contain sinkholes and fracture bedrock areas (Richards *et* *al*. 2010), which allows precipitation to enter into the escarpment and the groundwater system to be stored throughout the year. Studies have demonstrated dynamic seasonal rises in the water table during the January to April time period (Richards and Craft 2008; Daniluk *et al*. 2008; Voortman and Simons 2009; Richards and Rhinehart 2006; Daniluk 2009; Dunn Geoscience Engineering Co. 1992) when water stored in the escarpment is likely discharged to surface waters. Since the groundwater direction is northward, the Black Creek watershed is the likely destination of this water. Previous studies have also noted that the Onondaga Formation has large annual water table variations in Erie County (Kappel and Miller 1996; Staubitz and Miller 1987).

Through consideration of the monthly deficit between SWAT output and the USGS water output, it was determined that within the Black Creek watershed the Onondaga Formation does not add water in January, but water is added from February through April. Throughout the month of January and the first week of February 2011, the SWAT water output without any additional water from the escarpment closely followed the USGS output where as the SWAT output with water added due to the escarpment was an overestimation. In the middle of February through the end of April as the observed water output from the USGS station increases, the SWAT output with water added from the escarpment is a better prediction of actual water discharged. This trend was seen in five out of six years (2000, 2001, 2002, 2003, and 2011). It is hypothesized that the trend may be due to groundwater discharge into Black Creek, typically starting during the two-three week period between the end of January to the middle of February. This enhanced contribution continues through the spring (personal communication: Dr. James Zollweg, SUNY Brockport Earth Science Department).

In a neighboring watershed to the west of Black Creek, Oak Orchard Creek, Richards *et al*. (2011) calibrated and validated a SWAT model using the addition of water from outside the watershed via the Onondaga Escarpment. The additional water was added to the subbasins where the escarpment cuts across the watershed and was based on the study of groundwater levels in the vicinity. In Black Creek, a similar approach was taken to account for the "missing" water; that is, subbasins at the base of the escarpment of the Black Creek were assumed to receive groundwater from outside the watershed via the Onondaga Escarpment.

The method used to add water from the escarpment within the model was to input a source of water within each of the subbasins within the watershed that cross the escarpment. Water was added into subbasins 24, 28, and 27 (Fig. 11; Table 5) at a daily resolution for the months of February, March, and April. The amount of water to be added was calculated based on the mean water discharge deficit for the months of February through April observed from an 11-year (1995-2005) initial SWAT model run (Fig. 12).

In addition to adding water through water-use parameters, model parameters for soil, surface water, and groundwater parameters were altered (Table 6). Surface runoff was calibrated by altering the curve number (CN) and ESCO to obtain observed peak flows. The CN for this model needed to be reduced by 25%, which is large compared to findings by Neitsch *et al*. (2002) who suggested that CN should not be changed by more than 10%. A substantial reduction in the CN was also necessary to calibrate a neighboring watershed to Black Creek, the Oak Orchard watershed SWAT model. Richards *et al.* (2010) relate this excessive reduction in CN to ‘the presence of flat and internally drained topography at watershed scales.” Another study on the Cannonsville Reservoir Watershed in Upstate New York reduced the CN by 20% to calibrate for water balance (Tolson and Shoemaker 2007). It is clear from recent model developments that a greater reduction in the SCS CN is required to reach adequate water output in watersheds in the Northeast United States.

For the water year June 2010 through May 2011, the fit of the model was excellent, where a 0.88 Nash-Sutcliffe efficiency coefficient rating (NS), a -3.6 PBIAS, and a 0.93 r^2 between USGS and SWAT output values were achieved (Figs. 13-14; Table 7). The validation year of January 2001 through December 2001 also had an excellent agreement, 0.71 NS, -14.3 PBIAS, and 0.73 r^2 for USGS versus SWAT values (Figs. 15-16; Table 7).

Sediment and Nutrient Loading Calibration

After flow was successfully calibrated, the model was calibrated for TSS and TP from measured values at the Churchville monitoring station (Middle BC) from June 2010 through May 2011. Several studies have observed that sediment and TP fluxes are highly correlated (Folle 2010). These two parameters are also highly impacted by surface runoff and movement of sediments. These two parameters are strongly impacted by agricultural activities, crop distribution, and the timing and location of fertilizer and tillage practices. Because these two parameters are closely related, they were calibrated simultaneously in the BCSWAT model.

In addition to tillage and fertilizer applications, the erodibility of sediments, sediment routing method, and phosphorus soil partitioning and percolation were parameters that were most sensitive for TSS and TP calibration (Table 6). Because the spring of the calibration year (2011) was considered a ‘wet year’ with frequent and intense rain, the tillage and initial fertilization of croplands occurred in May rather than in April as in the Oak Orchard study. This shift in tillage and fertilization enforces the importance of these practices on the fluxes of sediment and phosphorus in Black Creek. The final parameters which heavily influenced the calibration of sediments and phosphorus are summarized in Table 6. The resulting calibration criterion for sediment was 0.71 Nash-Sutcliffe, 0.74 r^2, and +2.0 PBIAS (Figs. 17 and 18, Table 7). And the resulting calibration criterion for TP was 0.78 Nash-Sutcliffe, 0.80 r^2, and +9.8 PBIAS (Figs. 19 and 20, Table 7). The calibration criterion for these two parameters is considered to have a very good performance rating as they are on the high end of the model evaluation guideline for SWAT created by Moriasi *et al.* (2007).

To verify that the output from the other routing monitoring stations (Upper BC, Lower BC, Spring Creek, and Bigelow Creek) was being accurately predicted, the predicted TP and TSS loads (MT/year) were compared to the actual observed loads and the percent bias was calculated. To calibrate for TSS several routing parameters including; Manning’s N, channel and bank erodibility, and channel cover were slightly altered by subbasin (refer to Appendix B for extended calibration parameters table). To calibrate for TP several management, stream water quality, and HRU parameters were altered by subbasin (refer to Appendix B for extended calibration parameters table). The TP PBIAS was under ±35% for all sites and the TSS PBIAS was less than ±25% (Table 8). These values for PBIAS reflect that all sites predict the actual loads with confidence (Moriasi *et al*. 2007).

Model Simulations

After calibration and verification were completed for BCSWAT, the model was used to simulate management practices throughout the watershed. Scenarios were broken down into several categories based on source type and management option. These categories were as follows: natural forested simulation, agricultural BMPs, wastewater source options, and CAFO management operations.

Natural Forested Simulation

The model was first used to determine the natural, background levels of phosphorus coming out of Black Creek. This would simulate the phosphorus and sediment if all anthropogenic impacts were removed from the watershed. This was done by converting all agricultural, urban, and residential land uses to mixed forest. All wetlands and forested wetlands were not removed from the land use layer. All point and nonpoint sources were removed from the entire watershed. The model was run and the reductions in phosphorus and sediment were determined.

Wastewater Source Options

The model was also used to determine the impact of upgrading treatment or rerouting all WWTPs and SPDES sites outside the watershed. The Bergen WWTP was removed from the watershed, and the output was logged to determine the percent reduction in TP and TSS. A simulation was also run to determine the percent reduction of upgrading the Bergen WWTP to tertiary treatment with a chemical addition, two-stage filtration system. The concentration used for this scenario was based on other wastewater treatment plants in New York State of similar size that utilize this treatment system (USEPA 2007). Additionally, a scenario was run to determine the impact of removing all point sources from the watershed. To determine impact of septic systems, all septics within the watershed were deactivated.

Agricultural BMPs

Black Creek SWAT was used to predict the impact of changes in agricultural land-use through BMPs. To accomplish this task several feasible BMPs were simulated: no till/conservation tillage, grassed waterways, terrace farming, contour farming, filter strips, strip cropping, retirement of agricultural land, and cover cropping. Nutrient management scenarios were run using a 25, 50, 75, and 100 % reduction in the quantity of fertilizer spread over cropland excluding the manure applications from CAFO operations. The removal of spreading of manure to croplands from CAFOs was treated as an entirely separate entity. The percent reduction in TSS and TP through the use of these scenarios was determined. The BMPs that had the greatest percent reductions in nutrients and sediment were deemed the most effective and allowed for recommendations to be made.

Confined Animal Feeding Operations (CAFO) Management

To determine the impact of CAFOs on the Black Creek watershed and on the TP and TSS load the manure application from all CAFOs throughout the watershed was removed. This would simulate the effect of using alternative manure practices and thereby completely eliminating the runoff from manure waste application fields from Black Creek.

Stream bank Erosion Mitigation

Stream bank stabilization and protection mitigate the effects that erosion of stream banks has on streams through vegetation or structural techniques. To simulate the stabilization of stream banks in the SWAT model, several routing parameters were altered by decreasing channel erodibility (CH_EROD), increasing stream bank vegetation cover (CH_COV), and increasing Manning's n Stream Roughness Coefficient (CH_N2) by 50%. This approach is consistent with previous studies in modeling stream bank stabilization (Tuppad *et al.* 2010; Narasimhan *et al.* 2007). This stream bank stabilization BMP was used at the basin scale (applied to the entire Black Creek watershed) as well as in areas shown to be highly erodible (Lower Black Creek segment).

Tributary Remediation

There are two heavily impacted tributaries within the Black Creek watershed that were monitored in this study: Bigelow Creek and Spring Creek. The SWAT model was used to simulate the remediation of these two tributaries by applying all effective and applicable BMPs to these two subwatersheds of Black Creek. In the

Spring Creek subwatershed, the manure application from all four CAFOs was removed; a conservation no-till BMP, grassed waterways, and nutrient management (50% reduction in fertilizer to crops excluding CAFO manure) were applied. In the Bigelow Creek subwatershed, SPDES sites were removed; a conservation no-till BMP, filter strips, and nutrient management (50% reduction in fertilizer excluding manure produced from CAFOs) were applied. These BMPs were used to simulate a remediation of these two tributaries.

Black Creek Watershed Management

Two scenarios were run to simulate the effect of remediating Black Creek to achieve water quality standards of 65µg P/L and 45 µg P/L at Lower BC near the outlet of the watershed. To achieve a concentration of less than 65 µg P/L at the Middle BC location, Spring Creek and Bigelow Creek remediation scenarios were run as well as an upgrade of the Bergen WWTP to tertiary treatment, removal of all CAFOs in the headwaters, stabilization of stream banks, and addition of buffer strips above Lower BC. The 45-µg P/L target was simulated using the Spring Creek and Bigelow Creek remediation scenario: the removal of all point sources, CAFOs, and septic systems and the addition of basin-wide stream bank stabilization, filter strips, contour farming, and conservation tillage.

Source P Load Allocation

The Black Creek SWAT model was used to allocate the TP load from Black Creek to specific source types such as: agricultural land, tile drainage, farm animals, stream bank erosion, wetlands, quarries, groundwater, forests, urban runoff, sewage treatment, and septic systems. Agricultural land includes the runoff of all phosphorus from crops excluding the contribution of P from CAFOs and was derived by computing the difference between the calibrated model run versus a scenario where all crops (crops, hay, and pasture) are converted to forest minus the contribution from CAFOs. The manure produced from CAFOs was applied to crops above the crop nutrient requirements and therefore was accounted for separately. This source of P from farm animals (CAFOs) was obtained by the difference between the calibrated BC SWAT model run and a scenario where the manure from all CAFOs was removed. Tile drainage or subsurface drainage from croplands was obtained from the difference in the calibrated model and a scenario with 16% tile drainage added (personal communication: Wayne Howard, Center for Environmental Information).

Erosion associated with stream banks was the difference in the calibrated model and the stream bank stabilization scenario, where erodibility and channel cover are decreased and Manning's n is increased by 50%. The P contribution from wetlands, groundwater, and forests was determined using direct output from the calibrated model (HRU output). Urban runoff was determined from the difference in the calibrated BC SWAT model and a scenario where all residential areas are converted to forested while septic remains in the model. By keeping septic systems in the model for this run, the amount of P from urban runoff rather than the entire contribution from residential/urban areas is identified. Septic systems were considered a separate entity and were derived from the difference in the calibrated model and a scenario where septic is inactive. Lastly, the phosphorus from sewage treatment was the difference between the calibrated P output and a scenario where all WWTPs are removed from the model. This analysis allows for identification and quantification of P from different sources in the watershed.

Results

Segment and Tributary Loading

Discharge Measurements

Discharge rating curves were established at Lower Black Creek (Fig. 4), Upper Black Creek (Fig. 5), the east (Fig. 6) and west (Fig. 7) culverts at Bigelow Creek, and Spring Creek (Fig. 8). The correlations between discharge and stream depth were high ($R^2 \geq 0.90$).

Average Concentration

The average concentration of all constituents (TP, SRP, TN, nitrate, TSS, and TC) was calculated for the one-year sampling period (Fig. 21, Table 9). Samples were collected at all five routine monitoring stations on 55 dates between 1 June 2010 through 7 June 2011. Samples were collected at these sites on 20 dates with event conditions and 35 dates with nonevent conditions.

The average concentrations of TSS (mg/L), TP (µg P/L), and SRP (µg P/L) were all elevated in the upstream segment (Upper BC) and the tributaries of Spring and Bigelow Creeks (TSS >15 mg/L, TP>90 µg P/L, and SRP>40 µg P/L) in comparison to the middle and lower segments (Middle BC and Lower BC) (TSS<12 mg/L, TP<70 µg P/L, and SRP<30 µg P/L) (Fig. 21). These upstream segments

(Upper BC, Spring Creek, and Bigelow Creek) represent the area of Black Creek with the most water quality issues in terms of concentration. In addition to high TSS, TP, and SRP concentrations, Spring Creek also had on average the highest TN and nitrate concentrations (3.43 and 2.73 mg N/L), and total coliform bacteria abundance (16,082 CFU/100 mL) (Fig. 21, Table 9). A segment analysis was conducted on this tributary, in addition to several other segments, to determine the source of high concentrations.

Total Annual Nutrient and Sediment Loading Estimates

Nutrient, sediment, and bacteria loadings were calculated annually (MT/yr) at the five routine monitoring sites within Black Creek watershed (Lower BC, Middle BC, Upper BC, Spring Creek, and Bigelow Creek). Total annual loadings of TP and TSS (TP = 16.5 MT/yr; TSS = 8,360.6 MT/yr) were highest at Lower Black Creek, which is the site closest to the outlet to the Genesee River (Table 10a). The load of TP and TSS were highly correlated throughout the Black Creek watershed (Fig. 22). The load of TP and TSS that is carried by the stream increases from the most upstream site (main stem at Upper BC = 6.9 and 1,327.4 MT/yr) to the most downstream site (main stem at Lower BC = 16.5 and 8,360.6 MT/yr), respectively (Figs. 23 and 24, Table 10a). The Spring Creek and Bigelow Creek Tributaries contributed 4.3 and 2.9 MT/yr, respectively, of TP and 955.3 and 597.8 MT/yr of TSS, respectively, to Black Creek (Table 10a). Of the 16.5 MT/yr load of TP at Lower BC, 83.7% is attributable to the watershed area above Middle BC; that is, only 16.3% of the loss from the watershed as TP is from the reach between Middle and

Lower BC (Table 10a). However, the loss of TSS is much greater for this same reach of Black Creek, as more than 6,000 MT/yr is added to Black Creek between the Middle and Lower sites (8,360.6 MT/yr compared to 2,239.1 MT/yr at Middle BC) (Fig. 24, Table 10a). The percent contributions of TSS from all other reaches of the stream (Bigelow 7.2%, Upper BC 15.9%, Spring 11.4%, and Middle 26.8%) to the Lower BC site were all fairly low which indicates that there is a source of TSS between Middle and Lower Black Creek (Table 10a).

The annual loads of N, SRP, TSS, and total coliform were all highest at main stem Black Creek sites and were substantially lower at the Spring and Bigelow Creek tributaries (Figs. 23-26, Table 10a). The mass loss of TN, nitrate, and SRP is higher at the Middle BC site than at the downstream Lower BC site (Table 10a). The majority of the TN, nitrate, and SRP loads from the Black Creek watershed is lost from the watershed area above Middle BC. The lower mass values of dissolved substances at Lower BC are most likely due to uptake of aquatic plants. Downstream of Middle BC the stream meanders more, stream velocity drops, and aquatic plants are more abundant on stream banks.

The loss of total coliform bacteria from the watershed was more variable overall. Total coliform bacteria loading from Bigelow Creek was much less than from all other sites, accounting for only 17.7% of the load at Lower BC (1.2E15 CFU/yr) (Fig. 26, Table 10a). Although the bacteria loss generally increased downstream, Spring Creek loses more bacteria per year than Upper BC (3.9E15 CFU/year compared to 3.5E15 CFU/year) and accounts for 55.5% of the bacteria load through Lower BC, which indicates that Spring Creek is a source of bacteria to Black Creek (Fig. 26, Table 10a). Middle BC also accounts for almost all of the bacteria loading through Lower BC, 96% (Table 10a). The middle and upper segments of Black Creek account for a substantial portion of the nutrient and bacteria loads from Black Creek, but the lower segment accounts for most of the sediment load.

Areal Load of Sediments and Nutrients Normalized for Segment Area

The areal annual loads for TP, SRP, TN, nitrate, TC, and TSS indicate that the small watersheds of Bigelow Creek (5% of Black Creek watershed area) and Spring Creek (11% of Black Creek watershed area) are major contributors to Black Creek (Figs, 27-30, Table 10b). Bigelow Creek (1.1 kg TP/ha/yr, 0.4 kg SRP/ha/yr, and 228.5 kg TSS/ha/yr (Figs. 27 and 29, Table 10b) and Spring Creek (17.3 kg TN/ha/yr, 13.2 kg NO_3/ha/yr, and 7.0E11 CFU/ha/yr, respectively) are similar or higher than main stem locations (Table 10b). For example, the Bigelow Creek watershed, which is the smallest of the subwatersheds, delivers annual areal loads that are highest per unit area of watershed for TP and SRP and second highest for TSS and total coliforms (Table 10b). Such results suggest areas to focus management efforts.

It is evident that there is a substantial amount of sediment exiting Lower Black Creek. Even when the loading is weighted by unit area, the TSS loading from Lower Black Creek is significantly higher than from any other segment (Table 10b). A substantial source of sediment between Middle and Lower Black Creek appears to exist. This was further explored to determine if the source was stream bank erosion or surface (agricultural field) erosion and runoff. In the 5.12-km reach of Black

Creek from the Middle BC site to the Lower BC monitoring site, 1.66-km or 32.4% of the stream bank was found to be highly erodible. Within this 5.12-km reach, 11 sites were found to have eroded stream banks, and 10 sites had an erosion inventory score above 20 (Fig. 31, Table 11). Inventory score accounts for the length, width, and incline of the stream bank as well as observed cause of erosion and proximity to buildings and structures. A score of above 20 on the erosion inventory is considered to be highly erodible and in need of stabilization. All of these sites which scored above 20 were adjacent to agricultural fields. In comparison, a 5.24-km length of Black Creek upstream of the Upper BC sampling site had only seven sites amounting up to 0.24-km of stream banks, which were characterized as eroded (Fig. 32, Table 11). This segment was also found to have less unbuffered stream banks with only 5.2% unbuffered compared to the 45.5% unbuffered stream banks in the Lower BC segment (Table 11).

In addition to the stream bank erosion, surface erosion and runoff during events is a suspected cause of high TSS concentrations found at Lower BC. The dominant land-use within the watershed area of this segment of Black Creek directly upstream of Lower BC is agriculture (59.6% pasture and cultivated crops). From aerial photography, it is evident that there is little to no buffer strip between the agricultural fields and the stream, which will greatly impact the runoff of sediment during events (Fig. 31).

Monthly Loading

Monthly load was also calculated for each of the five sites for all analytes. With the exception of total coliform bacteria monthly loading, all other analytes (TP, SRP, TN, nitrate, and TSS) are all much lower during the late summer and fall months (August through November) than in the winter and spring months (December through June) (Figs. 33-37; Table 12). Total coliform tends to fluctuate less throughout the year although the spring and summer seasons had the highest bacteria loads (Fig. 38). High bacteria load was highly influenced by events as well as water temperature. Losses of nutrients and sediments start to increase in December particularly at the downstream sites of Lower and Middle Black Creek. The peak loss of nutrients and sediments occurs during the spring months (March and April) during which snowmelt and rainstorm events occurred in high frequency (Fig. 39; Table 12).

Stressed Stream Analysis

Event and Nonevent Tributary Sampling

<u>Chronological Account of Stressed Stream Analysis</u>

15 June 2010 (nonevent)

Initial sampling of 17 stations within the Black Creek watershed (Fig. 3) occurred during baseline flow conditions on 15 June 2010. The purpose of this was to initiate the stressed stream analysis program and to determine the variability of nutrient concentrations along the main stem and major tributaries of Black Creek (Table 13).

Typically, SRP and TP had a similar relationship throughout the watershed; where SRP was high so was TP (Fig. 40). Total phosphorus ranged from 15.0 µg P/L at Robin's Brook to 93.3 µg P/L at Lower Black Creek. Lower, Middle, Upper, Main stem 2, and Main stem 3 were all main stem sites, which had high TP concentrations. Northeast Tributary, Mill Creek, and Bigelow Creek also had high TP concentrations of 80.1 µg P/L, 79.6 µg P/L, and 79.2 µg P/L, respectively. Soluble reactive phosphorus ranged from 13.4 µg P/L at Robin's Brook to 49.3 µg P/L at Upper Black Creek. Main stem sites (Lower, Middle, Upper, Middle Upper, and Main stem 3) all had high SRP levels (Fig. 40). Northeast Tributary, Spring Creek, and Bigelow Creek all had high SRP concentrations of 44.0 µg P/L, 40.9 µg P/L, and 40.9 µg P/L, respectively. Main stem sites along Black Creek [Lower BC, Middle BC, Upper BC, Headwaters BC, Main stem 2 and Main stem 3 (Fig. 3)] generally had high SRP and/or TP concentrations (SRP > 40 µg P/L or TP > 65 µg P/L) compared to tributary values on 15 June 2010 (Fig. 40).

Generally, nitrate and TN had a direct correlation ($r^2 = 0.98$) at these sites. A major source of nitrate and TN is evident in Robin's Brook with concentrations of nitrate and TN of 8.22 mg N/L and 8.25 mg N/L, respectively (Fig. 41). Spring Creek, Main stem 2, Upper Black Creek, and North East Tributary also had high (>2.00 mg N/L) TN and nitrate concentrations (Fig. 41).

Total suspended solids was relatively low for the samples taken at all 17 sites but was found to be higher at main stem sites than within tributaries (Fig. 42). Total suspended solids ranged from 0.1 mg/L at Headwaters Bigelow to 0.9 mg/L at Main stem 2 (Fig. 42). Total coliform bacteria abundance ranged from 1,920 to 20,660 CFU/100 mL in the Black Creek watershed (Fig. 42). The highest numbers of bacteria were found at headwaters of Bigelow Creek with 64,480 CFU/100 mL and Mill Creek with 20,660 CFU/100 mL.

Chronological Account of Stressed Stream Analysis

26 July 2010 (event)

Spring Creek and Robin's Brook tributaries of Black Creek (Fig. 3) were further segmented to identify the sources of high nutrient and sediment levels found from initial sampling. The Spring Creek subwatershed had high TN and nitrate concentrations of 4.13 mg N/L and 3.57 mg N/L, respectively, on 15 June 2010 (Fig. 41). Robin's Brook had high TN values of 8.25, 8.57, and 14.96 mg N/L and nitrate values of 8.22, 8.52, and 8.95 mg N/L on three previous sampling days (Table 14).

Spring Creek

A total of six samples were taken from the Spring Creek subwatershed on 26 July 2010 (Fig. 43). Total phosphorus and SRP steadily increased from upstream to downstream at Spring Creek sites. Site SC1, the most downstream site on this tributary, had the highest TP (175.7 µg P/L) and SRP (90.2 µg P/L) values (Fig. 43). Total phosphorus increased 121% between site SC2 and SC1 (79.6 µg P/L to 175.7 µg P/L) and SRP increased 85% between these two sites (48.9 µg P/L to 90.2 µg P/L). This large increase in phosphorus between these two sites indicates a P source between sites SC1 and SC2.

Total nitrogen and nitrate increased drastically from upstream site SC6 to SC5 (Fig. 44); TN increased 158% (0.90 mg N/L to 2.32 mg N/L); nitrate increased 776% (0.17 mg N/L to 1.49 mg N/L). Total nitrogen and nitrate continued to increase at downstream sites in the Spring Creek subwatershed from SC5 to SC1.

Total coliform also increased 163% between sites SC6 and SC5 in Spring Creek (8,100 CFU/100 mL to 21,300 CFU/100 mL) (Fig. 45). Site SC1 had the highest TSS within the tributary with 14.6 mg/L, a 49% increase from site SC2. Site SC6 upstream also had high TSS with 13.6 mg/L (Fig. 45). There is likely a source of TSS and total coliform bacteria above site SC6 and a source of TSS above SC1.

Robin's Brook

A total of seven samples were taken from the Robin's Brook subwatershed on 26 July 2010 (Fig. 46). Total phosphorus increased 150% between RB6 and RB5 sites (36.0 μg P/L to 89.9 μg P/L) and increased 22% between sites RB5 and RB4 (89.9 μg P/L to 109.4 μg P/L) (Fig. 46). Soluble reactive phosphorus also increased 140% from RB6 to RB5 (20.1 μg P/L to 48.3 μg P/L) and increased 55% between RB5 and RB4 (48.3 μg P/L to 74.8 μg P/L).

Robin's Brook site RB5 had high levels of nitrate and TN (7.91 mg N/L and 8.74 mg N/L, respectively) (Fig. 47). There was an 810% increase in nitrate between sites RB6 and RB5 (0.96 to 8.74 mg N/L); this indicates a possible source of nitrate above RB5.

In addition to increasing TP, SRP, and nitrate between RB5 and RB6, TSS increased 196% (from 2.8 mg/L to 8.3 mg/L) (Fig. 48). These sites also had the highest total coliform counts of all the Robin's Brook sites (Fig. 48). Total coliform increased 116% between RB 7 and RB 6 (11,800 CFU/100 mL to 25,500 CFU/100 mL). This indicates a source of bacteria from waterfowl, cattle, or human sewage in this area.

Chronological Account of Stressed Stream Analysis

17 August 2010 (nonevent)

Sampling occurred during nonevent conditions with a slight increase in flow on all initial main stem and major tributary node sites on 17 August 2010. Seventeen stations were sampled in the Black Creek watershed. Stressed stream samples were also taken in the Mill Creek subwatershed; a total of five samples were taken. On 17 August 2010 there was 0.25 inches of rainfall in the Black Creek watershed which raised the discharge slightly but not enough to cause event conditions (Fig. 49).

All Major Tributary Nodes

Total phosphorus ranged from 10.9 µg P/L at Robin's Brook to 228.8 µg P/L at Headwaters BC, and SRP ranged from 4.9 µg P/L in Black Creek Tributary to 162.4 µg P/L at the Headwaters BC site (Fig. 40). Total phosphorus and SRP concentrations were generally the highest at all three Upper Black Creek sites (Upper, Middle Upper, and Headwaters of Upper). Concentrations of TP for Headwaters of BC, Middle Upper BC, and Upper BC were 228.8, 84.0, and 90.8 µg P/L, respectively, while SRP concentrations for these sites were 162.4, 62.9, and 60.0 µg P/L, respectively.

Total nitrogen values ranged from 0.47 mg N/L at the headwaters of Bigelow Creek to 9.98 mg N/L in Robin's Brook, and nitrate ranged from non-detectable to 8.27 mg N/L at the same sites (Fig. 41). Total nitrogen (8.25 mg N/L) and nitrate (8.27 mg N/L) values were very high at Robin's Brook (Fig. 41). Spring Creek and Northeast Tributary also had elevated TN and nitrate concentrations compared to other sites (Spring Creek: 2.33 mg N/L, 2.13 mg N/L; Northeast Tributary: 3.60 mg N/L, 2.73 mg N/L).

Total suspended solids ranged from 0.9 mg/L at Robin's Brook to 18.1 mg/L at Lower BC and were the highest at the main stem sites (Lower BC, Middle BC, and Headwaters BC) (Fig. 42). Values for TSS at these sites were 18.1, 11.3, and 11.3 mg/L, respectively. Total coliform count was the highest at Spring Creek and main stem site 2 with 104,000 CFU/100 mL and 254,000 CFU/100 mL, respectively (Fig. 42).

Mill Creek

A total of five samples at sites M1 through M5 were taken in the Mill Creek subwatershed on 17 August 2010 (Fig. 50). Total phosphorus ranged from 14.0 µg P/L at M4 to 73.3 µg P/L at M2, and SRP ranged from 6.9 µg P/L at M4 to 63.5 µg P/L at M3 (Fig. 50). Total phosphorus increased 414% (14.0 to 71.9 µg P/L) and SRP increased 820% (6.9 to 63.5 µg P/L) between M4 and M3, indicating that there is a source of P between these two sites in the Mill Creek subwatershed (Fig. 50).

Total nitrogen ranged from 0.57 µg P/L at M2 to 1.17 mg N/L at M1 in Mill Creek, and nitrate ranged from 0.15 µg P/L at M3 to 0.80 mg N/L at M4 (Fig. 51).

There were large increases in the concentration of TN and nitrate between sites M2 and M1 (105% and 281%) as well as M5 and M4 (43% and 116%). The higher TN and nitrate concentrations at these sites indicate that there are sources of N upstream of M1 and M4.

There was generally a decreasing trend in TSS from upstream to downstream with the highest TSS value at M6 with 8.6 mg/L and 2.5 mg/L at M1 (Fig. 52). Total coliform ranged from 11,800 at M1 to 40,300 CFU/100 mL at M2 within the Mill Creek subwatershed (Fig. 52).

Chronological Account of Stressed Stream Analysis

23 August 2010 (event)

Sampling occurred at six sites during event conditions (12.7-19.5 mm of rainfall, Fig. 53) on the Spring Creek subwatershed on 23 August 2010.

Total phosphorus ranged from 64.8 µg P/L at SC3 to 177.5 µg P/L at SC1. The highest values were found at SC1 with 177.5 µg P/L and SC7 with 121.1 µg P/L. There was a large increase in P between SC2 and SC1 (146.4%; 72.0 to 177.5 µg P/L (Fig. 43). Soluble reactive phosphorus followed a similar trend in the downstream portion of Spring Creek but not in the upstream portion of the creek. There was a 260% increase in SRP between SC2 and SC1 (34.5 to 122.7 µg P/L) (Fig. 43). Although SC7 had high TP, it was not among the highest SRP concentrations found within the Spring Creek tributary. This indicates that there is another source of P other than SRP. Further sampling needs to be conducted between SC2 and SC1 on both tributaries of Spring Creek.

Total nitrogen ranged from 1.43 mg N/L at SC5 to 2.77 mg N/L at SC2. A high concentration of TN (1.97 mg N/L) was found at SC7 in the upstream portion of Spring Creek, suggesting that there is a source of nitrogen within the headwaters of Spring Creek (Fig. 44). There is also a source of TN in the downstream portion of Spring Creek. Total nitrogen was high (>2.5 mg N/L) at sites SC 1 and SC2. Nitrate follows a similar trend with high concentrations found at SC7 with 1.04 mg N/L and high concentrations downstream at SC2 and SC1 with 2.06 and 1.71 mg N/L, respectively (Fig. 44).

Total suspended solids ranged from 4.0 mg/L to 16.9 mg/L and showed a consistent downward trend from SC7 downstream to SC1 (Fig. 45). High bacteria counts were found throughout the Spring Creek watershed on 23 August 2010 with a range from 22,000 CFU/100 mL at SC2 to 82,000 CFU/100 mL at SC1 (Fig. 45). Total coliform was consistent throughout Spring Creek with a spike at the most downstream site at SC1. This indicates recent fecal contamination between SC2 and SC1.

Chronological Account of Stressed Stream Analysis

28 September 2010 (event)

Sampling of seven sites (Fig. 54) in the headwaters of the main stem of Black Creek occurred during post-event conditions on 28 September 2010. Within this segment, there were major increases and decreases of P from site to site. This likely reflects an input at one upstream location and then a dilution by the next system. Large increases were observed in both TP (1,501%, 22.0 µg P/L to 352.2 µg P/L) and

SRP (859%, 16.5 µg P/L to 158.3 µg P/L) from site HW6 to HW5 (Fig. 54). There was also a large increase in TP (573%, 32.9 µg P/L to 221.3 µg P/L) and SRP (313%, 12.6 µg P/L to 52.1 µg P/L) between sites HW4 and HW3 (photo of site; Fig. 55), respectively (Fig. 54).

Total nitrogen and nitrate followed a similar trend with TP and SRP with large increases in TN between HW6 and HW5 (752%, 0.46 mg N/L to 3.92 mg N/L) and nitrate (3325%, 0.04 mg N/L and 1.37 mg N/L). There was also a high increase in TN and nitrate between HW4 and HW3 (66%, 0.56 mg N/L to 1.64 mg N/L) (Fig. 56).

Total suspended solids ranged from 5.5 mg/L at site HW0 to 38.6 mg/L at site HW5. The largest percent increase was between HW6 and HW5 (338%, 8.4 mg/L to 38.6 mg/L). Total coliform bacteria ranged from 4,800 CFU/100 mL at site HW0 to 84,000 CFU/100 mL at site HW5. Site HW5 had high TSS and the highest count of total coliform bacteria of 84,000 CFU/100 mL (Fig. 57).

Chronological Account of Stressed Stream Analysis

5 October 2010 (event)

Sampling of four sites in the Northeast Tributary subwatershed occurred on 5 October 2010 during event conditions (12.7-19.5 mm of rainfall, Fig. 58). Within this segment, the upper reach of the tributary had the highest concentrations of sediments and nutrients while the lower reach concentrations were lower. Total phosphorus was the highest at the farthest upstream site of Northeast Tributary 5 (NET5) at 186.4 µg P/L, which decreased by 41 % to 109.2 µg P/L at site NET4 (Fig. 59). Soluble reactive phosphorous was highest at site NET5 (80.6 µg P/L) and decreased 33% to 54.1 µg P/L at site NET4. No further increases in TP and SRP were observed downstream (Fig. 59). This large decrease in elevated nutrient concentrations upstream to downstream is likely the effect of dilution.

Total nitrogen and nitrate followed a similar trend with TP and SRP with the highest concentrations upstream. Total nitrogen had the highest values at sites NET5 and NET4 (1.02 mg N/L and 1.26 mg N/L), which decreased 77% by site NET3 (1.26 mg N/L to 0.71 mg N/L) (Fig. 60). Nitrate was also highest at sites NET5 and NET4 (1.16 mg N/L and 1.38 mg N/L), which then decreased 1,871% at site NET3 (1.38 mg N/L to 0.07 mg N/L) (Fig. 60) that is likely due to dilution.

Total suspended solids followed a similar trend as P and N decreasing from sites NET5 to NET2 (20.4 mg/L to 6.8 mg/L) (Fig. 61). High sediment concentrations upstream at sites NET5 and NET4 (20.4 mg/L and 18.5 mg/L, respectively) were likely diluted and decreased by 79% by site NET3 (3.9 mg/L) (Fig. 61). Total coliform was relatively constant between all five sites and ranged from 16,300 CFU/100 mL to 29,900 CFU/100 mL (Fig. 61). Figure 42 is an orthophoto that shows the location of site NET 2.

Chronological Account of Stressed Stream Analysis

12 October 2010 (nonevent)

On 12 October 2010 Spring Creek and its two tributaries (Trib 1 and Trib 2) were sampled during a nonevent period to determine the contribution of each subwatershed to the routine site (SC1) (Fig. 43). Tributary 2 (SC2) was previously sampled as well as the routine Spring Creek site.

Tributary 1 had generally higher concentrations of TP, SRP, TN, and nitrate than Tributary 2 (Figs. 43-44). Concentrations in Tributary 1 were also higher than site SC1 below the juncture of Tribs 1 and 2. Total phosphorus, SRP, TN, and nitrate were 198.1%, 75.2%, 98.2%, and 96.8% higher in Tributary 1 of Spring Creek than in Tributary 2, respectively. Total suspended solids and total coliform had the opposite trend where TSS (100%) and bacteria (436.4%) were higher in Trib 2 than in Trib 1 (Fig. 45). Total suspended solids were non-detectable in Tributary 1 and were 4.1 mg/L in Tributary 2 (Fig. 45).

Chronological Account of Stressed Stream Analysis

19 October 2010 (nonevent)

Four sampling sites in the Northeast Tributary were revisited during a nonevent period, and one new site was sampled. Total phosphorus was highest at site NET1 (94.7 µg P/L), the site within the Northeast Tributary farthest downstream (Fig. 62: orthophoto of site), while Site NET5 in the headwaters also had elevated TP concentrations (57.3 µg P/L) (Fig. 59). Nonevent SRP on the other hand, was fairly low compared to event sampling at Northeast Tributary: the highest SRP concentration was found at Site NET2 with 34.3 µg P/L (Fig. 59).

Total nitrogen and nitrate had more definitive results than phosphorus (Fig. 60). Although all sites had high levels of TN and nitrate compared to previous sampling, the highest concentrations were at site NET4 (TN: 3.94 mg N/L, 69%

increase from site NET5, nitrate: 3.33 mg N/L, 102% increase from NET5), respectively.

Total suspended solids followed a trend similar to that of TP where the highest concentration was at site NET1 (34.3 mg P/L, 444% increase from site NET2) while all other sites had low concentrations (Fig. 61). This suggests that TP is being loaded into the creek along with sediments. Total coliform followed a similar trend as nitrate and TN where the highest bacteria abundance was found at NET4 (2,500 CFU/100 mL, 108% increase from site NET5) (Fig. 61).

Chronological Account of Stressed Stream Analysis

3 November 2010 (nonevent)

Bigelow Creek

Six sites in the Bigelow Creek subwatershed (Fig. 63) were sampled during a nonevent period. Total phosphorus was relatively low throughout the watershed but was highest at Bigelow 6 and Bigelow 2 with 29.5 µg P/L and 25.1 µg P/L, respectively (Fig. 63). A notable increase (51%) was seen between Bigelow 3 and Bigelow 2 (16.6 to 25.1 µg P/L). Soluble reactive phosphorus was also elevated at Bigelow 2 with 20.4 µg P/L (Fig. 63).

Total nitrogen was highest at Bigelow 4 with 3.19 mg N/L and nitrate was highest at Bigelow 6 with 1.08 mg N/L (Fig. 64). At the mouth of the tributary, TN was 2.23 mg N/L (19% increase from Bigelow 6) and nitrate was 0.01 mg N/L (10,700% decrease from the headwaters at Bigelow 6).

Total suspended solids was highest at Bigelow 6 (3.8 mg/L) and total coliform bacteria was highest at Bigelow 5 (1,900 CFU/100 mL) (Fig. 65). These results from nonevent sampling were inconclusive; these sites were resampled during event conditions to pinpoint sources.

North Branch Tributary

Five sites in the North Branch Tributary subwatershed (Fig. 66) were sampled on 3 November 2010 during a nonevent. Total phosphorus and SRP were highest at site North Branch 5. Total phosphorus concentration was 75.9 µg P/L and decreased 270% to the discharge point to Black Creek at North Branch 1; the SRP concentration was 15.8 µg P/L and decreased 464% to the outlet (Fig. 66).

Total nitrogen was highest at North Branch 5 with 1.88 mg/L, decreased steadily downstream to 1.06 mg N/L, and then increased 42% at site North Branch 1 to 1.42 mg N/L (Fig. 67). The nitrate concentration was 0.31 mg/L at Site North Branch 5 and remained relatively constant with movement downstream to North Branch 1 where it increased 116% to 0.67 mg N/L (Fig. 67).

Total suspended solids and total coliform bacteria abundance followed a similar trend as P and N where the highest concentrations were found at North Branch 5 and decreased drastically with movement downstream (Fig. 68). Total suspended solids were 17.4 mg/L at North Branch 5 and decreased to 2.4 mg/L at North Branch 1 (a 625% decrease). Total coliform bacteria abundance was 400 CFU/100 mL at North Branch 5 and decreased to 200 CFU/100 mL at North Branch 4 and remained the same to the outlet (Fig. 68). It is evident that there is a source above North Branch 5 (Fig. 69).

Chronological Account of Stressed Stream Analysis

8 March 2011 (event)

Bigelow Creek

Six sites in the Bigelow Creek subwatershed of Black Creek were resampled during event conditions on 8 March 2011. Total phosphorus concentrations increased drastically between Bigelow 5 and Bigelow 4 (209% increase 52.6 µg P/L to 162.7 µg P/L) and remained elevated to site Bigelow 1 (Fig. 63). The same trend was seen in SRP (211% increase 14.5 µg P/L to 45.2 µg P/L).

Total nitrogen and nitrate both increased between sites Bigelow 5 and Bigelow 4 (TN: 65% increase 1.51 mg N/L to 2.49 mg N/L; nitrate: 95% increase, 1.00 mg N/L to 1.95 mg N/L). This indicates a source of N between these two sites (Fig. 64).

Similar to P and N, total coliform bacteria abundance increased dramatically from 0 to 3,700 CFU/100 mL between the same two sites, Bigelow 5 and Bigelow 4. Total coliform slightly decreased downstream of site Bigelow 4 to the outlet (Fig. 65). Total suspended solids increased drastically from Bigelow 6 to Bigelow 5 (304% increase, from 4.7 mg/L to 19.0 mg/L) and had the highest concentration at Bigelow 2 of 31.5 mg/L (Fig. 65).

Chronological Account of Stressed Stream Analysis

15 March 2011 (event)

Mill Creek

Seven sites in the Mill Creek Tributary of Black Creek were sampled during event conditions on 15 March 2011. Total phosphorus and SRP were fairly low throughout the tributary (<30 µg P/L). Total phosphorus and SRP increased between sites 5 and 4, 12% (20.7 µg P/L to 23.3 µg P/L) and 68% (2.2 µg P/L to 3.7 µg P/L), respectively. These higher concentrations are likely due to the Mill Creek Farm, which is between sites 5 and 4 and had elevated TP (41.0 µg P/L) and SRP (12.8 µg P/L) (Fig. 50).

Total nitrogen and nitrate also increased between sites 5 and 4 on Mill Creek and then decreased downstream to the outlet. Total nitrogen increased 16% (1.87 mg N/L to 2.17 mg N/L) and nitrate increased 5% (1.67 mg N/L to 1.76 mg N/L) from sites 5 to 4. As with P, the increase in N is likely due to the influence of the farm in the Mill Creek subwatershed. A sample taken below the farm had TN of 4.15 mg N/L and nitrate of 3.89 mg N/L (Fig. 51). This farm is on a small stream that runs into Mill Creek between sites 5 and 4.

Total suspended solids and total coliform bacteria concentrations varied throughout the subwatershed on the 15 March 2011. Similar to P and N results, TSS and total coliform increased between sites 5 and 4. Total suspended solids increased 48% (4.3 mg/L to 6.4 mg/L) and total coliform increased from 0 to 300 CFU/100 mL. The sample taken below Mill Creek Farm in the tributary that enters Mill Creek had TSS of 11.1 mg/L and total coliform abundance of 200 CFU/100 mL (Fig. 52). It is evident that the Mill Creek Farm is affecting the water quality of Mill Creek.

North Branch Tributary

Five sites (Fig. 66) in the North Branch Tributary of Black Creek were resampled during event conditions on 15 March 2011. Total phosphorus steadily increased downstream of the North Branch 5 site which had a TP concentration of 12.5 µg P/L and increased to 21.9 µg P/L (Fig. 66). Soluble reactive phosphorus was very low at all of the sites sampled (<4 µg P/L) and therefore there is not a source of SRP within this subwatershed. Total phosphorus and SRP were both comparable at North Branch 1, 2, and 3 but were much lower at North Branch 4 and 5 than on the previous sampling date (Fig. 66).

Total nitrogen and nitrate on the other hand were high (>1.0 mg N/L) at all North Branch Tributary sites on 8 March (Fig. 67). Total nitrogen was the highest at North Branch Tributary site 5 with 2.05 mg N/L and decreased 12% at North Branch Tributary site 1 (1.83 mg N/L). Nitrate followed a similar trend with the highest concentration at North Branch 5 with 1.48 mg N/L and decreased 11.5% at North Branch 1 (1.31 mg N/L) (Fig. 67).

Total suspended solids and total coliform bacteria varied substantially between all of the sites sampled on North Branch Tributary (Fig. 68). Total suspended solids was fairly low at all of the sites but was highest at North Branch 1 with 5.4 mg/L. Total coliform bacteria did not follow a decipherable pattern on this sampling date as it did previously. Total coliform bacteria were the lowest at North Branch sites 1 and 5 with 100 CFU/100 mL and was higher at North Branch 2 with

600 CFU/100 mL (Fig. 68). Any increase in bacteria within the watershed is diluted by the time it reaches the outlet.

Wastewater Treatment Plants

Churchville WWTP:

The Churchville WWTP was closed in 2002 and therefore does not have an allowable discharge (personal communication: Charles L. Knauf, Monroe County Health Department). Significantly lower TP, TN, nitrate, and TSS concentrations were observed in stream samples from below the Churchville WWTP compared to above the WWTP (Table 15). Total phosphorus, TN, and TSS decreased; 66% (54.5 ± 2.8 µg P/L to 32.7 ± 6.7 µg P/L), 10% (1.81 ± 0.01 mg N/L to 1.65 ± 0.02 mg N/L), and 149% (12.2 ± 0.3 mg/L to 4.9 ± 0.2 mg/L), downstream of the Churchville WWTP, respectively. The nitrate concentration increased significantly from 1.11 ± 0.01 mg N/L to 1.21 ± 0.01 mg N/L, which represents a 9% increase. No significant differences ($P>0.05$) in SRP concentrations and total coliform abundances were observed downstream of the Churchville WWTP (Table 15).

Bergen WWTP:

The Bergen wastewater treatment plant has an allowable discharge of up to 787 m^3/d (208,000 GPD) into Minny Creek but on average discharges 481 m^3/d (127,000 GPD). Significant ($P<0.05$) increases in TP, SRP, TN, nitrate, and TC were observed downstream of the wastewater treatment plant (Table 15). Total phosphorus, SRP, TN, nitrate, and TC increased; 18,984% (20.1 ± 1.3 µg P/L to 3,835.8 ± 703.8 µg P/L), 40,445% (5.8 ± 0.2 µg P/L to 2,351.6 ± 261.3 µg P/L), 611% (2.80 ± 0.00 mg N/L to 19.9 ± 2.90 mg N/L), 546% (2.70 ± 0.01 mg N/L to 17.44 ± 2.90 mg N/L), and 741% (3,025 ± 516 CFU/100 mL to 25,475 ±1,882 CFU/100 mL) downstream of the Bergen plant, respectively. There was no statistical difference in TSS above and below the WWTP (5.7 ± 1.2 mg/L to 3.6 ± 0.1 mg/L; Table 15), which suggests that the plant is not having a significant impact on TSS in Minny Creek.

On 26 July 2011 the Bergen WWTP was resampled due to an upgrade put into place in January 2011. Sites below the WWTP were found to have significantly ($P<0.05$) high levels of TP, SRP, TN, and nitrate similar to the previous sampling results above (Table 16), but there was no significant difference in total coliform above and below the plant (Table 16). Total coliform bacteria increased only 11% downstream of the plant on 26 July 2011 (9,225 ± 727 CFU/100 mL to 10,200 ± 187 CFU/100 mL) compared to the 742% increase observed on 19 October 2010 (3,025 ± 516 CFU/100 mL to 25,475 ±1,882 CFU/100 mL). These results suggest that an upgrade to the Bergen WWTPs bacterial treatment processes was implemented.

Effluent from the Bergen WWTP sampled on 26 July 2011 had high TP, SRP, TN, and nitrate concentrations. Total phosphorus and SRP concentrations were both 13,335.5 µg P/L, which indicates that TP is entirely SRP with no particulate, organic, or acid-hydrolyzable phosphorus. Total nitrogen and nitrate were very high with concentrations of 48.04 mg N/L and 37.45 mg N/L, respectively. Conversely, TSS and TC were both low (2.0 mg/L and 100 CFU/100 mL, respectively), which suggests that the Bergen WWTP is not a significant source of either of these analytes.

Central Byron Municipal Leachfield:

The Central Byron municipal leachfield has an allowable discharge of up to 201 m^3/d (53,000 GPD) into Black Creek but has an average discharge of 125 m^3/d (33,000 GPD). Significant increases in TP, SRP, TN, nitrate, and TSS were observed below the Byron leachfield ($P<0.05$) (Table 15). Total phosphorus, SRP, TN, nitrate, and TSS increased; 21% (80.4 ± 1.4 µg P/L to 97.2 ± 0.9 µg P/L), 21% (53.4 ± 0.4 µg P/L to 64.4 ± 0.6 µg P/L), 18% (1.43 ± 0.01 mg N/L to 1.69 ± 0.02 mg N/L), 24% (0.86 ± 0.01 mg N/L to 1.07 ± 0.00 mg N/L), and 123% (3.0 ± 0.4 mg/L to 6.7 ± 0.8 mg/L) downstream of the Byron leachfield, respectively. There was no significant difference between total coliform bacteria above and below the WWTP (Table 15), which suggests that the Byron leachfield does not significantly impact the TC abundance of Black Creek.

North Byron Municipal Leachfield:

The North Byron municipal leachfield has an allowable discharge of up to 23 m^3/d (6,000 GPD) but has an average discharge of 15 m^3/d (4,000 GPD) into Spring Creek. Significant increases in TC were observed below the North Byron leachfield where TC increased 114% (525 ± 63 CFU/100 mL to 1,125 ± 309 CFU/100 mL; Table 15). Significantly lower TSS was observed below the leachfield, which decreased 47% (3.8 ± 0.1 mg/L to 2.0 ± 0.3 mg/L; Table 15). There was no significant difference between TP, SRP, nitrate, and total coliform upstream and downstream of the community leachfield in North Byron ($P>0.05$) (Table 15) suggesting that it does not have a significant impact on the nutrient concentrations of Spring Creek.

South Byron Municipal Leachfield:

The South Byron municipal leachfield discharges on average their allowable discharge of 95 m^3/d (25,000 GPD). Total phosphorus concentrations were significantly higher downstream than upstream of the South Byron municipal leachfield. Observed TP increased 15% (50.9 ± 0.3 µg P/L to 58.3 ± 0.7 µg P/L) downstream of the leachfield. On the other hand, SRP, nitrate, TSS, and total coliform were not significantly different upstream and downstream of the South Byron leachfield (Table 15) and TN had significantly lower concentrations ($P<0.05$) below the leach field, which decreased 8% (2.51 ±0.03 mg N/L to 2.42 ± 0.02 mg N/L; Table 15).

Quarry Results

Total phosphorous, SRP, TSS, total coliform bacteria, potassium, alkalinity, chloride, and sodium concentrations detected in the ditch draining the Quarry downstream of the pump station (Fig. 70) were all not found to have a statistically significant effect ($P> 0.05$) on the water quality of Black Creek (mean concentrations from quarry drainage: 19.3 µg P/L, 1.93 µg P/L, 3.7 mg/L, 212.5 CFU/100 mL, 4.5 mg/L, 265.7 mg/L, 61.8 mg/L, 25.3 mg/L, respectively; and mean concentrations from headwaters site: 139.3 µg P/L, 63.5 µg P/L, 21.1 mg/L, 3587.5 CFU/100 mL, 3.9 mg/L, 255.2 mg/L, 58.4 mg/L, 23.0 mg/L, respectively). Total nitrogen ($P=0.00$) and nitrate ($P=0.00$) concentrations were significantly lower at the quarry drainage than at the headwaters of Black Creek site (mean concentrations from quarry: 2.0 mg N/L and 1.8 mg N/L; mean concentrations from headwaters site: 2.9 mg N/L and 2.3 mg N/L). Sulfate and calcium were the only analytes that were found to have a significant negative effect on Black Creek (mean sulfate concentrations: from quarry drainage 255.2 mg/L and headwaters site 85.6 mg/L, P=0.00; mean calcium concentrations: from quarry drainage 246.7 mg/L and at the headwaters site 175.2 mg/L, P=0.04) (Figure 71).

SWAT Model Results

Model Performance

The Black Creek SWAT model was calibrated for water balance, TP, and TSS for the 2010-2011 monitoring period at Middle BC (Churchville USGS monitoring station). Additionally, the model predictions were verified using the percent bias (PBIAS) calibration criterion at the remaining four monitoring stations (Upper BC, Lower BC, Bigelow Creek, and Spring Creek) to ensure that the entire watershed was being simulated accurately. All locations within the Black Creek watershed had at minimum a ‘good’ performance rating (Moriasi *et al.* 2007) for TP load. Bigelow and Spring Creeks have a tendency to underpredict the amount of TP with 2.0 MT/yr (-31 PBIAS) and 3.4 MT/yr (-20.9 PBIAS), respectively, compared to the observed 2.9 and 4.3 MT/yr (Table 8). On the other hand, the main stem sites at Upper, Middle, and Lower BC tend to overpredict TP loads with 7.0 (1.4 PBIAS), 15.1 (9.8

PBIAS), and 17.3 (4.8 PBIAS) compared to the observed values of 6.9, 13.8, and 16.5 MT/yr, respectively (Table 8).

Total suspended solids had minimally a 'good' performance rating (Moriasi *et al.* 2007). Spring Creek and Lower BC both underpredict the annual TSS load with simulated loads of 841.7 (11.9 PBIAS) and 6,659.9 MT/yr (20.3 PBIAS) compared to the observed loads of 955.3 and 8,360.6 MT/yr, respectively (Table 8). Bigelow Creek, Upper BC, and Middle BC all slightly overpredict the total annual TSS load with simulated loads of 626.1 (4.7 PBIAS), 1,335.7 (PBIAS 0.6), and 2,284.4 MT/yr (2.0 PBIAS) compared to observed TSS loads of 597.8, 1,327.4, and 2,239.1 MT/yr, respectively.

Sources of Phosphorus

After the calibration and validation step of the model-building process the point and nonpoint sources of phosphorus were quantified. These sources were broken down into the following groups: agriculture, forest/other, wastewater, and urban areas. Within each source category, several distinct sources of P were quantified. More than 70% of the total annual TP load from the Black Creek watershed at the Middle BC site is due to anthropogenic sources: primarily point discharges, animal farm operations, and croplands (Table 17). Agricultural sources make up more than 47% of the total TP load from Black Creek at Middle BC - manure from farm animals contributes over 17% (2,800 kg TP/yr), agriculture 24.3% (3,874 kg TP/yr), and 5.5% from tile drainage (877 kg TP/yr). Point sources contribute 17.5% of the total TP load (2,797 kg TP/yr), which is almost entirely due to the village of Bergen wastewater treatment plant (Table 17). Several other phosphorus sources such as forested areas, wetlands, the limestone quarry, and septic systems appear to have a minimal impact on the TP load from Black Creek (Table 17). This allocation of the TP load allows us to organize the criteria necessary to develop a total maximum daily load (TMDL) for the Black Creek watershed. The largest sources, farm animal operations and point sources, are the areas where remediation should be focused.

Effectiveness of Best Management Practices (BMPs)

Several management practices were simulated with the SWAT model to determine the methods that reduce TP and TSS loads most effectively. A total of 25 different management scenarios were simulated using BCSWAT to determine the percent reduction in TP and TSS from various BMPs (Table 18). For example, if Black Creek were converted to a natural watershed (100% forested), the TP load would be reduced approximately 60-70% and the TSS load 91-100% (Table 18). Additionally, the TP concentration would be reduced from 79.6 µg P/L to 36.2 µg P/L at Lower BC (Table 19), the site closest to the watershed outlet. A 60-70% reduction in P load and a 91-100% reduction in TSS load represent the maximum possible reduction in sediment and nutrients from the Black Creek watershed.

Several agricultural management practices effectively reduced both TP and TSS loads at all five monitoring stations (buffer strips, conservation tillage, grassed waterways, contouring, terracing, strip cropping, agricultural land retirement, cover crops, nutrient management (reducing routine fertilizer applications to crops), and removing manure applications from CAFOs). The largest reductions in nutrients and sediments were from buffer strips, conservation tillage, and grassed waterways which reduced TP 15-24%, 14-27%, and 19-43% and TSS 43-62%, 7-58%, and 5-65%, respectively (Table 18). If all fertilizer from CAFOs was contained rather than spread on agricultural fields, TP would be reduced 0-26% and TSS 0-20%. Removing the impacts of CAFO manure applications to croplands generally impacted those subbasins that contain the operations the strongest such as the Spring Creek subwatershed where four CAFOs currently spread manure (21% reduced TP and 2% reduced TSS).

Urban, residential, and erosion management were also simulated in BCSWAT (removal of Bergen WWTP, upgrade of Bergen WWTP, removal of point sources and septic systems, and stream bank stabilization). The removal or upgrade of the Bergen WWTP (upstream of Middle BC) to tertiary treatment can reduce TP loads by 19% and 18%, respectively, at the Middle BC and 16% at Lower BC sites (Table 18). Removal of other point sources and septic systems had minimal impacts on load reductions (0-2% reduction in TP and 0-4% reduction in TSS) (Table 18). Basin-wide stream bank stabilization greatly reduced the sediment loads (20-84%) but had little to no impact on TP load (Table 18). The TSS load was reduced 71% at Lower BC by targeting highly erodible areas upstream of this site.

Once the effectiveness of different BMPs was quantified, the most effective and applicable BMPs were used to remediate impacted tributaries such as Bigelow Creek and Spring Creek as well as the entire Black Creek watershed. Remediation of

Spring Creek included removal of manure applications from CAFOs to agricultural fields, 50% nutrient management (50% reduction in routine fertilizer applications to crops), conservation tillage, removal of septic systems, and applications of grassed waterways and buffer strips to agriculture. This remediation reduced TP 49% and TSS 16% of the current load (Table 18); the remediation of this creek reduced downstream TP loads by 7% and 6% and TSS loads 4% and 1% at Middle BC and Lower BC, respectively. The remediation of Bigelow Creek included 50% nutrient management by reducing the amount of fertilizer routinely applied to croplands by 50% (excluding CAFO manure applications), conservation tillage, buffer strips, and terrace farming on all agriculture and reduced the TP load 24% and TSS 21% at Bigelow Creek and the downstream TP loads 5%, 1%, and 1% and TSS loads 4%, 2%, and 1% at Upper BC, Middle BC, and Lower BC, respectively. A whole watershed remediation utilizing effective and applicable BMPs throughout the Black Creek watershed (Management Scenario 1) included cleaning up of both Bigelow and Spring Creek tributaries, upgrading the Bergen WWTP to tertiary treatment, eliminating manure applications to farm fields, and stabilizing highly erodible stream banks above Lower BC. The TP reduction by applying this scenario had a range from 13% at Upper BC and 49% at Spring Creek and TSS loads by a range from 10% at Upper BC and 73% at the Lower BC site (Table 18). A management scenario applying additional BMPs to the entire watershed (Management Scenario 2; Table 20) included all management applied in Management Scenario 1 as well as removing all point sources and septic systems and adding basin-wide applications of conservation tillage, filter strips, contour farming, and stream bank stabilization. Application of these BMPs resulted in a TP reduction ranging from 36% at Bigelow Creek and 56% at Lower BC and a TSS reduction ranging from 10% at Upper BC and 86% at the Lower BC site (Table 18).

Discussion

An assessment of the Black Creek watershed was undertaken to determine the nutrient and sediment contribution of Black Creek to the Genesee River and to determine sources of nutrient and sediment loss geospatially within the watershed. To accomplish this task, a multifaceted, integrated approach was taken by a combination of monitoring, segment analysis, and modeling (Soil and Water Assessment Tool). Thus, the creek was monitored for discharge, water chemistry, and loss of nutrients and soil for an entire year (1 June 2010 to 31 May 2011) at three main stem sites (Upper BC, Middle BC, and Lower BC) and two major tributaries (Bigelow Creek and Spring Creek) to determine monthly losses from each subbasin (Fig. 3). Based on these data, the Black Creek Soil and Water Assessment Tool (BCSWAT) model was created, calibrated, and verified for discharge, sediment, and phosphorus loss. Based on the loading data to a subbasin outlet and the SWAT model, segment analysis (Makarewicz and Lewis 2001) was performed on selected subwatersheds to determine sources of material loss. Together these two bodies of information, the total amount of nutrients, sediments, and bacteria lost from the watershed and the sources of these losses, served as a valuable tool for directing watershed management. Lastly, the BCSWAT model was employed to test the effectiveness of best management practices (BMPs) on land-use and to determine the minimum potential phosphorus concentration expected in a forested Black Creek watershed as a nutrient target for TMDL development.

Water Quality Targets

Nutrient enrichment from nonpoint source pollution, particularly nitrogen and phosphorus, is a primary cause of water quality impairment throughout the United States (USEPA 2000b). New York State has recognized the impact of nutrient pollution of surface waters within the state and has developed water quality guidance criteria to reduce these impacts and protect beneficial uses of lakes, streams, and reservoirs (NYSDEC 2011). Within New York State, nearly all freshwater systems are phosphorus-limited rather than nitrogen-limited. Nitrogen criteria for the state will only apply when a waterbody is shown to be nitrogen-limited (NYSDEC 2011). As a result, the development of freshwater phosphorus concentration targets for stream waters is a priority for New York.

The existing New York narrative ambient water quality standards for phosphorus and nitrogen (6NYCRR 703.2) limit these nutrients to “none in amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages.” The current numerical guidance value of 20 µg P/L for phosphorus has been established to protect the recreational uses of Classes A through B for ponds, lakes, and reservoirs (NYSDEC 2011). Smith *et al*. (2007) developed a nutrient biotic index based on macroinvertebrate tolerance values for species found in watersheds throughout New York State. Based on macroinvertebrate data, a phosphorus concentration target of 65 µg P/L was proposed (Smith *et al.* 2007). Phosphorus values above this target will likely cause impairment of a stream. A target of 45 µg P/L is a representative median value between the other two targets in New York State: 20 µg P/L and 65 µg P/L (USEPA 2003). Several other US states have designated different numeric P criteria targets for streams (100 µg P/L in NJ, NM, AK, ND; 50 µg P/L in UT and IL) and lakes (50 µg P/L in NJ, IL, AK; 25 µg P/L in NJ, IL, AK) throughout the state whereas others designate targets for specific waterbodies (VT, AL, GA) (USEPA 2003).

Within the Black Creek watershed the average annual SWAT simulated TP concentrations ranged from 79.6 µg P/L at Lower BC to 110.5 µg P/L at Bigelow Creek (Table 19) and TSS ranged from 13.6 mg/L at Middle BC to 33.8 mg/L at Bigelow Creek (Table 19). These concentrations are comparable to the observed, which ranged from 67.7 µg P/L at Lower BC to 117.7 µg P/L at Upper BC for TP and 11.9 mg/L at Lower BC and 19.8 mg/L at Bigelow Creek for TSS (Table 9). If the Black Creek watershed was converted to its natural state, simulated average annual phosphorus and sediment concentrations from Black Creek would range from 38.0 µg P/L at Lower BC to 54.2 µg P/L at Upper BC and 0.4 mg/L at Spring Creek to 4.1 mg/L at Bigelow Creek (Table 19). These concentrations represent the absolute minimum average concentration of phosphorus and suspended sediment of water expected in Black Creek. A target stream TP concentration of 65 µg P/L, often suggested as a goal for surface waters in New York, can be achieved at Middle BC and Lower BC (Management Scenario 1; Table 20) by remediating only Bigelow and Spring Creeks, by removing CAFOs manure applications to farm fields in the headwaters of Black Creek, by upgrading Bergen WWTP to tertiary treatment, and by stabilizing/buffering stream banks above Lower BC (Table 19). This target can be reached by focusing remediation on the two largest loads (point sources and farm animal operations) to reduce the TP load by 6,118 kg TP/yr. A much more stringent target of 45 µg P/L that has been proposed was reached at Middle BC and Lower BC by removing all point sources, manure applications from CAFOs, and septic systems; by applying basin-wide stream bank stabilization, conservation tillage, and basin-wide contour farming and buffer strips; and remediating Spring and Bigelow Creeks (Table 19). A target of 20 µg P/L is below the level of a simulated natural, forested Black Creek and is therefore unattainable.

When setting nutrient concentration targets and/or developing regulatory standards for streams and rivers, the natural or background concentration expected should be determined. At a minimum, stream phosphorus standards should not be below the background levels from an entirely natural watershed with no anthropogenic inputs. Also, soil type and geology clearly impact phosphorus loss from a watershed. For example, stream concentration of P draining forested watersheds on granitic rock as opposed to sedimentary rock is likely to be different. Phosphorus concentrations in Adirondack streams draining undeveloped, forested granitic basins are generally much lower [Mean <10 µg P/L (Table 21); Raquette River Streams 2011] (personal communication: Dr. Daniel Kelting, Adirondack

Watershed Institute of Paul Smith's College) than P concentrations in forested Finger Lake streams draining calcareous dominated soils such as in Conesus Lake [Mean 21 µg P/L (Table 21); North McMillan Creek 2007] (Makarewicz *et al*. 2009). Stream monitoring by the USGS in the Tualatin River watershed showed that the five streams with the highest TP concentrations were underlain by sedimentary material where as the ten streams with the lowest TP concentrations were underlain by volcanic rock (Kelly *et al*. 1999). Variation in P concentration based on bedrock characteristics suggests that it may be more appropriate to implement different nutrient criteria for regions throughout the state based on soil and bedrock type.

Over the past few decades, interest in determining the background load of nutrients from natural watersheds has increased dramatically due to the greatly increased influence of human activity on water quality in the United States (Smith *et al.* 2003). This is often difficult to determine through direct field measurements because watersheds untouched by human development are scarce. Other methods, such as watershed modeling, have since been developed that aid in this process. Here the Soil and Water Assessment Tool was used to determine the background or uncontrollable P concentration from the Black Creek watershed by converting all developed areas (agriculture, residential, and urban areas) to a forested land-use. The resulting concentration at Lower BC, 38.3 µg P/L (Fig. 3, Table 19), represents the minimum concentration of P that would be attainable for Black Creek. The 65-µg P/L target proposed by Smith *et al.* (2007) for New York State is a reachable target for Black Creek because it is both attainable based on background levels and allows for some human interaction with the watershed in Black Creek. Whether or not a 65-µg P/L target is an appropriate target that will improve stream and lake water quality in downstream ecosystems has not been determined.

Identifying appropriate nutrient target concentrations is important to water quality assessment and management as they represent the goal for remedial action plans for watershed remediation in the state. Since a regulatory target goal has not been established in NYS, three proposed phosphorus concentrations (20, 45, and 65 µg P/L) were used as targets for determining a TMDL; that is, land-use practices necessary to reach nutrient goals in segments in the Black Creek watershed were set at 65, 45, and 20 µg P/L. The Lower BC and minor tributaries, Upper BC and minor tributaries, Spring Creek, and Bigelow Creek segments in the Black Creek watershed are Class C waters listed as impaired on the NYS 303(d) list of priority waterbodies due to phosphorus inputs from agricultural and municipal sources (NYSDEC 2003). The Middle BC segment is not listed as impaired, but it is suspected to have impairments to its beneficial uses (NYSDEC 2003). The degree to which these segments are impacted can be put into perspective by comparing the load of nutrients and sediments from these areas to other tributaries in the Lake Ontario drainage basin.

Black Creek in Comparison to Other Tributaries

By determining annual sediment and nutrient loads that are normalized for watershed area, tributary catchments of varying watershed size may be compared, allowing a quantitative perspective on land-use and prioritizing management within a watershed. Field-observed total (MT) and areal (kg/ha) TP loading from various tributaries to Lake Ontario were obtained (Booty *et al.* in Press) to compare to the observed areal loads from three main stem (Upper BC, Middle BC, and Lower BC) and two tributary segments (Bigelow Creek and Spring Creek) in the Black Creek watershed (Table 10b) to other tributaries of Lake Ontario. Throughout the Lake Ontario basin, tributaries with the highest percentage of agriculture tend to have the highest areal loads (Table 22). Similarly, phosphorus losses from the tributaries of the Black Creek watershed (Bigelow Creek and Spring Creek) are comparable to losses from other agricultural watersheds. The areal TP loads from Bigelow Creek (82% agriculture), 1.1 kg TP/ha/yr, and Spring Creek (96% agriculture), 0.8 kg TP/ha/yr (Table 10b), were similar to other agriculturally dominated Lake Ontario tributaries (Oak Orchard, Golden Hill, and Wolcott Creeks; 1.04, 0.88, and 1.37 kg TP/ha/yr, respectively; Table 22).

The main stem segments with lower areal loads, Upper BC (82% agriculture), 0.6 kg TP/ha/yr, and Middle BC (76% agriculture), 0.3 kg TP/ha/yr (Table 10b), are more comparable to mixed agricultural and suburban watersheds such as Johnson, Buttonwood, and Irondequoit Creeks (0.54, 0.57, and 0.53 kg TP/ha/yr, respectively) (Table 22). The areal loads from these segments are all much higher than from forested watersheds in the Lake Ontario drainage basin such as First, Clark, and Bobolink Creeks with less than 0.2 kg TP/ha/yr (Table 22). Lower BC has less agricultural land (63%) and more forest and wetland forest areas (23%) and a much lower areal TP load (0.2 kg TP/ha/yr; Table 10b). Such comparisons point out the connection between land-use practices and water quality issues within the Lake

Ontario watershed and help to prioritize different subwatersheds. Because the high areal loads of portions of Black Creek are comparable to other impacted tributaries of Lake Ontario, it is of concern and is a priority watershed for management. Sources of impairment were located within the Black Creek watershed by identifying losses of nutrients and sediments using segment analysis to determine where management could be facilitated effectively. The locations of point and nonpoint sources identified via segment analysis were used as inputs to the Black Creek Soil and Water Assessment Tool (BCSWAT) to accurately portray sediment and nutrient losses from the watershed.

Black Creek Soil and Water Assessment Tool (BCSWAT) Performance

Prior to using BCSWAT to determine the impacts of changing land-use practices, the model was calibrated and validated to improve predictive accuracy. The Black Creek Soil and Water Assessment Tool was successfully calibrated at Middle BC (Churchville USGS station: Fig. 3, Table 3) for water balance, TSS, and TP for the water year June 2010 through May 2011 based on monthly observed discharge, TSS load, and TP load. Model Validation for water balance was for the water year of January 2001 through December 2001. Several calibration criteria were used including the Nash-Sutcliffe efficiency coefficient (NSE), coefficient of correlation (r^2), percent bias (PBIAS), and graphical comparisons to verify that the model is accurately predicting water, TSS, and TP from Black Creek.

Moriasi *et al.* (2007) developed a performance rating system for hydrologic models based on published literature. An NSE of greater than 0.65 represented a ‘good’ model performance while a NSE greater than 0.75 represented ‘very good’ performance for all model parameters (water, nutrient, and sediment balance). The PBIAS performance ratings, on the other hand, are specific to the parameter being calibrated (water, sediment, or nutrients). A PBIAS less than ±10% for water balance, <±15% for sediment, and <±25% for nutrients is considered a very good performance; a PBIAS between ±10% and ±15% for water balance, between ±15 and ±30% for sediment, and between ±24% and ±40% for nutrients would indicate good performance. Using the Moriasi *et al.* (2007) criteria, the BCSWAT model yielded a ‘very good’ performance rating for water balance with a NSE of 0.88, r^2 of 0.93, and -3.6 PBIAS (Table 7, Figs. 13-14) and a ‘good’ performance rating for water balance validation with a NSE of 0.71, r^2 of 0.73, and -14.3 PBIAS (Table 7, Figs. 15-16). The BCSWAT model yielded a ‘good’ to ‘very good’ performance for sediment with a NSE of 0.71, r^2 of 0.74, and PBIAS of +2.0 (Table 7, Figs. 17-18) and a ‘very good’ performance for TP prediction with a NSE of 0.78, r^2 of 0.80, and PBIAS of ±9.8 (Table 7, Figs. 19-20). The results from BCSWAT calibration and validation with high NSE and r^2 values and low PBIAS for water balance, sediment, and phosphorus indicated that this model is accurately predicting these parameters at Middle BC and increase confidence in the model to make predictions of water, nutrient, and sediment output based on land-use changes from implementing management practices.

Model performance was also verified spatially in the Black Creek watershed. After model calibration and validation were completed at the Middle BC site, model predictions were further verified at the four other field monitored sites in the Black

Creek watershed (Bigelow Creek, Upper BC, Spring Creek, and Lower BC) (Fig. 3). In doing so, the BCSWAT model was found to be a ‘good’ predictor of TP at Bigelow Creek (PBIAS -31.0; Table 8) and a ‘very good’ predictor of TP at Upper BC (PBIAS +1.4), Spring Creek (PBIAS -20.9), and Lower BC (PBIAS +4.8; Table 8). Similarly, the model was found to accurately predict sediment output with a ‘very good’ performance rating at Bigelow Creek (PBIAS +4.7), Upper BC (PBIAS +0.6), and Spring Creek (PBIAS -11.9) and a ‘good’ performance at Lower BC (PBIAS -20.3; Table 8). The low percent bias values for phosphorus and sediment at these four sites, in addition to the calibration site at Middle BC, not only allow us to assess the loss of nutrients and sediments from the watershed at these locations but also lend further evidence to the predictive strength of BCSWAT and instill confidence in the ability of the model to predict the effect of management on nutrient and sediment loss throughout the watershed.

Efficacy and Limitations of SWAT

Although the SWAT model is a very practical and useful tool for modeling and investigating the connections between hydrology, land use management, and watershed dynamics there are several limitations. Many of these limitations arise from insufficient knowledge and input data about the watershed for calibration as well as issues in the underlying equations within the model itself. To successfully calibrate the model for a given watershed a large amount of data is required above and beyond the three core datasets (land use, soils, and topography). The model is ultimately limited by the completeness of the weather data that is used. Ideally the model should use fully distributed climate data from Doppler data rather than sparsely distributed climate stations. Additionally, to accurately predict the impact of a specific source it needs to be incorporated into the model by the user as realistically as possible. To predict current watershed conditions with confidence all sources affecting water quality such as CAFOs or WWTPs need to be input into the model. If the user does not incorporate these sources into the model the source does not exist in SWAT simulation. This is particularly troublesome when the modeler lacks first-hand knowledge of the watershed. Without this knowledge important watershed characteristics can go unnoticed. An example of this is the need for the addition of water from the Onondaga escarpment to BCSWAT, which was a pivotal aspect of water balance calibration for this model. The approach used in this study combats this issue by utilizing stressed stream analysis to locate point and nonpoint sources of pollution as well as field observations and incorporating those results into the calibration of the SWAT model. In doing so the sources found to have the greatest impact on water quality can be modeled accurately and predictably.

Several other issues became evident in the calibration of BCSWAT. Many calibration parameter values were either based on previous studies or best judgment from knowledge of the Black Creek watershed and the conditions typical of the Northeastern US. Of particular concern is the drastic change of the SCS curve number in BCSWAT needed for calibration. These changes were also necessary to calibrate other SWAT models in the Northeast such as in the Oak Orchard and the Cannonsville Reservoir watersheds (Richards *et al.* 2010, Tolson and Shoemaker

2007). This reduction could be necessary due to the flat topography and internally drained soils in western NY (Richards *et al*. 2010). Because SWAT uses the CN to determine the amount of runoff that will occur at the watershed scale the actual amount of runoff is over-predicted. A possible solution to this issue is to use a SWAT model that incorporates the variable source area concept to more realistically define where runoff will occur in the watershed.

It is also important to note that although the SWAT model was successfully calibrated at the Middle BC (Churchville USGS) site in Black Creek, locations upstream needed further calibration to accurately predict observed loads. This calls into question whether the calibration site is representative of the models predictions throughout the entire watershed. Therefore, we can only consider sites that have been calibrated based on field measurements of nutrient and sediment loads.

Other issues stem from the routing modules and equations within the SWAT model itself. Typically, the peak flow simulation for specific events is not modeled well within SWAT, which is partly due to insufficient weather data, the time-step of the model, and use of the curve number method for runoff determination. Another major flaw in the model is the poor link between the sediment and phosphorus routing modules (see streambank erosion section on pg. 107 for detailed discussion).

These limitations in the application and use of hydrologic models are a byproduct of a deficiency in our understanding of hydrologic processes and the complexities in modeling the dynamic system of a watershed. As we improve our knowledge of science and the underlying equations used to explain these complex phenomena our ability to simulate the natural environment will undoubtedly become more realistic. The SWAT model is one of the best methods available to predict the effect of changing land uses in a watershed and should be used to make management decisions with these weak points kept in mind.

Load Allocations using SWAT

Allocation of the annual TP load by source was accomplished with the BC SWAT model. Knowledge of the proportion of phosphorus coming from natural and anthropogenic sources allows targeting of management efforts and is an integral part of the development of a TMDL. By quantifying the sources and amounts of phosphorus lost from a watershed, the load reductions necessary to improve water quality and to reduce detrimental impacts on beneficial usages are possible.

For the Black Creek watershed, a major source of the total load to the Genesee River (15,136 kg TP/yr) was agriculture (47% of the total). Of the 15,126 kg TP lost from the watershed from agricultural sources, 24.3% was from agricultural crops (3,864 kg TP/yr), 5.5% from tile drainage (877 kg TP/yr), and 17.5% from farm animal operations (2,800 kg TP/yr) (Table 17). Another large source of phosphorus was from municipal wastewater treatment, which contributes 17.5% (2,797 kg TP/yr) to the total TP lost from the Middle BC watershed. Urban runoff contributes approximately 7.1% (1,134 kg TP/yr), while septic systems contribute only 1.4% of the total load to downstream systems (231 kg TP/yr) (Table 17). All other sources were considered natural and contributed 26.6% or 4,244 kg TP/yr (1,047 kg TP/yr from erosion, 844 kg TP/yr from wetlands, and 2,349 kg TP/yr from groundwater) of the nutrient load (Table 17). The P load allocation analysis demonstrates that more than 70% of the total phosphorus load is due to anthropogenic sources and only 26% is due to natural inputs. The large loss of P from anthropogenic sources from the BC watershed suggests that management changing the current land-use practices will likely improve the water quality of Black Creek. To identify the specific location of individual sources of phosphorus subbasins of the Black Creek watershed were monitored and prioritized and stressed stream analysis was employed.

Sources and Sinks of Pollutants from Subbasins

The SWAT derived P allocation table indicated that 70% of the TP from the Black Creek watershed was due to anthropogenic sources, specifically agriculture and municipal sewage systems. The possibility existed that portions of the watershed were contributing varying amounts of P. I compared and prioritized field-measured losses from three main stem reaches (Upper BC, Middle BC, and Lower BC) and two tributaries (Bigelow Creek and Spring Creek) of the Black Creek watershed. Areal loading was chosen as this metric of comparison and evaluation as it normalizes losses from the watershed per unit area. Thus the approach is to compare and evaluate the field-observed areal nutrient, sediment, and bacteria losses of each of the five segments of the Black Creek watershed (main stem sites of Upper, Middle, and Lower BC, and the Bigelow and Spring Creek tributaries) from headwaters to outlet reach by reach and to assess sources of nutrients, sediment, and bacteria within these reaches based on segment analysis and erosion inventories. This two-step approach allowed characterization of the severity of the land-use impacts within the watershed both qualitatively and quantitatively. Once sources were located within each reach, BCSWAT was used to simulate various management practices to determine effective potential remediation strategies for Black Creek. A discussion follows of the field-measured segment load, sources and causes of material losses from the watershed, and potential remediation strategies starting from the headwaters of Black Creek via the Upper BC segment to the outlet at Lower BC (Fig. 3).

Upper Black Creek (BC) Subbasin

Observed Loads from Upper Black Creek and Bigelow Creek

The Upper BC segment (Fig. 3) covers 11,784 ha starting from the headwaters in East Bethany, NY, down to its outlet in Byron, NY. The Upper BC subbasin includes the headwaters of Black Creek and the Bigelow Creek subwatershed. Upper Black Creek, the furthest upstream and the smallest of the main stem segments of Black Creek (11,784 ha; Table 10b), has the highest field-observed areal TP (0.6 kg/ha/yr) and SRP (0.2 kg/ha/yr) loads of the three main stem sites (Upper BC, Middle BC, and Lower BC) (Table 10b). In addition, Upper BC has high TSS and bacteria loads in comparison with Middle BC and Lower BC downstream. Bigelow Creek, an agriculturally dominated (>80%) tributary of Black Creek, discharges into the Upper BC reach and has a major impact on Upper BC water quality due to high areal TP, SRP, TSS, and bacterial loads (Table 10b). Results from BCSWAT simulations also suggest that the Upper BC subbasin is a major contributor of TP to downstream systems. Hotspots of TP losses in the Upper BC reach were verified when subbasins in BCSWAT were ranked based on TP load (Fig. 72). In summary, the Upper BC subbasin, an agriculturally dominated segment, is losing TP and SRP at a higher rate than other main stem reaches.

The Bigelow Creek subwatershed (Fig. 3) (2,616 ha; Table 10b) is a tributary to Black Creek and the smallest segment of the five monitored but has the highest phosphorus load, both total and soluble, per unit area (Table 10b) and, with the exception of Lower BC, a relatively high TSS load (228.5 kg/ha/yr) to the downstream system. Bigelow Creek is also a substantial contributor of total coliform bacteria to Black Creek per unit area with a load of 4.7xE11 CFU/ha/yr. These high losses of material suggest that land-use in the Bigelow Creek subbasin, mostly agricultural row crops and pasturelands, is responsible for the major loads of TP, SRP, TSS, and bacteria into downstream systems and losses from the watershed itself. Results from BCSWAT simulations indicate the Bigelow Creek subbasin as a hotspot and major contributor of TP to Black Creek (Fig. 72).

The results of areal load and an initial segment analysis through field work in the Black Creek watershed suggest that the Bigelow Creek subwatershed is a major contributor to the high phosphorus, sediment, and bacteria issues in Upper BC (Figs. 40-42, Table 10b). The initial stressed stream analysis also indicated that there is a substantial source of phosphorus and nitrogen in the headwaters of BC (Figs. 40-41). These two areas, Bigelow Creek and the headwaters of BC, were further segmented to pinpoint the sources of these issues.

Sources and Modeling Conclusions: Bigelow Creek Subwatershed

The Bigelow Creek subwatershed was segmented on 3 November 2010 during a nonevent and on 8 March 2011 during an event due to previously observed high TP, SRP, TSS, and bacteria losses (Table 10b). This subwatershed has the most densely aggregated SPDES (State Pollutant Discharge Elimination System) sites of any tributary in the Black Creek watershed with a total of seven in a 2,616-ha area. The event and nonevent stressed stream results indicate a source of TP, SRP, TN, nitrate, TSS, and total coliform bacteria upstream of Bigelow 4 due to large increases observed at this site (Figs. 63-65). Site Bigelow 4 is directly downstream of the Batavia Country Club, which has a maximum discharge of 2,000 gallons of wastewater per day (USEPA 2011). However, increases in TP between Bigelow 5 and Bigelow 4 were significantly greater during an event (209% increase) than during a nonevent (4%), which suggests that there is likely a nonpoint source in the area contributing P to Bigelow Creek. Generally, losses of nutrients from croplands are evident during storm events during which a high percentage of sediment-bound nutrients such as TP are lost due to surface scouring, soil erosion, and overland runoff (Pionke *et al.* 1999). Point sources, on the other hand, usually have a pronounced impact on nutrient concentrations during nonevents when discharge will not be diluted by precipitation (Makarewicz and Lewis 2004). Because TP increased dramatically (209%) during a storm event and only slightly (4%) during a nonevent suggests that nonpoint agriculture is the issue here rather than the SPDES site. There is a small farm (Kuszlyk Milk Hauling) between Bigelow 5 and Bigelow 4 that likely contributes to increased nutrient concentrations found during events. Another farm downstream (L. Brooke Farms) between Bigelow 3 and Bigelow 2 likely contributes to the moderate increases in TP during events and nonevents (3% and 51.2%, respectively) (Fig. 63). These nonpoint sources are substantial contributors of nutrients to Bigelow Creek and elevate the phosphorus concentration well above the highest proposed water quality target of 65 µg P/L; and this high concentration propagates downstream to the outlet of this creek (153.5 µg TP/L; Fig. 63).

Several management scenarios were simulated in BCSWAT to determine which management operations were the most successful in reducing nutrient and sediment losses from the entire Bigelow Creek subwatershed. Not surprisingly, the removal of the SPDES sites (Batavia CC and Country Meadows Mobile Home Park) within the Bigelow Creek subwatershed had no effect on the TP load (0% reduction; Table 18) and little effect on the TSS load (1% reduction; Table 18), which was also observed through field-stream sampling above and below Bigelow 6 and 5 and Bigelow 5 and 4 (Fig. 63). This provides verification that most of the phosphorus and sediment load is due to the large amount of agriculture (82%) in this area.

In general, the most effective agricultural operations found through model simulations to reduce TP and TSS include buffer strips (24% reduction in TP, 43% reduction in TSS) and terracing (24% reduction in TP, 29% reduction in TSS) (Table 18). These management practices would be most applicable to the farm fields between Bigelow 5 and Bigelow 4 as well as between Bigelow 3 and Bigelow 2 from where most of the P is coming (Fig. 73). Buffer strips or vegetative filter strips involve the installation of a length of herbaceous vegetation between agricultural lands and stream channels (Tuppad *et al*. 2010), and terraces are broad embankments or channels that are implemented across the slope of the landscape to intercept and slow runoff and control erosion (Tuppad *et al*. 2010). These findings are comparable to Secchi *et al.* (2007) who analyzed the impact of several different BMPs (land set-asides, terraces, grassed waterways, contouring, conservation tillage, and nutrient reduction strategies) and found a 6% to 65% reduction in sediment loss and a 28% to 59% reduction in TP loss from the watershed.

To simulate a remediation of Bigelow Creek, a combination of management practices (buffer strips, terracing, conservation tillage, and a 50% reduction in routine fertilizer to croplands exluding manure produced from CAFOs) was modeled using BCSWAT (Bigelow Creek Tributary Remediation; Table 20). This tributary remediation scenario reduced TP 24% and TSS 21% to the outlet of Bigelow Creek (Table 18). However, these large reductions predicted at Bigelow Creek by SWAT did not result in major improvement at main stem sites downstream (Upper BC, Middle BC, and Lower BC). Predicted reductions of TP (5% to 1%) and TSS (4% to 1%) were small at Upper BC and Lower BC, respectively (Table 18). Although Bigelow Creek does have a high areal TP load, the total annual TP load to Black Creek was low compared to other segments (only 17.8% of the total load, Table 10). Also, a 24% reduction in the already low annual inputs of TP from Bigelow Creek by itself will not have a substantial impact on the total load of Black Creek to the Genesee River. Although remediation of Bigelow Creek does not significantly impact the total load to the Genesee, it is an important factor affecting the Upper BC segment which is listed as impacted on the NYSDEC 303(d) list (NYSDEC 2003). If Bigelow Creek and the headwaters of BC (Management Scenario 2) were both remediated, the total TP load at Upper BC would be reduced 42% (Table 18) and the 65 μg P/L water quality target could be attained for Black Creek.

Sources and Modeling Conclusions: Upper BC Subwatershed

In addition to those in the Bigelow Creek subwatershed, there are many sources of nutrients, sediment, and bacteria in the headwaters of Black Creek that impact losses from the Upper BC segment including several animal farms (Fig. 3). Although the nutrient content of animal wastes can be useful for fertilizer for row crops if kept on the land, overfertilization can saturate soils with N and P which may move into receiving water bodies from runoff and leaching of soils (Chambers *et al*. 2006). Large increases of TP (1,501%), SRP (859%), TN (752%), nitrate (3,325%), TSS (338%), and total coliforms (360%) (Figs. 54-57) were observed from field measurements at Headwaters 5 on 28 September 2010 likely due to the farm owned by Herman Berkemeir and Sons located in East Bethany, NY, directly upstream of site Headwaters 5. Large increases in TP (573%), SRP (313%), and TN (66%) were also found downstream at Headwaters 3 (Figs. 54 and 56). The high values found at this site are most likely due to the covered silage feed composed of corn or hay (personal communication: George Squires, Genesee County Soil and Water Conservation District) (Fig. 55), owned by Lor-Rob Farms as part of the Heifer Farm on McLernon Road in East Bethany. During events the sediment and nutrients at this facility will flow directly into the stream above site Headwaters 3. Lor-Rob Dairy and Lor-Rob Heifer Farms are also located above Headwaters 3. Lor-Rob Dairy is a large CAFO, which has 1,700 dairy cattle, 1,000 heifers, and 1,000 calves (2007 estimate) (personal communication: George Squires, Genesee County Soil and Water Conservation District).

There are also four nonagricultural facilities located in the headwaters of Black Creek: the Carriage Village SPDES site, the Hanson-Stafford Limestone Quarry, and two municipal leach fields. The Carriage Village, a small mall of gift shops that has a maximum discharge of 2,500 gallons per day, is not likely a source affecting high concentrations of nutrients found in the headwaters because immediately downstream of this site (Headwaters 6), low concentrations of nutrients and sediments were observed (Figs. 54-57).

The Hanson-Stafford Limestone Quarry is located in the headwaters of Black Creek upstream of site HW1. The quarry is periodically pumped out into a drainage ditch leading to Black Creek (Fig. 70) (personal communication: Hanson Aggregates). The water in this quarry results from precipitation and groundwater and if left unattended can erode surfaces, lead to rock slope instability, or limit operations within the quarry (Thompson *et al*. 1998). Some of the water quality concerns from pumping water into surface waters or groundwater supplies include: suspended sediments, toxic dissolved heavy metals, oil and grease, minerals, salts, and bacteria (Thompson *et al*. 1998). The Hanson-Stafford Limestone Quarry was found to significantly contribute sulfate and calcium to Black Creek through field-observation but was not found to have a significant effect on TP, SRP, TN, nitrate, total coliform, alkalinity, TSS, potassium, sodium, or chloride (Fig. 71).

Within the Upper BC segment, two municipal leach fields are permitted to discharge into Black Creek in the towns of Byron and South Byron. Leach fields are soil treatment systems, also referred to as septic drainage fields, which treat effluent from home septic systems as it percolates through soil. These fields consist of a network of trenches containing perforated pipes that are then covered by soil. If properly designed and installed, leach fields can remove pathogens and nutrients from septic effluent (Potts 2002). However, the Byron leach field discharges significantly elevated amounts of TP, SRP, TN, nitrate, and TSS into the stream while the South Byron leach field discharges a significant amount of TP into the stream (Table 15). Neither the Byron nor South Byron leach fields discharge a significant amount of total coliform bacteria (Table 15). Although it is important to note that these municipal drainage fields do affect water quality, the amount of nutrients, sediments, and bacteria is much lower than in a secondary sewage treatment facility. These two leachfields together have a smaller impact on Black Creek (1% of TP load) than the Bergen WWTP, which discharges incredibly high levels of P and N (18% of the TP load to Middle BC) (Table 15).

In summary, the sources within this segment that are of the highest concern are the large dairy farms in the headwaters of Black Creek as well as agriculture within the Bigelow Creek tributary (Fig. 73). These farms located in the Upper Black Creek subbasin likely have a large impact on the water quality of downstream systems. However, Makarewicz and Lewis (2009) have shown that proper management (buffer strips, no tillage farming, grassed waterways, erosion control weirs, construction of retention ponds and gully plugs, and total farm planning) of subwatersheds dominated by dairy cattle can lead to significant reductions of nutrient loss from watersheds in the Finger Lakes Region.

The BCSWAT model was used to simulate potential management practices within the Upper Black Creek segment to reduce TP and TSS load. The most effective simulated agricultural BMPs to reduce the phosphorus load from the Upper BC segment were retiring all agriculture (41% reduction), grassed waterways (28% reduction), and conservation tillage (21% reduction) and to reduce sediment loss were buffer strips (62% reduction), conservation tillage (25% reduction), and contouring (25% reduction) (Table 18). Because these practices provide the largest reduction in sediment and phosphorus in this segment, they are the most appropriate options for agricultural management. Through segment analysis conducted in the field it was determined that nutrient losses in the Upper BC segment are highly influenced by the runoff from manure application fields of CAFOs in the headwaters (Fig. 54). Manure application areas are an important source of phosphorus because P applied to cropland (row crops and hay) through manure is often in excess of the growth requirements of the crop (Santhi *et al.* 2001). The amount of phosphorus in runoff is also relative to the history of manure applications and soil phosphorus buildup (Santhi *et al.* 2006). Therefore these BMPs (grassed waterways, conservation tillage, buffer strips, and contour farming) would be most applicable to the croplands where manure from the CAFOs is applied as fertilizer, such as between Headwaters 6 and 5 or between Headwaters 4 and 3 (Fig. 73). Another option is to manage the area near Headwaters 3 to mitigate the effects of runoff from the corn silage that was found to contribute high concentrations of TP to Black Creek by either applying buffer strips, providing a better containment system, or moving the silage farther from the stream (Figs. 54 and 55).

Another option to reduce the loss of P and sediment from the watershed in the headwaters of Black Creek, other than applying cropland management practices, is to remove the application of manure as fertilizer from CAFO operations. In doing so, the impact on water quality due to the runoff of manure from croplands and the overall effect of CAFO operations would be eliminated from the watershed. If the manure produced by CAFOs in this area were used in another manner rather than as crop fertilizer, the phosphorus load to Upper BC could be reduced by 17% (Table 18). Alternative manure disposal could include anaerobic digestion, liquid storage, or stacking which would reduce the nonpoint runoff of manure applied to cropland. This would be a quick and fairly cost effective fix to reduce the loss of TP from farmland. Dairy farm operations are the largest source of nutrients and sediments in the headwaters of Black Creek, and it is therefore important to investigate the possible management practices that will reduce their impact on water quality downstream. The storage of manure from these operations is a feasible solution to abate this large source of P.

New York State has proposed several potential water quality targets in streams: 20, 45 and 65 µg P/L. To reach a target of 65 µg P/L in the Upper BC subbasin, a stringent management plan (Management Scenario 2) is needed to achieve 62.8 µg P/L. This plan would include a remediation of the Bigelow Creek subwatershed (see above), alternative manure management, conservation tillage, buffer strips, and contour cropping. Other proposed targets by the DEC (45 or 20 µg P/L) for phosphorus in streams are not attainable for this segment because these targets are below the level of Black Creek in its natural state (50.1 µg P/L) (Table 19).

Middle Black Creek (BC) Subbasin

Observed Loads from Middle Black Creek and Spring Creek

The Middle BC subbasin (Fig. 3) spans 22,662 ha between Byron, NY, and its outlet at the USGS station in Churchville, NY. The Middle BC subbasin includes the Spring Creek subwatershed, the mainstem of Middle Black Creek, and several small tributaries. The Middle Black Creek (BC) segment (Fig. 3), downstream of Upper BC, has a high observed load of TN and nitrate (10.7 and 8.0 kg/ha/yr, respectively) (Table 10b). A major contributor to this high load is the Spring Creek tributary of Black Creek which discharges directly into this main stem segment and has the highest areal TN and nitrate loads observed in the Black Creek watershed (17.3 and 13.2 kg/ha/yr, respectively; Table 10b). Phosphorus, sediment, and bacteria loads, however, were very low from Middle BC. The loss of sediment within this reach was only 40.2 kg/ha/yr compared to 112.6 kg/ha/yr from Upper BC and 407.5 kg/ha/yr at Lower BC. The nitrogen losses from this segment, rather than phosphorus, sediment, or bacteria as in Bigelow Creek, are an area of concern.

Spring Creek, which is the largest tributary monitored within the Black Creek watershed (5,820.2 ha), empties directly into the Middle BC segment. Losses of TN, nitrate, and total coliform bacteria are high (17.3 kg TN/ha/yr, 13.2 kg nitrate/ha/yr, and 7.0E11 CFU/ha/yr, Table 10b) and indicate a major anthropogenic source of these constituents in this subwatershed. Loads from Spring Creek were observed to be much higher than from main stem sites (-1.3 to 10.9 kg TN/ha/yr, -1.1 to 8.0 kg NO_3/ha/yr, and 1.4E10 to 3.0E11 CFU/ha/yr) (Table 10b). Although the loss of nitrogen and bacteria is the greatest from this segment, the Spring Creek subbasin is also the second largest contributor of TP and SRP per unit area (0.8 and 0.3 kg/ha/yr) within the Black Creek watershed (Table 10b). Results from BCSWAT indicate that the Spring Creek subbasin is a hotspot for losses of TP to Black Creek (Fig. 72). The Spring Creek tributary strongly influences the water quality of the Middle BC segment.

Within the Middle BC segment there are five tributaries (from upstream to downstream): Spring Creek, North Branch Tributary, Robin’s Brook, Black Creek Tributary, and Minny Creek (Figs. 2 and 3). An initial stressed stream analysis indicated that the Black Creek Tributary does not impact the quality of waters in the Black Creek watershed (Figs. 40-42). On the other hand, Spring Creek, North Branch Tributary, and Robin’s Brook were all found to be large sources of nitrate and TN

(Figs. 40-42). These tributaries were further segmented to locate the sources of high N concentrations. Minny Creek was also sampled due to the presence of the Bergen WWTP.

Sources and Modeling Conclusions: Spring Creek Subwatershed

The Spring Creek subwatershed is a large source of nutrients (TN and nitrate in particular), sediment, and bacteria (Figs. 43-45, Table 10b) to Black Creek. This subwatershed is highly agricultural (96%) and the cropland in this area receives a dense application of manure from the four CAFOs in this area (personal communication: George Squires, Genesee County Soil and Water Conservation District) (Fig. 43). In the Spring Creek subwatershed of Black Creek, four registered CAFOs are known to exist; three are large CAFOs (Zuber Farms, CY Farms LLC, and Offhaus Farms Inc.) and one is a medium CAFO (Daniel Bridge Farms). During both hydrologic events and nonevents, there is evidence that indicates CAFOs are impacting Black Creek. Elevated levels of TN, NO_3 and total coliform together are indicators of animal waste in streams. For example, TN and nitrate increased dramatically (98.2%, 96.8%) downstream of a large CAFO owned by Offhaus Farms Inc. during a rain event (23 August 2010) in the headwaters of Spring Creek. This CAFO has 950 dairy cattle, 300 heifers, and 200 calves (2007 estimate) (personal communication, George Squires, Genesee County Soil and Water Conservation District). Similarly a large increase in TSS (49%: 9.3 mg/L to 14.6 mg/L), SRP (85%: 48.9 µg P/L to 90.2 µg P/L), and TP (121%: 79.6 µg P/L to 175.7 µg P/L) occurred between sites SC2 and SC1 (Figs. 43-45). Between SC1 and SC2 are three

CAFOs [Zuber Farms with 940 cattle and 760 heifers, CY Farms LLC, and Daniel Bridge Farms with 350 cattle and 135 heifers (2007 estimate)] (personal communication: George Squires, Genesee County Soil and Water Conservation District) from which runoff is fed into Spring Creek by tributary 1 (Fig. 43). The three CAFOs upstream from SC1 on tributary 1 are suspected to be the cause of increased nutrients in the lower portion of Spring Creek, and the CAFO found above SC7 is likely contributing to high concentrations of nutrients and sediment in the headwaters. In addition to four CAFOs, there are four SPDES sites within the Spring Creek subbasin. The impacts of all of the four SPDES sites, including the North Byron leach field, were deemed minimal due to no notable increase in material loss at sampling locations downstream of each site (Figs. 43-45, Table 15).

Using BCSWAT several management practices were used to simulate potential reductions in TP and sediment loss from the Spring Creek subbasin. The most effective management practices were buffer strips (TP 22% reduction), conservation tillage (TP 14% reduction, TSS 32% reduction), and grassed waterways (a natural or constructed channel lined with vegetation that provides safe water disposal from croplands (USDA NRCS 2007)) (TP 43% reduction, TSS 65% reduction) (Table 18). Additionally, sequential reduction of fertilizer applications for nutrient management excluding manure from CAFOs (25%, 50%, 75%, and 100% reduction in fertilizer applied) achieved a reduction in TP ranging from 6 to 21%. However, significant reductions in the amount of fertilizer applied to croplands (100%) may have detrimental impacts on crop productivity and is not recommended.

A segment analysis conducted in the field on the Spring Creek subwatershed pinpointed four CAFOs (Zuber, Daniel Bridge, and CY Farms above SC 1 and Offhaus Farm above SC 7) as the major sources of nutrients and sediments in the Spring Creek subwatershed due to large increases in material observed below these areas (Figs. 43-45). Confined animal feeding operations in this watershed generally apply waste manure to croplands as fertilizer (personal communication: George Squires, Genesee County Soil and Water Conservation District) which will runoff into streams and contribute to water quality degradation. Therefore these management practices (buffer strips, conservation tillage, and grassed waterways) found to substantially reduce TP and sediment from BCSWAT simulations should be applied to manure application areas (above SC1 and SC7, Fig. 73) where they will be the most effective. Another option to mitigate the impact of CAFOs in Spring Creek rather than implement structural agricultural BMPs is to eliminate dairy cattle manure as a crop fertilizer. Management of dairy operations using alternative manure uses, such as anaerobic digestion or storage in manure lagoons, can reduce TP 26% and sediment 20%. The reductions found from these management practices are similar to several other studies (Santhi *et al*. 2006, Secchi *et al.* 2007, Inadmar *et al.* 2001, and Vache *et al*. 2002).

A remediation of the Spring Creek subwatershed was simulated using BCSWAT by applying all effective management practices [alternative manure uses, grassed waterways, conservation tillage, buffer strips, and nutrient management (50% reduction in fertilizer excluding manure from CAFOs); Table 20] to croplands and effectively reduced TP 49% and sediment 16%. These high percent reductions seen at the outlet of Spring Creek were not as effective at reducing phosphorus and sediment losses to the Middle and Lower Black Creek sites downstream (reduced TP 6-7% and TSS 1-4%; Table 18). Spring Creek only accounted for 26.2% of the TP load and 11.4% of the total TSS load at Lower BC (Table 10). If the Spring Creek subwatershed were converted to 100% forested land-use, the TP load from this tributary would be reduced 60%. Therefore the maximum reduction in the total TP load to Lower BC from remediating Spring Creek was only 15.6% (60% of 4.3 MT/yr (the annual TP load from Spring Creek)) (Table 10). A similar result was also observed in the Bigelow Creek remediation scenario. Although remediation of Spring Creek only reduced TP 7% at Middle BC and 6% at Lower BC, it is still a valid option for management scenarios to reach water quality targets downstream using whole watershed remediation strategies.

Sources and Modeling Conclusions: Middle Black Creek Subwatershed

Several other smaller tributaries within the Middle BC segment (North Branch Tributary, Robin’s Brook, and Minny Creek) were found to contribute nutrients, sediment, and bacteria to Black Creek from initial segment analysis and thus were further segmented. Within the North Branch Tributary there was one source of N and P found in the headwaters above North Branch 5 (Figs. 66-68). There are no CAFOs, certified SPDES sites, nor WWTPs in this subwatershed of Black Creek. Above North Branch 5 is the Windy Meadow Christmas Tree Farm that can be seen by using orthoimagery (Fig. 69) and is the suspected source of high concentrations of constituents because there are no other agricultural practices north of the farm up to the watershed boundary (Fig. 73). It is likely that the farm periodically applies fertilizer to the base of the trees (personal communication: Tucker Kautz, Monroe County SWCD), which is the likely source of P and N.

In the Robin's Brook subwatershed (Fig. 3), there are observed water quality issues in the upstream reach of the tributary and at the downstream location at site Robin's Brook 1. This area of the watershed is highly agricultural, and there is runoff from corn and soybean fields impacting the water quality. During a nonevent period, large increases in nutrients and sediment were found at site Robin's Brook 5 compared to upstream sites: TP (150%: 36.0 to 89.9 µg P/L), SRP (140%: 20.1 to 48.3 µg P/L), TN (132%: 3.41 to 7.91 mg N/L), NO_3 (810%: 0.96 to 8.74 mg N/L), TSS (196%: 2.8 to 8.3 mg/L), and total coliform (122%: 11,800 to 26,200 CFU/100 mL) (Figs. 46-48). The high nutrient and sediment concentrations found at Robin's Brook 5 and 6 are likely due to the two small farms directly upstream where manure is probably used as fertilizer (Fig. 73). Within the Robin's Brook subwatershed there are also three certified SPDES sites, Byron-Bergen Elementary School, Southwoods RV Resort, and the Sherman Residence (Fig. 48) that are sources that influence the TN and nitrate concentrations found at the outlet of Robin's Brook.

Lastly, there is one large point source located within the Minny Creek tributary to Black Creek: the Bergen WWTP. Despite progress since the Federal Water Pollution Control Act was passed that established the National Pollutant Discharge Elimination System, wastewater treatment plants are still a significant source of pollution to surface waters (NYS Department of State 2000). Many problems include the high levels of nutrients, such as phosphorus and nitrogen, from effluent that can only be removed with tertiary treatment that has higher costs for both initial implementation and maintenance (NYS Department of State 2000). The Bergen WWTP is an older plant that only performs secondary treatment on its effluent (personal communication: George Squires, Genesee County Soil and Water Conservation District). This WWTP clearly has an impact on the downstream system as significantly elevated (p-value <0.05) levels of nutrients and bacteria were observed downstream of the effluent pipe (Tables 15 and 16). Effluent pipe concentrations were excessively high (13,335.5 μg P/L and 37.45 mg N/L; Table 16). An upgrade to the system drastically reduced the abundance of bacteria in the effluent from the plant but had little to no impact on the concentration of nutrients (Table 16).

In summary, there are several sources within the Middle BC segment that impact water quality: nonpoint source agriculture, four CAFOs in the Spring Creek subbasin, a Christmas tree farm in the North Branch Tributary subwatershed, several farms and SPDES sites located within the Robin’s Brook reach, and the Bergen WWTP discharging into Minny Creek. All of these sources were incorporated into the Black Creek SWAT model to determine the most effective BMPs to reduce their impact.

The most effective agricultural BMPs found to reduce phosphorus and sediment lost from the watershed in this reach from BCSWAT simulations were grassed waterways (26% and 63% reduction, respectively) and conservation tillage

(25% and 58% reduction, respectively) (Table 18). These BMPs would be most applicable to the farm fields in the Robin's Brook subwatershed between Robin's Brook 5 and 4 and the manure application fields in the Spring Creek subwatershed above SC 1 and SC 7 (Fig. 73) which were found to contribute nutrients and sediment to Black Creek from segment analysis. Using alternative manure disposal for all manure produced by CAFOs upstream of Middle BC rather than spreading manure as fertilizer on croplands can reduce TP 19% and TSS 18%.

The Bergen WWTP is the largest point source in the watershed and was found to be a significant contributor of nutrients to Black Creek (Table 15) using stressed stream analysis techniques. If this WWTP was renovated to a tertiary treatment system (chemical addition, two-stage filtration) rather than a secondary treatment system, the TP load to the Middle BC site would be reduced 18% (Table 18). If this source were to be shut down and pumped to the Van Lare plant in Monroe County for treatment, there would be a 19% reduction in the TP load at Middle BC and a 16% reduction at Lower BC. This action was successfully used when the Churchville WWTP was closed in 2002 (personal communication: Charles L. Knauf, Monroe County Health Department) and its influence on Black Creek was eliminated (Table 15).

Using a combination of management practices throughout the Black Creek watershed (Management Scenario 1; Table 20) including a remediation of Bigelow and Spring Creeks, upgrade of Bergen WWTP to tertiary treatment, and alternative manure disposal at the CAFOs in the headwaters, the total TP load would be reduced

40% and TSS 11% at Middle BC (Table 18). Applying these practices can reduce the annual TP concentration from 90.4 µg P/L to 60.3 µg P/L, which is less than the target of 65-µg P/L proposed by the DEC for streams in New York (Table 19). Because more than 70% of the annual TP load is due to anthropogenic sources (Table 17), there is opportunity to improve water quality by changing human land-use and water-use practices. By focusing remediation on the two largest sources of phosphorus, farm animals (2,800 kg TP/yr, 17.5% of the total; Table 17) and sewage treatment (2,797 kg TP/yr, 17.5% of the total; Table 17), the annual TP load can be reduced by 5,597 kg (37%). A more stringent water quality target of 45-µg P/L (Management Scenario 2; Table 20) can be met at Middle BC (43.1 µg P/L) by applying buffer strips, conservation tillage, contour farming, alternative manure operations, elimination of the Bergen WWTP from the watershed, tributary remediation, and stream bank stabilization. Lastly, the 20-µg P/L proposed water quality target is not attainable in the Black Creek watershed because it is below the P concentration at Middle BC in a completely forested state (Table 20).

Lower Black Creek (BC) Subbasin

Observed Loads from Lower Black Creek

The Lower BC segment (Fig. 3) of Black Creek covers an area of 15,021 ha and reaches from Caroll Road in Churchville, NY, to Archer Road in Chili, NY (Fig. 3, Table 1). The Lower Black Creek segment, which is closest to the watershed outlet and downstream of Middle BC (Fig. 3), is not a significant contributor of nutrients

(TN, nitrate, TP, and SRP) nor bacteria to losses from the watershed (Table 10b). In fact, the negative areal loads (Table 10b) observed indicate this downstream segment is a sink of nutrients rather than a source. For example, Lower BC has an observed areal load of -1.3 kg TN/ha/yr where -1.3 kg of TN is sequestered in the catchment (Table 10b). This segment of Black Creek has flat topography, begins to meander more, and has much slower flow velocity. There are also 3,646.1 ha of wetlands (24% of the land-use) in this segment with wetland plants capable of soluble nutrient uptake (Hall *et al*. 2002). Large and frequent natural dams were observed within this segment during the erosion inventory as well. The flat topography, meandering of the stream, wetlands, and natural dams allow adequate time for aquatic plants to uptake the soluble nutrients (SRP and nitrate) for growth and reproduction (Hall *et al*. 2002, Bukaveckas 2007). Conversely, Lower BC is a large source of total suspended solids. The total and areal loss of TSS from the Lower BC reach was extremely high (8,360.6 MT/yr and 407.5 kg/ha/yr) compared to all other segments (ranging 597.8 to 2,239.1 MT/yr and 40.2 to 228.5 kg/ha/yr) (Table 10b).

Sources and Modeling Conclusions: Lower Black Creek

There are three tributaries that flow into the Lower BC segment: Hotel Creek, Northeast Tributary, and Mill Creek (Fig. 3). From the results of an initial stressed stream analysis of all tributary nodes in the Black Creek watershed, Hotel Creek was found to have little influence on water quality due to low nutrient, sediment, and bacteria concentrations (Figs. 40-42 and 73). Mill Creek and Northeast Tributary were further segmented to determine the source of elevated phosphorus and nitrogen concentrations (Figs. 50-52 and 59-61, respectively).

In the Mill Creek subwatershed, increases in TN and nitrate were found between M5 and M4 (Fig. 51); this was first thought to be due to the golf course which runs along the stretch of Mill Creek between these two sites. The Mill Creek Golf Course is located in Churchville, NY, and covers 130 ha of land in the Mill Creek subwatershed. Golf courses generally impact nitrate-nitrogen levels more than orthophosphates from excess fertilization of greens and fairways (Wong *et al.* 1998). Intensely managed golf courses can significantly increase nitrates in ground and surface water through leaching and runoff depending on the fertilizer application and soil percolation rates (Shuman 2001). The clubhouse also has a septic system that discharges 3,308 gallons of treated effluent per day into a drainage ditch leading to Mill Creek. This permit contains seasonal effluent limits for biological oxygen demand, suspended solids, pH, ammonia, dissolved oxygen, and fecal coliform (NYSDEC 2010b).

Additionally, a small farm exists in the Mill Creek subwatershed whose runoff is fed into Mill Creek from a small tributary. This is likely impacting water quality between M5 and M4 (Fig. 50) more than the Mill Creek Golf Course. High concentrations of TP, SRP, TN, nitrate, and TSS were found in drainage downstream of this farm on 15 March 2011 during an event period. These high concentrations are diluted by the main stem of Mill Creek but slightly raise nutrient and sediment concentrations within the creek (Figs. 50-52). This farm is the suspected source of high nutrient, sediment, and bacteria levels found at Mill Creek 4 although it is important to note that the Mill Creek Golf Course is a possible secondary source of nitrogen nearby (Figs. 50-52).

Within the Northeast Tributary (Fig. 3) elevated nutrient and sediment concentrations were found at the outlet on 15 June and 17 August 2010. In the Northeast Tributary there is one Large CAFO (Zuber Farms), one medium CAFO (Leibeck Farms), and one small horse farm that impact the stream. Leibeck Farms has 345 dairy cattle (2010 estimate) (personal communication: Tucker Kautz, Monroe County Soil and Water Conservation District) and is suspected as the source of high concentrations of nutrients and sediments found above NET5 (Fig. 59) during an event period: TP (186.4 µg P/L), SRP (80.6 µg P/L), TN (2.02 mg N/L), nitrate (1.16 mg N/L), TSS (20.4 mg/L), and TC (22,500 CFU/100 mL) (Figs. 59-61). The high concentrations of nutrients and sediments in conjunction with high levels of bacteria indicate the presence of fecal contamination in this area. The pasture farm above NET4 owned by Zuber Farms has approximately 1000 dairy cattle (2010) (personal communication: Tucker Kautz, Monroe County Soil and Water Conservation District) and is a suspected source of TN, nitrate, and total coliforms during both event and nonevent periods (5 October and 19 October 2010). The small horse farm (Fig. 62) which is directly downstream of NET2 is likely the source of TSS and TP at NET1 (Figs. 63-66). This farm is sloped downward towards the stream and does not have any means to keep soil on the land. When the soil runs off into the water from this site, it will also increase phosphorus loading as well. Loss of phosphorus from soil due to surface runoff has a significant effect on water quality in receiving waters (McDowell and Sharpley 2001).

Although these two tributaries (Mill Creek and Northeast Tributary) are not of utmost concern for management because the Lower BC segment has low areal loading for nutrients and bacteria, it is important to locate these sources that may impact water quality seasonally or during events. Dissimilar to the nutrient load, the loss of TSS from the Lower BC segment is the highest both in total amount of sediment exported and sediment load per unit area. The total annual field-observed TSS load was 8,360.6 MT/yr from Lower BC where only 26.8% can be attributed to the watershed area above Middle BC (Table 10a). During the 2010-2011 field season over 85% of the TSS load occurred at Lower BC during events where as only 15% occurred during nonevents (Table 23). The vast majority of this load occurred during the 'wet' season in the spring and winter months where rain and snowmelt events occur in high frequency and magnitude (Figs. 33-39). During these events the landscape surface is scoured and runoff carries high concentrations of constituents to surface waters (Pionke *et al.* 1999).

Streambank Erosion

According to the Genesee/Finger Lakes Regional Planning Council, stream bank erosion is a major issue in the Black Creek watershed and is a significant source of sediment in Black Creek (GFLRPC 2004). The results from an erosion inventory study suggest that the approximately 6,000 MT/yr load from Lower BC is mostly due to stream bank erosion. It is also evident that runoff from agricultural fields is magnified due to the large amount of unbuffered stream banks within this segment. In the 5.12 km of Black Creek directly upstream of the Lower BC segment, 1.66 km or 32.4% of the stream bank was found to be highly eroded compared to 4.6% in a reference area (Table 11). In addition, 2.33 km or 45.5% of this segment has less than a 50-ft buffer between agricultural fields and the stream compared to only 5.2% in a reference area (Table 11). Recommendations for riparian buffer zone widths are commonly between 10 to 100 m (Allan *et al*. 1997). The Lower BC segment is also prone to excessive flooding due to the relatively flat topography. The ability of a stream to erode and transport sediment is increased when the amount of runoff increases due to rain or snowmelt (Leopold and Maddock 1953). Flooding and event conditions ease the transport of nutrients and sediments from the nearby agricultural fields to the stream (He and Crowley 2007). When the amount of runoff is increased, it is possible that channels in the stream network may become steeper and have unstable eroding stream banks (Fitzpatrick *et al.* 1999) that cause strong positive feedback where erosion of stream banks continues or even intensifies (Fitzpatrick *et al.* 1999). Due to this issue, management of sediment in this area is imperative, particularly during event periods where 85% of the load is occurring (Table 23). This site is directly above the outlet to the Genesee River so it is important to manage these sources to reduce the total load to the Genesee. Increasing the buffer zone between agricultural fields and stream banks, as well as providing stream bank stabilization in highly impacted zones, will reduce the load of sediment from this area significantly.

Several agricultural, wastewater, and stream bank management scenarios were simulated in the Lower BC segment using BCSWAT, and the percent reduction in TP and sediment was found. The most effective agricultural practices applied to croplands in Lower BC were buffer strips (17% reduced TP, 35% reduced TSS), conservation tillage (27% reduced TP, 39% reduced TSS), and grassed waterways (28% reduced TP, 50% reduced TSS). These BMPs would be most applicable to the small farm in the Mill Creek subwatershed between Mill Creek 5 and 4, to the CAFO and small horse farm in the Northeast Tributary subwatershed, and to the farm fields directly above the Lower BC site, which were all found to be sources of nutrient and sediment losses (Fig. 73). Applying structural BMPs to these areas would provide the greatest and most efficient reduction in P and sediment lost to Lower BC.

The focus for management within this segment was on mechanisms to reduce sources of sediment because the areal TSS load was high (407.5 kg/ha/yr; Table 10), and a field erosion inventory identified the major source of sediment in this reach to be stream bank erosion. The results of a SWAT model analysis of erosion on this segment provide further evidence that stream bank erosion is the underlying cause of the high areal load of TSS in this area. A management scenario where the highly erodible areas above Lower BC were stabilized by simulating the application of vegetative cover and reducing the erodibility of stream banks caused a 71% reduction in the sediment load (Table 18).

Although stabilizing stream banks in this area simulated a large reduction in sediment, there was only a small reduction in TP (2%). This same result was found by Tuppad *et al*. (2010) where a large reduction in sediment in the Bosque River watershed in Texas was observed from stabilizing stream banks (34%) but only a slight reduction in TN and TP was seen (~4%). This differs from the predicted response due to the high correlation (r^2=0.90) between sediment and phosphorus in Black Creek found in this study (Fig. 22). The method used to simulate stream bank stabilization in SWAT, that is, increasing the channel roughness to reduce peak flow rate, increasing channel cover, and decreasing channel erodibility to reduce channel degradation, successfully reduces the sediment that is reentrained in the channel segment (Tuppad *et al*. 2010). However, a reduction in sediment-bound nutrients, which we would expect, was not seen. This is due to a disconnect in the routing of sediment and nutrients within the SWAT model itself because only peak flow rates influence the nitrogen and phosphorus transport simulated in the QUAL2E model (Brown and Barnwell 1987). The QUAL2E in-stream algorithms of SWAT also do not consider channel cover and erodibility mechanisms in the nitrogen and phosphorus transformations within the channel (Tuppad *et al.* 2010). It is likely that the actual TP load from Black Creek will be reduced by a higher percentage by implementing stream bank stabilization techniques than is simulated by the model. In the future it would be beneficial to modelers and managers of watersheds to incorporate a mechanism into the SWAT model that would more accurately simulate the effect of implementing stream bank stabilization techniques on nutrient load.

Once reductions in TP and sediment from BMPs were quantified the Black Creek SWAT model was then utilized to determine the management necessary to reach certain water quality targets proposed by the Department of Environmental Conservation. A target of 65-μg P/L was achieved at Lower BC by remediating impacted tributaries (Spring and Bigelow Creeks), applying buffer strips to agricultural areas near streams, utilizing alternative manure operations such as anaerobic digestion and manure storage for CAFOs in the watershed, upgrading the Bergen WWTP to tertiary treatment, and stabilizing erodible stream banks above Lower BC (Management Scenario 1; Table 20). The TP concentration was reduced from 79.6 μg P/L to 60.3 μg P/L and the TSS concentration from 30.6 mg/L to 8.7 mg/L. A more stringent water quality target of 45-μg P/L was achieved at Lower BC by utilizing all management used in Management Scenario 1 (Table 20) as well as buffer strips, conservation tillage, and grassed waterways applied to all croplands, by rerouting all effluent from Bergen WWTP and septic systems to an WWTP outside of the watershed, and by stabilizing all stream banks within Black Creek (Management Scenario 2; Table 20). The above described management scenario reduced the annual TP concentration to 38.3 μg P/L, well below the 45-μg P/L target. A target of 20-μg P/L is not attainable in Black Creek because it is below the natural state of the watershed (36.2 μg P/L) (Table 19). By meeting the 65-μg P/L target in the Black Creek watershed, the annual TP load to the Genesee River can be reduced by 27% (Management Scenario 1; Table 18); alternatively, reaching the 45-μg P/L target (Management Scenario 2; Table 18) can reduce the annual TP load by 56%. In doing so, the impact that this area has on water quality as well as the beneficial use impairments in Lake Ontario will be greatly reduced.

Conclusions and Recommendations

Human activities within the Black Creek watershed have significant impacts on land-use and water-use patterns. Over 70% of the TP load can be attributed to anthropogenic sources (Table 17). Point and nonpoint sources such as runoff of sediments and nutrients from croplands, agricultural chemical pesticides and fertilizers, human and animal wastes, and residential and industrial discharges can all lead to water quality issues. The excess nutrients from these sources in streams can have devastating impacts on downstream ecosystems. Nearshore Lake Ontario in the Rochester embayment is affected by the high load of nutrients and sediment from its tributaries and suffers from many beneficial use impairments such as eutrophication, nuisance algae, beach closings, reduced aesthetics, and degradation of habitat for many organisms (Makarewicz 2010). Because of these issues, it is imperative that sources of nutrients and sediments be better managed within the tributaries to Lake Ontario.

Black Creek is one of the most impacted tributaries within the Genesee River basin, and therefore determining the most appropriate methods to manage its inputs is imperative. This study quantified the total loss of nutrients and sediments from the Black Creek watershed, identified the location of point and nonpoint sources of nutrients and sediment (Fig. 73), and determined the most effective practices to manage these sources using the soil and water assessment tool. A water quality target of 65-µg P/L for phosphorus in streams is the most practical target for the Black Creek watershed because it is attainable without making unrealistic land-use changes to the entire watershed area, which would be necessary to reach a goal of 45-µg P/L. The most effective management operation that should be utilized to reduce the total load of P to the Genesee River is to either upgrade the Bergen WWTP to tertiary treatment or pipe the effluent from this plant to a larger plant with newer treatment technologies. Alternative manure disposal for dairy operations in Black Creek should also be considered when constructing a management plan for the watershed as it can cause large reductions in nutrient and sediment load. These are two valid options for reducing the TP output from the watershed significantly. Another issue that should be managed is the high loss of sediment above Lower BC, particularly due to its close proximity to the watershed outlet (Fig. 73). Stabilizing and buffering the stream banks in this highly erodible area will drastically lessen this issue and reduce the total load of sediment from Black Creek.

The results from this study identified several effective management operations using BCSWAT that can be used to reduce the amount of nutrients and sediment lost from the Black Creek watershed. By reducing the loss of material from the watershed, the water quality in Black Creek can be improved and its impact on the Genesee River and nearshore Lake Ontario can be reduced. Implementing several best management practices throughout the Black Creek watershed is necessary to attain a Total Maximum Daily Load to meet water quality standards. Once this level is met, the beneficial use impairments to nearshore Lake Ontario in the Rochester Embayment can be removed and the quality of habitat in this region will be restored.

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Tables

Table 1. Routine sampling sites sampled weekly from 1 June 2010 to 30 June 2011.

Site	Town	Road Name	Lat. Dec.	Long. Dec.
BC Bigelow Creek	Byron	Cockram Road	43.32278	-78.11583
BC Upper*	Byron	Rt. 237	43.18333	-78.31444
BC Spring Creek	Batavia	Rt. 237	43.24333	-78.25306
BC Middle*	Churchville	Carroll Street	43.10861	-78.12694
BC Lower *	Chili	Archer Rd	43.22361	-77.94500
* segment designations of Black Creek				

Table 2. Location and information on the five wastewater treatment plants (WWTP) within the Black Creek Watershed. WWTP=Wastewater treatment plant, MGD=Million Gallons per Day.

Name	Town	County	Lat.	Long.	Watershed	Treatment	Max Discharge (MGD)	Notes
Churchville WWTP	Churchville	Monroe	43.0536	-77.5252	Black	NA	0.3000	Closed in 2002
Village of Bergen: WTP	Bergen	Genesee	43.0525	-77.5625	Minny	Secondary	0.2080	
North Byron SD WWTP	Byron	Genesee	43.0537	-78.0406	Spring	Leachfield	0.0060	
Byron SD WWTP	Byron	Genesee	43.0504	-78.0342	Black	Leachfield	0.0530	
S. Byron SD WWTP	Byron	Genesee	43.0306	-78.0400	Black	Leachfield	0.0250	

Table 3. The USGS gage site information for Black Creek. This is the site that was used as the observed data for the validation and calibration of the SWAT model.

Site	Subbasin (ID)	Latitude	Longitude	USGS Gage#
USGS Gage, Churchville, NY	6	43°06'02"	77°52'57"	04231000

Table 4. Point source inputs (WWTPs, SPDES, Leachfields) into the Black Creek SWAT model. Source type, tributary to which the source discharges to, source name, discharge (m^3/d), and total phosphorus (TP) concentration (µg P/L) are provided.

Source	Tributary	Name	Discharge (m^3/d)	TP (µg P/L)
WWTP/SPDES	Minny Creek	Village of Bergen Wastewater treatment plant	472.6	13,335.5
SPDES	Groundwater	Town & Country Family Restaurant	90.9	29.4
SPDES	Bigelow Creek	Batavia Country Club	9.1	110.1
SPDES	Bigelow Creek	Country Meadows Mobile Home Park	363.6	29.4
SPDES	Groundwater	Hidden Meadows Manufactured Home Community	63.6	29.4
SPDES	Groundwater	Southwoods R.V. Resort	42.3	16.2
Leachfield/SPDES	Black Creek	Byron S.D. WWTP	159.1	16.8
Leachfield/SPDES	Spring Creek	North Byron S.D. WWTP	19.1	16.8
Leachfield/SPDES	Black Creek	South Byron S.D. WWTP	81.8	16.8
SPDES	Groundwater	Barber's Party House	204.5	9.7
SPDES	Minny Creek	Barbary Coast Mobile Home Park	44.1	20.2
NPDES	Minny Creek	Allens Inc	181.8	20.2
NPDES	Mill Creek	Chili Country Club	45.4	41
NA	Headwaters	Hanson Stafford Limestone Quarry	1,363.4	19.3

Table 5. Water added to subbasins 24, 28, and 27 in the Black Creek SWAT model to account for the quantity of water added to Black Creek due to the Onondoga Escarpment in February, March, and April.

Escarpment Water Added as Water Use			
	Subbasins		
	24	28	27
Q ($m^3 x 10^4$) per day	0.33%	0.18%	0.49%
February	11.69	6.29	17.43
March	19.2	10.34	28.63
April	12.57	6.77	18.74

Table 6. Final parameter values for calibration of water balance, total suspended solids, and total phosphorus in BCSWAT.

A.	**Water Balance**	
Parameter	*Description*	*Value*
CN2	SCS Curve Number	-25%
SFTMP/SMTMP	Snow Fall Temperature	-5/-5
PET	Potential Evapotranspiration Method	Hargreaves
ESCO	Soil Evaporation Compensation Factor	0.3
EPCO	Plant Evaporation Compensation Factor	0.8
CN_Froz	Curve Number Adjusted for Frozen Soil	Active
SURLAG	Surface Runoff Lag Factor	3.65
GW_Delay	Groundwater Delay Time (days)	38
ALPHA_BF	Baseflow Alpha Factor (days)	0.11
GW_REVAP	Groundwater 'revap' Coefficient	0.02
B.	**Total Suspended Solids**	
Parameter	*Description*	*Value*
CH_N2	Mannings 'n' Value for the Main Channel	0.094
CH_K2	Effective Hydraulic Conductivity in Main Channel	15
CH_COV1	Channel Erodibility Factor	0.55
CH_COV2	Channel Cover Factor	0.55
ALPHA_BNK	Baseflow Alpha Factor for Bank Storage	0.12
CH_EQN	Sediment Routing Method	3
USLE_P	USLE Eqn. Cropping Practices Factor	0.55
ADJ_PKR	Peak Rate Adjustment for Sediment in Tributary Channels	0.5
PRF	Peak Rate Adjustment Factor for Sediment in the Main Channel	0.0001
SPCON	Factor for Maximum Amount of Sediment to be Reentrained	0.0002
SPEXP	Exponent Parameter for Calculating Sediment Reentrained	1
C.	**Total Phosphorus**	
Parameter	*Description*	*Value*
P_UPDIS	Phosphorus Uptake Distribution Parameter	10
PPERCO	Phosphorus Percolation Coefficient	13
PHOS_KD	Phosphorus Soil Partitioning Coefficient	178
PSP	Phosphorus Availability Index	0.6
RSDCO	Residue Decomposition Coefficient	0.035
BC4	Rate Constant for Mineralization of Organic P to Dissolved P	0.28
RS2	Benthic Sediment Source Rate for Dissolved P	0.05
RS5	Organic P Settling Rate in the Reach	0.05
RSDIN	Initial Residue Cover	1150
ERORGP	Phosphorus Enrichment Ratio for Loading with Sediment	0.03
BIOMIX	Biological Mixing	0.65

Table 7. Final values for all BCSWAT calibration criterion [Nash-Sutcliffe efficiency (NSE), correlation coefficient (**r^2**), and percent bias (PBIAS) for observed versus modeled values] for water balance calibration (June 2010 through May 2011), water balance verification (January to December 2001), total suspended solids (TSS) (June 2010 through May 2011), and total phosphorus (TP) (June 2010 through May 2011).

Black Creek Soil and Water Assessment Tool			
Calibration Criterion			
Type	NSE	r^2	PBIAS
Water Calibration	0.88	0.93	- 3.6
Water Verification	0.71	0.73	- 14.3
TSS	0.71	0.74	+ 2.0
TP	0.78	0.80	+ 9.8

Table 8. Summary of observed total phosphorus (TP) load and total suspended solids (TSS) load and simulated TP and TSS from the BCSWAT model at five routine monitoring sites. The percent bias (PBIAS) between observed and simulated load is given. BC=Black Creek, M=Main stem, T=Tributary.

Total Phosphorus				
Site	Watershed Area (ha)	Observed TP (MT/yr)	Simulated TP (MT/yr)	PBIAS (%)
Bigelow (T)	2,616	2.9	2.0	-31.0
Upper BC (M)	11,784	6.9	7.0	1.4
Spring (T)	5,542	4.3	3.4	-20.9
Middle BC (M)	34,446	13.8	15.1	9.8
Lower BC (M)	49,467	16.5	17.3	4.8
Total Suspended Solids				
Site	Watershed Area (ha)	Observed TSS (MT/yr)	Simulated TSS (MT/yr)	PBIAS (%)
Bigelow (T)	2,616	597.8	626.1	4.7
Upper BC (M)	11,784	1327.4	1335.7	0.6
Spring (T)	5,542	955.3	841.7	-11.9
Middle BC (M)	34,446	2239.1	2284.4	2.0
Lower BC (M)	49,467	8360.6	6659.9	-20.3

Table 9. Average field observed concentration and standard error of samples taken from five routine monitoring sites (Bigelow Creek, Upper BC, Spring Creek, Middle BC, and Lower BC) for a period of one year. Samples were taken on a total of 55 sampling dates (20 during event conditions, and 35 during nonevent conditions). TP=Total Phosphorus, SRP=Soluble Reactive Phosphorus, TN=Total Nitrogen, TSS=Total Suspended Solids, TC= Total Coliform Bacteria, BC= Black Creek, M=Main stem, T= Tributary.

Site	TP (μg P/L)	SRP (μg P/L)	TN (mg N/L)	Nitrate (mg N/L)	TSS (mg/L)	TC (CFU/100 mL)
Bigelow (T)	114.5 ± 21.5	48.5 ± 9.0	1.42 ± 0.14	0.75 ± 0.11	19.8 ± 5.7	8,549 ± 1,793
Upper (M)	117.7 ± 18.3	59.5 ± 6.7	2.45 ± 0.21	1.68 ± 0.15	18.5 ± 4.8	8,876 ± 1,998
Spring (T)	96.0 ± 19.1	41.7 ± 5.6	3.43 ± 0.33	2.74 ± 0.23	17.9 ± 5.2	16,082 ± 4,529
Middle (M)	70.0 ± 4.9	27.3 ± 3.4	2.02 ± 0.14	1.33 ± 0.13	10.9 ± 1.2	6,513 ± 1,468
Lower (M)	67.7 ± 3.9	29.3 ± 2.4	1.55 ± 0.10	1.05 ± 0.10	11.9 ±1.0	5,676 ± 915

Table 10. A. Field observed results for total annual load of nutrients (MT/yr), sediments (MT/yr), and bacteria (CFU/yr) at five monitoring sites in the Black Creek watershed. The percent contribution of each site (Bigelow Creek, Upper BC, Spring Creek, and Middle BC) to the total annual load (MT/yr) at the outlet (Lower BC) is provided. **B.** Field observed areal total annual loads normalized for segment reach area for main stem sites Upper, Middle, and Lower Black Creek and tributary sites, Bigelow and Spring Creeks. **C.** Field observed areal total annual loads normalized for the entire Black Creek watershed area. TP=Total Phosphorus, SRP=Soluble Reactive Phosphorus, TN=Total Nitrogen, TSS=Total Suspended Solids, TC= Total Coliform Bacteria, BC= Black Creek, M=Main stem, T= Tributary.

A.	**Total Annual Loading**						
Site	Watershed Area (ha)	TP (MT/yr)	SRP (MT/yr)	TN (MT/yr)	Nitrate (MT/yr)	TSS (MT/yr)	TC (CFU/yr)
Bigelow (T)	2,616	2.9 (17.8%)	1.0 (18.7%)	32.0 (9.2%)	18.4 (7.2%)	597.8 (7.2%)	1.2E+15 (17.7%)
Upper BC (M)	11,784	6.9 (42.1%)	2.8 (49.7%)	128.1 (36.7%)	90.1 (35.6%)	1,327.4 (15.9%)	3.5E+15 (50.9%)
Spring (T)	5,542	4.3 (26.2%)	1.5 (27.2%)	96.0 (27.5%)	73.2 (28.9%)	955.3 (11.4%)	3.9E+15 (55.5%)
Middle BC (M)	34,446	13.8 (83.7 %)	6.3 (112.4%)	369.5 (105.8%)	270.4 (106.7%)	2,239.1 (26.8%)	6.7E+15 (96.0%)
Lower BC (M)	49,467	16.5	5.6	349.4	253.4	8,360.6	7.0E+15

B.	**Areal Total Annual Loading for Segment Reach Area**						
Site	Segment Area (ha)	TP (kg/ha/yr)	SRP (kg/ha/yr)	TN (kg/ha/yr)	Nitrate (kg/ha/yr)	TSS (kg/ha/yr)	TC (CFU/ha/yr)
Bigelow (T)	2,616	1.1	0.4	12.2	7.0	228.5	4.7E+11
Upper BC (M)	11,784	0.6	0.2	10.9	7.6	112.6	3.0E+11
Spring (T)	5,542	0.8	0.3	17.3	13.2	172.4	7.0E+11
Middle BC (M)	22,662	0.3	0.2	10.7	8.0	40.2	1.4E+10
Lower BC (M)	15,021	0.2	-0.1	-1.3	-1.1	407.5	1.8E+10

C.	**Areal Total Annual Loading for the Black Creek Watershed**						
Site	Watershed Area (ha)	TP (kg/ha/yr)	SRP (kg/ha/yr)	TN (kg/ha/yr)	Nitrate (kg/ha/yr)	TSS (kg/ha/yr)	TC (CFU/ha/yr)
Black Creek	49,467	0.3	0.1	7.1	5.1	169.0	1.4E+14

Table 11. Results from an erosion inventory study conducted in the field on the Lower BC segment and a reference site in the upper reaches of Black Creek. The distance measured, distance of erodible stream bank, percent eroded stream bank, number of sites recorded, distance of unbuffered stream bank, percent unbuffered stream bank, average distance from agricultural fields, and the percent agriculture land-use of each study site are given. The reference site was chosen based on an area along the main stem of Black Creek known to have low TSS loading (less than Lower BC). BC=Black Creek.

	Lower BC Reach	Reference Site
Distance Measured (km)	5.12	5.24
Erodible Stream bank (km)	1.66	0.24
Percent Eroded Stream bank (%)	32.4	4.6
Sites Recorded	11	7
Stream bank with No Buffer Zone (km) < 25ft	1.53 km	0.00 km
Stream bank with Low Buffer Zone (km) < 50ft	2.33 km	0.27 km
Percent Unbuffered Stream bank (%)	45.5	5.2
Average Dist. from Ag. Fields (km)	0.09	0.27
Segment Land-use: % Agriculture	59.6%	77.2%
Segment Areal Load (kg/ha/yr)	407.5	112.6

Table 12. Observed seasonal load of nutrients (Mtons/season), sediment (Mtons/season), and bacteria (CFU/season) from Lower Black Creek at the outlet of the watershed. TP=Total Phosphorus, SRP=Soluble Reactive Phosphorus, TN=Total Nitrogen, TSS=Total Suspended Solids, TC= Total Coliform Bacteria.

Seasonal Load	Spring	Summer	Fall	Winter	Total
TP (Mtons)	5.4 (33%)	1.4 (9%)	2.0 (12%)	7.7 (47%)	16.5
SRP (Mtons)	2.0 (36%)	0.7 (12%)	0.7 (13%)	2.2 (40%)	5.6
TN (Mtons)	129.0 (37%)	43.8 (13%)	43.0 (12%)	133.7 (38%)	349.4
Nitrate (Mtons)	88.3 (35%)	31.4 (12%)	30.0 (12%)	103.7 (41%)	253.4
TSS (Mtons)	930.1 (11%)	222.6 (3%)	403.5 (5%)	6804.3 (81%)	8360.6
Total Coliform (CFU)	3.16E+15 (45%)	1.69E+15 (24%)	1.12E+15 (16%)	9.91E+14 (14%)	6.96E+15

Table 13. Summary table of critical areas identified from initial stressed stream sampling from major tributary nodes and main stem sites on 15 June 2010 and 17 August 2010. Critical areas define those areas that should be further segemented to identify the source of nutrients, sediments, or bacteria. TP=Total Phosphorus, SRP=Soluble Reactive Phosphorus, TN=Total Nitrogen, TSS=Total Suspended Solids, Total Coli=Total Coliform Bacteria.

Critical areas identified from initial sampling:						
Site	TP	SRP	TN	Nitrate	TSS	Total Coli
Lower	X	X			X	
Middle	X	X			X	X
Upper	X	X			X	
Headwaters of Upper BC	X	X				
Main stem 2					X	
Main stem 3					X	
Spring Creek			X	X		X
Bigelow Creek	X	X				X
Mill Creek	X	X				X
Robin's Brook			X	X		
North Branch Tributary			X	X		
Northeast Tributary	X	X	X			

Table 14. Total nitrogen (TN) and nitrate values concentrations from samples taken at Lower Robin's Brook (RB1) on 10 July 2010, 29 June 2010, and 15 June 2010.

Site	Date	TN (mg-N/L)	Nitrate (mg-N/L)
Robin's Brook Lower (RB1)	7/10/2010	14.96	8.95
Robin's Brook Lower (RB1)	6/29/2010	8.57	8.52
Robin's Brook Lower (RB1)	6/15/2010	8.25	8.22

Table 15. Comparison of nutrient and bacteria abundance observed upstream and downstream of wastewater treatment plants in the Black Creek watershed. Values are the average of 5 samples upstream and 5 samples downstream of the WWTP ± the standard error. The significance of the results derived from a paired T-Test are shown * designates significance at P=0.05, ** at P=0.01, and *** at P=0.001. TP=Total Phosphorus, SRP=Soluble Reactive Phosphorus, TN=Total Nitrogen, TSS=Total Suspended Solids.

WWTP Site		TP (µg P/L)	Nitrate (mg N/L)	TSS (mg/L)	SRP (µg P/L)	TN (mg N/L)	Total coli (CFU/100mL)
Churchville	Upstream	54.5 ± 2.8	1.1 ± 0.01	12.2 ± 0.3	5.6 ± 0.2	1.81 ± 0.01	5,380 ± 1,114
	Downstream	32.7 ± 6.7	1.2 ± 0.01	4.9 ± 0.2	5.9 ± 2.0	1.65 ± 0.02	4,260 ± 805
	P-Value	_*0.04_	_**0.002_	_***<0.001_	_0.89_	_**0.003_	_0.42_
Bergen	Upstream	20.1 ± 1.3	2.70 ± 0.01	5.7 ± 1.2	5.8 ± 0.2	2.80 ± 0.00	3,025 ± 516
	Downstream	3,835.8 ± 703.8	17.44 ± 2.90	3.6 ± 0.1	2,351.6 ± 261.3	19.9 ± 2.90	25,475 ± 1,882
	P-Value	_**0.006_	_***0.001_	_0.12_	_***0.001_	_***0.001_	_***0.001_
Byron	Upstream	80.4 ± 1.4	0.86 ± 0.01	3.0 ± 0.4	53.4 ± 0.4	1.43 ± 0.01	10,280 ± 1,308
	Downstream	97.2 ± 0.9	1.07 ± 0.00	6.7 ± 0.8	64.4 ± 0.6	1.69 ± 0.02	9,660 ± 2,734
	P-Value	_***<0.001_	_***<0.001_	_*0.02_	_***<0.001_	_***0.001_	_0.82_
S. Byron	Upstream	50.9 ± 0.3	1.19 ± 0.01	2.7 ± 0.3	15.7 ± 0.7	1.81 ± 0.02	1,450 ± 263
	Downstream	58.3 ± 0.7	1.17 ± 0.02	2.0 ± 0.3	16.1 ± 0.2	1.67 ± 0.01	2,350 ± 384
	P-Value	_**0.004_	_0.57_	_0.29_	_0.43_	_**0.002_	_0.25_
N. Byron	Upstream	16.6 ± 0.2	2.32 ± 0.02	3.8 ± 0.1	7.0 ± 0.2	2.51 ± 0.03	525 ± 63
	Downstream	16.5 ± 0.5	2.23 ± 0.02	2.0 ± 0.3	7.0 ± 0.2	2.42 ± 0.02	1,125 ± 309
	P-Value	_0.83_	_0.07_	_**0.004_	_0.83_	_*0.05_	_0.15_

Table 16. Comparison of nutrient, sediment, and bacteria concentrations observed above and below the Bergen Wastewater treatment plant before and after an upgrade put into place in January 2011. TP=Total Phosphorus, SRP=Soluble Reactive Phosphorus, TN=Total Nitrogen, TSS=Total Suspended Solids.

		TP (µg P/L)	Nitrate (mg N/L)	TSS (mg/L)	SRP (µg P/L)	TN (mg N/L)	Total coli (CFU/100 mL)
Before Upgrade	Upstream	20.1 ± 1.3	2.70 ± 0.01	5.7 ± 1.2	5.8 ± 0.2	2.80 ± 0.00	3,025 ± 516
	Downstream	3,835.8 ± 703.8	17.44 ± 2.90	3.6 ± 0.1	2,351.6 ± 261.3	19.90 ± 2.90	25,475 ± 1,882
	P-Value	*0.006***	*0.001****	*0.120*	*0.001****	*0.001****	*0.001****
After Upgrade	Upstream	19.1 ± 0.4	3.51 ± 0.02	6.5 ± 0.8	6.4 ± 0.1	3.73 ± 0.06	9,225 ± 727
	Downstream	3,155.4 ± 151.2	12.95 ± 0.60	6.8 ± 0.2	2,968.4 ± 187.1	15.20 ± 1.00	10,200 ± 187
	P-Value	*0.001****	*0.000****	*0.409*	*0.000****	*0.001****	*0.098*
Bergen Pipe	Effluent	13,335.5	37.45	2.0	13,335.5	48.04	100

Table 17. Total phosphorus load allocation by land-use or activity for the Black Creek watershed at Middle BC as derived from SWAT predictions for the period 1 June 2010 to 31 May 2011.

Land-use / Activity	Current Load kg TP/yr	Percent of Predicted Load (%)	Method of Determination
Agricultural Crops	3,874	24.3	Subtraction
Tile Drainage	877	5.5	Subtraction
Farm Animals (CAFO only)	2,800	17.5	Subtraction
Stream bank Erosion	1,047	6.6	Subtraction
Wetlands	844	5.3	HRU Table
Quarry	0	0.0	Subtraction
Groundwater	2,349	14.7	HRU Table
Forest	4	0.0	HRU Table
Urban Runoff	1,134	7.1	Subtraction
Wastewater Treatment	2,797	17.5	Subtraction
Septic Systems	231	1.4	Subtraction
Sum of Allocated Loads	15,957	100.0	
Total Predicted Load (from SWAT)	**15,136**		
Allocation Error	821		

Table 18. The percent effectiveness of implementing Best Management Practices (BMPs) in reducing total annual total phosphorus (TP) and total suspended solids (TSS) load at all monitoring sites determined using the SWAT model. BC= Black Creek. * designates the reduction in fertilizer applied to crops excluding manure produced from CAFOs which was considered a separate entity.

			Bigelow		Upper BC		Spring		Middle BC		Lower BC	
Category	Subcategory	BMP	TP	TSS	TP	TSS	TP	TSS	TP	TSS	TP	TSS
Forest	Forest	Natural Watershed	70	91	63	95	60	100	70	97	69	99
Agriculture	Cropland	Buffer Strips	24	43	18	62	22	-20	15	50	17	35
		Conservation Tillage	18	7	21	25	14	32	25	58	27	39
		Grassed Waterways	19	5	28	21	43	65	26	63	28	50
		Contouring	19	24	6	25	3	-9	1	18	2	19
		Terracing	24	29	11	44	0	-26	5	28	6	28
		Strip Cropping	18	22	4	14	0	4	1	1	0	5
		Retire Ag. Land to Forest	39	27	41	24	46	81	36	68	37	59
		Cover Crops (Rye)	4	2	10	10	12	0	6	17	5	14
		*Nutrient Management 25%	3	0	6	0	6	-7	9	1	11	0
		*Nutrient Management 50%	6	0	10	0	9	-7	13	1	16	0
		*Nutrient Management 75%	9	0	11	0	16	-7	18	1	21	0
		*Nutrient Management 100%	11	0	11	0	21	2	20	0	23	0
	Farm Animals	Alternative Manure Operations	0	0	17	0	26	20	19	18	21	0
Wastewater	WWTP	Remove Bergen WWTP	0	0	0	0	0	0	19	27	16	0
		Upgrade Bergen WWTP -Tertiary	0	0	0	0	0	0	18	0	16	0
	SPDES	Remove all Point Sources	0	1	0	2	0	0	18	27	16	0
	Septic	Remove all septic systems	0	0	2	4	1	0	1	0	1	1
Stream banks	Stabilization	Basin wide stabilization	0	25	5	20	7	84	7	55	5	84
		Stabilize highly eroded areas	0	0	0	0	0	0	0	0	2	71
Remediation	Tributary	Spring Creek	0	0	0	0	49	16	7	4	6	1
		Bigelow Creek	24	21	5	4	0	0	1	2	1	1
		Both Spring and Bigelow	24	21	5	4	49	16	9	6	7	2
	Watershed	Management Scenario 1	24	21	13	10	49	16	40	11	27	73
		Management Scenario 2	36	21	42	10	49	86	55	75	56	86

Table 19. Simulated annual average concentration of total phosphorus (TP) and total suspended solids (TSS) at all routine monitoring sites with current land-use patterns (June 2010 through May 2011), a completely natural Black Creek watershed, and from two different management scenarios (Table 20) to achieve water quality targets of 65-µg P/L and 45-µg P/L of the entire Black Creek watershed.

	BC Current 2010-2011		BC Natural 2010-2011		BC Mgmt. 1 Target 65-µg P/L		BC Mgmt. 2 Target 45-µg P/L	
Site	TP (µg P/L)	TSS (mg/L)	TP (µg P/L)	TSS (mg/L)	TP (µg P/L)	TSS (mg/L)	TP (µg P/L)	TSS (mg/L)
Bigelow (T)	110.5	33.8	45.6	4.2	85.6	27.2	71.7	27.2
Upper BC (M)	99.9	19.1	50.1	1.3	88.6	17.5	62.8	18.7
Spring (T)	103.4	25.7	52.3	0.1	55.3	7.7	55.1	7.2
Middle BC (M)	90.4	13.6	41.3	0.6	64.1	12.4	43.1	3.6
Lower BC (M)	79.6	30.6	36.2	0.5	60.3	8.7	38.3	4.7

Table 20. Outline of management practices applied in remediation scenarios simulated by BCSWAT for impacted tributaries, Bigelow Creek and Spring Creek, and management scenarios to meet water quality targets of either 65-µg P/L or 45-µg P/L at the outlet of Black Creek. For each management scenario the BMPs that were applied are indicated (X). In the Bigelow and Spring Creek scenarios the BMPs indicated were only applied to those subwatersheds where as the Management 1 and Management 2 scenarios were applied to the entire Black Creek watershed.

	Bigelow Creek	Spring Creek	Black Creek Watershed	Black Creek Watershed
Management Operation			Management Scenario 1: 65-µg P/L Target	Management Scenario 2: 45-µg P/L Target
Buffer Strips	X	X	X	X
Conservation Tillage	X	X		X
Grassed Waterways	X	X		X
Terracing	X			
Nutrient Management	X	X		
Alternative Manure Operations		X	X	X
Upgrade Bergen WWTP			X	
Re-routing Bergen WWTP				X
All Septic to Sewer Districts		X		X
Stream bank Stabilization				X
Stabilize Highly Erodible Areas			X	
Tributary Remediation			X	X

Table 21. Summary of observed total phosphorus (TP) concentrations (µg P/L) from forested Adirondack streams in the Raquette River watershed (data collected from Adirondack Watershed Institute of Paul Smith's College) and a forested subwatershed in the Conesus Lake basin (Makarewicz *et al.* 2009).

Stream Name	Mean TP Concentration (µg P/L)
Raquette River	
Bog Brook	10
Follensby Brook	9
Mt. Morris Brook	3
Suckie Brook	5
Little Notch Brook	8
Conesus Lake	
North McMillan Creek	21

Table 22. Measured annual and areal tributary total phosphorus (TP) loading to Lake Ontario from New York watersheds of differing dominant land-uses. Loading data collected from Booty *et al.* (in review).

Tributary	Dominant Land-use	TP Load (Mton/yr)	Area (ha)	Areal Load (kg/ha/yr)
Oak Orchard	Agriculture	38.29	36,989	1.04
Golden Hill Creek	Agriculture	5.28	5,973	0.88
Wolcott Creek	Agriculture	6.04	4,416	1.37
Johnson Creek	Agriculture/Suburban	13.87	25,530	0.54
Salmon River	Agriculture/Forested	14.0	61,642	0.23
Irondequoit Creek	Sewage Treatment	23.0	43,771	0.53
Northrup Creek	Urban	4.50	1,863	2.42
Buttonwood Creek	Suburban	1.31	2,308	0.57
Larkin Creek	Suburban	0.80	3,132	0.26
First Creek	Forested	0.08	800	0.10
Clark Creek	Forested	0.03	155	0.21
Bobolink Creek	Forested	0.00	278	0.01

Table 23. Summary table presenting the field-observed average annual daily discharge (m³/d), mean concentration and total loading (kg/yr) of total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), nitrate, total suspended solids (TSS), and abundance of total coliform bacteria (CFU/yr) at five routine monitoring sites (Bigelow Creek, Upper BC, Spring Creek, Middle BC, and Lower BC) during events and nonevents (June 2010-May 2011). The proportion of the total loading during events versus nonevents is also given. BC= Black Creek, T=Tributary, M=Main stem.

Site	Bigelow (T)		Upper (M)		Spring (T)		Middle (M)		Lower (M)	
Condition	Event	Nonevent	Event	Nonevent	Event	Nonevent	Event	Nonevent	Event	Nonevent
Discharge (m^3/d)	90,418	30,860	234,168	80,817	146,626	50,218	899,873	245,521	870,325	354,508
Mean TP (µg P/L)	200.4	60.2	198.5	69.0	175.3	47.4	94.6	54.9	81.9	59.9
Mean SRP (µg P/L)	81.6	27.7	90.0	41.1	90.0	41.1	37.6	21.0	34.2	26.6
Mean TN (mg N/L)	2.12	0.97	3.18	1.97	3.18	1.97	2.24	1.89	1.72	1.46
Mean NO_3 (mg N/L)	1.13	0.49	2.01	1.46	2.01	1.46	1.46	1.25	1.17	0.98
Mean TSS (mg/L)	41.2	5.7	37.9	6.3	37.9	6.3	17.4	6.8	15.3	10.0
Mean TC (CFU/100 mL)	15,246	4,513	16,016	4,483	16,016	4,483	8,907	5,062	7,665	4,650
Total TP Load	2,071	855	4,630	2,301	2,928	1,390	8,848	4,942	10,093	6,376
Percent of TP Load	70.8%	29.2%	66.8%	33.2%	67.8%	32.3%	62.4%	35.8%	61.2%	38.8%
Total SRP Load	752	293	1,812	957	960	555	4,129	2,134	2,853	2,719
Percent of SRP Load	72.0%	28.0%	65.4%	34.6%	63.4%	36.6%	65.9%	34.1%	51.2%	48.8%
Total TN Load	17,546	14,445	62,321	65,776	45,449	50,581	181,507	188,036	152,634	196,809
Percent of TN Load	54.8%	45.2%	48.7%	51.3%	47.3%	52.7%	49.1%	50.9%	43.7%	56.3%
Total NO_3 Load	9,916	8,446	40,409	49,712	33,881	39,363	133,959	136,452	108,932	144,513
Percent of NO_3 Load	54.0%	46.0%	44.8%	55.2%	46.3%	53.7%	49.5%	50.5%	43.0%	57.0%
Total TSS Load	446,124	151,708	942,765	384,603	692,000	263,285	1,444,245	794,837	7,099,703	1,260,862
Percent of TSS Load	74.6%	25.4%	71.0%	29.0%	72.4%	27.6%	64.5%	35.5%	85.0%	15.0%
Total TC Load	8.7E+14	2.7E+14	2.6E+15	9.5E+14	2.7E+15	1.2E+15	3.7E+15	3.0E+15	4.0E+15	2.9E+15
Percent of TC Load	70.2%	29.8%	73.2%	26.8%	68.7%	31.3%	55.2%	44.8%	58.0%	42.0%

Figures

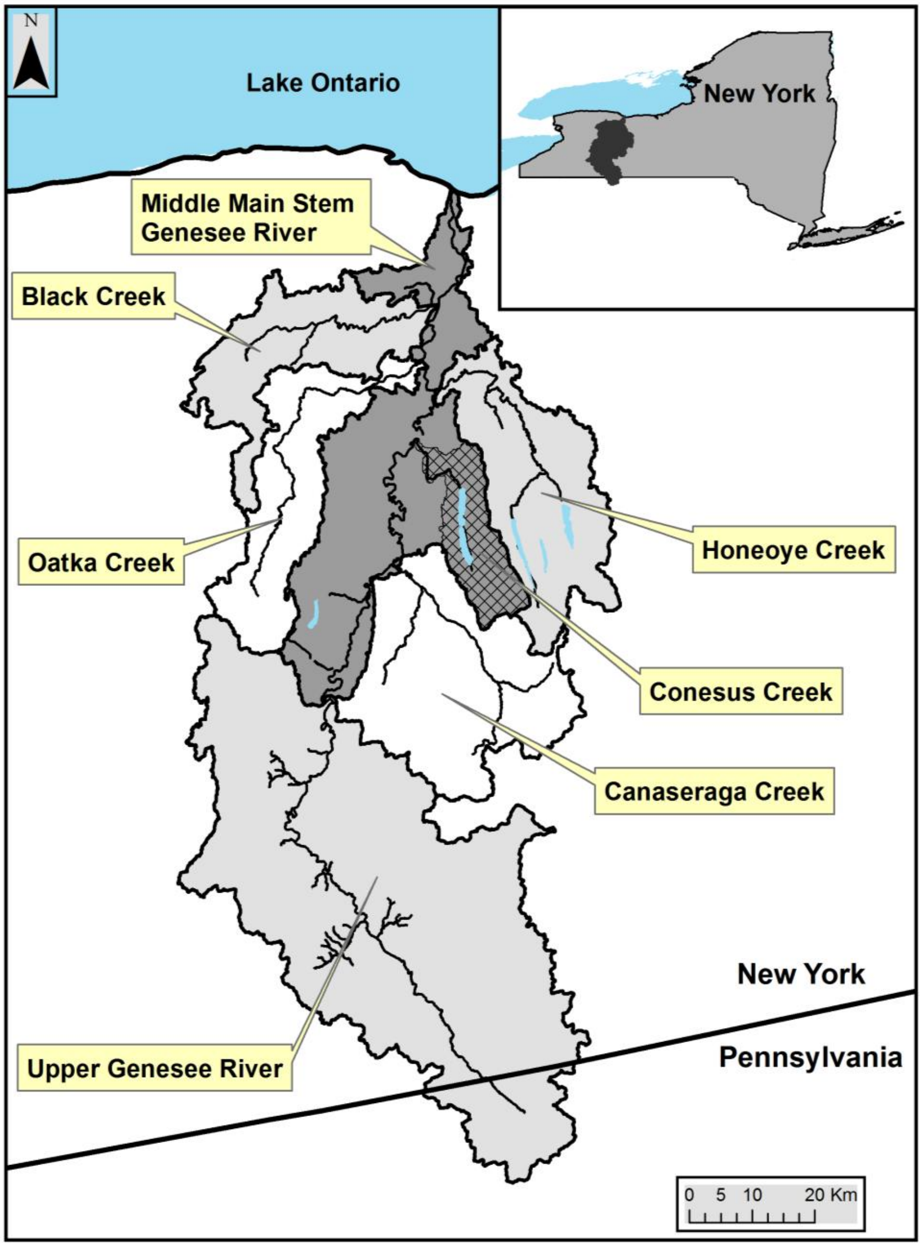


Figure 1. Map of the water features of the Genesee River watershed.

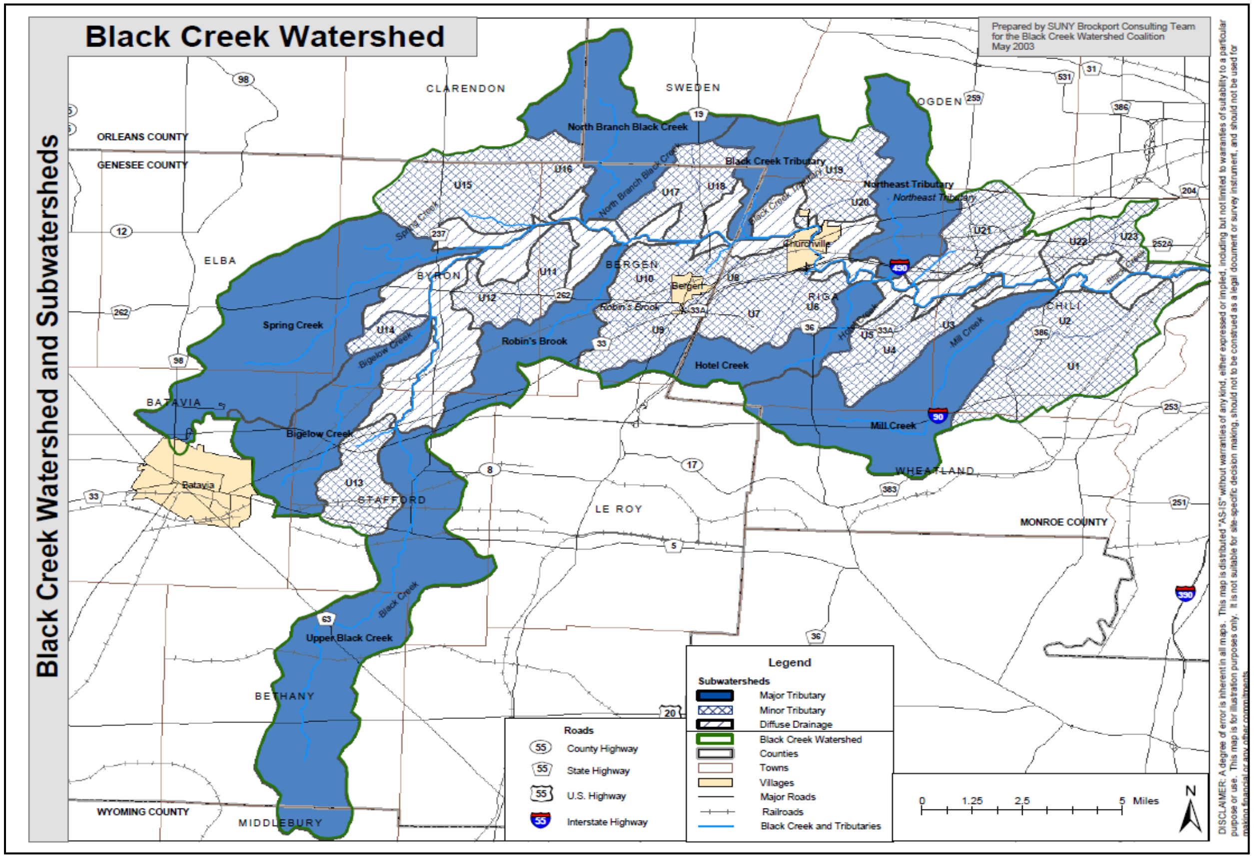


Figure 2. Map of Black Creek watershed and sub-watersheds. Major and minor tributaries are shown as well as counties, towns, villages, major roads, and railroads. 1 mile = 1.61 km.

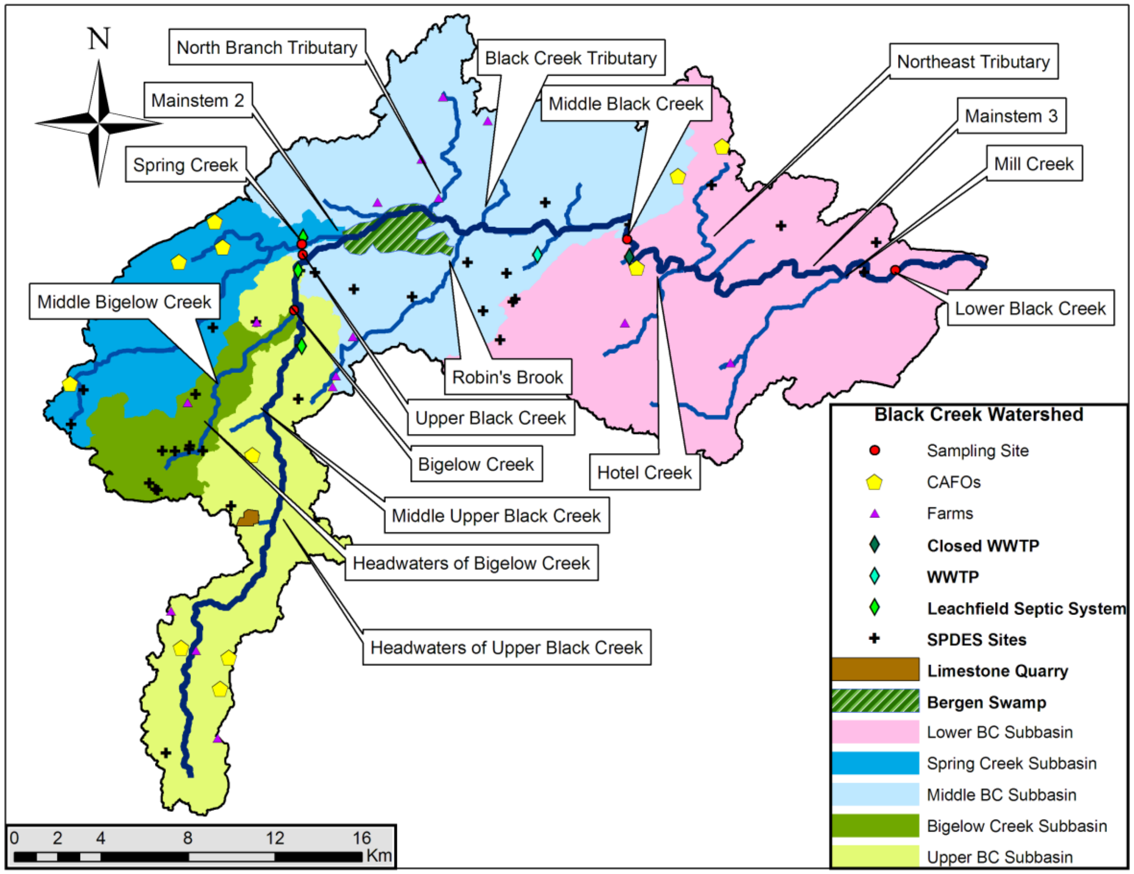


Figure 3. Site identification for all initial sampling sites throughout the Black Creek watershed. The Lower Black Creek, Middle Black Creek, Upper Black Creek, Spring Creek, and Bigelow Creek subbasins are depicted. BC=Black Creek.

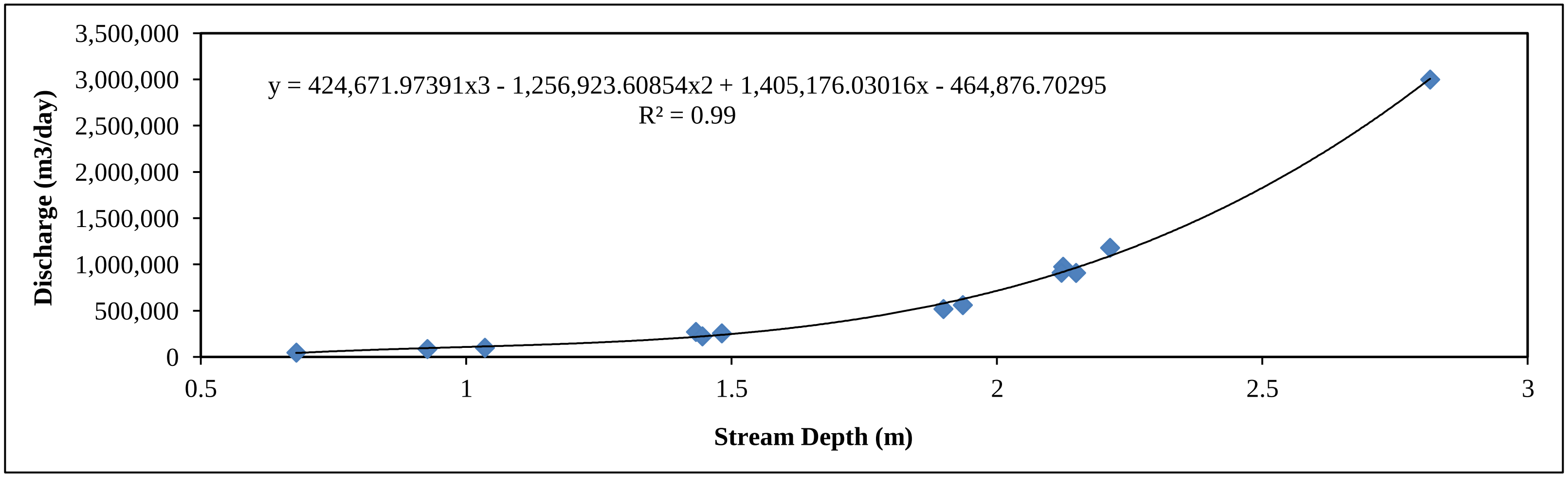


Figure 4. Rating curve for the Lower Black Creek sampling site (Table 1, Fig. 3), water year June 2010-May 2011.

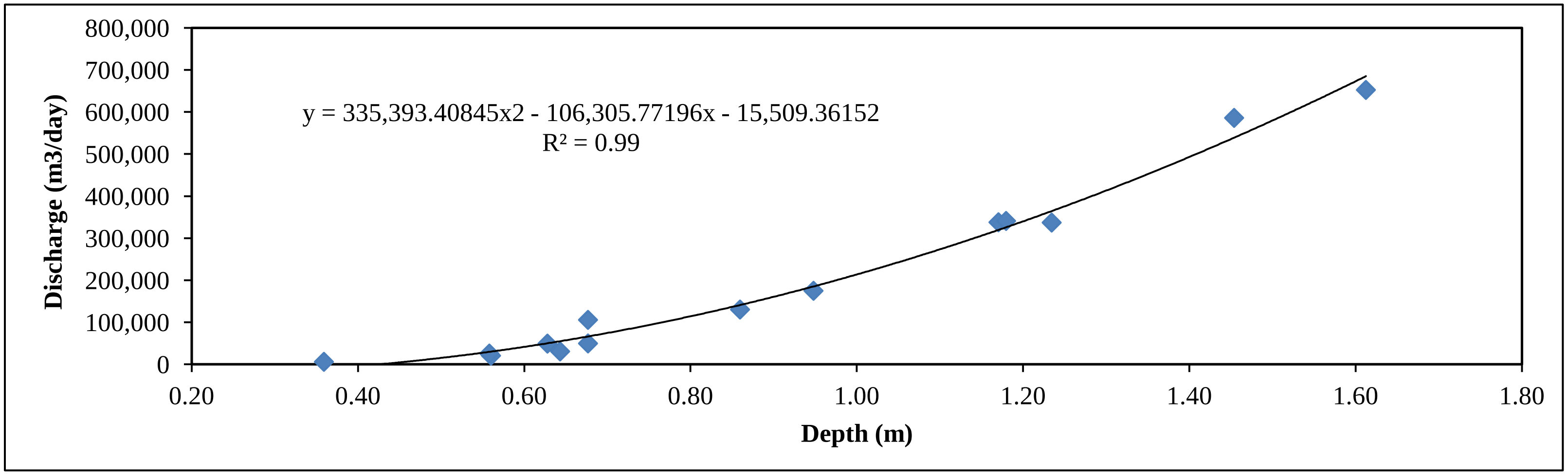


Figure 5. Rating curve for the Upper Black Creek sampling site (Table 1, Fig. 3), water year June 2010-May 2011.

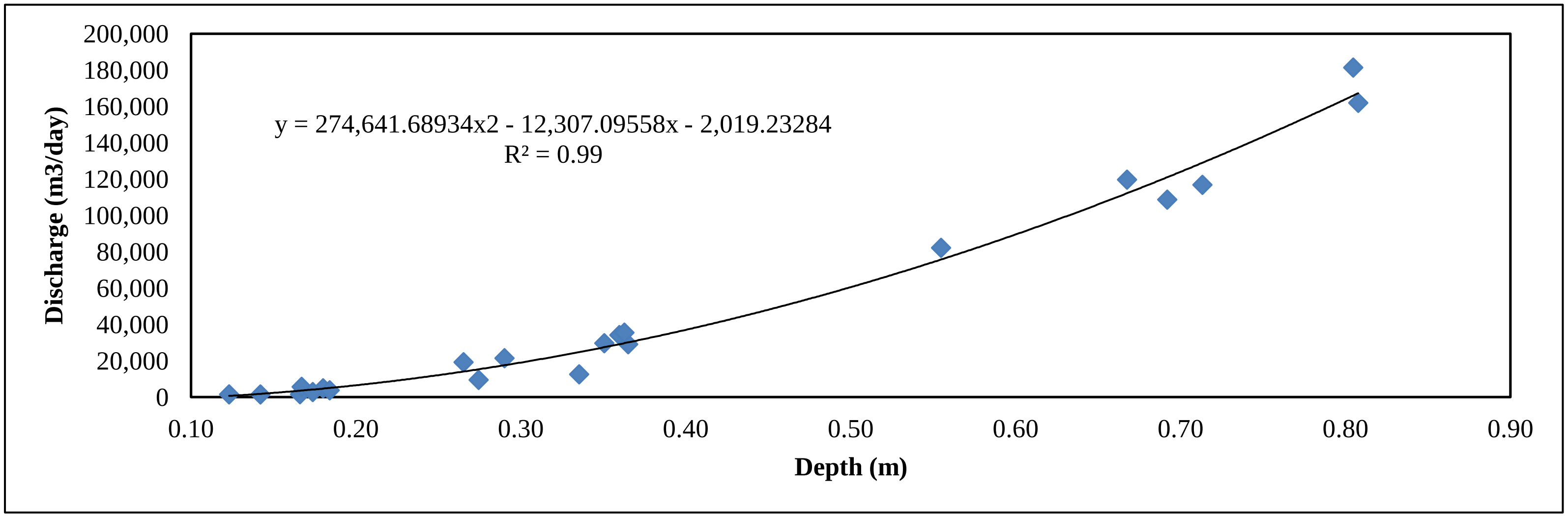


Figure 6. Rating curve for the east culvert at the Bigelow Creek sampling site (Table 1, Fig. 3), water year June 2010-May 2011.

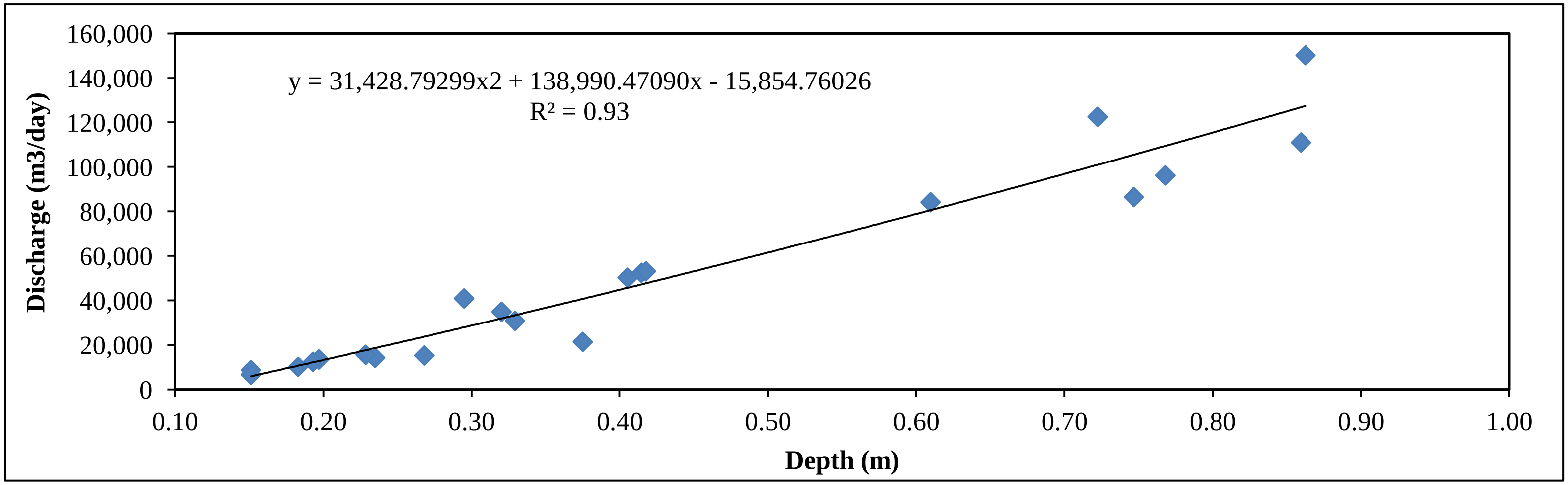


Figure 7. Rating curve for the west culvert at the Bigelow Creek sampling site (Table 1, Fig. 3), water year June 2010-May 2011.

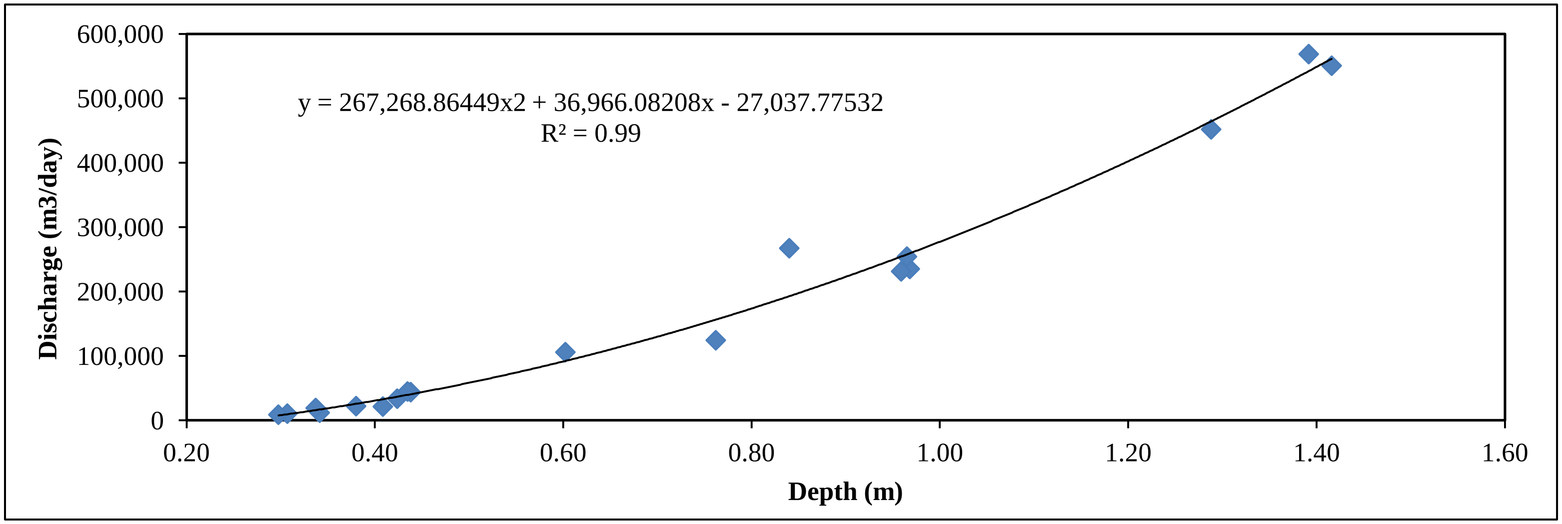


Figure 8. Rating curve for the Spring Creek sampling site (Table 1, Fig. 3), water year June 2010-May 2011.

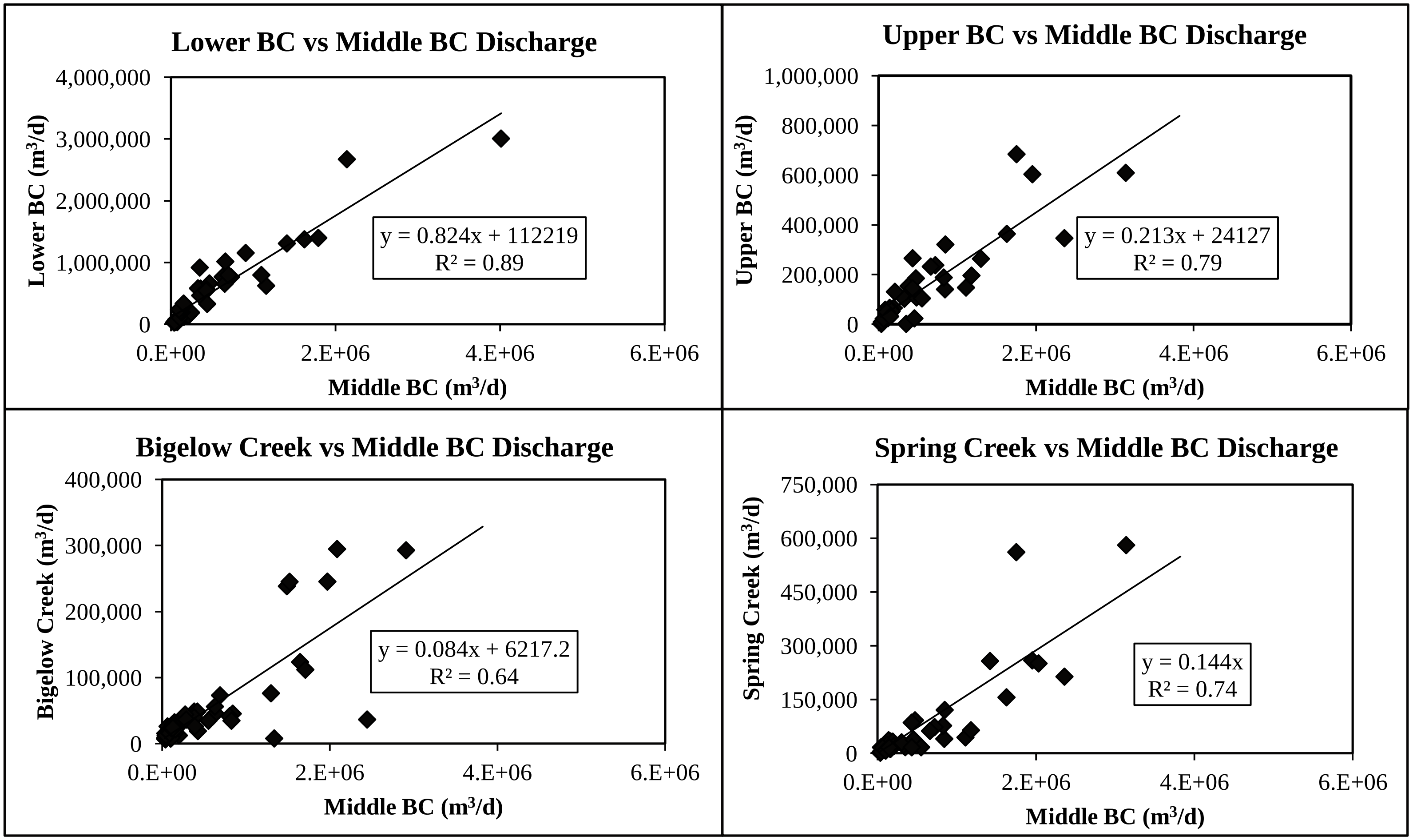


Figure 9. The regression lines for Lower Black Creek (top left), Upper Black Creek (top right), Bigelow Creek (bottom left), and Spring Creek (bottom right) versus Middle Black Creek (USGS site). From these regression equations daily discharge at sites without continuous discharge data (Lower BC, Upper BC, Spring Creek and Bigelow Creek) were predicted. Prediction of discharge based on USGS discharge at Churchville (Middle BC) for Lower BC did not require a correction for lag time between the two sites; Spring Creek and Upper BC versus USGS discharge at Churchville both are based on a one day lag time while Bigelow Creek had a two day lag time. BC= Black Creek.

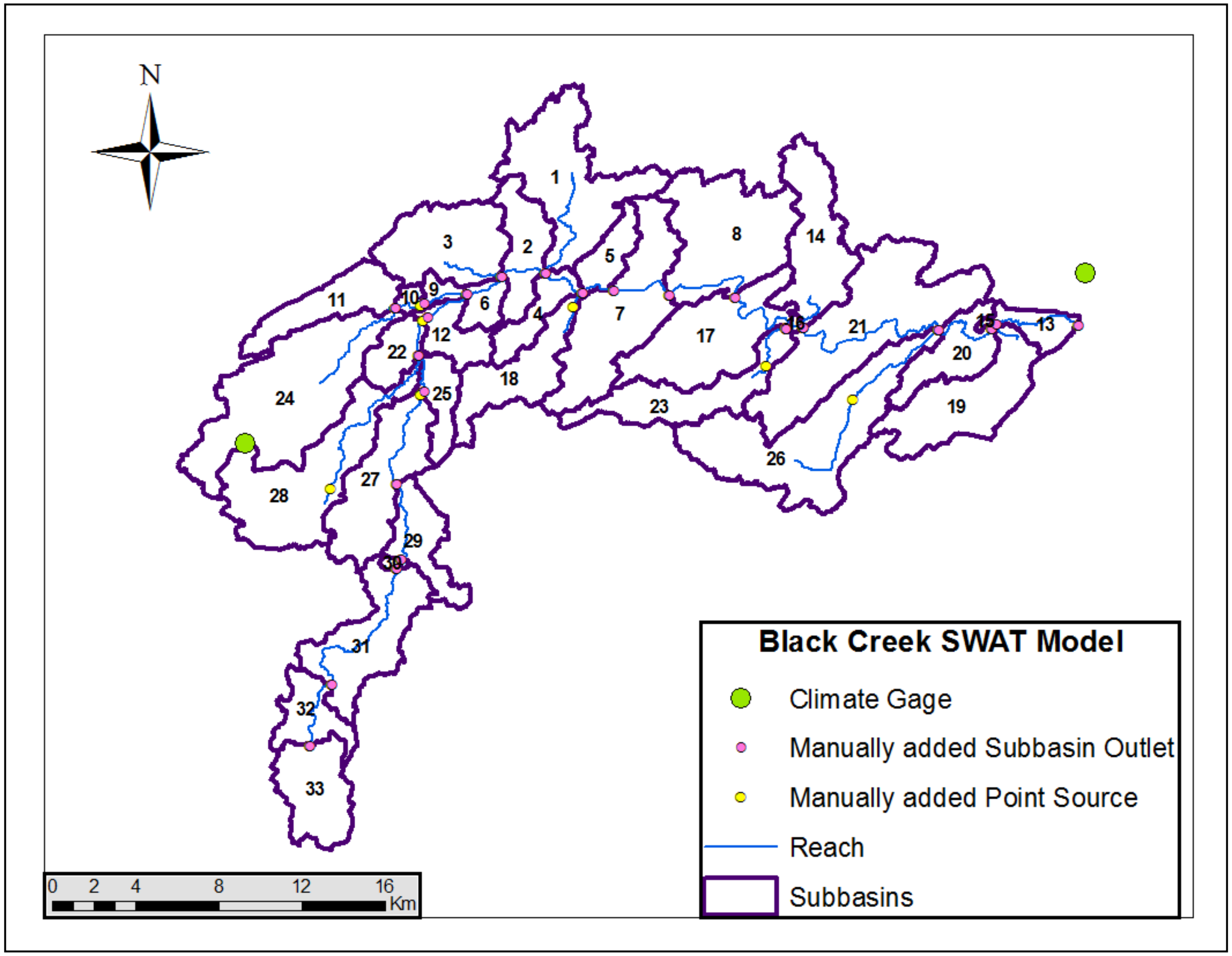


Figure 10. The Black Creek watershed Soil and Water Assessment Tool (SWAT) subbasins, monitoring sites, outlets (pour point), point source locations, and weather stations.

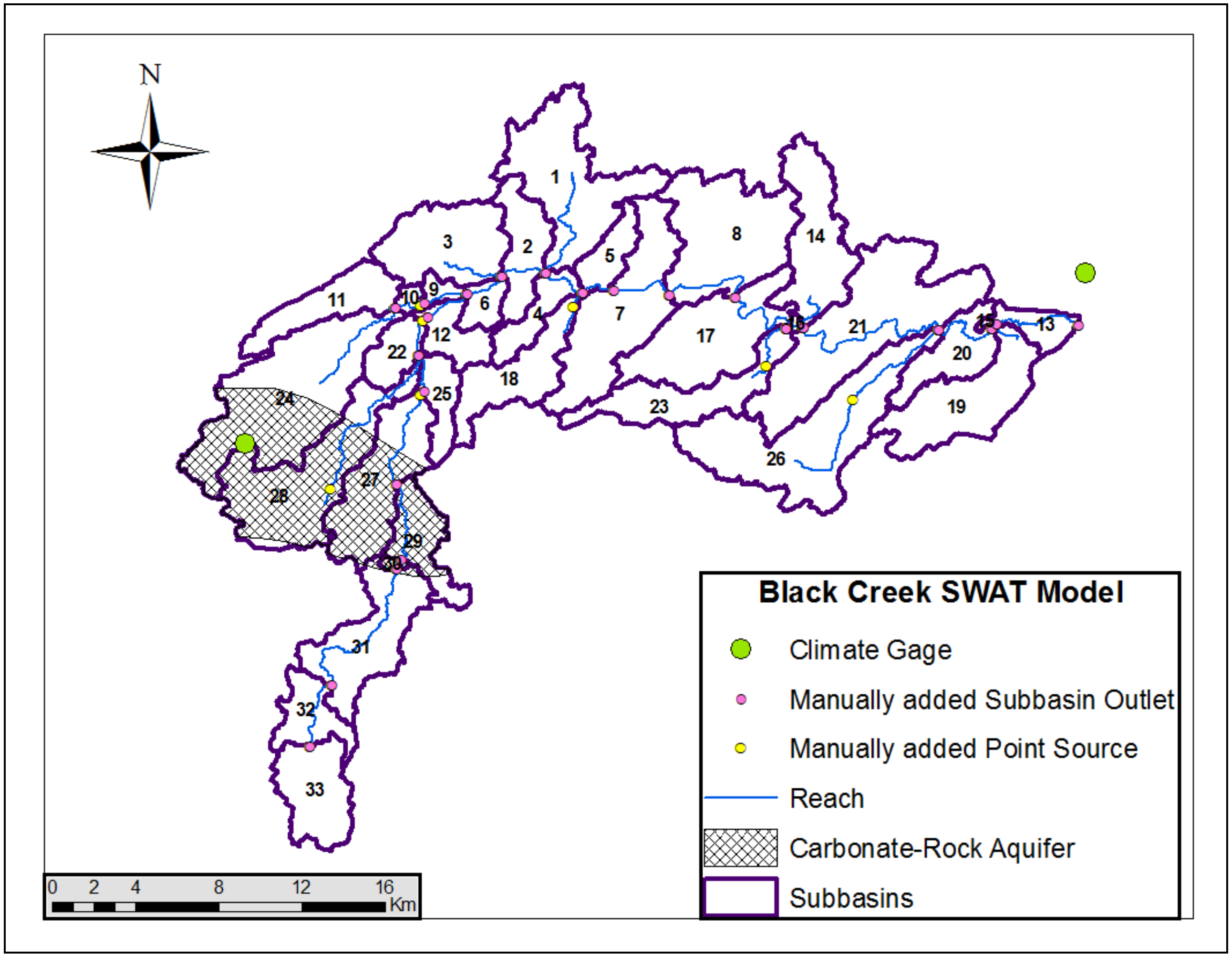


Figure 11. The Black Creek watershed delineated by BCSWAT indicating the location of the New York carbonate-rock aquifer where the Onondaga escarpment influences hydrology in the watershed in subbasins 24, 27, 28, and 29.

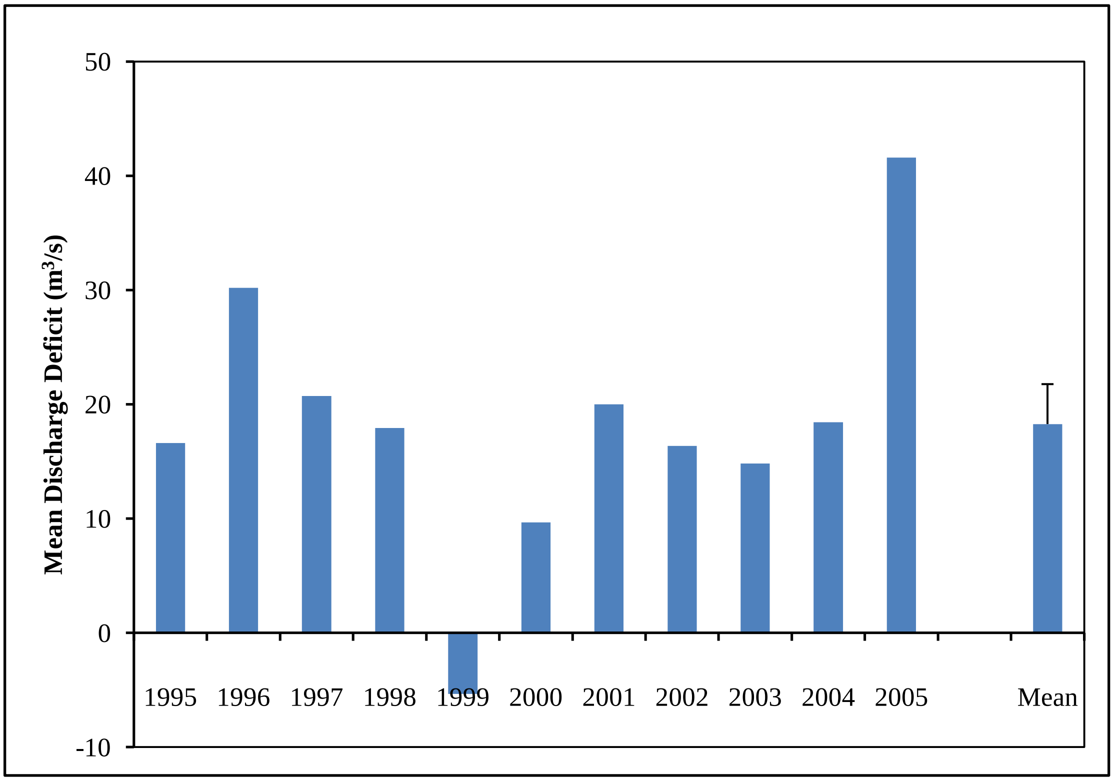


Figure 12. The mean February to April discharge deficit observed from an 11 year (1995-2005) initial SWAT model run. The overall mean (± standard error) was used as the amount of water added to the subbasins where the escarpment crosses Black Creek watershed.

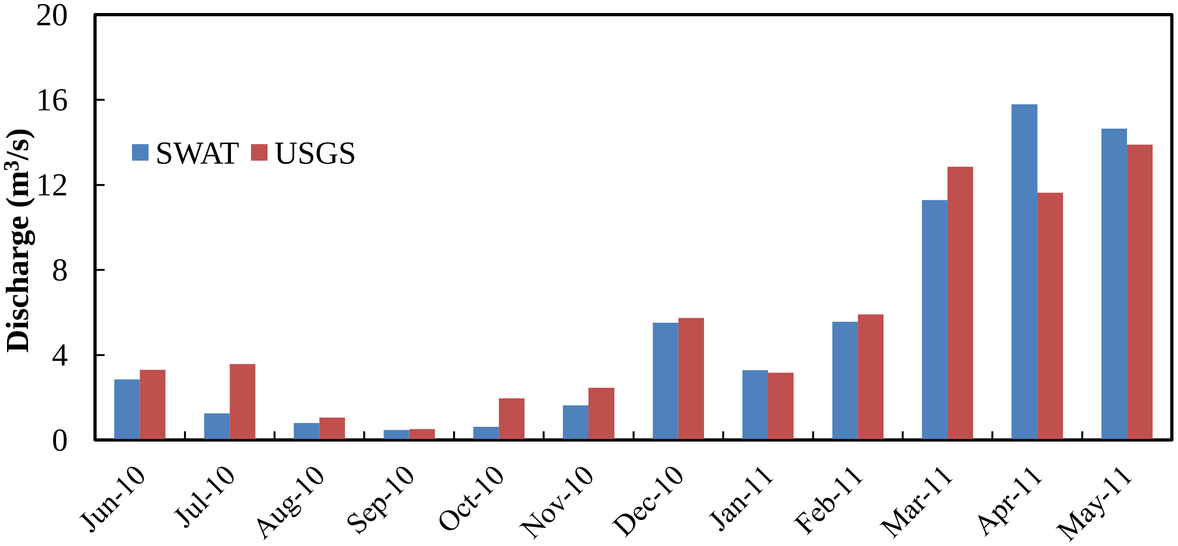


Figure 13. Measured (USGS gauged data) and simulated monthly data (SWAT model output) for the calibration period June 2010 through May 2011. This model yielded a Nash-Sutcliffe coefficient of 0.88, an r^2 of 0.93, and a PBIAS of -3.6 between USGS and SWAT output. PBIAS=Percent Bias, USGS=United States Geological Survey.

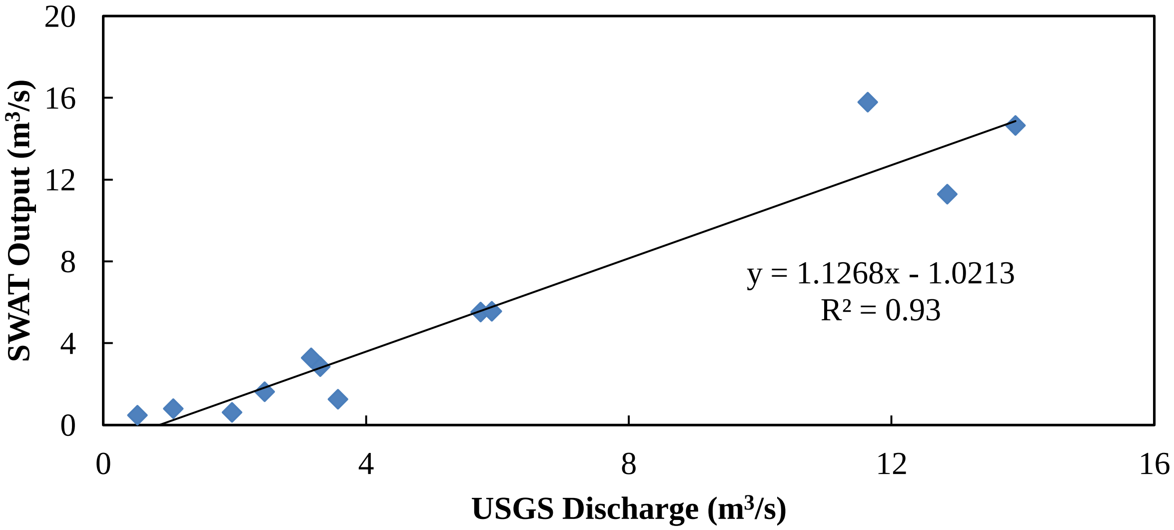


Figure 14. Observed (USGS gauged data) and simulated monthly data (SWAT model output) for the calibration period June 2010 through May 2011. This model yielded a Nash-Sutcliffe coefficient of 0.88, an r^2 of 0.93, and a PBIAS of -3.6 between USGS and SWAT output. PBIAS=Percent Bias, USGS=United States Geological Survey.

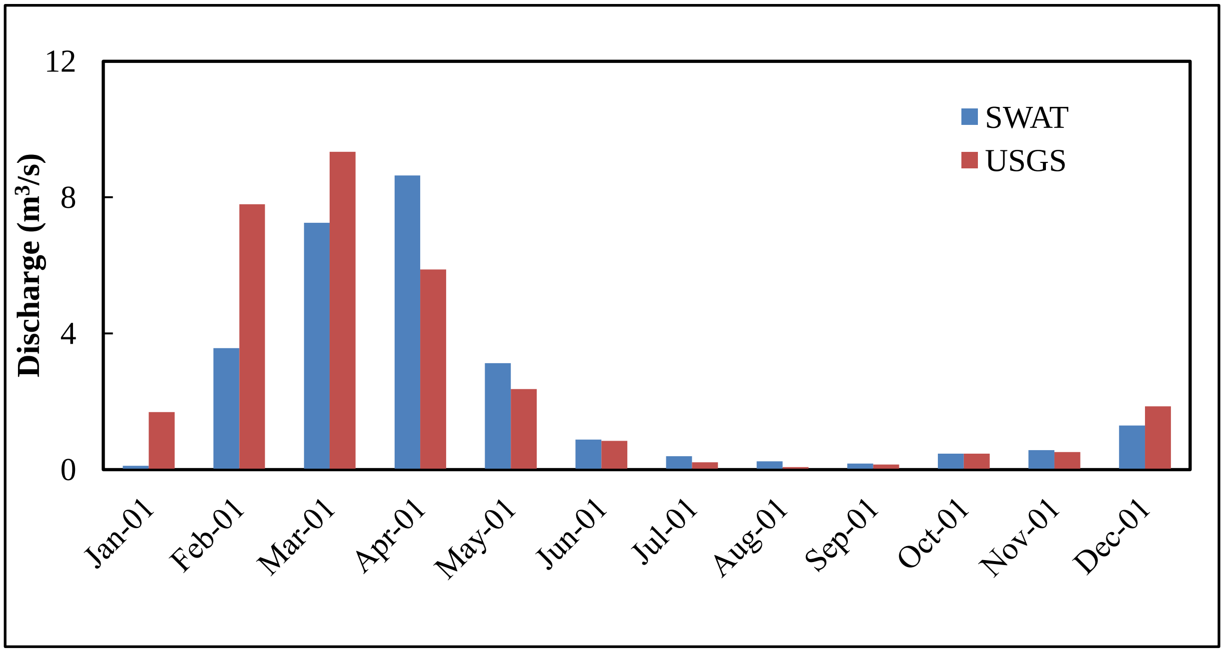


Figure 15. Measured (USGS gauged data) and simulated monthly data (SWAT model output) for the validation period of January 2001 through December 2001 at Middle BC. This model yielded a Nash-Sutcliffe coefficient of 0.74, a r^2 of 0.73, and a PBIAS of -14.36. PBIAS=Percent Bias, USGS=United States Geological Survey.

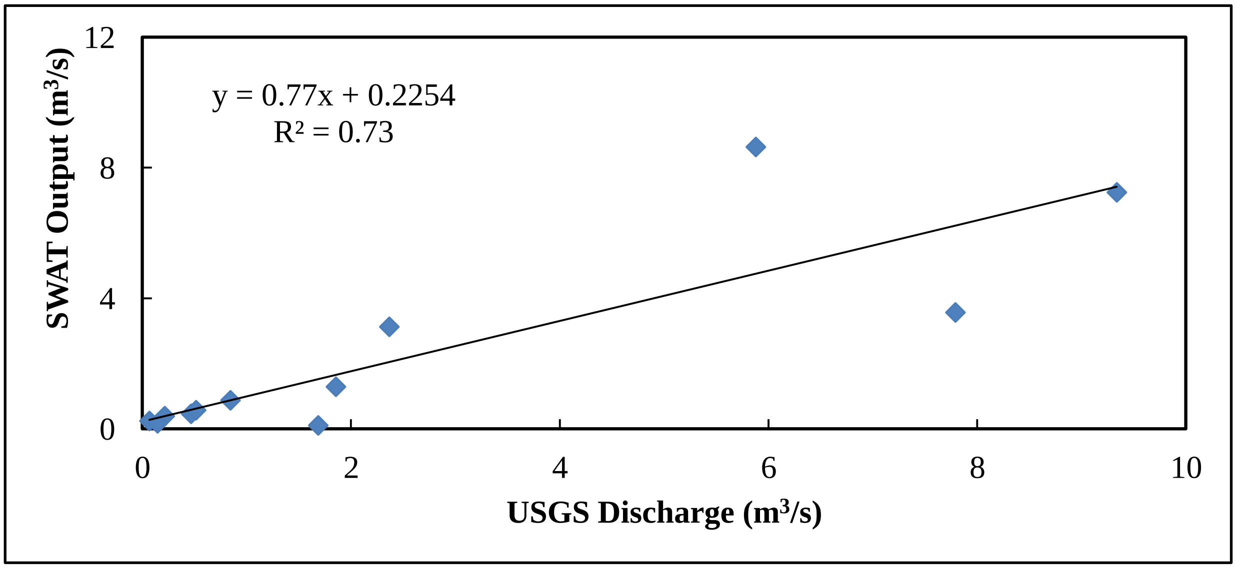


Figure 16. Measured (USGS gauged data) and simulated monthly data (SWAT model output) for the validation period of January through December 2001 at Middle BC. This model yielded a Nash-Sutcliffe coefficient of 0.74, a r^2 of 0.73, and a PBIAS of -14.36. PBIAS=Percent Bias, USGS=United States Geological Survey.

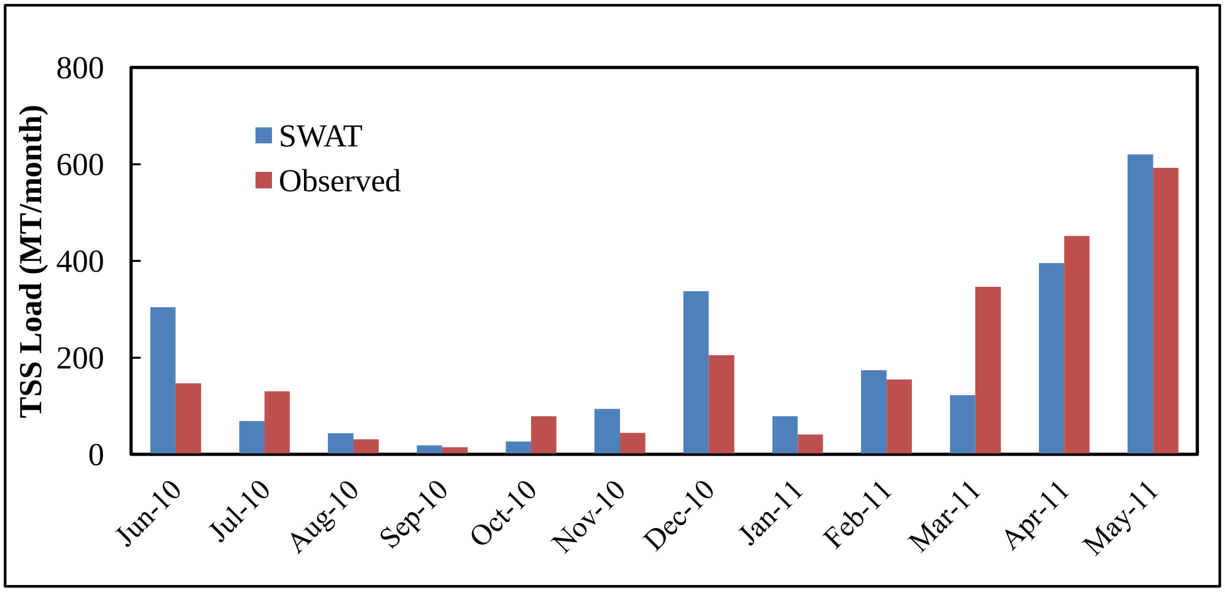


Figure 17. Observed total suspended solids (TSS) loads versus simulated monthly data (SWAT model output) for the calibration period of June 2010 through May 2011 at Middle BC. The model yielded a Nash-Sutcliffe coefficient of 0.71, an r^2 of 0.74, and a PBIAS of +2.0 for TSS. MT= metric tonnes. PBIAS=Percent Bias, USGS=United States Geological Survey.

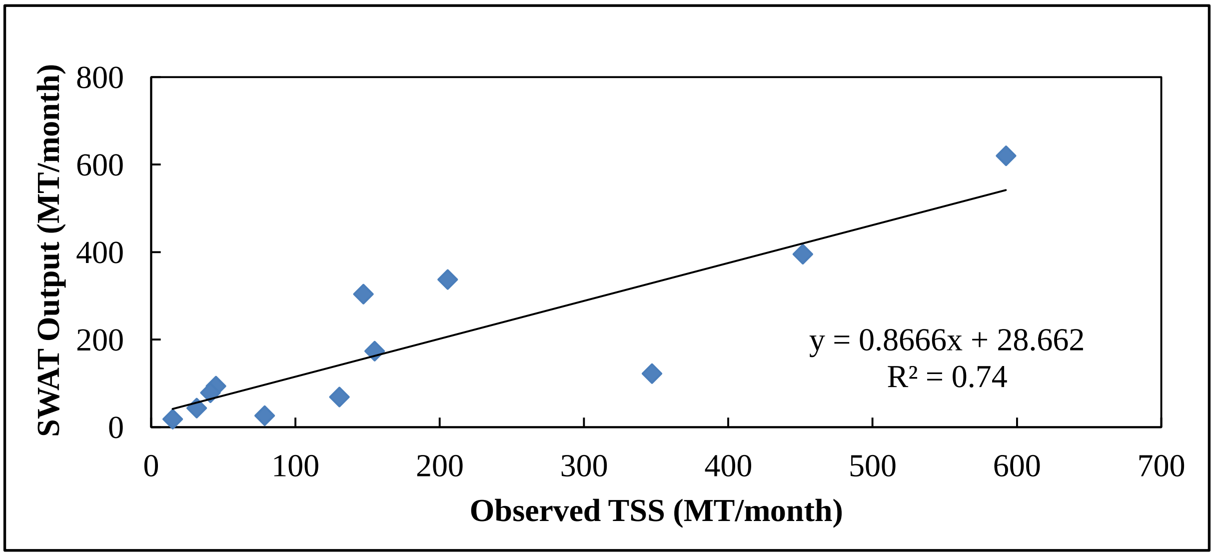


Figure 18. Observed total suspended solids (TSS) loads in MT/month versus simulated monthly data (SWAT model output) for the calibration period of June 2010 through May 2011. The model yielded a Nash-Sutcliffe coefficient of 0.71, an r^2 of 0.74, and a PBIAS of +2.0 for TSS. MT= metric tonnes. PBIAS=Percent Bias, USGS=United States Geological Survey.

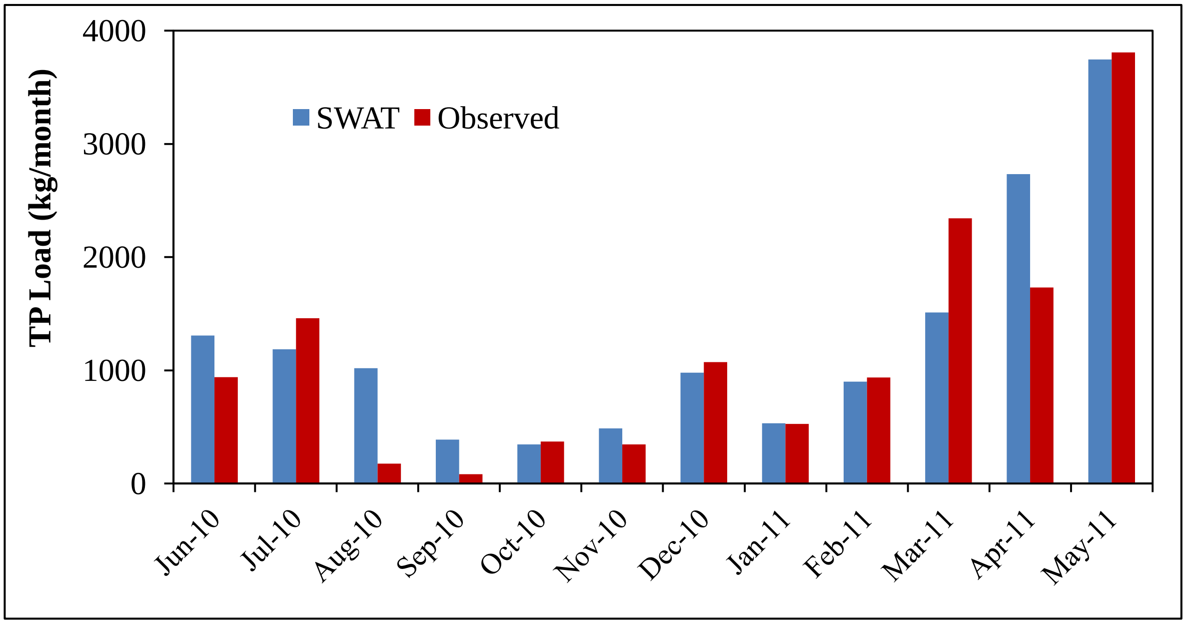


Figure 19. Observed total phosphorus (TP) loading in kg/month versus simulated monthly data (SWAT model output) for the calibration period of June 2010 through May 2011 at Middle BC. The model yielded a Nash-Sutcliffe of 0.78, an r^2 of 0.80, and a PBIAS of +9.8 for TP calibration. PBIAS=Percent Bias, USGS=United States Geological Survey.

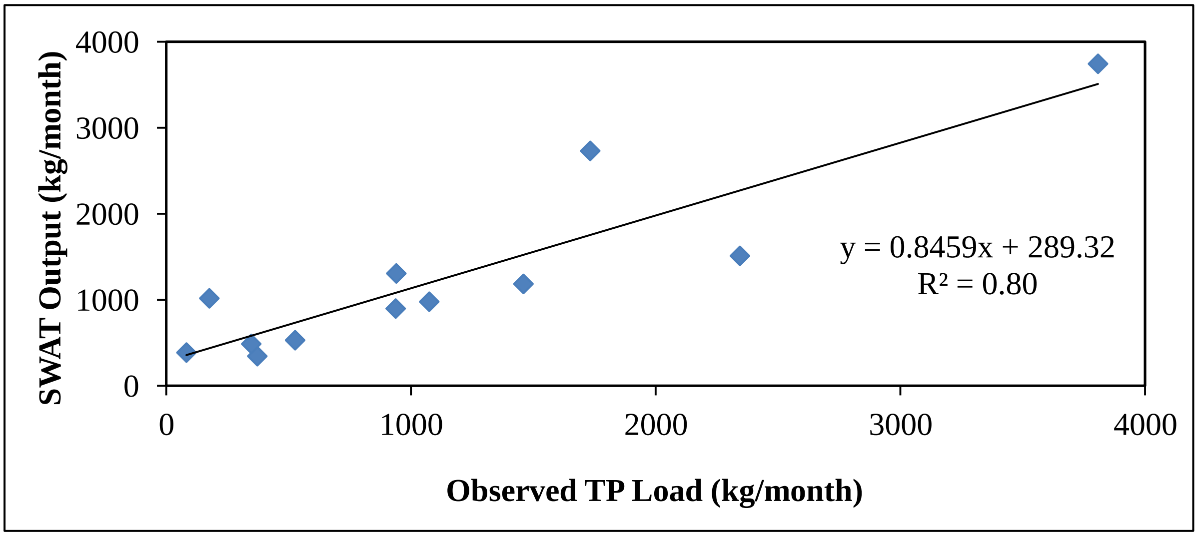


Figure 20. Observed total phosphorus (TP) loading in kg/month versus simulated monthly data (SWAT model output) for the calibration period of June 2010 through May 2011. The model yielded a Nash-Sutcliffe of 0.78, an r^2 of 0.80, and a PBIAS of +9.8 for TP calibration. PBIAS=Percent Bias, USGS=United States Geological Survey.

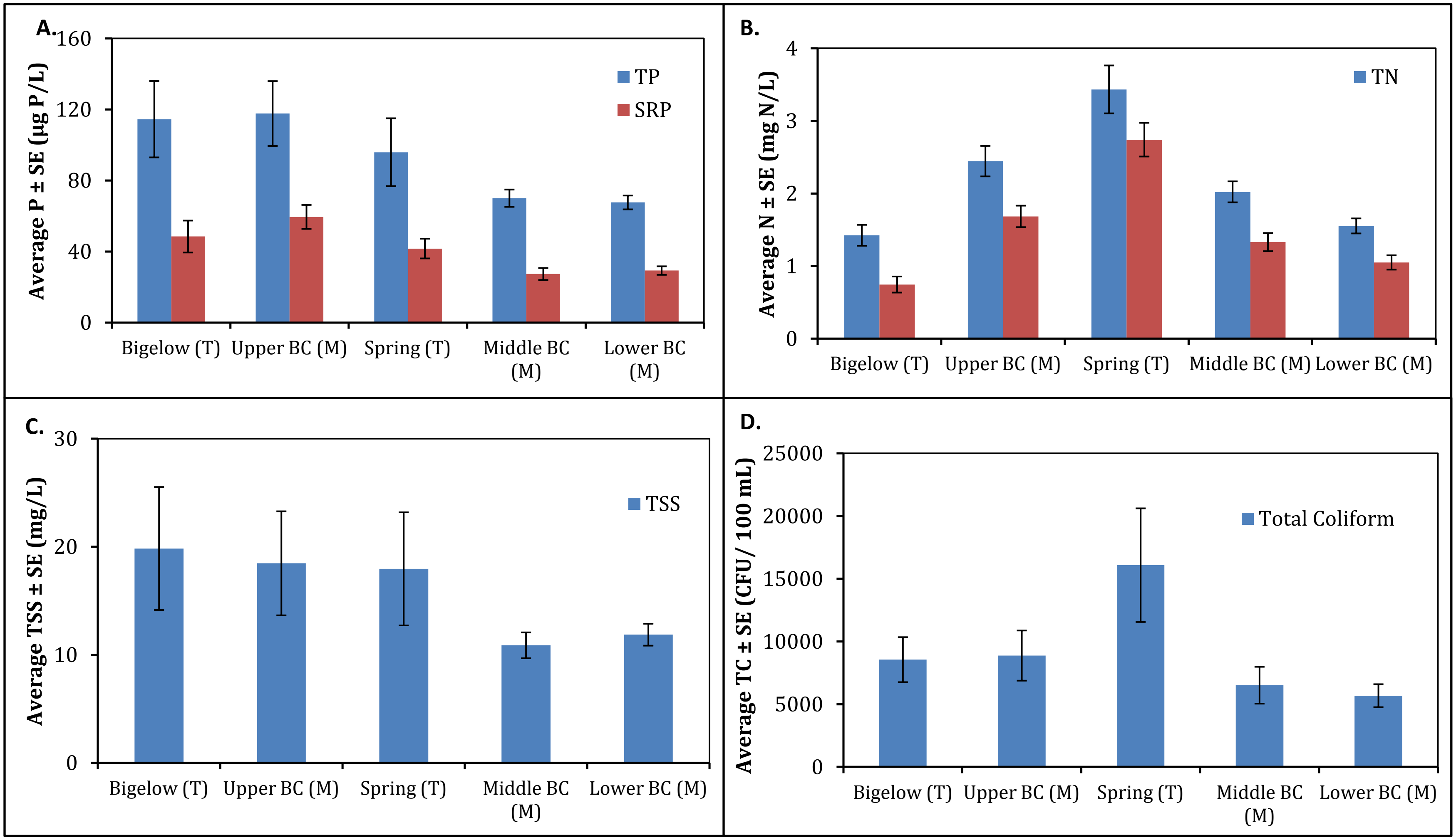


Figure 21. **A.** Average field observed total phosphorus (TP) and soluble reactive phosphorus (SRP) concentration (µg P/L) ± SE at five routine monitoring sites (June 2010-May 2011). **B.** Average observed total nitrogen (TN) and nitrate concentration (mg N/L) ± SE at five routine monitoring sites (June 2010-May 2011). **C.** Average observed total suspended solids (TSS) concentration (mg/L) ± SE at five routine monitoring sites (June 2010-May 2011). **D.** Average observed total coliform bacteria abundance ± SE at five routine monitoring sites (June 2010-May 2011). BC= Black Creek, T= tributary, M=mainstem.

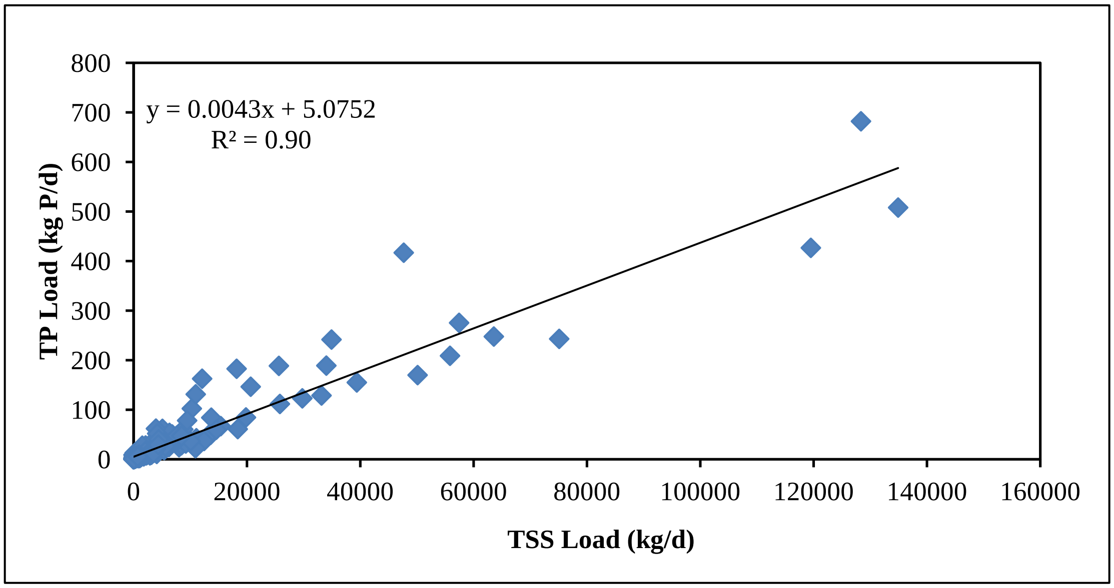


Figure 22. Correlation between observed total phosphorus (TP) and total suspended solids (TSS) loads in the Black Creek watershed.

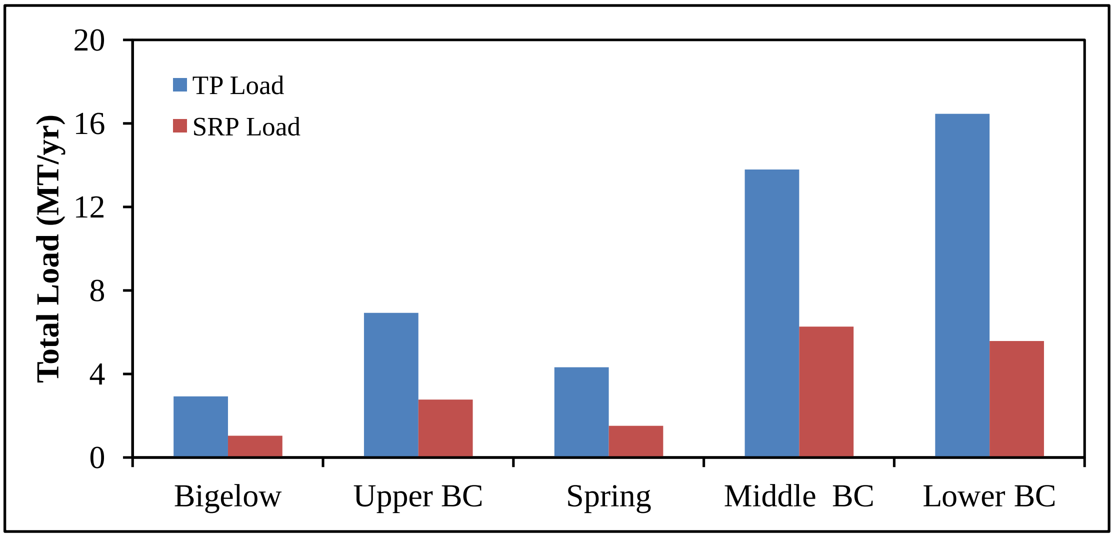


Figure 23. Observed annual total phosphorus (TP) and soluble reactive phosphorus (SRP) in metric tones (MT) at all routine monitoring sites (Bigelow Creek tributary, Upper BC, Spring Creek tributary, Middle BC, and Lower BC) from 1 June 2010 through 31 May 2011. BC = Black Creek.

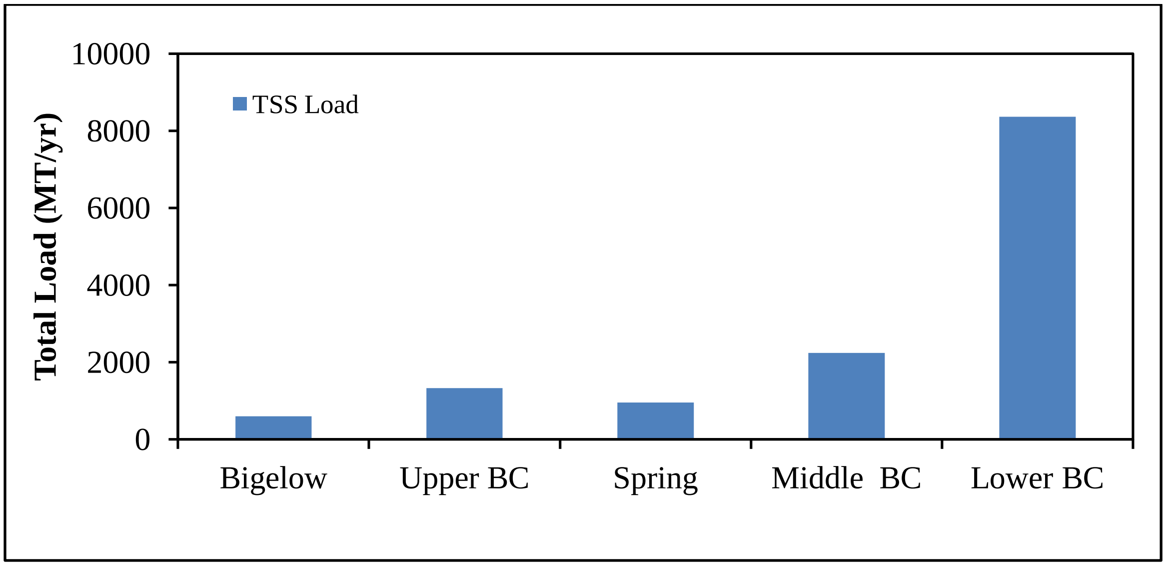


Figure 24. Observed annual observed total suspended solids (TSS) in metric tonnes (MT) at all routine monitoring sites (Bigelow Creek tributary, Upper BC, Spring Creek tributary, Middle BC, and Lower BC) from 1 June 2010 through 31 May 2011. BC = Black Creek.

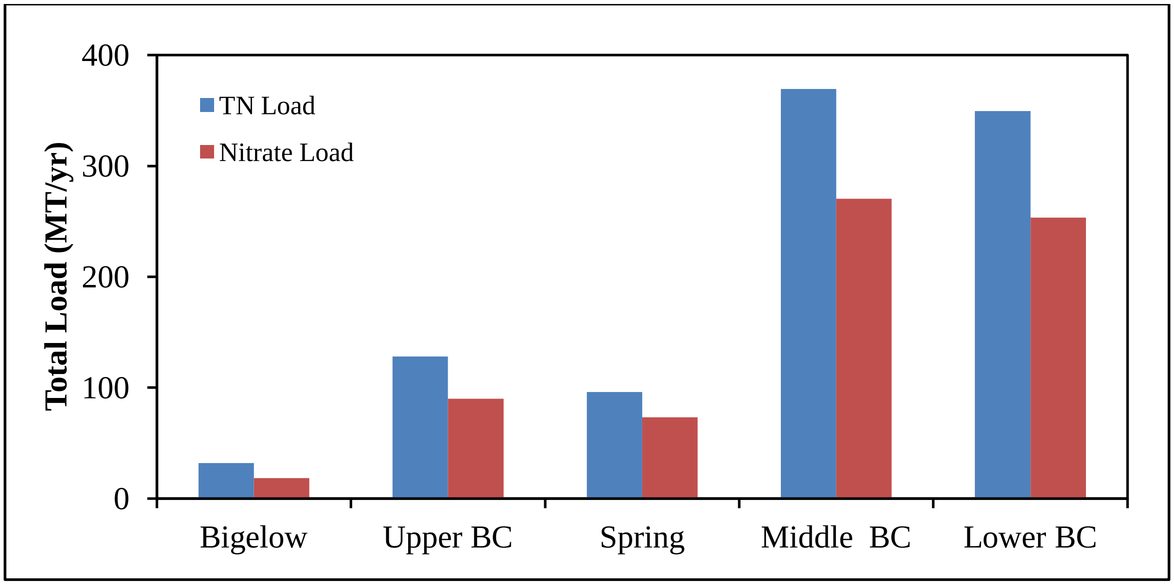


Figure 25. Observed annual observed total nitrogen (TN) and nitrate in metric tonnes (MT) at all routine monitoring sites (Bigelow Creek tributary, Upper BC, Spring Creek tributary, Middle BC, and Lower BC) from 1 June 2010 through 31 May 2011. BC= Black Creek.

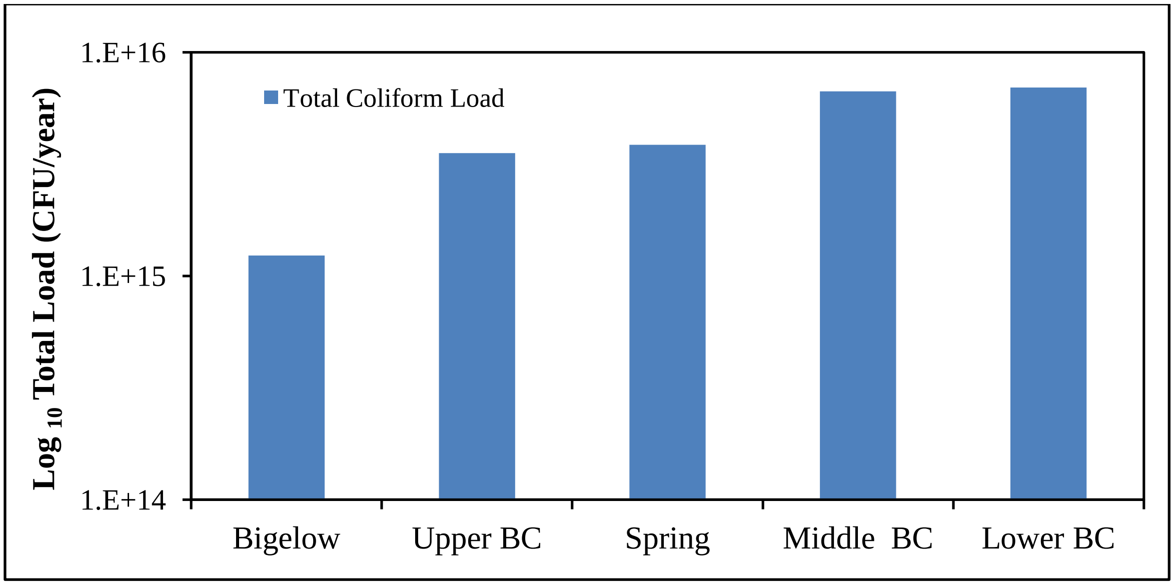


Figure 26. Observed annual observed total coliform loading in colony forming units (CFU) per year at all routine monitoring sites (Bigelow Creek tributary, Upper BC, Spring Creek tributary, Middle BC, and Lower BC) from 1 June 2010 through 31 May 2011. BC= Black Creek.

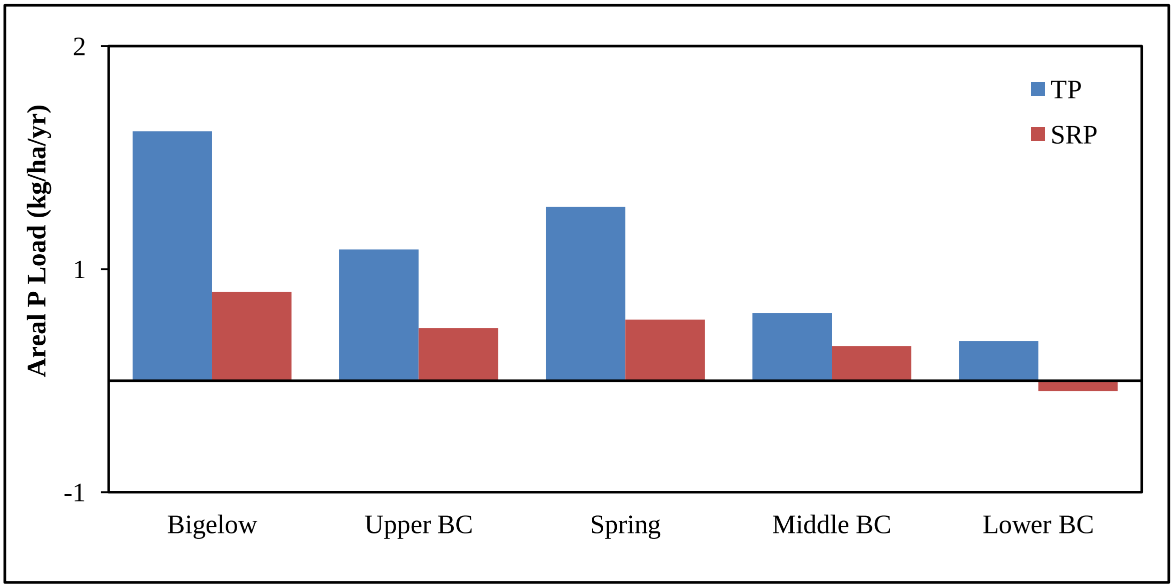


Figure 27. Observed areal annual total phosphorus (TP) and soluble reactive phosphorus (SRP) loads normalized for segment drainage area of each routine monitoring site (Bigelow Creek, Upper BC, Spring Creek, Middle BC, and Lower BC). BC= Black Creek.

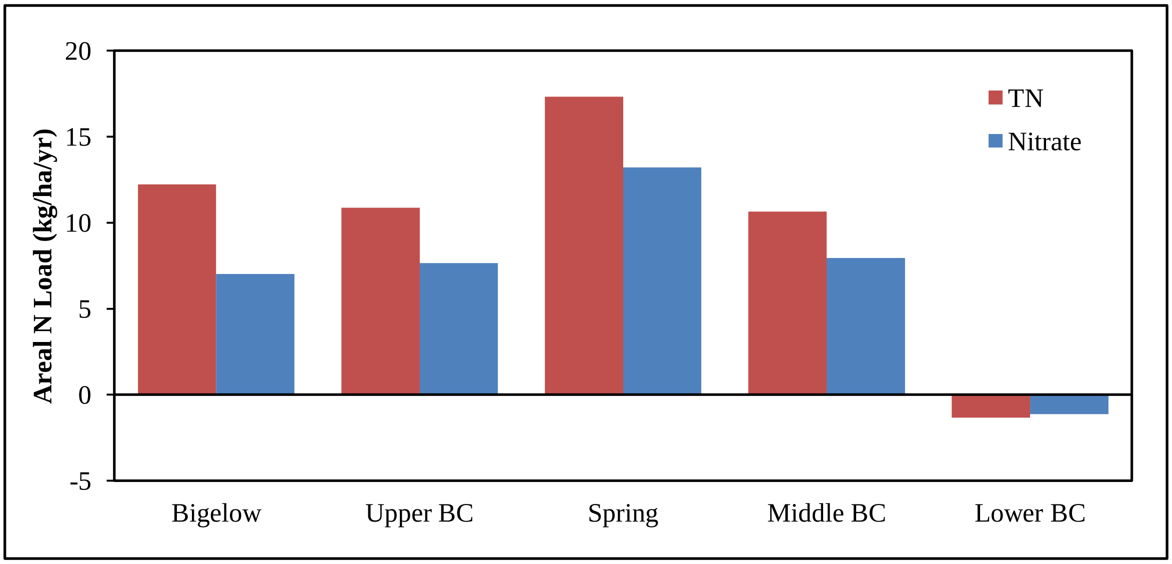


Figure 28. Observed areal annual total nitrogen (TN) and nitrate loads normalized for segment drainage area of each routine monitoring site (Bigelow Creek, Upper BC, Spring Creek, Middle BC, and Lower BC). BC= Black Creek.

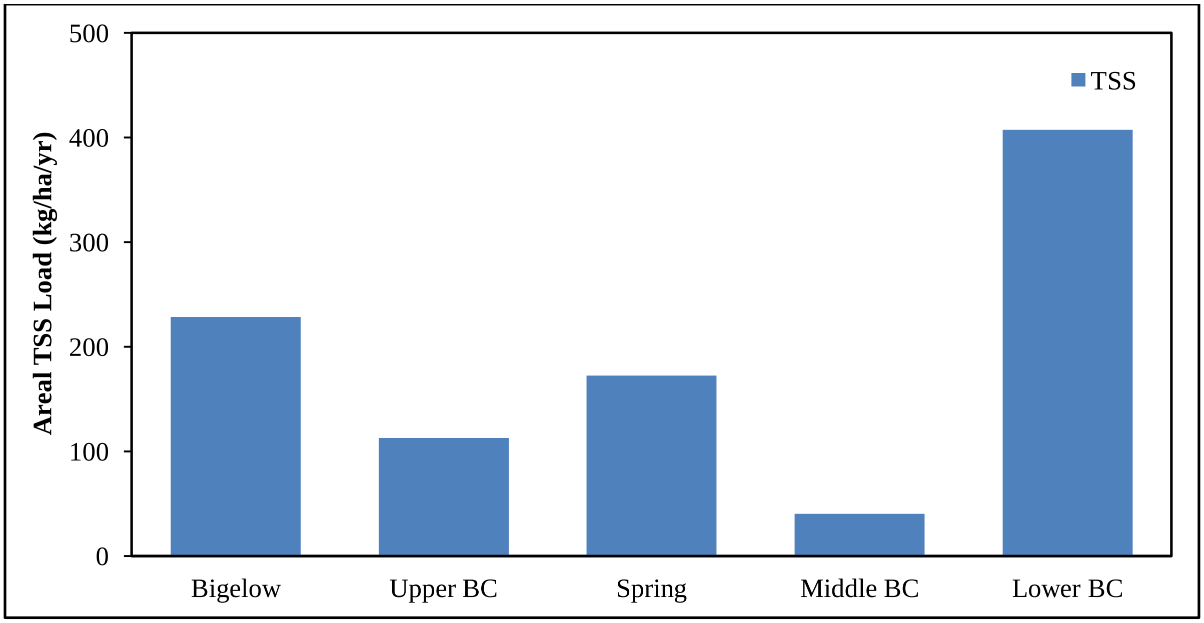


Figure 29. Observed areal annual total suspended loads (TSS) normalized for segment drainage area of each routine monitoring site (Bigelow Creek, Upper BC, Spring Creek, Middle BC, and Lower BC). BC= Black Creek.

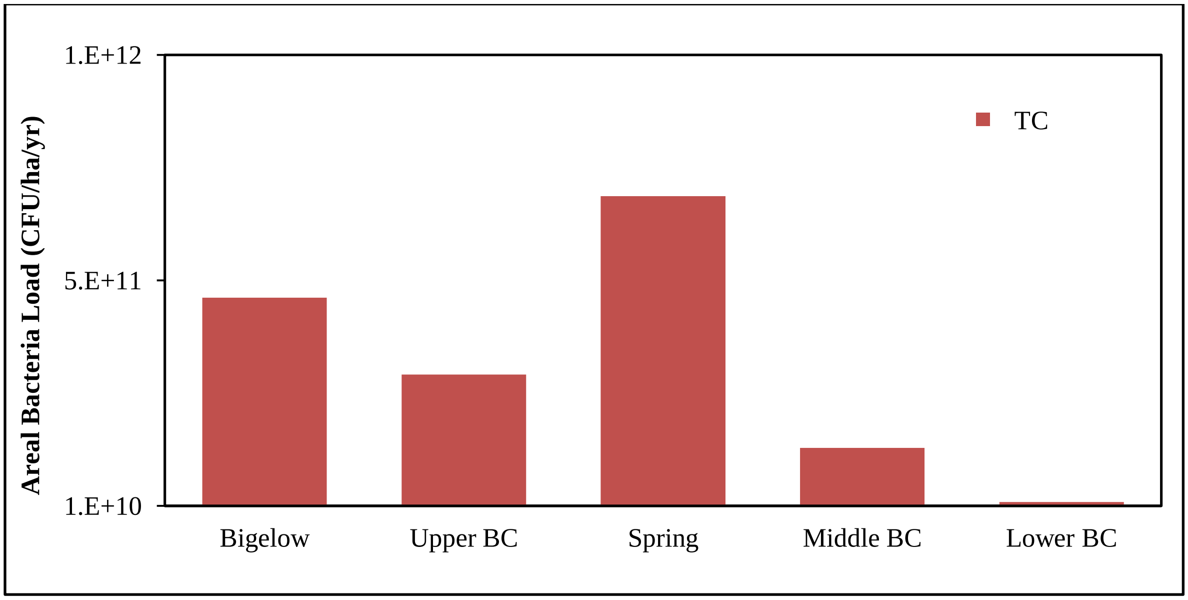


Figure 30. Observed areal annual total coliform bacteria (TC) loads normalized for upstream drainage area of each routine monitoring site (Bigelow Creek, Upper BC, Spring Creek, Middle BC, and Lower BC). BC= Black Creek.

Figure 31. Arial photograph of the segment of Lower BC used for an erosion inventory. Sites found to have stream bank erosion are depicted in red.

Figure 32. Arial photograph of the segment upstream of Upper BC used as a reference site for an erosion inventory. Sites found to have stream bank erosion are depicted in red.

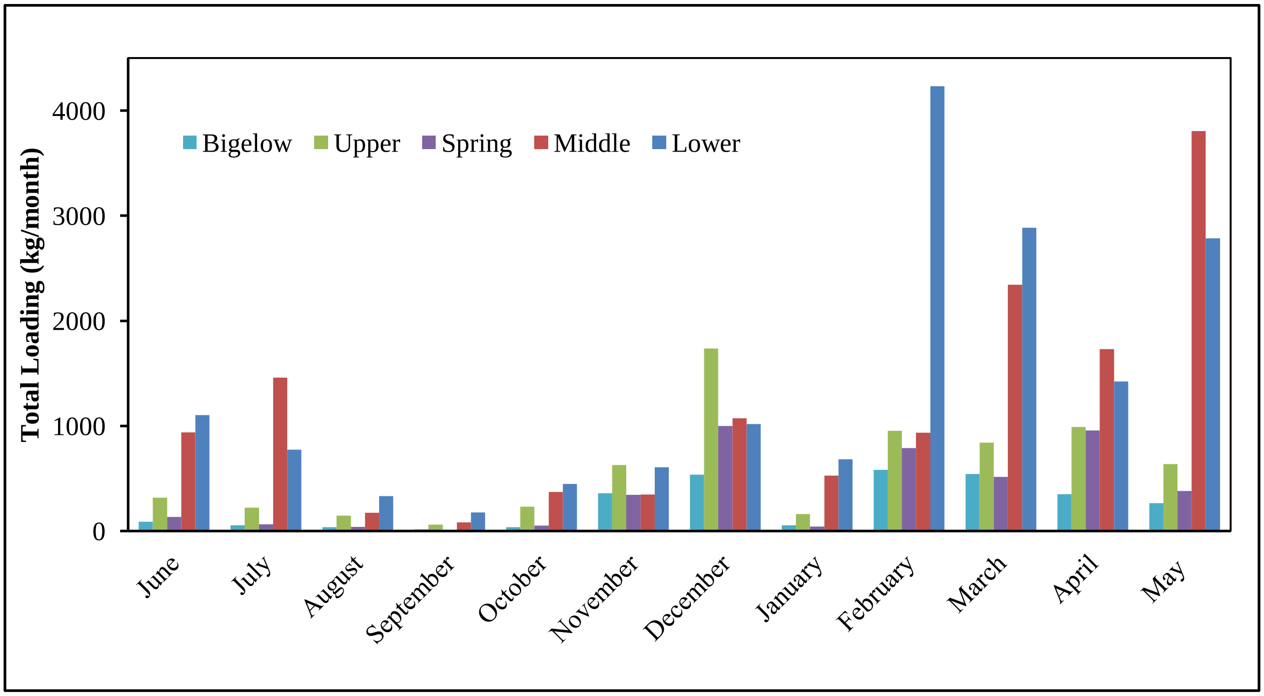


Figure 33. Observed total monthly total phosphorus (TP) loads in kg/month for June 2010 through May 2011 for all routine monitoring sites starting from upstream at Bigelow Creek to downstream at Lower Black Creek.

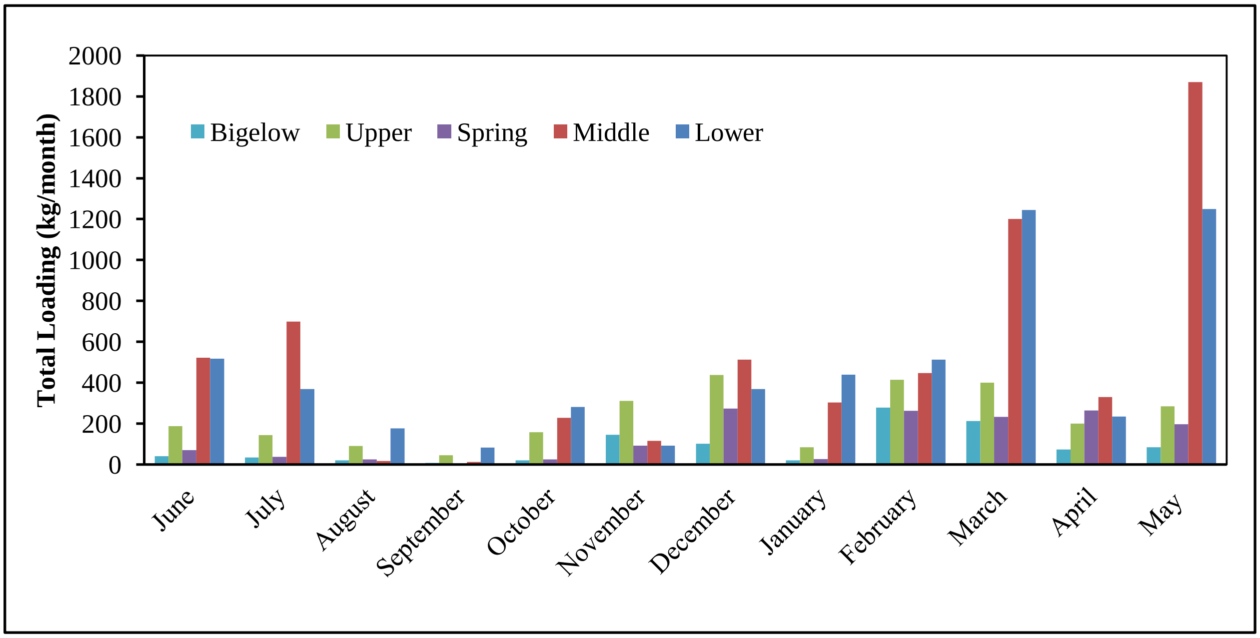


Figure 34. Observed total monthly soluble reactive phosphorus (SRP) loads in kg/month for June 2010 through May 2011 for all routine monitoring sites starting from upstream at Bigelow Creek to downstream at Lower Black Creek.

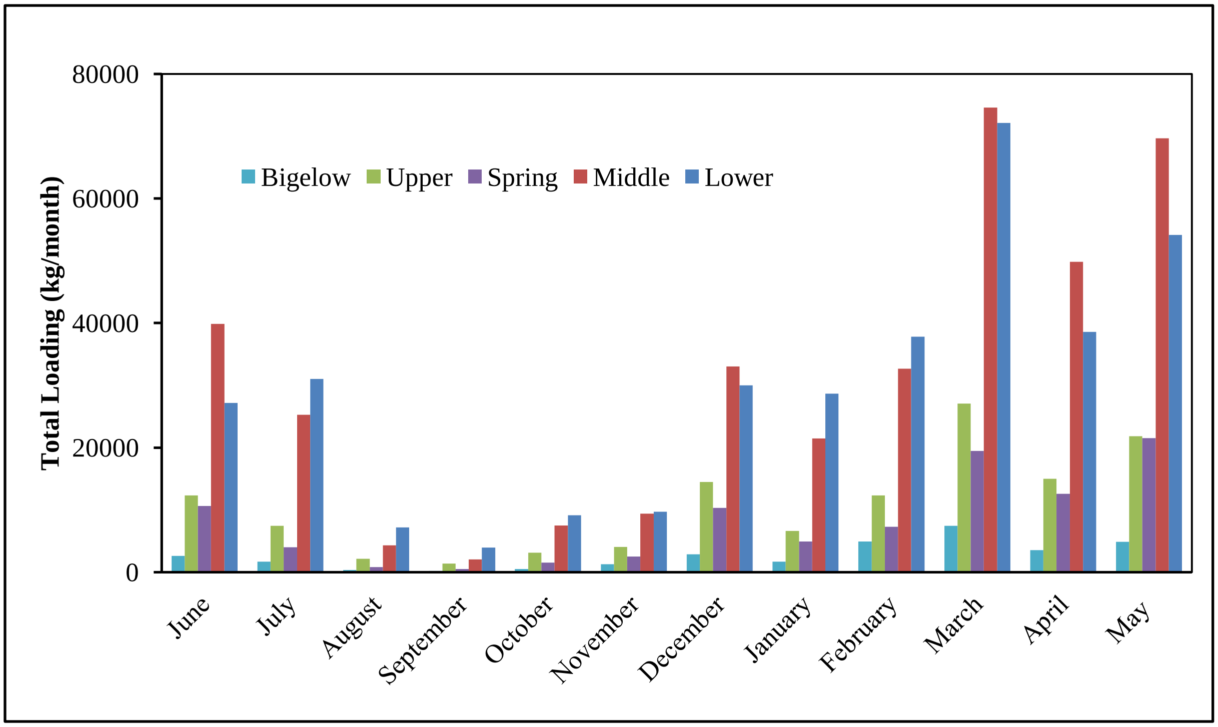


Figure 35. Observed total monthly total nitrogen (TN) loads in kg/month for June 2010 through May 2011 for all routine monitoring sites starting from upstream at Bigelow Creek to downstream at Lower Black Creek.

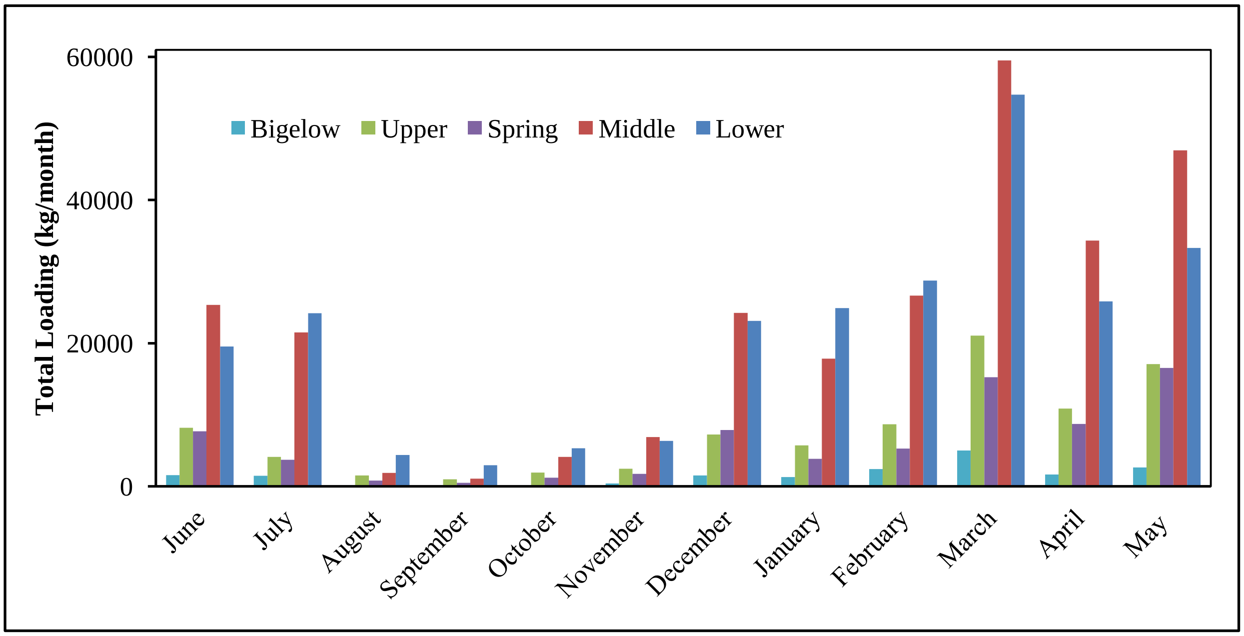


Figure 36. Observed total monthly nitrate loads in kg/month for June 2010 through May 2011 for all routine monitoring sites starting from upstream at Bigelow Creek to downstream at Lower Black Creek.

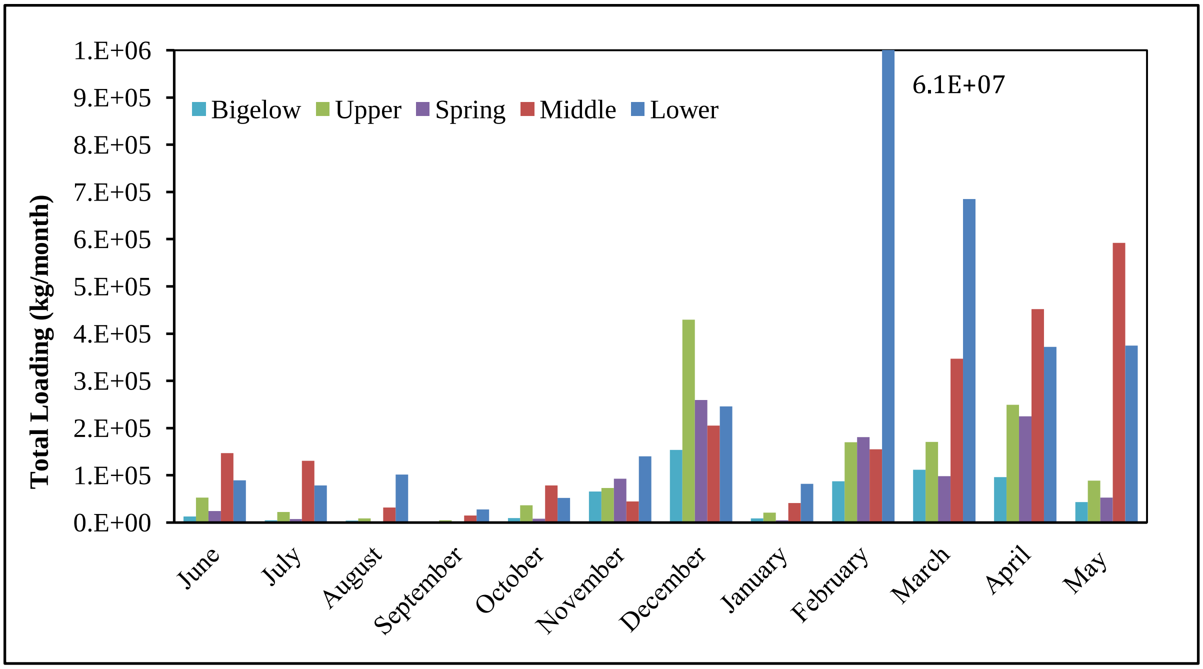


Figure 37. Observed total monthly total suspended solids (TSS) loads in kg/month for June 2010 through May 2011 for all routine monitoring sites starting from upstream at Bigelow Creek to downstream at Lower Black Creek

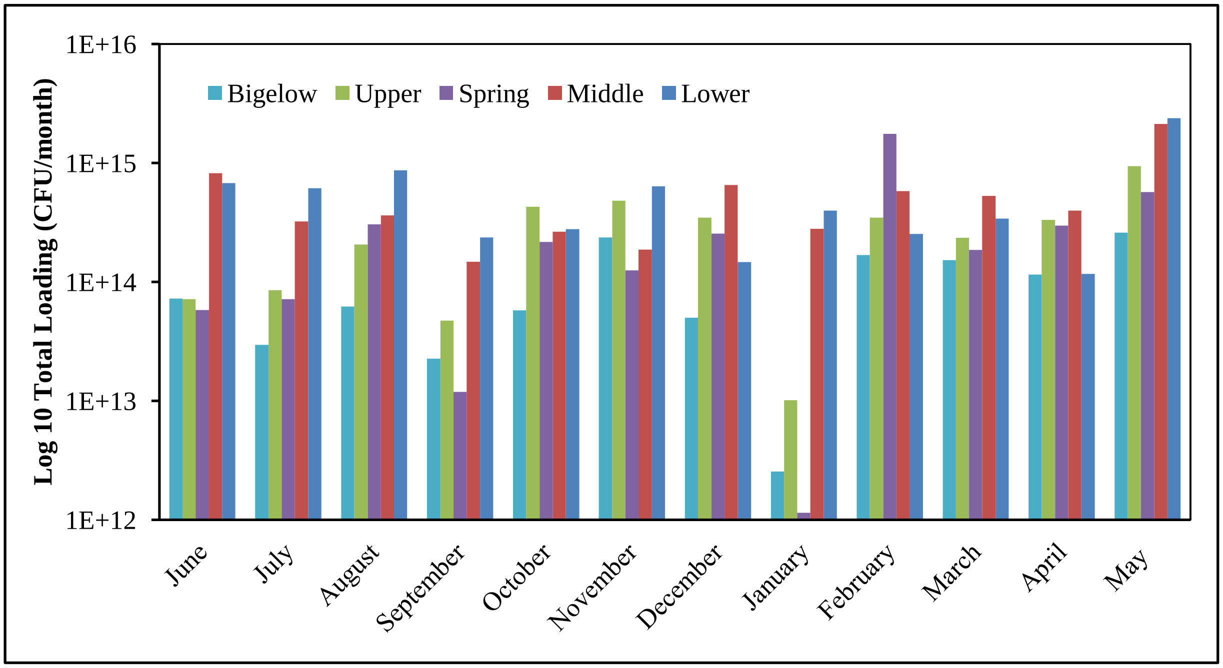


Figure 38. Observed total monthly total coliform bacteria (TC) loads in CFU/month for June 2010 through May 2011 for all routine monitoring sites starting from upstream at Bigelow Creek to downstream at Lower Black Creek.

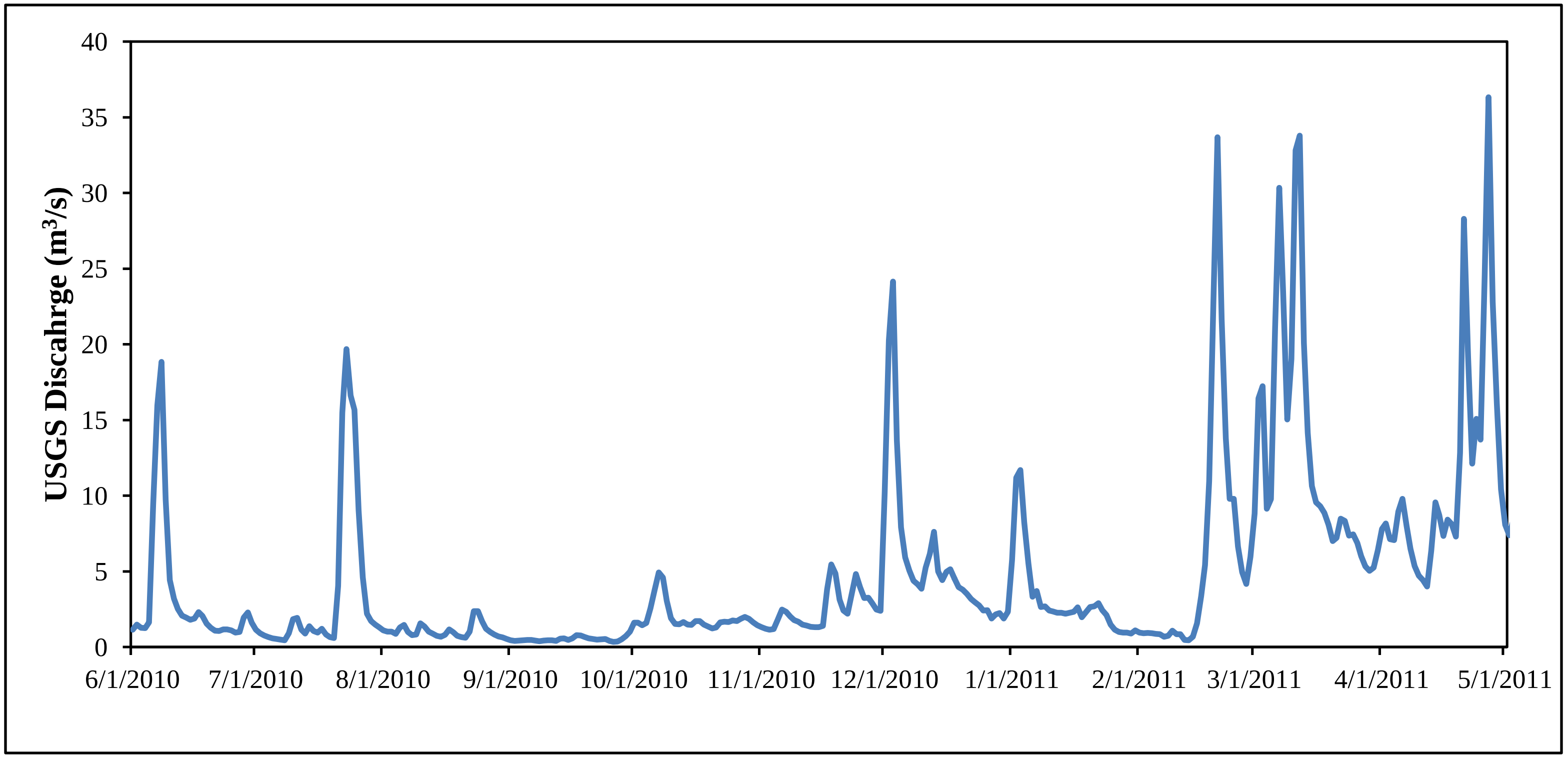


Figure 39. Discharge (m^3/s) from the USGS monitoring station at Middle Black Creek in Churchville, NY from 1 June 2010 through 31 May 2011.

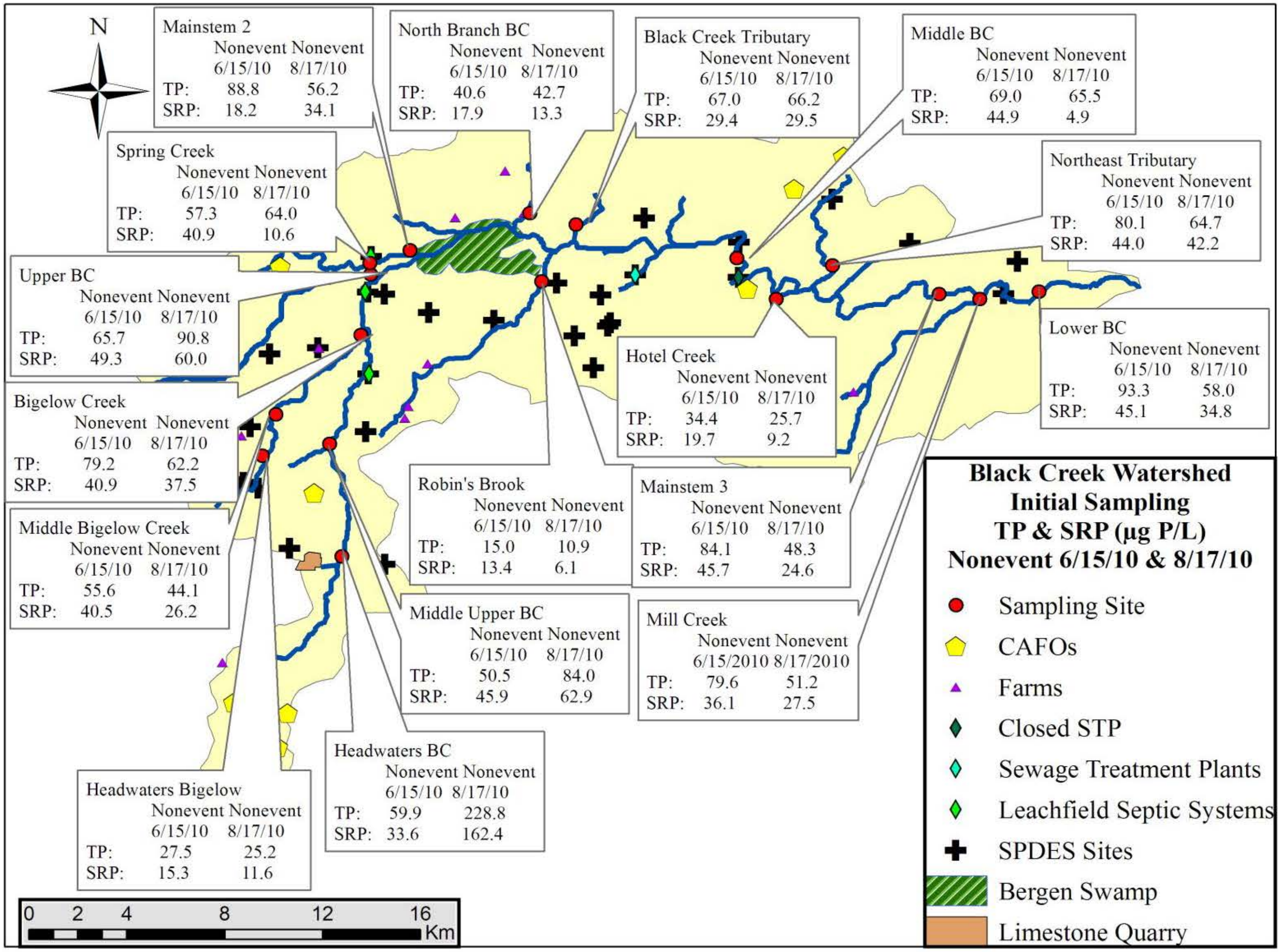


Figure 40.Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) at initial tributary outlet sampling sites of Black Creek on 15 June 2010 and 17 August 2010. Tributary outlet samples were collected at the segment on the tributary just upstream of the junction to Black Creek.

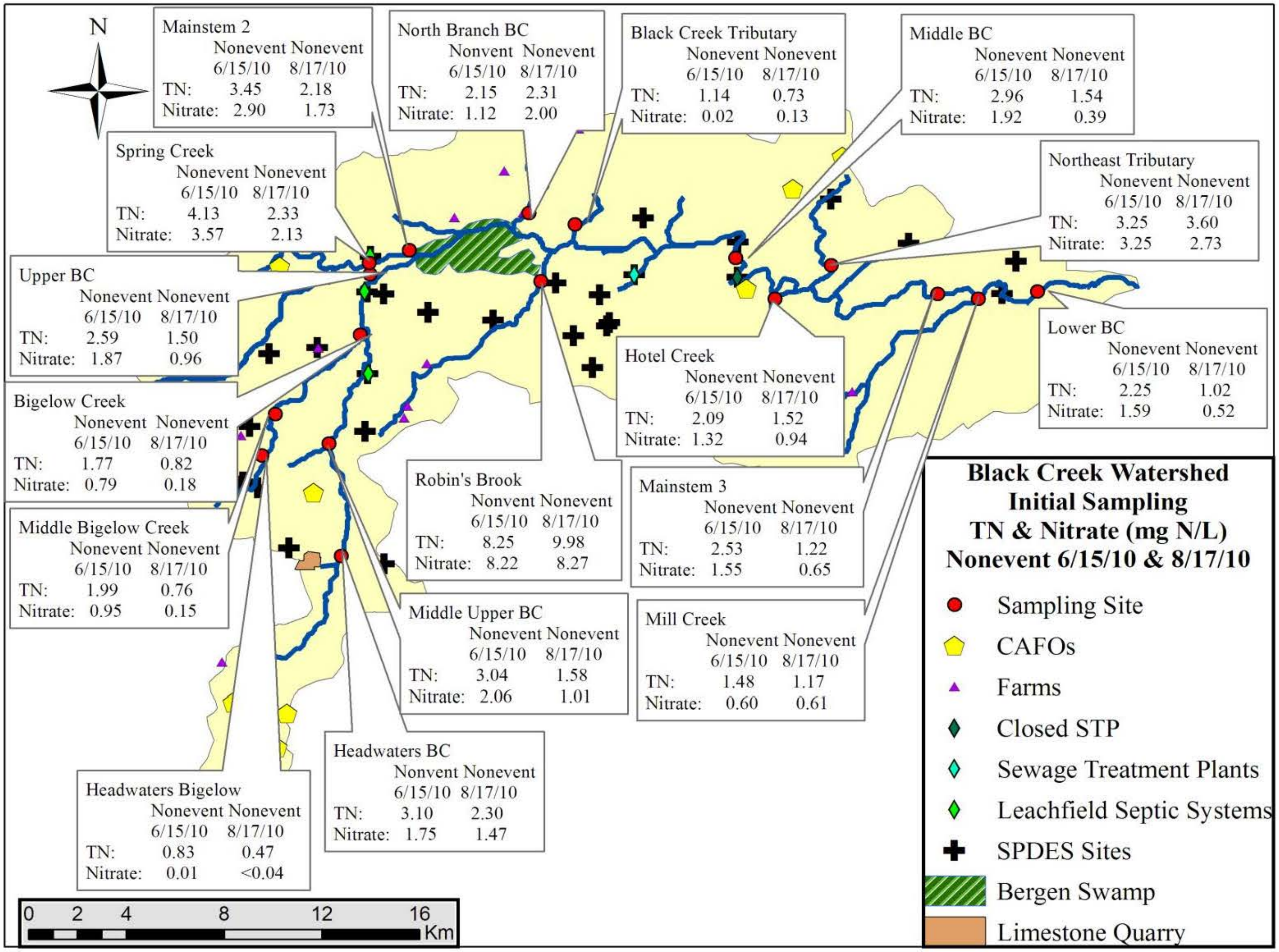


Figure 41. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from initial sampling of tributary outlet of Black Creek on 15 June 2010 and 17 August 2010. Tributary outlet samples were collected at the segment on the tributary just upstream of the junction to Black Creek.

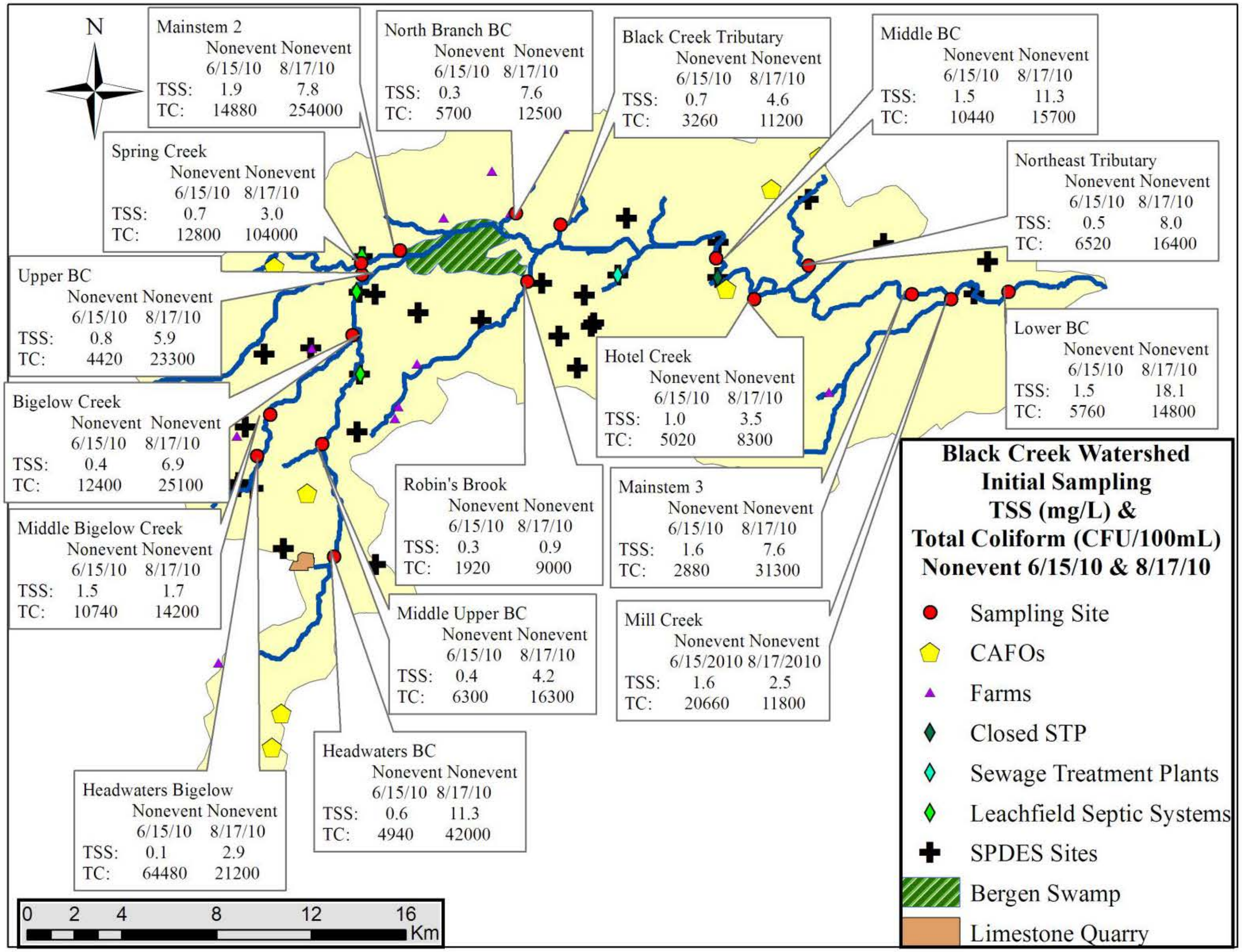


Figure 42. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/100 mL) from initial sampling of tributary outlets of Black Creek on 15 June 2010 and 17 August 2010. Tributary outlet samples were collected at the segment on the tributary just upstream of the junction to Black Creek.

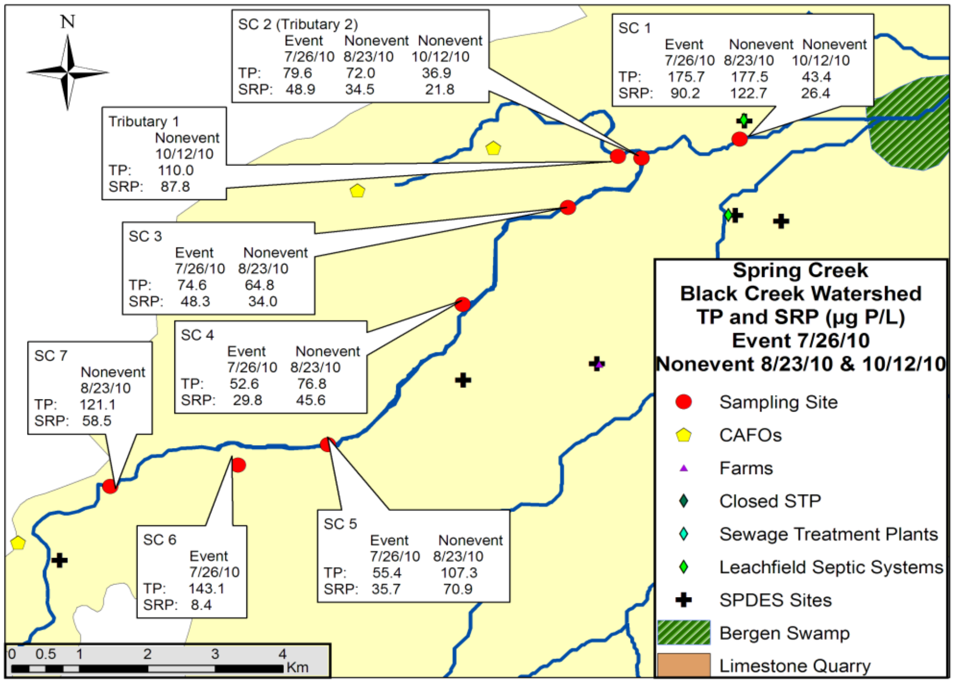


Figure 43. Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) from the Spring Creek (SC) subwatershed on 26 July 2010, 23 August 2010, and 12 October 2010.

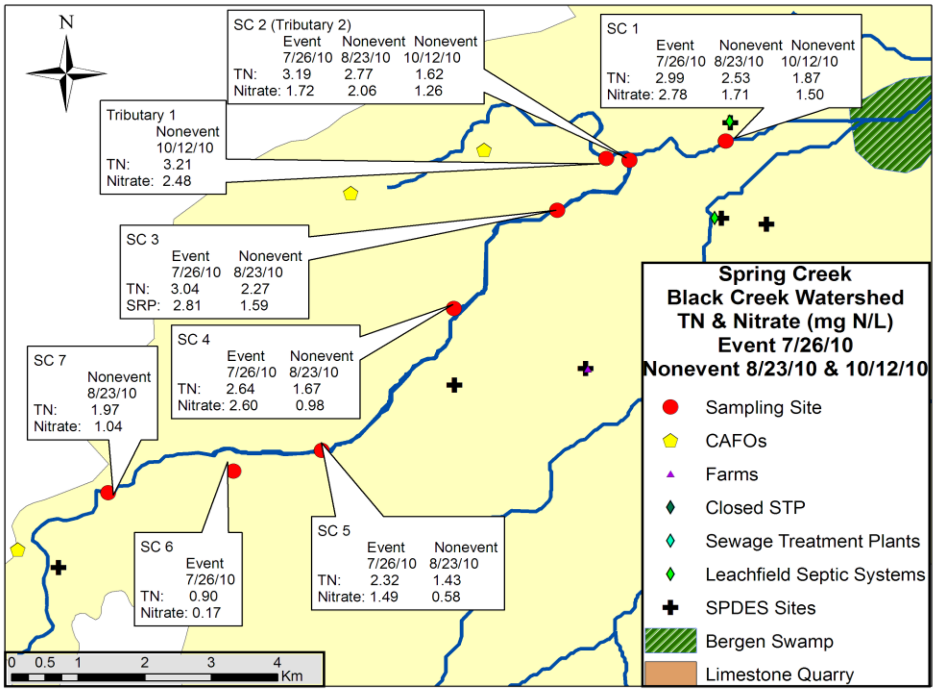


Figure 44. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from the Spring Creek (SC) subwatershed on 26 July 2010, 23 August 2010, and 12 October 2010.

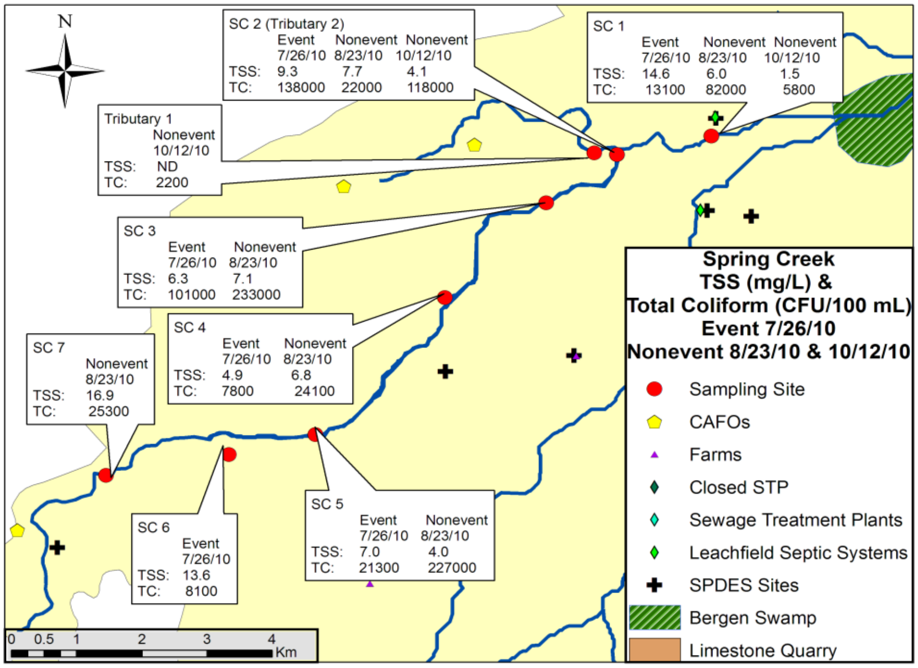


Figure 45. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/100 mL) from the Spring Creek (SC) subwatershed on 26 July 2010, 23 August 2010, and 12 October 2010.

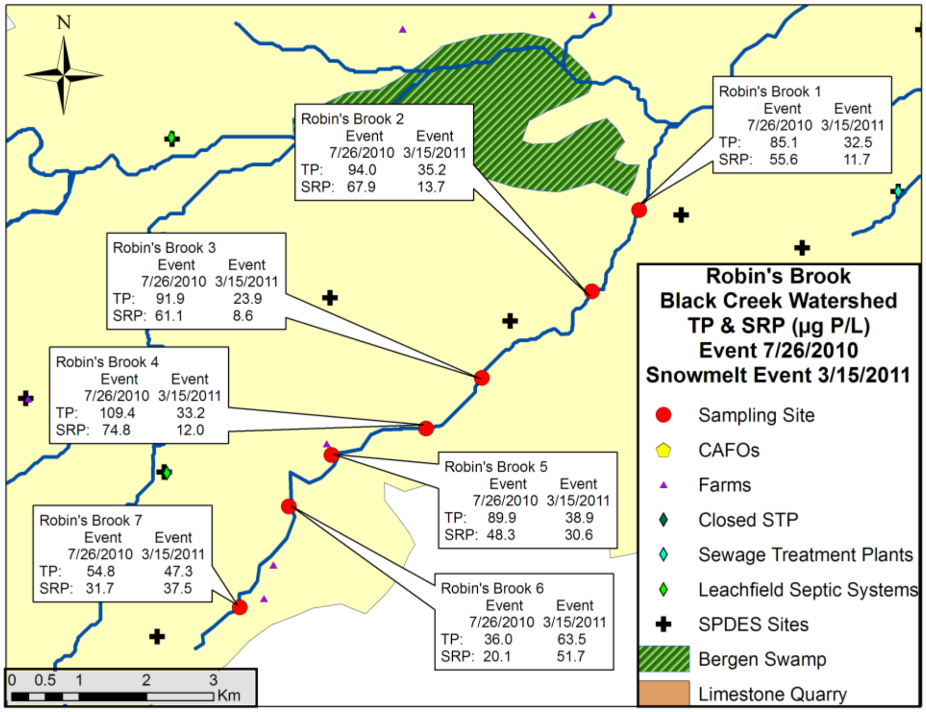


Figure 46. Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) from the Robin's Brook (RB) subwatershed of the Black Creek watershed on 26 July 2010 and 15 March 2011.

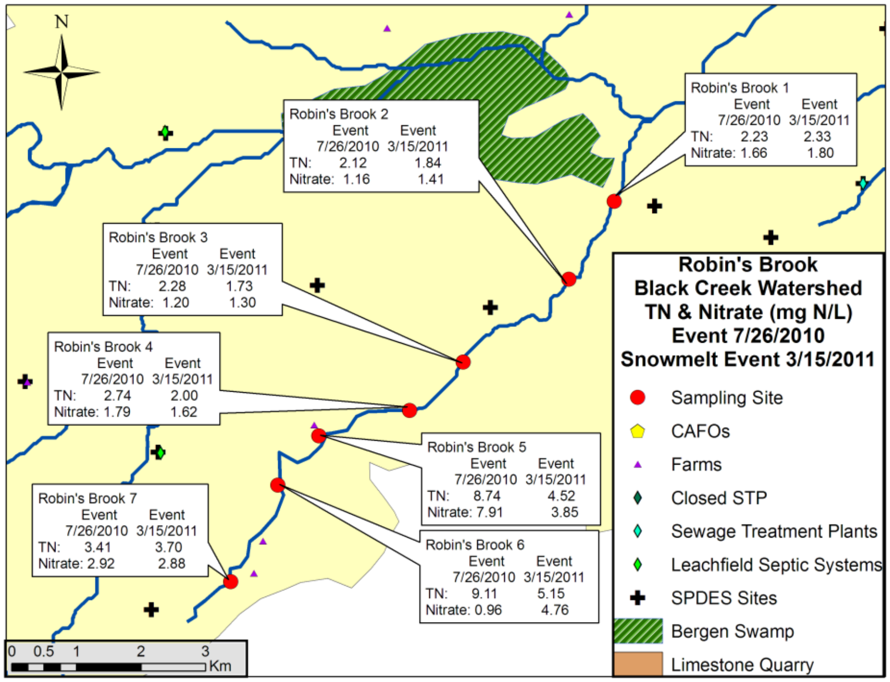


Figure 47. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from the Robin's Brook (RB) subwatershed of the Black Creek watershed on 26 July 2010 and 15 March 2011.

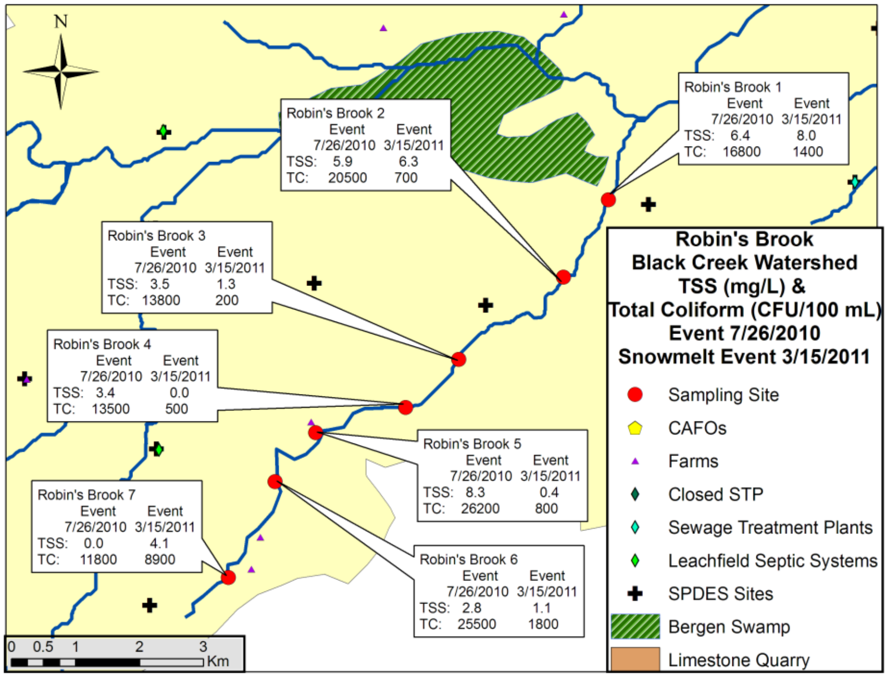


Figure 48. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/100 mL) from the Robin's Brook subwatershed of the Black Creek watershed on 26 July 2010 and 15 March 2011.

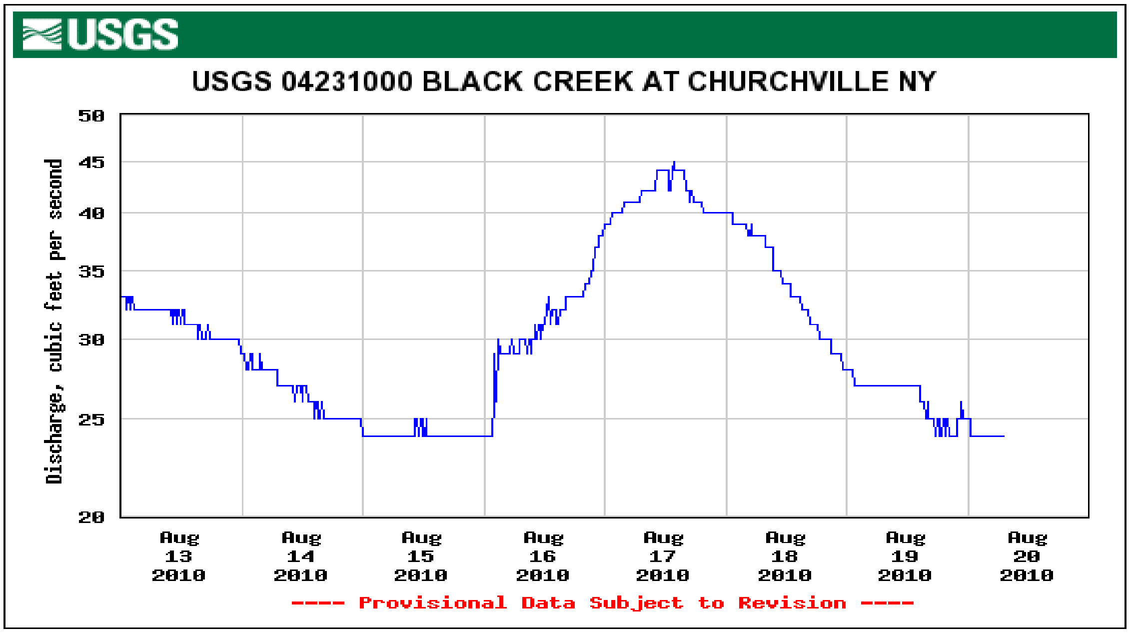


Figure 49. Hydrograph from the USGS site located at Middle Black Creek in Churchville, NY.

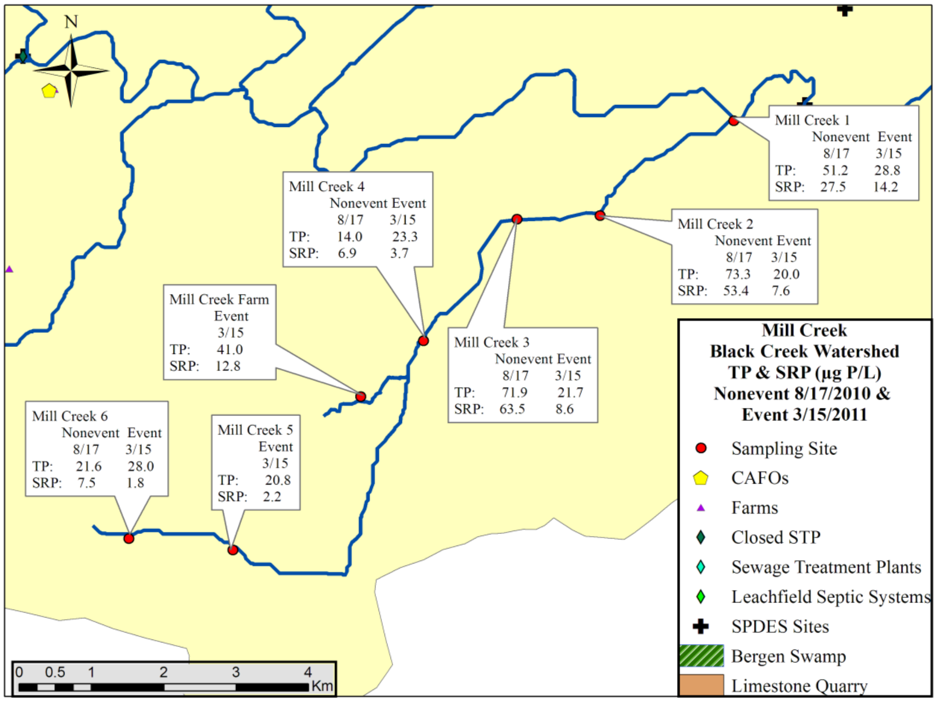


Figure 50. Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) from the Mill Creek subwatershed of the Black Creek watershed on 17 August 2010 and 15 March 2011.

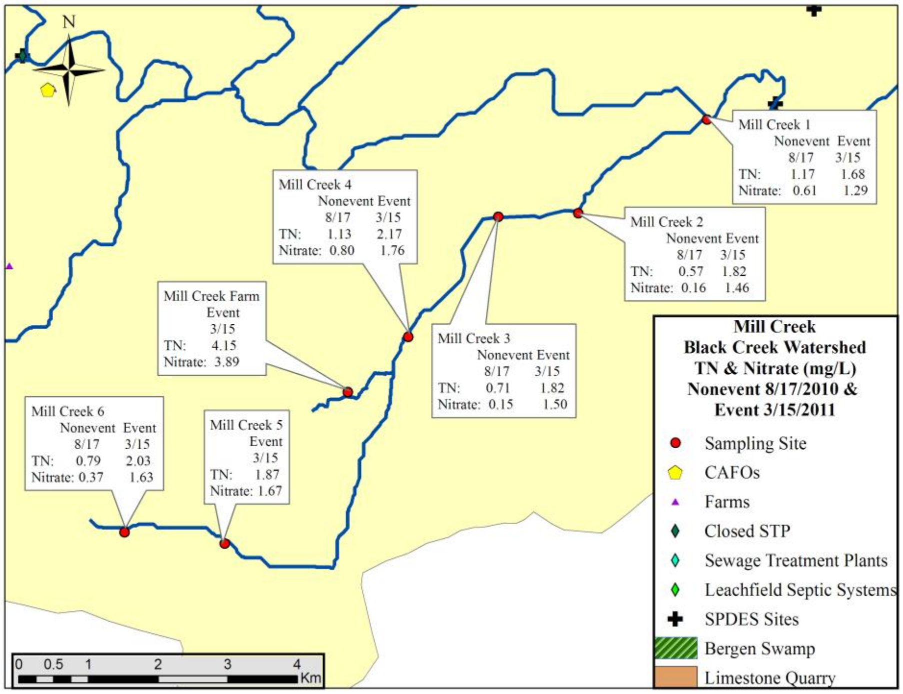


Figure 51. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from the Mill Creek subwatershed of the Black Creek watershed on 17 August 2010 and 15 March 2011.

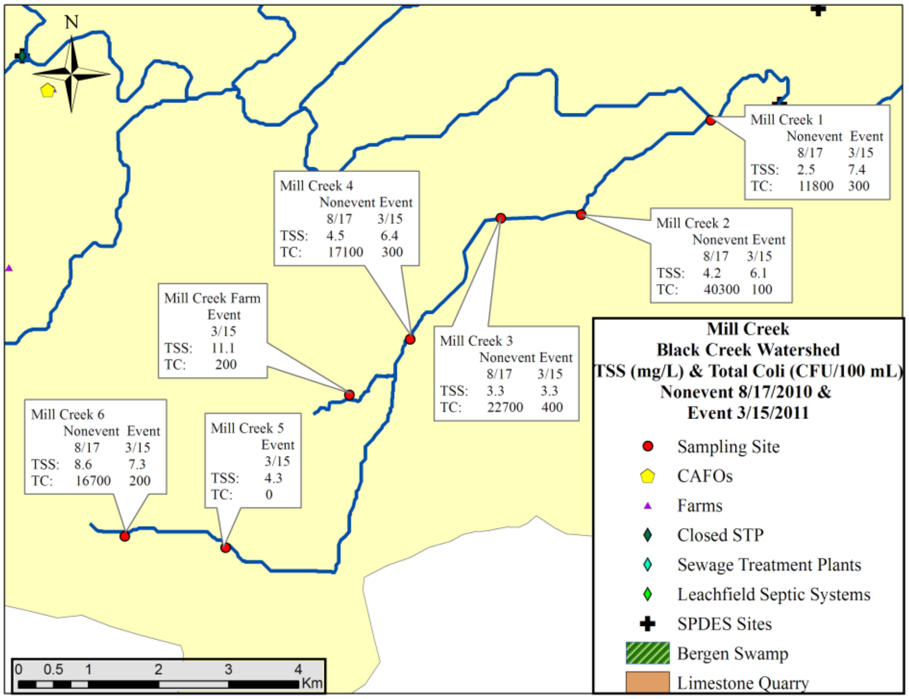


Figure 52. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/ 100mL) from the Mill Creek subwatershed of the Black Creek watershed on 17 August 2010 and 15 March 2011.

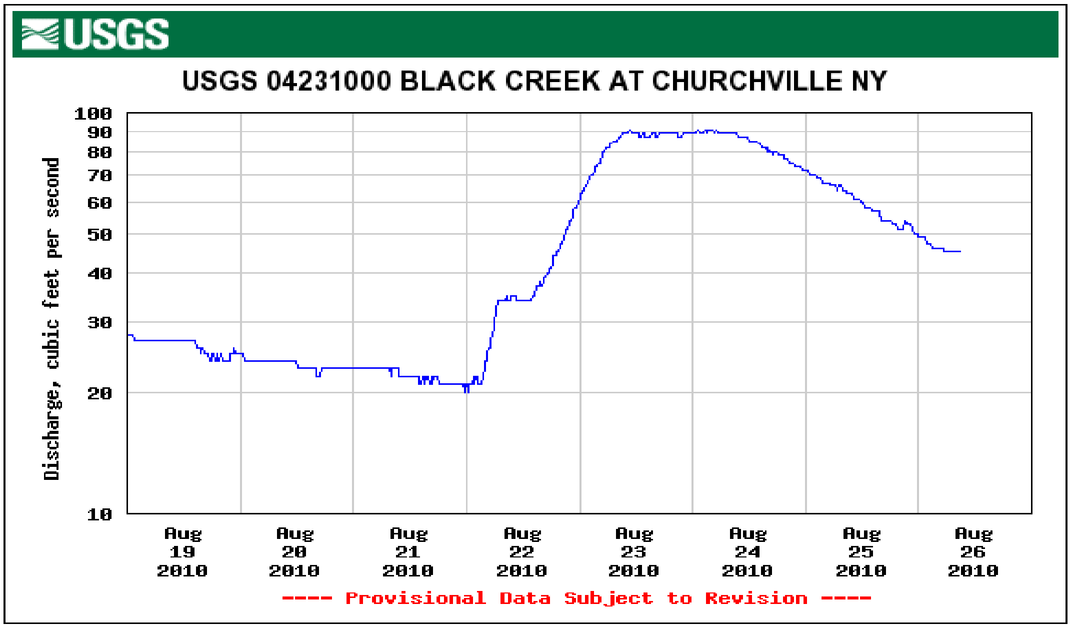


Figure 53. Hydrograph for the USGS site located at Middle Black Creek at Churchville, NY showing discharge for the week of August 19th to August 26th. Sampling occurred on 23 August 2010, which had elevated discharge.

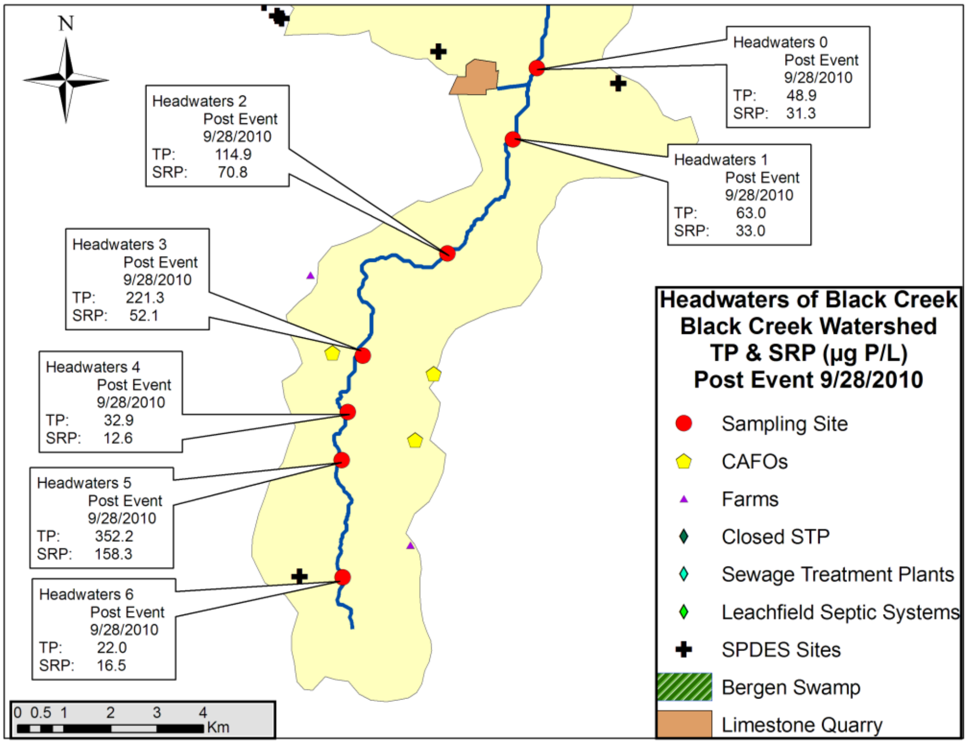


Figure 54. Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) from the Headwaters of Black Creek in the Black Creek watershed on 28 September 2010.

Figure 55. Photograph of headwaters of Black Creek site 3 (HW 3) facing upstream. The covered hay silage is shown on the left.

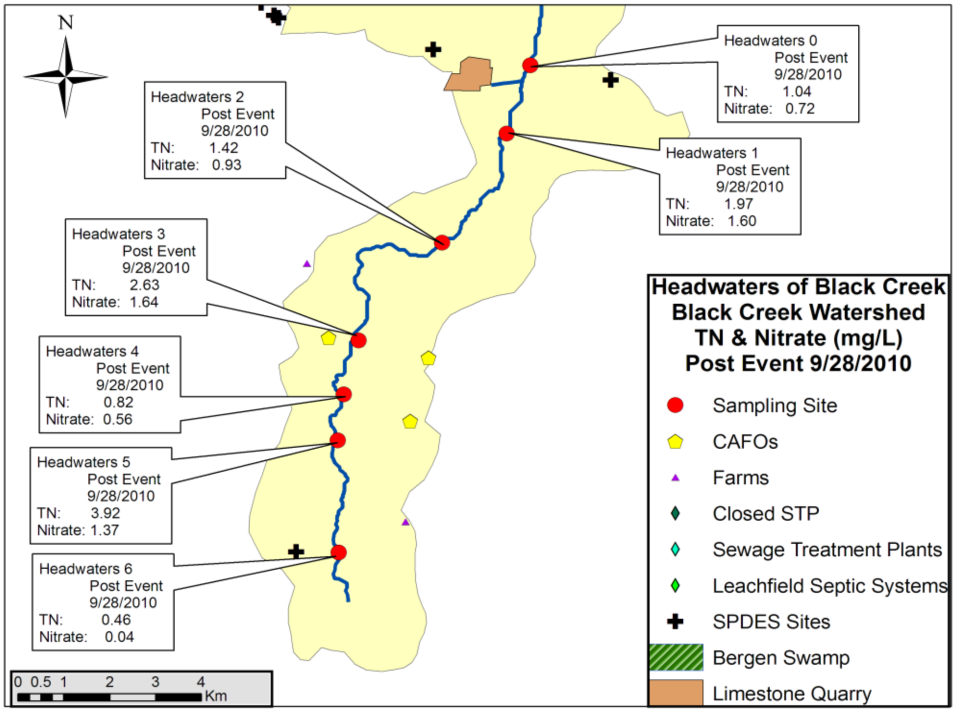


Figure 56. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from the Headwaters of Black Creek in the Black Creek watershed on 28 September 2010.

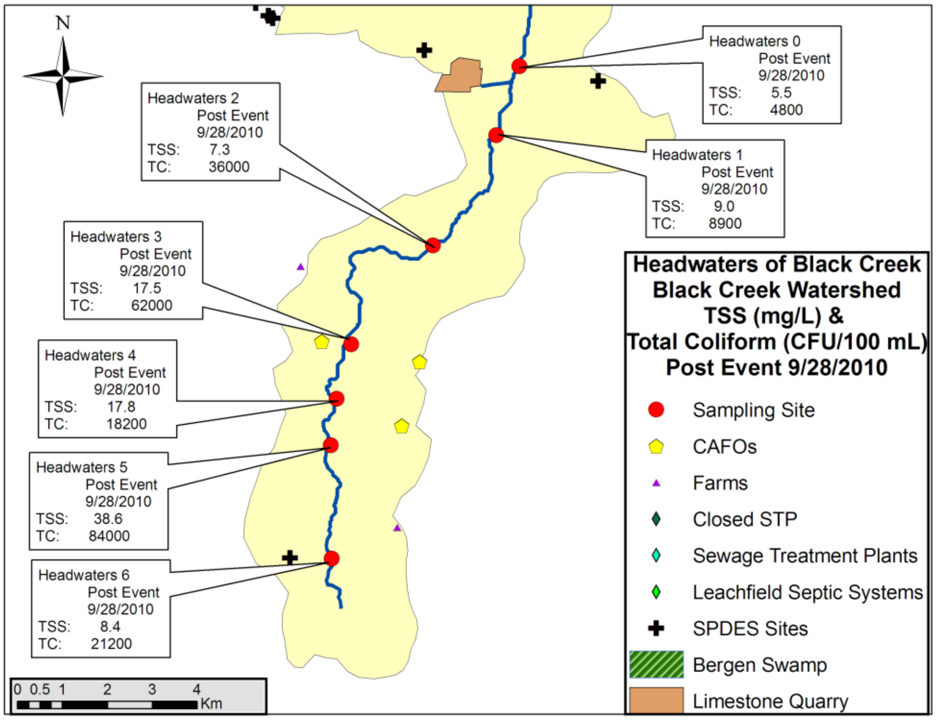


Figure 57. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/100 mL) from the Headwaters of Black Creek in the Black Creek watershed on 28 September 2010.

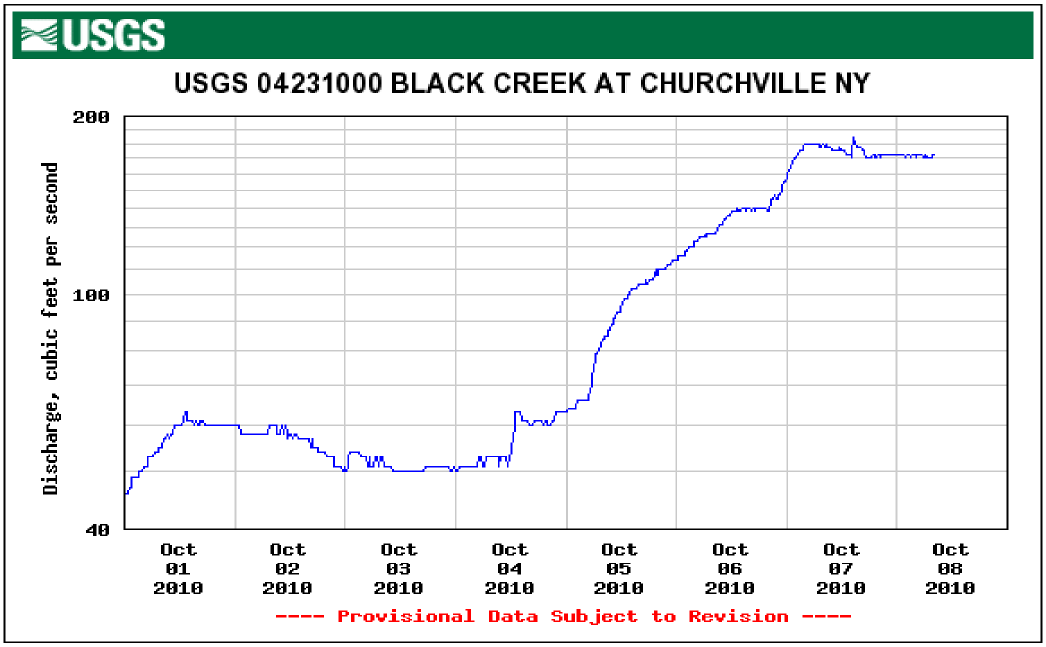


Figure 58. Hydrograph for the USGS site located at Middle Black Creek at Churchville, NY showing discharge for the week of 1 October 2010 to 8 October 2010. Sampling occurred on 5 October 2010, which had elevated discharge.

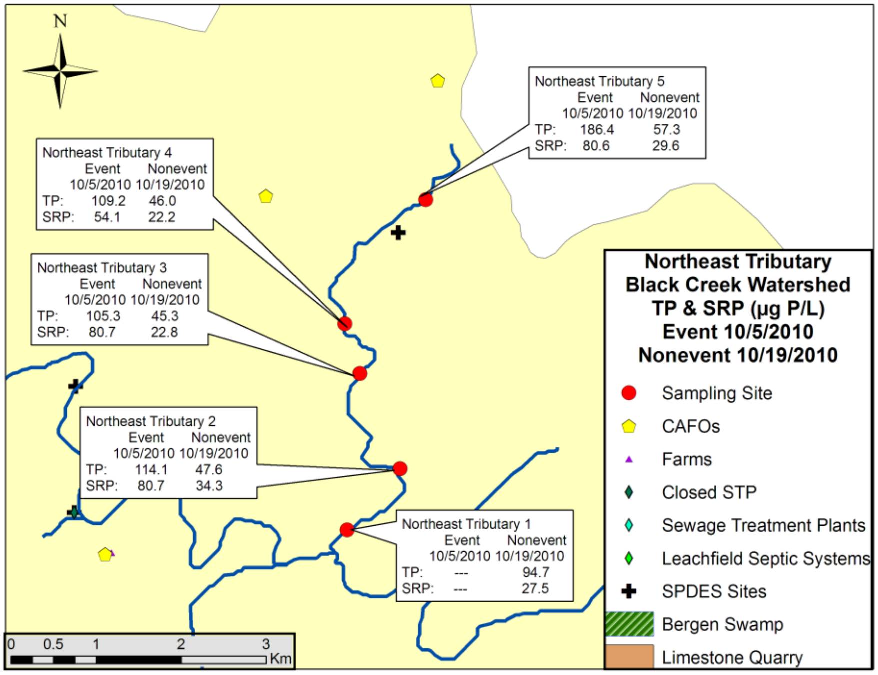


Figure 59. Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) from the Northeast Tributary (NET) subwatershed of the Black Creek watershed on 5 October 2010 and 19 October 2010.

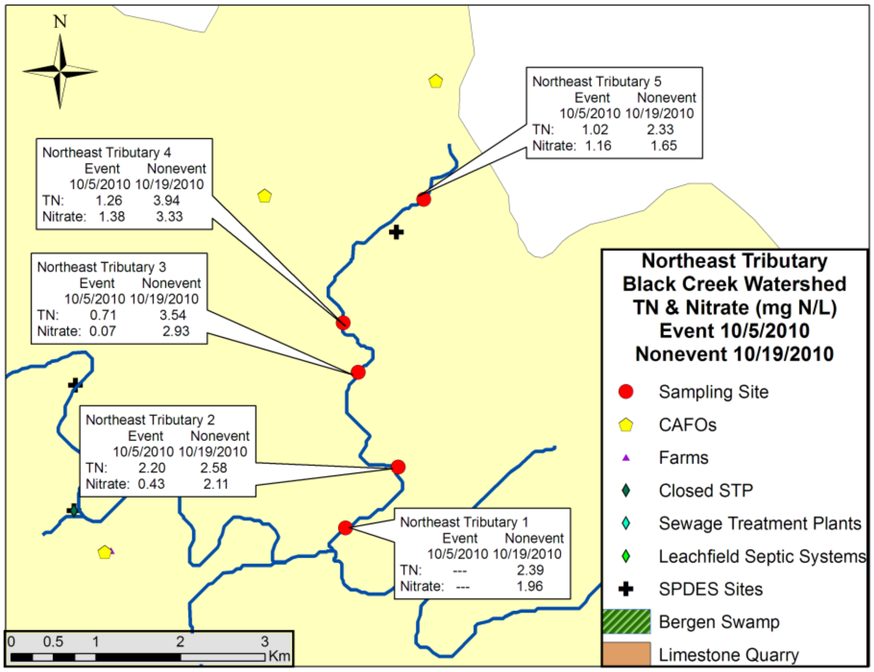


Figure 60. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from the Northeast Tributary (NET) subwatershed on 5 October 2010 and 19 October 2010.

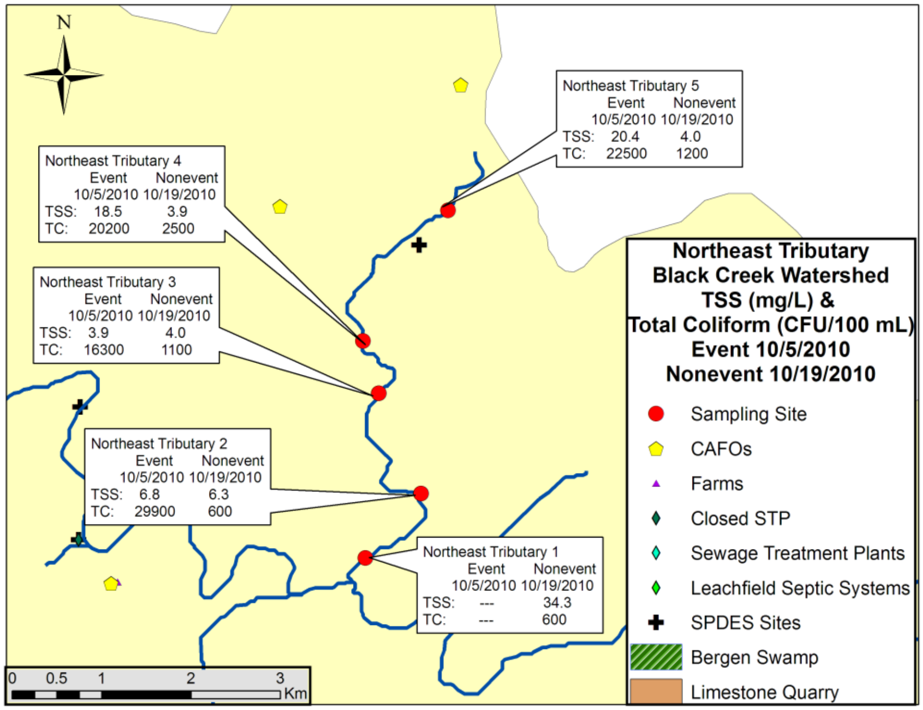


Figure 61. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/100 mL) from the Northeast Tributary (NET) subwatershed on 5 October 2010 and 19 October 2010.

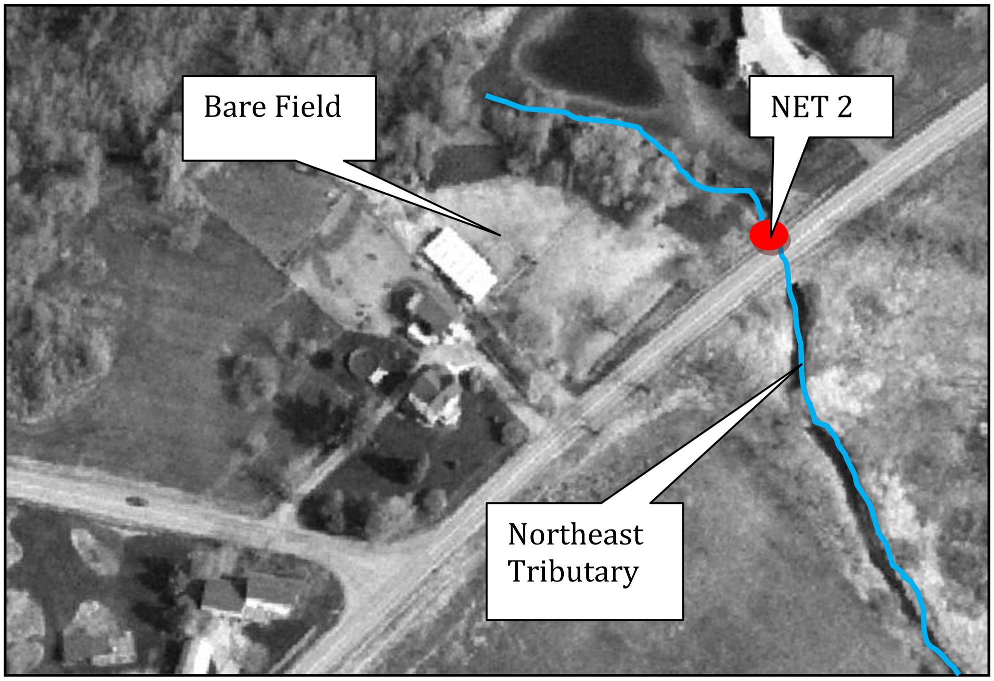


Figure 62. Orthoimage of the bare field below Northeast Tributary Site 2 (NET 2) (Fig. 60).

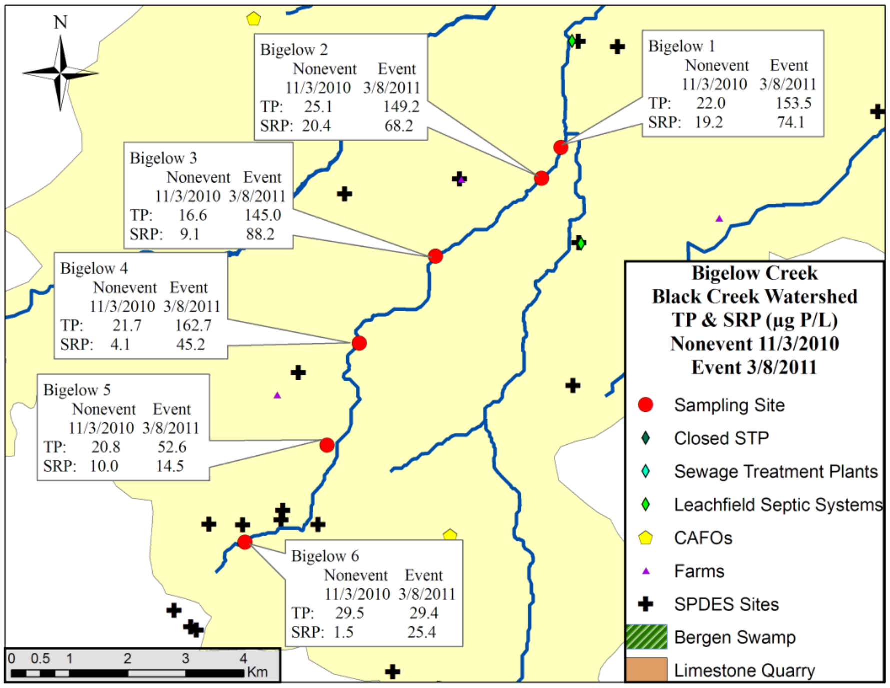


Figure 63. Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) from the Bigelow Creek subwatershed of the Black Creek watershed on 3 November 2010 and 8 March 2011.

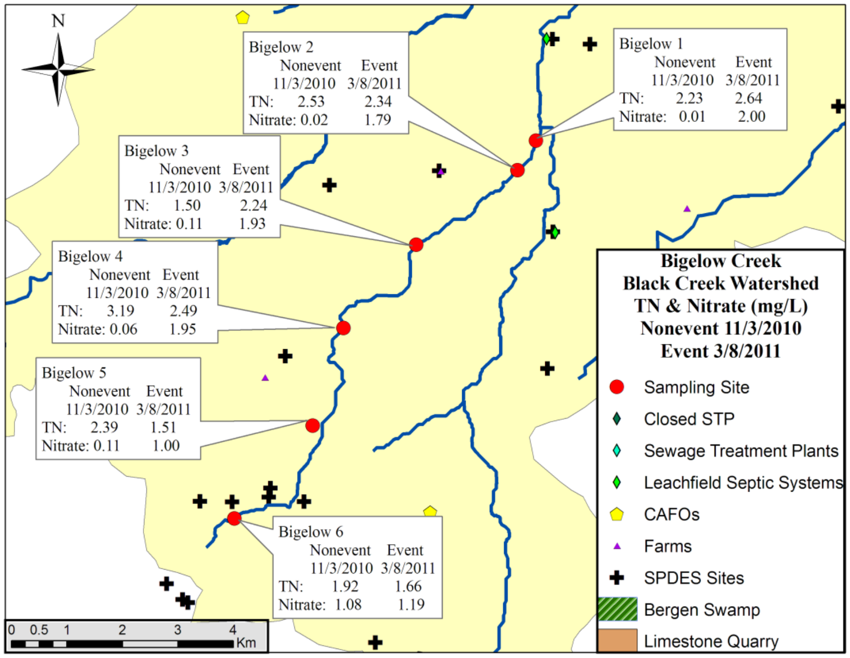


Figure 64. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from the Bigelow Creek subwatershed of the Black Creek watershed on 3 November 2010 and 8 March 2011.

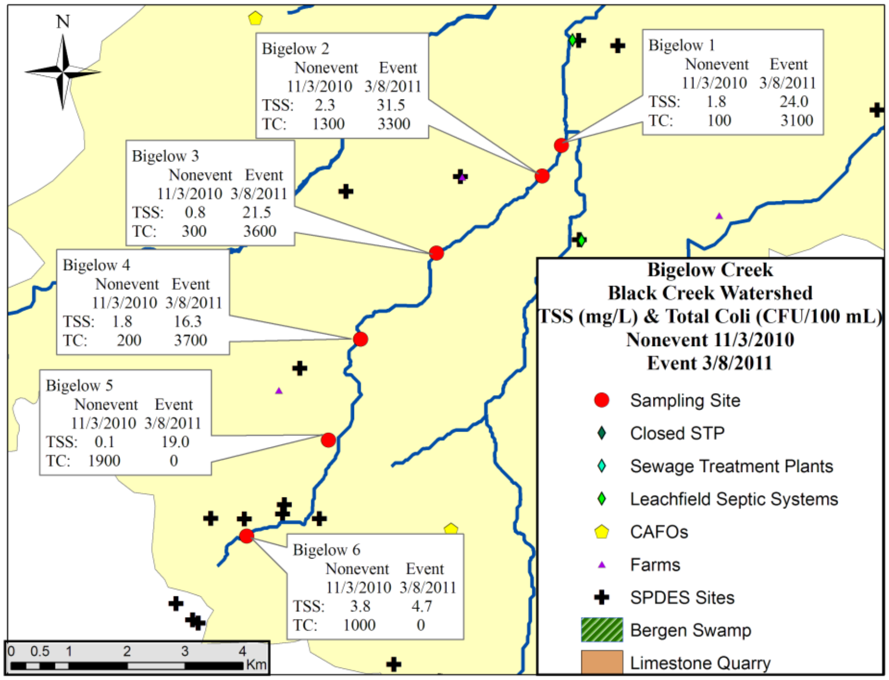


Figure 65. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/100 mL) from the Bigelow Creek subwatershed of the Black Creek watershed on 3 November 2010 and 8 March 2011.

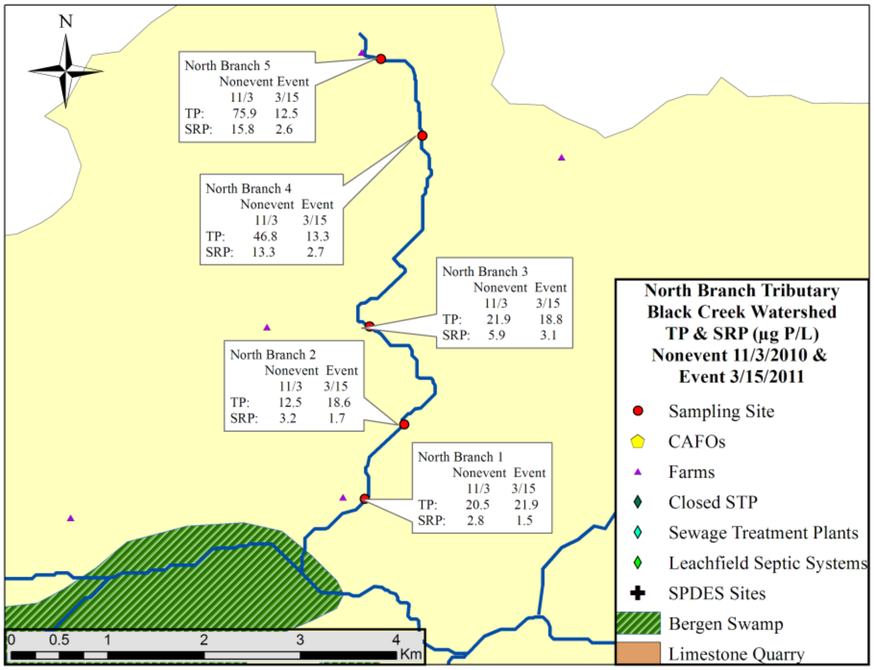


Figure 66. Concentrations of total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) from the North Branch Tributary (NB) subwatershed of the Black Creek watershed on 3 November 2010 and 15 March 2011.

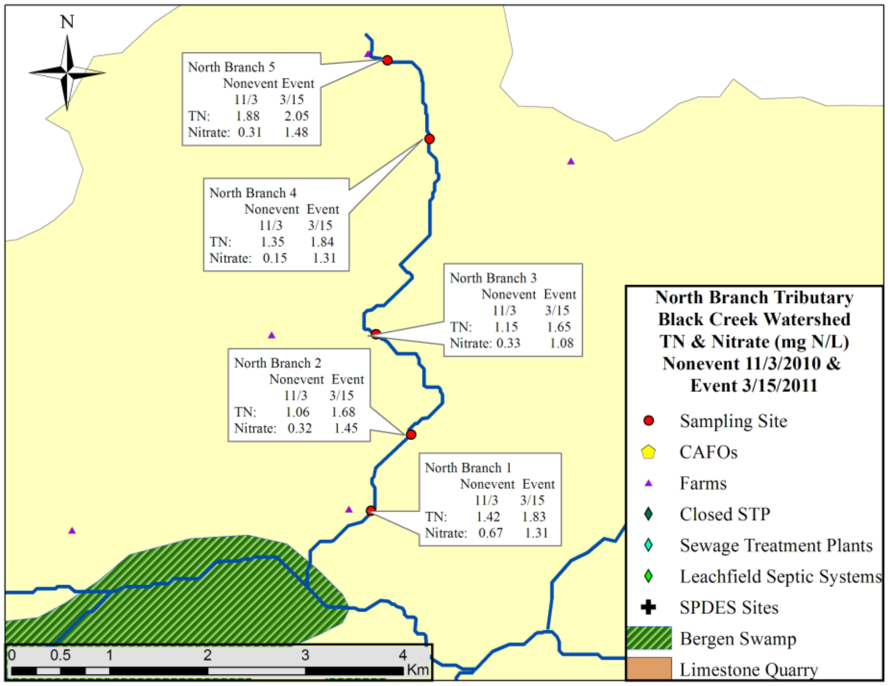


Figure 67. Concentrations of total nitrogen (TN) (mg N/L) and nitrate (mg N/L) from the North Branch Tributary (NB) subwatershed of the Black Creek watershed on 3 November 2010 and 15 March 2011.

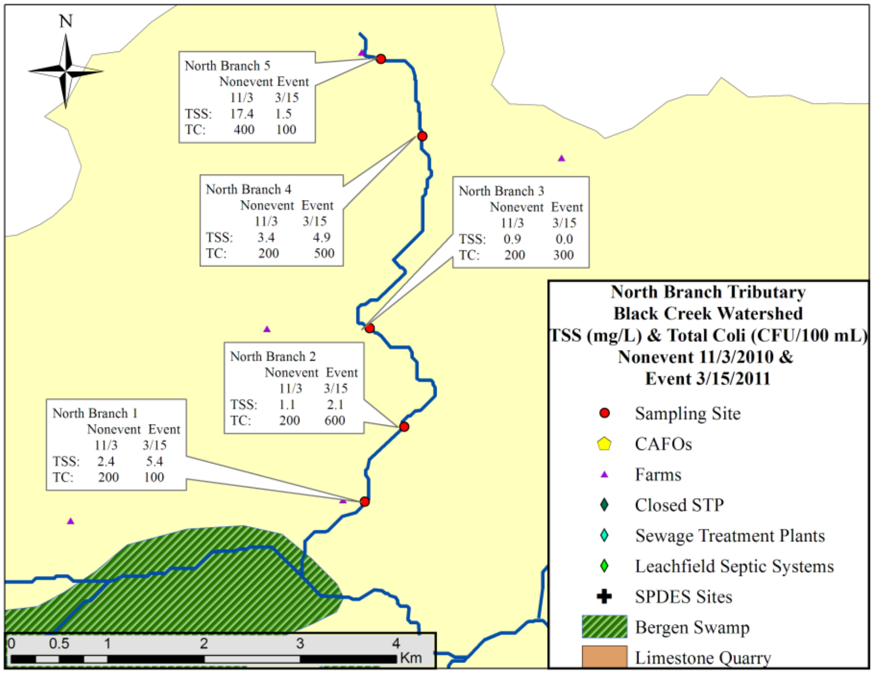


Figure 68. Concentration of total suspended solids (TSS) (mg/L) and abundance of total coliform bacteria (TC) (CFU/100 mL) from the North Branch Tributary (NB) subwatershed of the Black Creek watershed on 3 November 2010 and 15 March 2011.

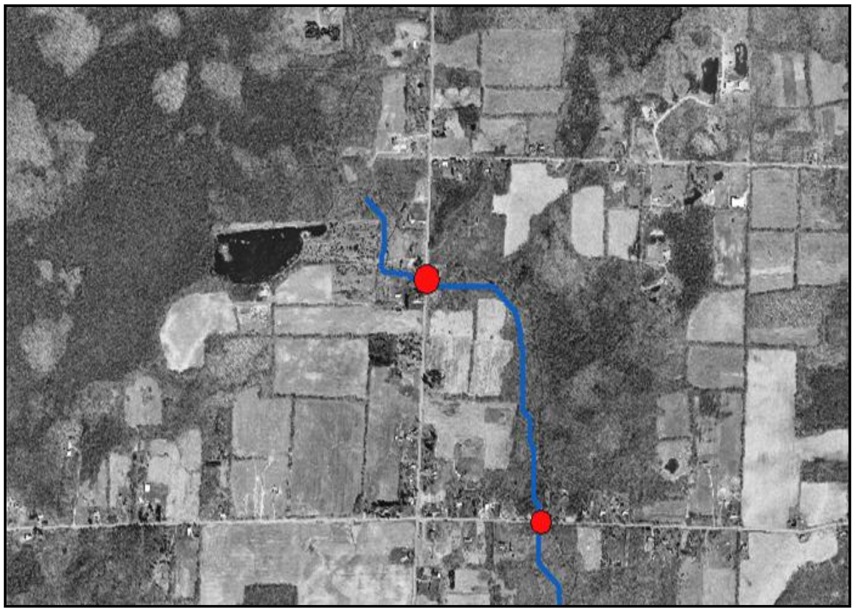


Figure 69. Orthoimage of the headwaters of North Branch Tributary. The stream reach and sampling sites of North Branch 5 and 4 (Fig. 47) depicted. The pond above North Branch 5 and the Windy Hills Tree Farm are the suspected sources of high concentrations of nutrients.

Figure 70. Photograph of pipes leading to the pump station at the southeast corner of the Hanson-Stafford Limestone Quarry (Fig. 3).

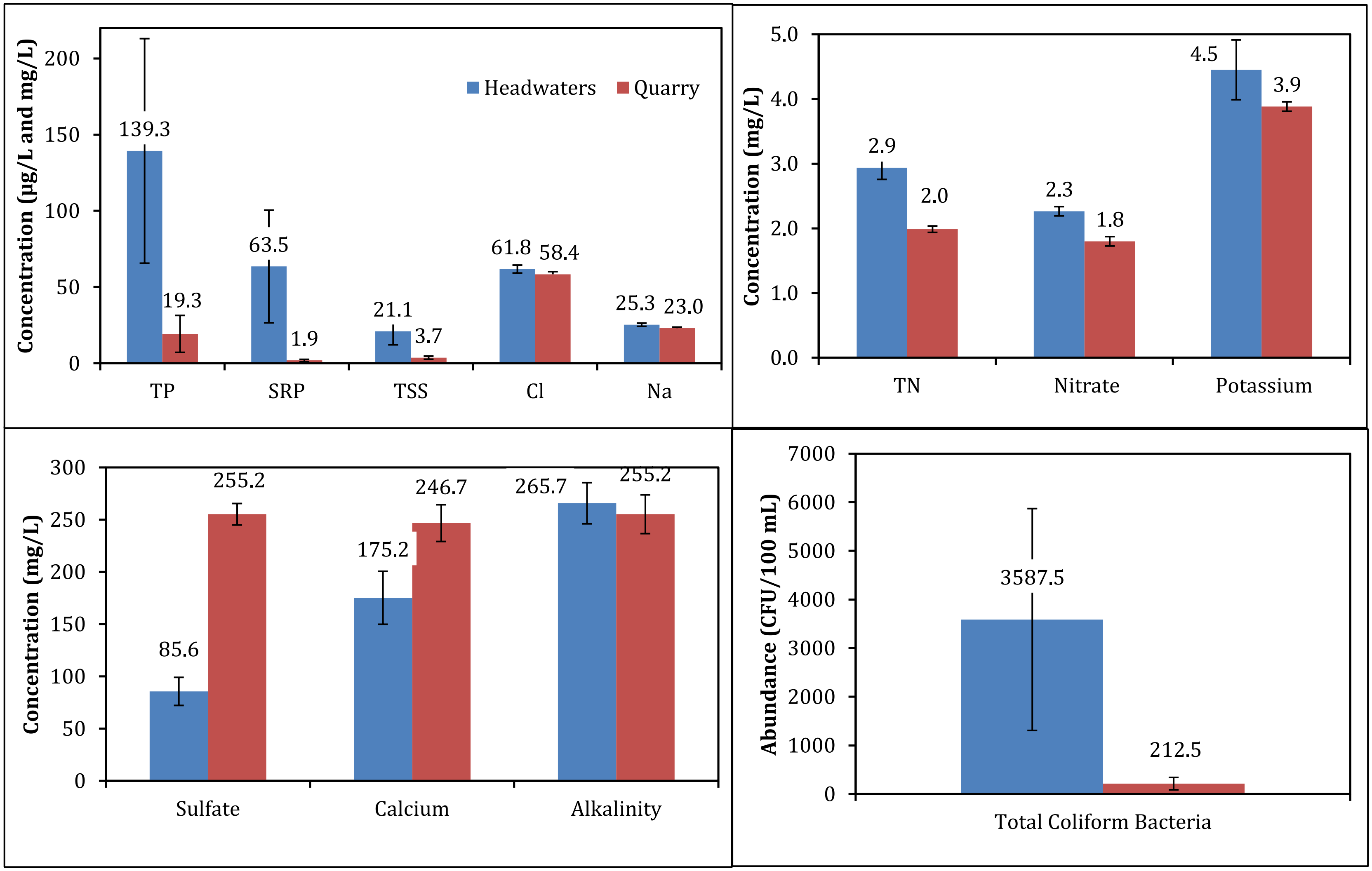


Figure 71. Observed average concentration (mean ± SE) of total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), chloride, sodium, total nitrogen (TN), nitrate, potassium, sulfate, calcium, and alkalinity, and total coliform bacteria abundance for data collected from the headwaters of Black Creek and a ditch draining effluent from the Hanson-Stafford Limestone Quarry.

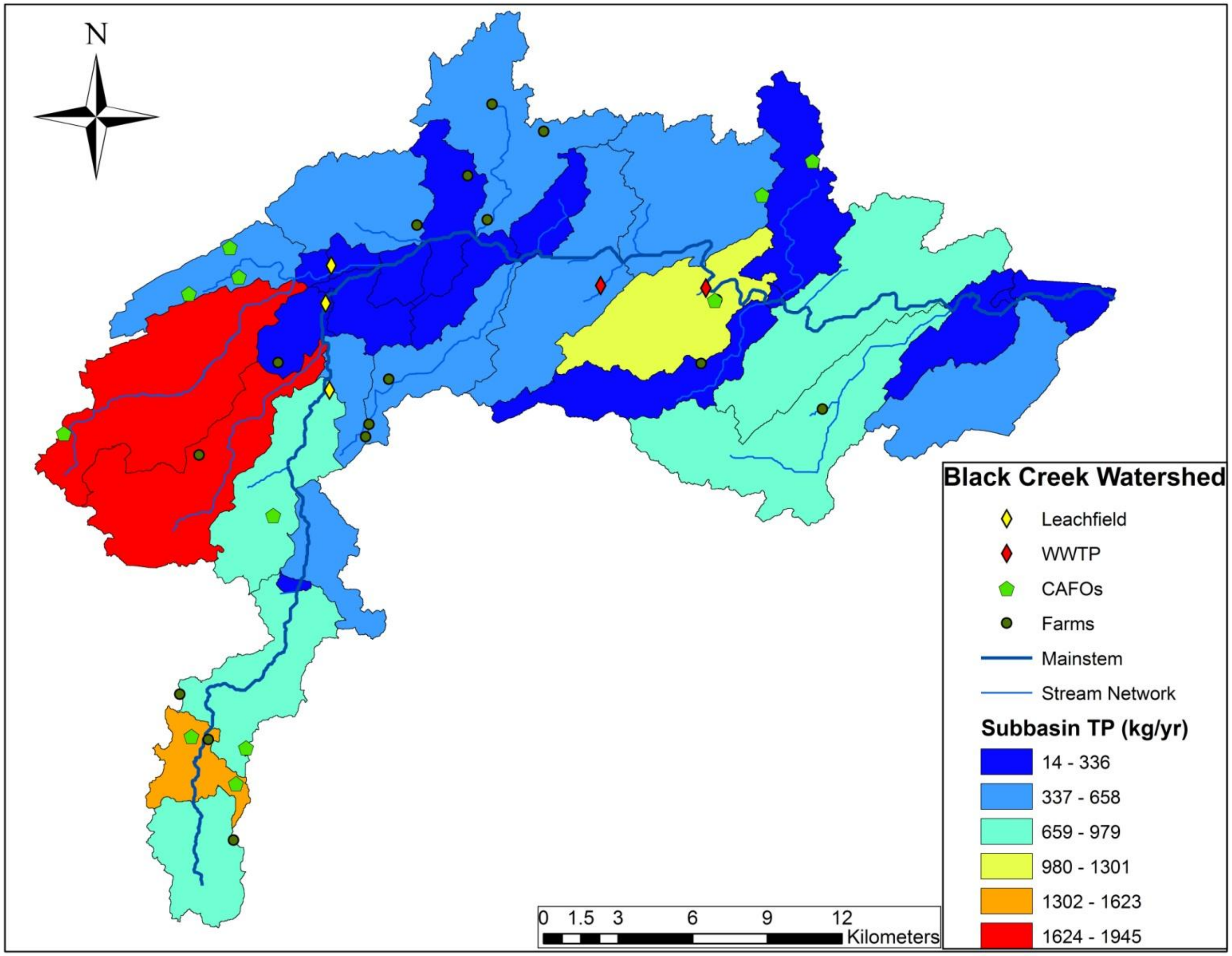


Figure 72. Map of annual total phosphorus (TP) loads from subbasins in the Black Creek watershed obtained from the Black Creek SWAT model. Subbasins with the lowest individual load are blue and those with the highest individual load are red. BC=Black Creek, WWTP=Wastewater Treatment Plant.

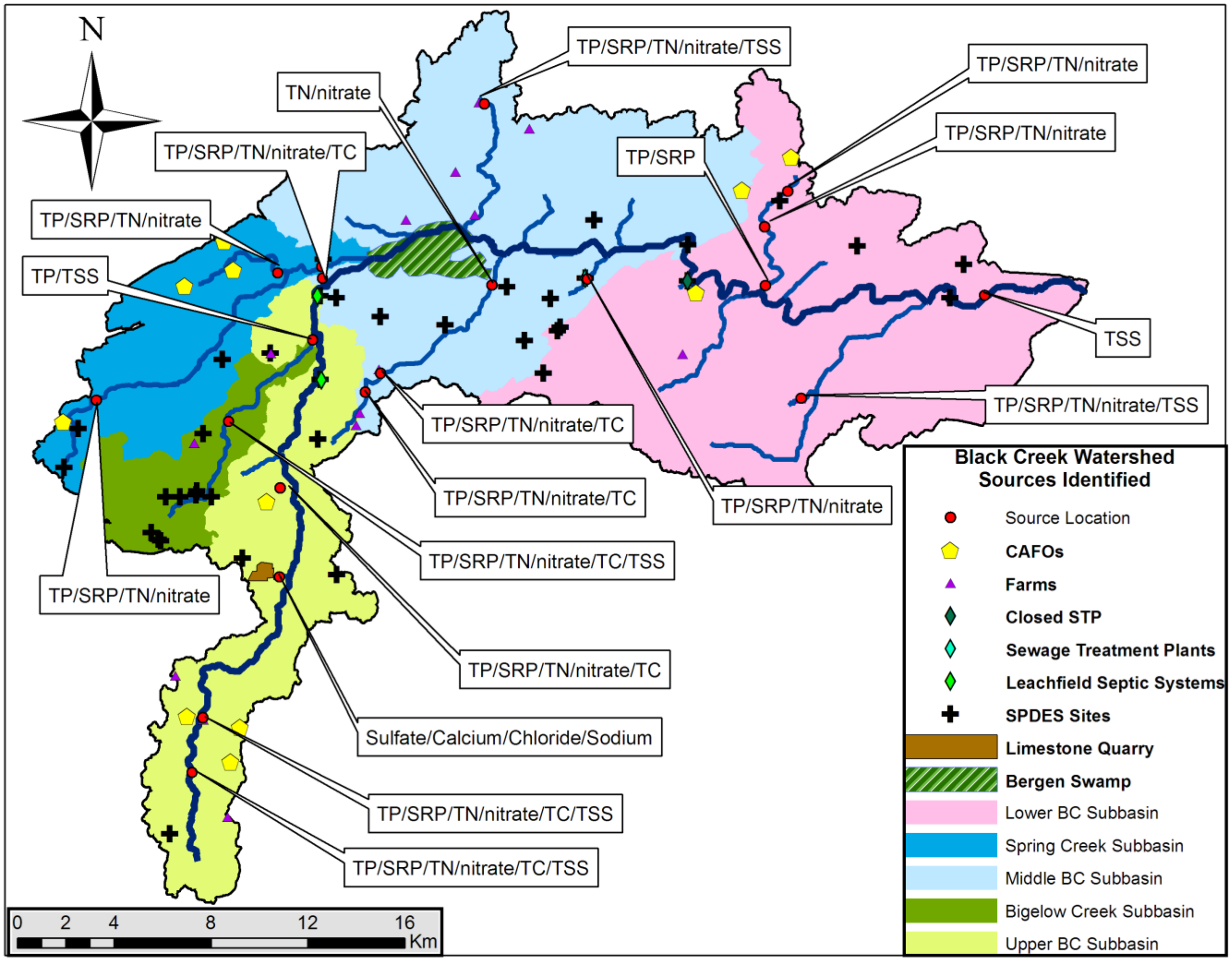
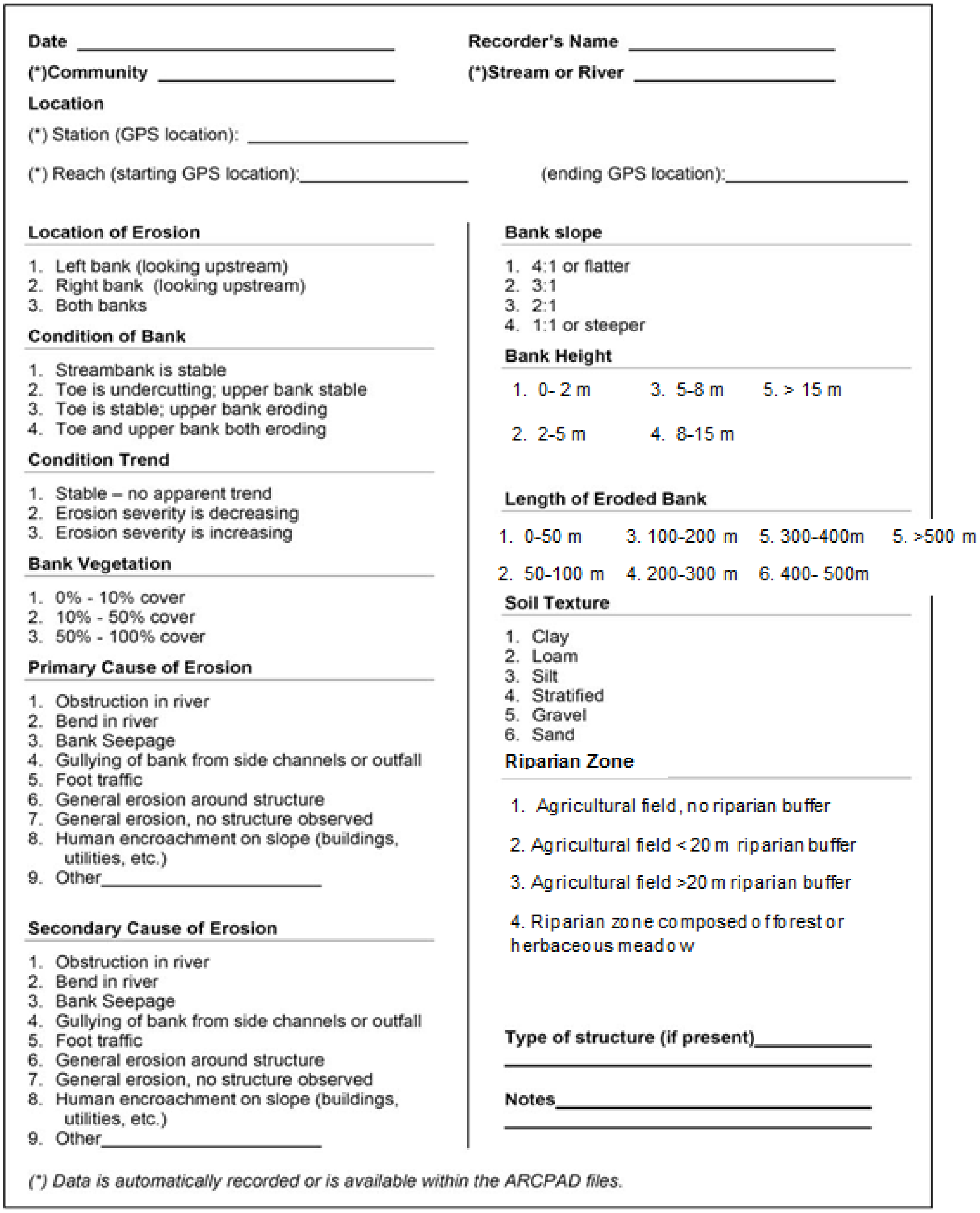


Figure 73. Summary map of all critical source areas within the Black Creek Watershed found using segment analysis. Subbasin boundaries for Lower Black Creek, Middle Black Creek, Upper Black Creek, Spring Creek and Bigelow Creek are shown. BC= Black Creek, TP= Total Phosphorus, SRP= Soluble Reactive Phosphorus, TN= Total Nitrogen, TSS=Total Suspended Solids, and TC=Total Coliform Bacteria.

Appendix A

Datasheet and scoring sheets used to assess sites with excessive stream bank erosion in the Black Creek watershed.



Date ______________________ **Recorder's Name** ______________

(*)Community ________________ **(*)Stream or River** _____________

Location

(*) Station (GPS location): ____________

(*) Reach (starting GPS location):__________ (ending GPS location):___________

Location of Erosion

1. Left bank (looking upstream)
2. Right bank (looking upstream)
3. Both banks

Condition of Bank

1. Streambank is stable
2. Toe is undercutting; upper bank stable
3. Toe is stable; upper bank eroding
4. Toe and upper bank both eroding

Condition Trend

1. Stable – no apparent trend
2. Erosion severity is decreasing
3. Erosion severity is increasing

Bank Vegetation

1. 0% - 10% cover
2. 10% - 50% cover
3. 50% - 100% cover

Primary Cause of Erosion

1. Obstruction in river
2. Bend in river
3. Bank Seepage
4. Gullying of bank from side channels or outfall
5. Foot traffic
6. General erosion around structure
7. General erosion, no structure observed
8. Human encroachment on slope (buildings, utilities, etc.)
9. Other______________

Secondary Cause of Erosion

1. Obstruction in river
2. Bend in river
3. Bank Seepage
4. Gullying of bank from side channels or outfall
5. Foot traffic
6. General erosion around structure
7. General erosion, no structure observed
8. Human encroachment on slope (buildings, utilities, etc.)
9. Other______________

Bank slope

1. 4:1 or flatter
2. 3:1
3. 2:1
4. 1:1 or steeper

Bank Height

1. 0- 2 m 3. 5-8 m 5. > 15 m

2. 2-5 m 4. 8-15 m

Length of Eroded Bank

1. 0-50 m 3. 100-200 m 5. 300-400m 5. >500 m

2. 50-100 m 4. 200-300 m 6. 400- 500m

Soil Texture

1. Clay
2. Loam
3. Silt
4. Stratified
5. Gravel
6. Sand

Riparian Zone

1. Agricultural field, no riparian buffer
2. Agricultural field < 20 m riparian buffer
3. Agricultural field >20 m riparian buffer
4. Riparian zone composed of forest or herbaceous meadow

Type of structure (if present)____________

____

Notes______________________

____

(*) Data is automatically recorded or is available within the ARCPAD files.

Field	Selection	Score
Location of Erosion	Left Bank	1
	Right Bank	1
	Both Banks	4
Condition of Bank	Streambank is stable	0
	Toe is undercutting; upper bank is stable	1
	Toe is stable; upper bank eroding	2
	Toe and upper bank both eroding	3
Condition Trend	Stable - no apparent trend	1
	Erosion severity decreasing	1
	Erosion severity increasing	5
Bank Vegetation	0% - 10% cover	5
	10% - 50% cover	3
	50% - 100% cover	1
Primary Cause of Erosion	Obstruction in river	1
	Bend in river	2
	Bank seepage	1
	Gullying from side channels or outfall	2
	Foot traffic	1
	General erosion around structure	4
	General erosion , no structure observed	3
	Human encroachment (buildings, utilities, etc.)	5
Bank Slope	4:1 or flatter	1
	3:1	2
	2:1	2
	1:1 or steeper	1
Bank Height	0-2 m	1
	2-5 m	3
	5-8 m	5
	8-15 m	7
	>15 m	10
Length of Eroded Bank	0-50 m	1
	50-100 m	2
	100-200 m	4
	200-300 m	6
	300-400 m	8
	400-500 m	10
	>500 m	12
Soil Texture	Clay	1
	Loam	1
	Silt	2
	Stratified	2
	Gravel	3
	Sand	3
Riparian Zone	Agricultural Field, no riparian buffer	15
	Agricultural Field < 20m riparian buffer	7
	Agricultural Field > 20m riparian buffer	4
	Forest or herbaceous meadow	1

Appendix B

Extended table of SWAT calibration parameters by input table. The parameter name, description of parameter, and value entered into the model are given. If a single value was applied to all BCSWAT subbasins only that value is shown. If different parameter values were used for separate subbasins all values are given. A=Subbasin 28, B=Subbasins 22, 25, 27, 29, 31, 32, and 33, C=Subbasins 9, 10, 11, and 24, D=Subbains 8 and all other unlisted subbasins, and E=Subbains 20 and 21.

Black Creek SWAT Calibration Parameters by Input Table						
Soils (.sol)						
Parameter	*Description*	*Value*				
CN2	Curve Number	-25%				
SOL_AWC	Soil Antecedent Water Content	Default				
All Other	Soil Specific Parameters	Default				
Subbasin (.sub)						
Parameter	*Description*	*Value*				
All Parameters	Subbasin Specific Parameters	Default				
HRU (.hru)						
Parameter	*Description*	*Value*				
		A	B	C	D	E
RSDIN	Initial Residue Cover	1150				
ERORGN	Nitrogen Enrichment for Loading with Sediment	0				
ERORGP	Phosphorus Enrichment for Loading with Sediment	0.90	0.30	0.50	0.03	0.30
POT_FR	Fraction of HRU Area that Drains Into Pothole	0				
FLD_FR	Fraction of HRU Area that Drains into Floodplain	0.3				
EVPOT	Pothole Evaporation Coefficient	0.5				
DIS_Stream (m)	Average Distance to the Stream	Default				
All Other	HRU Specific Parameters	Default				
Groundwater (.gw)						
Parameter	*Description*	*Value*				
SHALLST	Initial Depth of Water in the Shallow Aquifer	0.5				
DEEPST	Initial Depth of Water in the Deep Aquifer	1000				
GW_Delay	Groundwater Delay Time (days)	38				
ALPHA_BF	Baseflow Alpha Factor (days)	0.11				
GWQMIN	Threshold Depth in Shallow Aquifer for Return Flow	1				
GW_REVAP	Groundwater 'revap' Coefficient	0.02				
REVAPMN	Threshold Depth in Shallow Aquifer for Percolation	1				

RCHRG_DP	Deep Aquifer Percolation Fraction	0.02				
GWHT	Initial Groundwater Height	1				
GW_SPYLD	Specific Yield of Shallow Aquifer	0.003				
SHALLST_N	Initial Concentration of Nitrate in Shallow Aquifer	0				
GWSOLP	Soluble Phosphorus in Groundwater	0.012				
HLIFE_NGW	Halflife of Nitrogen in Water	0				
LAT_ORGN	Organic Nitrogen in Lateral Flow	0				
GWLATP	Organic P in Baseflow	0.4				
Routing (.rte)						
		Value				
Parameter	*Description*	A	B	C	D	E
CH_N2	Mannings 'n' Value for the Channel	0.210	0.220	0.093	0.094	0.075
CH_K2	Effective Hydraulic Conductivity in Channel	20	18	10	15	10
CH_COV1	Channel Erodibility Factor	0.05	0.1	0.2	0.55	0.3
CH_COV2	Channel Cover Factor	0.1	0.2	0.23	0.55	0.3
ALPHA_BNK	Baseflow Alpha Factor for Bank Storage	0.15	0.15	0.1	0.12	0.1
CH_BNK_BD	Bulk Density of Channel Bank Sediment	1.1	1.1	1.3	1.4	1.3
CH_BED_BD	Bulk Density of Channel Bed Sediment	1.1	1.1	1.3	1.4	1.3
CH_BNK_KD	Erodability of Channel Bank Sediment by Jet Test	1.1	1.1	1.2	1.4	1.2
CH_BED_KD	Erodability of Channel Bed Sediment by Jet Test	1.1	1.1	1.2	1.4	1.2
CH_BNK_D50	D50 Median Particle Size of Bank Sediment	200	200	200	200	200
CH_BED_D50	D50 Median Particle Size of l Bed Sediment	200	200	200	200	200
CH_BNK_TC	Critical Stress Range for Bank Erosion	100	100	100	100	100
CH_BED_TC	Critical Stress Range for Bed Erosion	100	100	100	100	100
CH_EQN	Sediment Routing Method	3	3	3	3	3
All Other	Other Sediment Parameters	Default				
Management (.mgt)						
Parameter	*Description*	*Value*				
		A	B	C	D	E
BIOMIX	Biological Mixing	0.80	0.55	0.55	0.65	0.55
CN2	Curve Number Factor	63.75	58.50	58.50	58.50	63.75
USLE_P	USLE Eqn. Cropping Practices Factor	0.57	0.55	0.55	0.62	0.55
BIO_MIN	Minimum Plant Biomass for Grazing	0				
FILTERW	Width of Edge-of-field Filter Strip	0				
All Other	Management Specific Parameters	Default				
Soil Chemical (chm.)						
Parameter	*Description*	*Value*				
SOL_NO3	Nitrate in Soil Layer	0				

SOL_ORGN	Organic Nitrogen in Soil Layer	0				
SOL_LABP	Labile Phosphorus in Soil Layer	0				
SOL_ORGP	Organic Phosphorus in Soil Layer	0				
PPERCO_SUB	Phosphorus Percolation Coefficient in Soil Layer	12				
Pond/Wetland (pnd.)						
Parameter	*Description*	*Value*				
All	Pond/Wetland Specific Parameters	Default				
Stream Water Quality (swq.)						
Parameter	*Description*	*Value*				
		A	B	C	D	E
RS1	Local Algal Settling Rate	1				
RS2	Benthic Sediment Source Rate for Dissolved P	0.08	0.05	0.05	0.05	0.05
RS3	Benthic Source Rate for NH4-N	0.5				
RS4	Rate Coefficient for Organic N Settling	0.05				
RS5	Organic P Settling Rate in the Reach	0.05				
RS6	Rate Coefficient Settling of Non-conservative	2.5				
RS7	Benthic Source Rate for Non-conservative	2.5				
RK1	Carbonaceous BOD Deoxygenation Rate	1.71				
RK2	Oxygen Reaeration with Fiction Diffusion	50				
RK3	Rate of Loss of Carbonaceous BOD Due to Settling	0.36				
RK4	Benthic Oxygen Demand Rate	2				
RK5	Coliform Die-off Rate	2				
RK6	Decay Rate for Arbitrary Non-conservative	1.71				
BC1	Rate Constant for Biological Oxidation of NH4 to NO2	0.55				
BC2	Rate Constant Biological Oxidation of NO2 to	1.1				
BC3	Rate Constant Hydrolysis of Org. N to NH4	0.21				
BC4	Rate Constant Mineralization of Org. to Dissolved P	0.28				
Basin (.bsn)						
Parameter	*Description*	*Value*				
SF/SMTMP	Snow Fall Temperature	-5/-5				
SMFMX	Snow Melt Factor Rate Maximum	5.7				
SMFMN	Snow Melt Factor Rate Minimum	2.0				
TIMP	Snow Pack Temperature Lag Factor	1.0				
SNOCOVMX	Min. Snow Water Content 100% Snow Cover	470				
SNO50COV	Fraction of Snow Volume to 50% Snow Cover	0.1				
PET	Potential Evapotranspiration Method	Hargreaves				
ESCO	Soil Evaporation Compensation Factor	0.3				
EPCO	Plant Evaporation Compensation Factor	0.8				

EVLAI	Leaf Area Index at Which No Evaporation Occurs	3
FFCB	Initial Soil Water Field Capacity Water Content	0
DEPIMP_BSN	Depth to Impervious Layer	0
CNCOEFF	Plant ET Curve Number Coefficient	1
CN_Froz	Curve Number Adjusted for Frozen Soil	Active
Crack Flow	Curve Number for Frozen Soils	Inactive
SURLAG	Surface Runoff Lag Factor	3.65
ADJ_PKR	Peak Rate Adjustment for Sediment in Trib. Channel	0.5
TB_ADJ	Adjustment Variable for Hydrograph Basetime	0.5
PRF	Peak Rate Adjustment for Sediment in the Main Channel	0.0001
SPCON	Maximum Amount of Sediment to be Reentrained	0.0002
SPEXP	Exponent for Calculating Sediment Reentrained	1
MSK_COV1	Storage Time Constant for Base Flow	0
MSK_CO2	Storage Time Constant for Low Flow	3.5
MSK_X	Inflow and Outflow for Reach Storage	0.2
Channel Deg.	Degradation of the Main Channel Sediment	Inactive
TRNSRCH	Transmission Losses from Channel to Deep Aquifer	0
EVRCH	Reach Evaporation Adjustment Factor	1
EROS_SPL	The splash erosion coefficient.	1.3
RILL_MULT	Multiplier for soil susceptible to rill erosion	1
EROS_EXPO	Exponent for the overland flow erosion equation	1.6
SUBDCHSED	Sub-Daily Channel Sediment Erosion Factor	0
C_FACTOR	Universal Soil Loss Equation (USLE) Cover (C)	0.03
CH_D50	Median particle diameter of channel bed (mm)	72
RCN	Concentration of Nitrogen in Rainfall	1
CMN	Rate for Humus Mineralization of Organic Nutrients	0.0003
CDN	Denitrification Exponential Rate Coefficient	0
SDNCO	Denitrification Threshold Water Content	0
N_UPDIS	Nitrogen Uptake Distribution Parameter	20
P_UPDIS	Phosphorus Uptake Distribution Parameter	10
NPERCO	Nitrogen Percolation Coefficient	0.2
PPERCO	Phosphorus Percolation Coefficient	13
PHOS_KD	Phosphorus Soil Partitioning Coefficient	178
PSP	Phosphorus Availability Index	0.6
RSDCO	Residue Decomposition Coefficient	0.035
PERCOP	Pesticide Percolation Coefficient	0.5
CHOPCO_BSN	Channel Organic P Concentration in Basin	85
BC4_BSN	Rate Constant for Hydrolysis of Organic N to NH4	0.2

Watershed Water Quality Parameters (.wwq)		
AI0	Ratio of Chl-a to Algal Biomass	50
AI1	Fraction of Algal Biomass that is Nitrogen	0.08
AI2	Fraction of Algal Biomass that is Phosphorus	0.015
AI3	Rate of Oxygen Production for Algal Photosynthesis	1.6
AI4	Rate of Oxygen Uptake Per for Algal Respiration	2
AI5	Rate of Oxygen Uptake of NH3-N Oxidation	3.5
AI6	Rate of Oxygen Uptake Per Unit of NO2-N	1.07
MUMAX	Maximum Specific Algal Growth Rate at 20C	2
RHOQ	Algal Respiration Rate at 20C	0.3
TFACT	Fraction of Solar Radiation in Temp. Heat Balance	0.3
K_L	Half-saturation Coefficient for Light	0.75
K_N	Michaelis-Menton Half-saturation Constant for N	0.02
K_P	Michaelis-Menton Half-saturation Constant for P	0.025
LAMBDA0	Non-algal Portion of the Light Extinction Coefficient	1
LAMBDA1	Linear Algal Self-shading Coefficient	0.03
LAMBDA2	Non-linear Algal Self-shading Coefficient	0.054
P_N	Algal Preference Factor for Ammonia	0.5
CHLASUBCO	Regional Adjustment on Sub Chl-a Loading	1