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Watershed Assessment of the Canaseraga Creek Watershed, Including Water Quality Analysis, SWAT Model, and Investigation of the Applicability of a Nutrient Biotic Index

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Watershed assessment of the Canaseraga Creek watershed, including water quality analysis, SWAT model, and investigation of the applicability of a nutrient biotic index

by
Evan Rea

A Thesis Presented to the Faculty of the Department of Environmental Science and Biology of the State University of New York College at Brockport In Partial Fulfillment for the Degree of Master of Science

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Abstract

Nearshore areas of Lake Ontario are suffering from persistent water quality impairments that were generally not resolved through programs such as the phosphorus abatement program and the Great Lakes water quality agreement. A major nearshore area of concern is the Rochester Embayment, which receives the discharge of the Genesee River. Due to the predominance of agriculture in the Genesee River basin and its largest tributary, Canaseraga Creek, agricultural areas were investigated using the segment analysis sampling technique and Soil and Water Assessment Tool (SWAT) modeling. Individual nonpoint areas were identified as nutrient sources as well as seven wastewater treatment plants. In general, loadings increased moving downstream as more source areas such as concentrated animal feeding operations, wastewater treatment plants, and small agricultural operations contributed to the nutrient load. Two tributaries, Twomile and Buck Run creeks, generally had the highest average annual concentrations and areal loadings of nutrients due to concentrated animal feeding operations (CAFOs) and dominance of agriculture in those areas. Observed loading data was used to calibrate a SWAT model for Canaseraga Creek. The most effective agricultural management practice was grassed waterways, while upgrading wastewater treatment plants to better (tertiary) treatment was also effective. By targeting just the areas that contribute the most P (Buck Run Creek, Twomile Creek, Groveland Flats) with grassed waterways, upgrading WWTPs, and stabilizing erodible main-stem streambanks, total phosphorus (TP) concentration was reduced by 31.4% from 104.3 µg P/L to 71.6 µg P/L. Of the three considered potential TP water quality targets (20, 45, 65 µg P/L), the 65 µg P/L target was attainable, while the 45 µg P/L standard was not achieved but is believed to be possible with more intensive management practices. A nutrient biotic index (NBI) using TP and nitrate concentrations with observed macroinvertebrate communities was also used to evaluate appropriate water quality criteria. When comparing trophic state from the NBI with an external classification scheme based on chemistry, the NBI-P trophic state designations were observed to agree more often than the NBI-N. Several reasons for the discrepancies were determined, namely the use of nitrate instead of TN for the NBI-N, number of chemistry samples used, period of time which chemistry averages were taken, tolerance values that may not completely represent nutrient ‘optima’, and lack of scores for many taxa.

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Introduction

Nutrient and soil loss are major sources of pollution to rivers, streams, and lakes (Dubrovsky *et al.* 2010, USEPA 2004, NYSDEC 2010). Even with the regulation of most point sources by the Clean Water Act, nutrient pollution continues to be a problem for our nation's waters, causing the focus of research and remediation to shift to address non-point sources. Underscoring the importance of this issue, the United States Environmental Protection Agency (USEPA) reported that agricultural nonpoint source pollution (NSP) was the leading cause of water quality impairment for lakes and rivers (USEPA 2010a), followed by hydromodification (e.g., channelization and dam modification) and unknown sources (USEPA 2004). Non-point losses of phosphorus and nitrogen are generally highest in agricultural areas associated with fertilizer and manure application (Dubrovsky *et al.* 2010).

Phosphorus and nitrogen are required by plants and as a result are commonly used as fertilizers on fields. When they remain on the field and are incorporated into the soil, these nutrients are used by plants in the intended way. The problem begins when the nutrients are carried from the field into the stream by runoff, which commonly occurs during routine manure spreading. Phosphorus is the limiting nutrient in most freshwater systems. Excessive phosphorus inputs to bodies of water can cause rapid and explosive increases in algae populations (Sharpley *et al.* 2001). These algae blooms are aesthetically unpleasing and therefore detrimental to lakefront property value, may reduce dissolved oxygen concentrations (thereby impacting fish and other aquatic life), and generally cause cultural eutrophication to lakes, as well as potentially causing harm as toxic algae to human and animal health (Codd 2000, Sharpley *et al.* 2001).

Similarly, nitrogen has the potential to cause a serious threat to human health with elevated levels of nitrate or nitrite. Nitrate and nitrite limit the blood's oxygen-carrying capacity and are especially harmful to babies, who may exhibit the telltale 'blue baby' symptom (methemoglobinemia) indicative of nitrate poisoning (Ward *et al.* 2005). As such, it is an issue of great concern with respect to drinking water quality, and national drinking water standards have been set (10 mg/L nitrate, 1 mg/L nitrite) (Dubrovsky *et al*. 2010, USEPA 2010b, USEPA 2010c).

Soil loss is another major concern for watersheds because of its two-fold effect of being washed away from productive farm fields and disrupting stream habitats where it is deposited. Total suspended solids (TSS) is a measure of soil and organic matter that either is too fine to settle out of the water or has not settled out due to fast flow. Total suspended solids can be a visual cue for when runoff is high, as water will appear brown, and in extreme cases it will be opaque. Some of the problems associated with TSS are that they decrease visibility in the water, which affects fish and bird predation, and TSS can suffocate fish and their eggs if present in high enough quantities (Dubrovsky *et al.* 2010, Wang and Wang 2008, Owens *et al.* 2005). One major concern about TSS is that nutrients, especially phosphorus, bind to the suspended particles (Dubrovsky *et al*. 2010, Wang and Wang 2008). Any place that soil is able to be carried away via runoff is a potential source of TSS. Agricultural fields are a large concern, as well as deforestation, mining, construction, or any other activity that removes soil cover (Owens *et al*. 2005).

An additional complication raised by runoff is bacterial contamination, especially fecal coliforms. Fecal coliforms originate in the gut of mammals, exiting via defecation and their presence in a water body is an indicator of fecal contamination. For example, manure usage can elevate levels of fecal coliform bacteria in streams due to runoff, especially during a large rainfall event (Mishra *et al.* 2008).

In the Canaseraga Creek watershed of New York State, there is a large agricultural presence comprising more than one third of its land use. Since agriculture has been associated with water quality impairment across the country (Dubrovsky *et al.* 2010, USEPA 2004), the water quality of the Genesee River's largest sub-basin (86,505 ha) is of concern because agriculture comprises 46.8% of the land use. An assessment of ecological health and identification of non-point sources in Canaseraga Creek watershed is critical to preservation and/or remediation of water quality in this watershed and the Genesee River. With knowledge of where the pollution is coming from, steps can be taken to reduce the export of nutrients and other contaminants into waterways through the use of best management practices (BMPs).

A BMP is a land use practice that acts to correct the impact of land use on water quality, and is accomplished in a myriad of ways. Best management practices can be quite simple, such as leaving portions of a crop on the ground to hold soil down (reduced tillage), leaving vegetation on stream banks to reduce erosion (stream bank buffer zones), and fencing to keep livestock out of waterways. With the application of a Soil and Water Assessment Tool (SWAT) model, BMPs can be evaluated if sources of nutrients are known. Segment analysis evaluates nutrient sources with actual data through a spatially systematic approach (Makarewicz and Lewis 1999). The most important precursor to any remediating action is knowledge of the nature and location of pollution sources; this is the main objective of this study. Pollution source identification will be determined by an integration of segment analysis, by SWAT model use, and by routine water quality sampling in the field.

Genesee River Basin

The Genesee River is 246 km long and has a drainage area of about 647,497 ha (Moran and Roebig 2000, Hetling *et al.* 1978; Fig. 1). At its headwaters in Pennsylvania, the Genesee's topography is characterized by steep slopes for its first 16 km, where it then levels out and is relatively flat until it reaches the village of Portageville, NY (Moran and Roebig 2000). Here, the river becomes surrounded by cliffs as high as 182 m and by three waterfalls in Letchworth State Park that have earned it the name "The Grand Canyon of the East" (Moran and Roebig 2000). The gorge also acts as the boundary between the Genesee's two major sub-basins: the Upper and Lower Genesee basins. The river continues to meander until it reaches the Erie Canal in Rochester, NY. In Rochester, the river drops 70 m to its exit in Lake Ontario (Moran and Roebig 2000).

Detailed land use data is provided by the USDA 2009 Cropland Data Layer (CDL), which includes the National Land Cover Database (NLCD) from 2001

(USDA NASS 2009). Approximately 46.0% of the land use in the basin is forested (combination of NCLD classifications deciduous, evergreen, and mixed forest), followed by agriculture (combination of all crops, 38.8%), and developed land (combination of NCLD classifications open space, and low/medium/high intensity, 8.4%; USDA NASS 2009). The three largest single land uses are deciduous forest (38.7%), hays (15.0%), and corn (11.5%; USDA NASS 2009); other land uses are provided in Table 1.

Even though urban areas are a relatively small percent of the basin's land use, New York’s third largest city, Rochester, resides directly along the Genesee River near its outlet at Lake Ontario. With 208,123 residents in the city and 1,098,201 in the metropolitan area (Visit Rochester 2010), this area contains the highest density of people in the Genesee River basin (Moran and Roebig 2000). With so many people tightly clustered directly on the banks of the river and with all the impervious surfaces that accompany high population density, storm water becomes an issue. In fact, the New York State Department of Environmental Conservation (NYSDEC) has determined that storm water pollution is the second largest contributor to impacted water bodies in NYS (NYSDEC 2010). To address this issue, the Genesee/Finger Lakes Regional Planning Council has been awarded money from the American Recovery and Reinvestment Act to work on green infrastructure to improve the impacts of storm water discharge (GFLRPC 2010).

Further justification for remedial action in the Genesee River basin is based on the 1996 NYSDEC Priority Waterbodies List (PWL). Human development accounted for 70% of the impairment to lakes (Moran and Roebig 2000), while in rivers, the impairment causes were more diverse, with agriculture being the largest source (29%), followed by hydrologic modification (24%) and streambank erosion (19%). Urban runoff accounts for only 8% of river impairment causes. The remaining 20% of impairment sources were comprised of land disposal, construction, septic, municipal, and other sources (Moran and Roebig 2000). Some uses, however, may have disproportionately high effects on water quality; thus, frequency of impairment causes does not necessarily mean largest negative effect. For example, urban runoff (8% of impairment sources) appears as a cause of stressed and impaired rivers and streams (those which sometimes or frequently do not support designated uses) but not of threatened waters (Moran and Roebig 2000). For comparison, agriculture was the leading cause of threatened waters (those which are in imminent danger of impairment due to land use changes) but was not listed as a cause of impaired waters (Moran and Roebig 2000). This means that not only should the cause of impairment be investigated but also the severity.

Based on the 2001 NYSDEC PWL and Waterbody Inventory (WI), one third of river kilometers (34%) in the Genesee River Basin (2,788 of 8,123 river kilometers) were listed on the PWL as either not supporting uses or being threatened (NYSDEC 2003). Only waters that are impaired, have minor impacts, or are threatened are listed on the PWL. Of stressed waters (those which support appropriate uses but still have water quality impacts), the majority were determined to have been caused by agriculture, while the second leading cause was due to streambank erosion

(NYSDEC 2003). For impaired waters, agriculture was still the leading cause of impairment, but the second largest cause was municipal discharge (NYSDEC 2003). The 2001 NYSDEC PWL/WI also targeted specific watersheds (Table 2), as well as main stem and tributary sites. In total, there were 155 segments, 43 (27.7%) of which are on the PWL (impaired, minor impacts, or threatened).

Fertilizers and manure are widely used in farming, and considering the prominence of agriculture in the basin, it is to be expected that they are a major concern. Phosphorus and nitrogen, found in components of fertilizer and manure, act as pollutants once they reach water bodies via runoff (Diebel *et al.* 2008). This creates a two-fold effect- the farmer loses his fertilizer (and soil), and the nutrients (and soil) pollute nearby lakes and streams.

Canaseraga Creek Watershed

Canaseraga Creek is the largest subbasin of the Genesee River, with a land area of 86,505 ha, and lies within the Upper Genesee basin (Fig. 1). The upper reaches of the watershed are steep, with an approximate slope of 211 m/km above Dansville. Below Dansville, the topography is flat, and the slope decreases to about 16 m/km (Beers *et al.* 2004). Starting approximately at Dansville and generally following I-390 going north, there is a broad alluvial plain that is dominated by corn cultivation, colloquially deemed the “Groveland Flats.” This plain follows both Bradner Creek and the main channel of Canaseraga Creek for at least 10 km (Fig. 2). This is an important feature of the watershed known to experience frequent flooding (Beers *et al*. 2004).

To combat the issue of flooding, the local farming community dug drainage ditches in the late 1960's throughout the area to carry water off the Flats and eventually into Twomile Creek. At the confluence of Twomile Creek and Canaseraga Creek (Fig. 3), a floodgate was installed to keep the waters of Canaseraga Creek from backing up into Twomile Creek, and thus exacerbating flooding in the Flats. Also, there is a pump at the floodgate to move the excess water from the Flats into Canaseraga Creek. The pump is used by the farmers mostly in the spring when flooding prevents seeding the fields. There appears to be no written records or schedules of when the pump is used, or how much water it pumps.

Canaseraga Creek has not been studied in great detail. Sedimentation in the subbasins of Canaseraga Creek was investigated by the USGS from 1975-1977 as part of a Genesee River Study published in 1991 by the USEPA (Mansue *et al.* 1991). They associated the majority of sediment yield with streambank failure (Mansue *et al.* 1991). The majority of current data was conducted by the NYSDEC's Rotating Integrated Basin Studies (RIBS) system, a biannual stream assessment using macroinvertebrate sampling. The 2001 PWL has made water quality determinations on 12 of 23 stream segments within Canaseraga Creek watershed, heavily using previous macroinvertebrate sampling results (NYSDEC 2003). Of these 12 assessed segments, one was designated as impaired (Mill Creek), two had minor impacts, three need verification, and the remaining five had no known impacts (NYSDEC 2003). The majority of segments were either known to have or were suspected to be suffering from agricultural impacts, whether by streambank modification/erosion or by nutrient runoff. However, since the RIBS program does not measure specific water quality parameters, it is very difficult or impossible to determine exactly what is causing the observed macroinvertebrate populations. It is therefore necessary to collect data on chemical factors that might not necessarily be reflected by macroinvertebrate sampling.

The dominant land use categories in Canaseraga Creek watershed (from the SWAT model) are agriculture (includes hay, pasture, and all row crops, 46.8%), followed by forest (includes deciduous, evergreen, and mixed forest, 44.4%), and developed land (includes all residential and industrial, 5.7%; Table 3; USGS MRLC 2006). More specifically, looking at single land uses, the top three are: deciduous forest (35.8%), hay (26.1%), and corn (8.2%; USDA NASS 2010).

Since crop fields tend to contribute large amounts of sediment and nutrients to streams due to runoff, their close proximity to the main channel makes them potential source areas. The Groveland Flats, which extends from just north of the village of Dansville to the Twomile Creek sampling site, is noteworthy because of its size, tendency to flood, modified drainage network, and lack of buffer zone (Beers *et al.* 2004; Fig. 2). In addition to this potentially large critical source area, there are: nine State Pollution Discharge Elimination System (SPDES) sites (seven of which are wastewater or sewage treatment plants); nine Confined Animal Feeding Operations (CAFOs; Table 4); five remediation sites (two Environmental Restoration Program sites, and three State Superfund Sites; state superfund sites are also known as Inactive Hazardous Waste Disposal Sites; Fig. 3).

SWAT Model

Over the past four decades, advances in computer technology have led to the increasing use of computer models in watershed management. Early models, however, had gaps that rendered them incomplete, insofar that they did not include important variables such as evapotranspiration and subsurface flow (Arnold *et al.* 1998). Furthermore, models that might include more watershed processes failed to incorporate them at high enough spatial resolution to be truly effective (Arnold *et al.* 1998). With the constant increase in computational power over the past decades has come the ability to include all these necessary parameters into a watershed model. Also, the simultaneous development of geographic information systems (GIS) has led to a great increase in model power. Geographic information systems allow a hydrologist to manage the scale issues that plagued past modelers because it allows for management of large data sets.

The Soil and Water Assessment Tool (SWAT) has become an important and prevalent model in watershed science today. The SWAT model is now a major tool of watershed management because of its ability to be applied to large scales, incorporate a wide variety of data inputs, and predict future outcomes of events. The SWAT model is capable of bringing all aspects of watershed dynamics together and creating one model for a given watershed that can be calibrated and validated for discharge, sediment, and phosphorus. The goal of a SWAT model is to accurately simulate current and potential nutrient fluxes.

Modern technology notwithstanding, there are still many challenges in making a hydrologic model. Arnold *et al.* (1998) identify six goals of a model: (1) is computationally efficient; (2) allows considerable spatial detail; (3) requires readily available inputs; (4) is continuous-time; (5) is capable of simulating land-management scenarios; and (6) gives reasonable results. A SWAT model achieves all six of these key goals due to its semi-distributed nature. A distributed model breaks a watershed into sub-basins and allows for definition of inputs specific to each sub-basin, such as soil and land use (Jayakrishnan *et al.* 2005). Compared to a lumped model, which uses averages across the system, a distributed model has a much higher degree of detail for inputs (Jayakrishnan *et al*. 2005).

A distributed model such as SWAT is ideal for allowing the spatial detail required in modeling large, spatially variable watersheds. The SWAT model is also continuous-time, meaning that it constantly simulates output based on daily weather data and thus can predict long-term changes in watershed dynamics. As such, the SWAT model specifically aims to predict impacts of differing land management practices over time and not specific to a single event. Since environmental variables such as temperature and precipitation are inherently variable, the model allows for the addition of user-defined long-term temperature and precipitation data at many different locations. This aspect of SWAT is what makes it a key component to large-scale watershed management. Even with the vast capabilities of the SWAT model, it is not a panacea for the hydrologic modeler. The inputs required to compile the SWAT model are enormous; many different large data sets, computations, and calibration are required. Further, though the SWAT model does account for many variables (such as snowfall, snowmelt, channel erosion, crop management, fertilizer application, and in-stream nutrient cycling), it cannot simulate everything- such as large water-body dynamics (Debele *et al*. 2008). However, the SWAT model is adaptable insofar that it can incorporate independent modules to make up for any shortcomings, including the lack of a fully-distributed groundwater routine (Kim *et al.* 2008). It can also be used in conjunction with other models that address areas that SWAT does not, such as pools of organic matter (Debele *et al.* 2008).

Calibrating a model is an important process to evaluate its accuracy and predictive capability. Calibration generally consists of running the computer simulation multiple times and comparing the simulated outputs to observed values (Anand *et al*. 2007, Srinivasan *et al.* 1998). By adjusting model parameters accordingly, the model will begin to give acceptable results that are close to measured or historical values. If a model is calibrated so that it accurately simulates past or current known conditions and is validated to simulate a different time period (other than the calibration period), it can then be used to predict unknown future conditions.

Nutrient Biotic Index

Aquatic benthic macroinvertebrates are a diverse group of organisms such as mayflies, stoneflies, and caddisflies [Orders *Ephemeroptera, Plecoptera,* and *Trichoptera* (EPT)] and are a common macroinvertebrate metric for evaluating the health of stream ecosystems. Their sensitivity to pollution, short life span, low mobility, importance in the food web, and ease of collection make them successful biological indicators for water quality (Bode *et al.* 2002, Smith *et al.* 2007). Significant correlations between four macroinvertebrate community measures [Hilsenhoff's Biotic Index (HBI), percentage of EPT individuals and taxa, and total number of taxa] and two nutrient measures (total phosphorus and NH_4-N) were observed by Wang *et al.* (2007), suggesting that the macroinvertebrate community responds to nutrient concentrations. Macroinvertebrate multi-metric indices are recognized by the USEPA as secondary response variables that have potentially high value in nutrient criteria development (USEPA 2000a). Additionally, the NYSDEC has been using macroinvertebrate sampling in their Stream Biomonitoring Unit since 1972, which they use to make water quality assessments that may be included in the PWL, 303(d) list, or used in SPDES permit compliance (Bode *et al.* 2002). Smith *et al.* (2007) developed a Nutrient Biotic Index (NBI) using benthic macroinvertebrates from streams, total phosphorus, and nitrate values to determine oligotrophic, mesotrophic, or eutrophic conditions based on observed fluctuations in macroinvertebrate community diversity and nutrient optima. The principal behind the Smith *et al.* (2007) methodology reflected that of Hilsenhoff (1977, 1982, 1987). However, it included weighted averaging to determine 'nutrient optima,' the concentration (of total phosphorus or nitrate) at which a taxon was found in highest abundance. These optima were in turn assigned tolerance values, from which NBI scores could be calculated (Smith *et al.* 2007).

The ultimate goal of the NBI was to develop a management and enforcement tool to determine a stream's general trophic state (oligotrophic, mesotrophic, eutrophic) and determine the point at which water quality can be classified as impaired (Smith *et al.* 2007). To aid in identifying the impairment threshold, NYSDEC's multimetric approach, which includes species richness, EPT richness, HBI, and percent model affinity was used to determine the level of impact at each trophic level. Higher abundances of pollution tolerant organisms correspond to decreasing water quality (non, slightly, moderately, or severely impacted water quality). Streams experienced the highest increase in percentage of impacted samples between the mesotrophic and eutrophic state (Smith *et al.* 2007). Moving from mesotrophic to eutrophic, percentage of impacted sites increased from 64-93% for TP and 67-87% for nitrate, which corresponds to the boundary threshold concentrations of 0.065 mg P/L for TP and 0.98 mg N/L for nitrate (Smith *et al.* 2007; Table 5). These concentrations represent levels that indicate the beginning of water quality impairment (Smith *et al.* 2007). Using the aforementioned concentrations as nutrient criteria provides for a preventative approach that can easily be implemented into preexisting macroinvertebrate biomonitoring programs. By developing the NBI, water chemistry (TP and nitrate) can be assessed simultaneously with benthic macroinvertebrate sampling, providing a simple and useful metric to strengthen biomonitoring programs.

Segment Analysis

Segment analysis is the process of determining pollution source areas by systematically analyzing water quality on stream segments (Makarewicz and Lewis 1999). The process begins with dividing a large watershed into subwatersheds and then targeting each separately for analysis. Each subwatershed is then sampled at the beginning and end of its reach, giving insight into pollutant concentration fluxes within the subwatershed (Makarewicz and Lewis 1999). This methodology is based largely on the concept that contaminants originate on land and migrate into streams via runoff from rain events or discharge pipes. Therefore if any contaminant is found to be higher in one segment than another, land use in that area can be investigated for potential causes (Makarewicz and Lewis 1999). By decreasing the size of land area that needs to be investigated for pollution sources, the identification and location of these sources becomes very efficient.

Thesis Questions

Water Quality in Canaseraga Creek Watershed

What and where are the major sources of pollution in Canaseraga Creek watershed? What is the status of water quality in Canaseraga Creek watershed?

What effects are those sources having on water quality?

Can this pollution be contained, controlled, or otherwise mitigated so that negative effects will be lessened or eliminated?

SWAT Model

Does the SWAT model accurately predict discharge based on past data?

Does the model accurately predict nutrient loadings based on observed nutrient concentration and simulated discharge?

Does the removal of point sources and/or the simulation of nonpoint source best management practices impact nutrient loading to streams?

If the watershed is modeled to be 100% forested, will it predict lower loadings than either current conditions or best management practice scenarios?

Can the model be used to determine an achievable nutrient goal for New York streams?

NBI

Does the NBI presented by Smith *et al.* work for a small watershed, and does it reflect water quality as found by this study's data?

Hypothesis: The water quality scores given by the NBIs will not agree with average nutrient scores for the respective site.

How do the NBI-P and NBI-N perform when encountering natural variability (i.e., streams outside this watershed)? Do they yield conflicting results? What does this imply for its use as a monitoring/assessment tool?

Hypothesis: There will be no significant difference in NBI scores between streams of similar size and habitat in two different small watersheds.

What are the implications for future use as a monitoring/assessment and enforcement tool?

Hypothesis: The results of the NBI-P and NBI-N agree with analytical water quality data and therefore serve as an acceptable, efficient replacement for chemical analysis.

Methods

Water Sampling and Study Site

Two United States Geological Survey (USGS) discharge monitoring sites on the main stem of Canaseraga Creek (Shaker's Crossing and Dansville) were sampled for water quality from 3 August 2010 to 14 February 2012. Other weekly water sampling began on 8 February 2011 and ended on 14 February 2012 at two additional main stem locations (Pioneer Road, Faulkner Road) and four tributaries (Buck Run Creek, Twomile Creek, Mill Creek, Stony Brook; Fig. 3; Table 6). Site locations were chosen based on accessibility, consistency of flows, and spatial coverage from an initial scoping visit of 13 samples on 8 February 2011 (Fig. 4). Event sampling occurred when rainfall was observed in the study area and/or when nearby real-time USGS stream gauges were elevated (target rise of 1 inch in 30 minutes; http://waterdata.usgs.gov).

In total, at Shaker's Crossing and Dansville, 77 water chemistry sampling dates comprised of 23 events and 54 nonevents (3 August 2010- 14 February 2012). Pioneer Road, Buck Run Creek, Stony Brook, Mill Creek, and Faulkner Road were sampled on 51 dates (18 events and 33 nonevents; 8 February 2011- 14 February 2012), while Twomile Creek was sampled on 50 dates because it was completely frozen once (18 events and 32 nonevents; 18 February 2010- 14 February 2012).

Water samples were taken by submerging the bottle upstream from the person taking the sample or by using a bucket and rope from a bridge. In either case, the sample bottle (and bucket, if used) was rinsed with sample before being filled. All bottles were pre-washed in phosphate free RBS solution and thoroughly dried before use. Samples were filtered in the field using MAGNA 0.45 µm, 25 mm filters for dissolved nutrient analysis (SRP and nitrate) and stored on ice in a cooler until transported to a refrigerator at SUNY Brockport. Upon arrival, samples were logged into a Microsoft Excel database in the Water Quality laboratory at SUNY Brockport.

Laboratory Analysis

Water samples were analyzed for total phosphorus (APHA Method 4500-P), soluble reactive phosphorus (APHA Method 4500-P F), total nitrogen (APHA Method 4500-N C), nitrate (APHA Method 4500-NO_3- F), and total suspended solids (APHA

Method 2540D; APHA 2005). Soluble reactive phosphorus was analyzed within 24 hours after sampling, while nitrate, TP, TN and TSS were analyzed within two days after sampling. Total coliforms (TC) were measured using 3M Petrifilm^{TM} Coliform Plates (1-mL sample), incubated overnight, and counted within 24 h.

Quality Control

The SUNY Brockport water chemistry laboratory has a National Environmental Laboratory Accreditation Conference (NELAC) certification (ID# 11439), which includes annual auditing and proficiency checks. Replicate samples, matrix spikes, method blanks, and quality checks were run every 20 samples and plotted on quality control charts with warning and control limits to ensure data integrity.

Discharge and Loading

Discharge (m^3/s) for the Shaker's Crossing and Dansville sites was obtained from the USGS gauging stations (http://waterdata.usgs.gov/ny/nwis/rt; personal communication: A.G. Morgan, USGS), while discharge for the remaining sites (Buck Run Creek, Twomile Creek, Stony Brook, Mill Creek, Faulkner Road, and Pioneer Road) was determined from field data taken during the study. A velocity (m/s) versus depth (m) regression was used to predict velocity at a given depth. For the non-USGS sites, velocity was measured with a Gurley velocity meter (Model D622 or D625) at 0.6 of the depth at discrete increments specific to the streams' width to provide stream velocity in: 0.9 m horizontal increments at Buck Run Creek; 1.2 m increments at

Faulkner Road; 1.5 m increments at Stony Brook; 1 m increments at Mill Creek; and 1.5 m increments at Pioneer Road. Cross-sectional areas of streams were determined from measurements of the bridge at each site (flood gate at Twomile Creek) by using a planimeter to measure precise drawings made from accurate field measurements of each sites' dimensions. Regressed velocity (m/s) was multiplied by cross-sectional area (m^2) to calculate discharge (m^3/s).

Twomile Creek was an exceptional case because of the presence of the flood gate. During low flows, it was necessary to wade into the stream to measure velocity. Only one to two measurements were taken at 1 m intervals during very low flows, while moderate flows allowed for up to six measurements taken at 1 m intervals. High flows were too deep to wade, and since there is no bridge crossing the gate, only one velocity measurement was able to be taken from the top of the gate wall.

Loadings (mass/time) were determined by multiplying discharge (m^3/s) and concentration (mg/L, µg/L, or CFU/100 mL) for each analyte measured: TP, SRP, TN, nitrate, TSS and total coliform bacteria. An extrapolation method was used to calculate daily loadings in which a weekly sample's concentration was expanded to a whole week, while event samples were extrapolated based on observed discharge. Predictive regressions were used to calculate daily discharge using observed discharge versus a USGS site (Shaker's Crossing or Dansville) with r^2 values ranging from poor (r^2= 0.22) to good (r^2=0.93) (Fig. 5). Once discharge was predicted, it was multiplied by concentration to get daily loading. Annual loadings were normalized by area (ha) for each segment (Shaker's Crossing, Pioneer Road, Buck Run Creek, Twomile Creek, Mill Creek, Stony Brook, Dansville, and Faulkner Road). Watershed area was obtained from the USGS StreamStats web-based geographic information system (http://water.usgs.gov/osw/streamstats/). Also, seasonal and monthly loads were calculated for each segment.

Segment Analysis

Segment analysis allowed the determination of locations of potential point and nonpoint sources in Canaseraga Creek watershed. Initially, the watershed was systematically divided into segments so that high nutrient concentrations could be investigated by revisiting a discrete segment and performing a stressed stream analysis on that subbasin. Five main stem samples were taken along with four major tributaries (8 February 2011). The results of this segment analysis were used to target segments where high nutrient concentrations were observed for stressed stream analysis in order to discover the cause of elevated nutrients. Additional segment analyses were conducted on Buck Run Creek (15 March and 10 May 2011), Twomile Creek (5 April, 24 May 2011 and 1 May 2012), Bradner Creek (7 September 2011), Mill Creek (16 August, 31 August 2011, 23 April 2012), Mud Creek (21 September 2011), and Sugar Creek (5 October 2011). Samples were analyzed for all parameters detailed in laboratory analysis (TP, SRP, TN, nitrate, TSS, and total coliform bacteria), and treated in the same manner discussed in water sampling and study site.

Wastewater Treatment Plant Sampling

Several wastewater treatment plants (WWTP) exist in the Canaseraga Creek watershed with a wide range of maximum flows (246-5,678 m^3/d; Table 7, Fig. 6).

Five replicate samples were taken upstream and downstream from the effluent pipe at each site. Upstream samples were taken in the receiving waters as close to the discharge point as possible so that the effluent would not affect the sample, ~1 m to ~30 m . Downstream sampling distance varied due to accessibility at each site and ranged from ~1 m to ~118 m downstream from the discharge point. Water samples were treated and analyzed as described in laboratory analysis. Data were analyzed using the Wilcoxon signed-ranks test, which used the difference of below samples – above and tested for the residual median to be greater than 0. The nonparametric Wilcoxon test was used in favor of the parametric t-test because of frequent departures from the assumption of normality, thus keeping the statistical methodology consistent for all WWTPs.

Erosion Inventory

An inventory of erodible areas was taken by canoe or by foot to assess erodible areas in Canaseraga Creek. Height and length of critically eroded areas were measured using a Nikon Prostaff 550 laser rangefinder. The location of the eroded areas was documented with a handheld global positioning system (GPS), photographed, and classified based on criteria from an erosion inventory checklist (Appendix A). The index, modified from LimnoTech Inc. (2006), provided a measure of the severity of erosion. Modifications to the index were made to include stream bank length and height to include more size classes, as well as a section to quantify erosion near agricultural fields. Erosion adjacent to agricultural fields was ranked highest on the index.

Nutrient Biotic Index

The nutrient biotic index was calculated at Canaseraga Creek on 23 August 2011. Two sites were sampled in the Canaseraga watershed: a tributary with nutrient impairment (Buck Run Creek) and a tributary with no observed nutrient impairment (Stony Brook; Fig. 3). Bigelow Creek in the Black Creek watershed and Oatka Creek were also sampled on 23 August 2011. Black Creek is listed as impaired on the NYS 303(d) list due to high phosphorus from the surrounding agriculture while having a low average nitrate concentration (Table 5). Oatka Creek at Garbutt, NY, had a high nitrate concentration and low TP concentration (Table 5). The trophic status of the four sites in the three watersheds were compared via the macroinvertebrate derived NBI trophic status and by the trophic status derived from water chemistry data.

Macroinvertebrates were collected using a D-shaped net in riffle habitats by the traveling kick sample method for 5 minutes along a 5 m diagonal line. Samples were placed in a labeled bottle and preserved in the field with ~70% ethanol, and then transported back to SUNY Brockport, where the sample was emptied completely and evenly into a 5 cm x 5 cm gridded pan. A 100 specimen subsample was taken using randomly generated numbers and letters to randomly select grids from the pan. All specimens were removed from each randomly selected grid until 100 specimens were obtained, or until all grids had been selected. Each 100 specimen subsample was stored in 70% ethanol in a labeled jar until identified to lowest taxonomic level in the laboratory using NYSDEC guidelines (Smith *et al.* 2009). Once identified, specimens of the same taxa were placed in labeled 20 mL scintillation vials filled with 70% ethanol.

Macroinvertebrate sampling occurred simultaneously with total phosphorus and nitrate sampling at the same locations, or as near as possible. Water chemistry data at each site are presented as both annual averages (‘long-term’) and as the average of all samples taken within 90 days prior to macroinvertebrate sampling (‘short-term’).

Nutrient Biotic Index (NBI) Calculation

The NBI is a linear scale from 0 (unpolluted) to 10 (polluted), calculated as a weighted average (Smith *et al.* 2007):

$$NBI\ score = \sum\left(\frac{ab}{c}\right)$$

where a is the number of individuals in each taxon, b is that taxon’s tolerance value, and c is the total number of individuals with tolerance values. Three ranges of NBI values characterized the general trophic state of the water body: 0-5 oligotrophic, 5-6 mesotrophic, and 6-10 eutrophic (Smith *et al.* 2009, Table 5). The scores above which a stream would exceed nutrient criteria are 6.1 for the NBI-P and 6.0 for the NBI-N (the mesotrophic-eutrophic boundary). The nutrient criteria for the mesotrophic-eutrophic boundary are 65.0 µg P/L for the NBI-P and 0.98 mg N/L for the NBI-N (Smith *et al*. 2007; Table 5)

The Shannon-Wiener diversity index (Weber 1973, Smith *et al.* 2009) is a combined measure of species richness and community balance (evenness) and was calculated as follows (Weber 1973):

$$D = \left(\frac{C}{N}\right)[(N \log_{10} N) - (\sum n \log_{10} n)]$$

where *D* is diversity, *N* is total number of individuals in the sample, and *n* is the total number of species in each sample. The range for *D* is 0 - 3.321928 log N, where larger numbers represent higher diversity (0 - 6.6 for 100 specimens; Weber 1973). Also included was taxa richness (*R*) using number of genera. The number of genera was used in order to include some taxa that were not identified to species.

Macroinvertebrate Identification and Quality Control

Since not all taxa have tolerance scores for calculating the NBI, the closest level of identification with a tolerance value was employed. For instance, if a specimen was identified to species and there was no NBI score, the score for "*Genus sp.*" was used. In other cases, if genus could not be identified nor had a tolerance score, the NBI score for "Undetermined Family" was used. If a taxon was identified with no known tolerance value, it was not used in the NBI calculation; only specimens with established tolerance scores were used. Since the NBI is calculated as a weighted average, it was not necessary to have a specific number of specimens for each sample.

A major effort was made to ensure accuracy in identifications, and a quality control protocol similar to that of Smith *et al.* (2009) was created (Appendix B). Once a subsample (100 specimens) was identified, 10 random specimens were checked by a second taxonomist. If nine or more specimen identifications agreed between the two identifications, the sample was considered finished. However, if eight or less identifications agreed, all specimens in the taxonomic Family where the disagreements occurred were checked and changed if necessary. This process was repeated until nine or more specimen identifications agreed between the two parties doing the identification. After all samples were considered finished, a random check of 10 specimens was selected and identified by two other taxonomists (personal communication: Peter Lent, retired NYSDEC Biologist; Gary Neuderfer, Adjunct Lecturer and retired NYSDEC Biologist)(Appendix B).

SWAT Model Setup

The SWAT model for Canaseraga Creek Watershed (CCSWAT) was built using ArcSWAT 2009. Topography was defined using a 1/3 arc-second digital elevation model (DEM, ~10-m resolution) from the National Elevation Dataset using the USGS's online Seamless Data Warehouse (USGS 2010). The stream network, sub-basins, and watershed boundary were defined using the 'burn-in' stream network option using the USGS's National Hydrography Dataset (USGS 2011) clipped to the Canaseraga Creek watershed boundary. The 'burn-in' option was chosen because the artificial drainage network in the Groveland Flats was not simulated properly with the 'DEM-based streams' option. Land use was obtained from the USGS via the National Land Cover Dataset 2006 (NLCD) (USGS MRLC 2006). Soil data was downloaded from the USDA National Resources Conservation Service's (USDA NRCS) soil data mart (USDA NRCS 2006). The STATSGO dataset was used for the Canaseraga Creek SWAT model with the MUID field to link the information within ArcSWAT. Five slope classes were employed (0-3%, 3-5%, 5-8%, 8-15%, 15+%).

Daily weather data (temperature and precipitation) were downloaded from the National Weather Service's National Climatic Data Center for stations closest to the watershed for the time period 1 January 2008 through 31 May 2012 (NOAA NWS 2011). Dansville and Mt. Morris, NY, were used for temperature data while Portageville and Hornell, NY, were added for precipitation. ArcSWAT's built-in weather generator from stations in Rochester, Arcade, and Bath, NY, were used to simulate all other weather parameters. Hydrologic response units (HRU's) were created using a 10/20/20% overlay of land use, soil type, and elevation, respectively. In order to ensure that small urban areas were not eliminated due to being under this threshold, all urban land uses were excluded from this process, thus creating their own HRU's.

Outlets were manually placed at two USGS gauging sites at Shaker's Crossing (hydrologic unit code 04227000) and Dansville, NY (hydrologic unit code 04224775) and at each routine water quality monitoring site (Buck Run Creek, Pioneer Road, Mill Creek, Stony Brook, Faulkner Road; Table 6) except Twomile Creek. The Twomile Creek routine site outlet was already simulated by the model, so the manual creation of an outlet was unnecessary. The whole watershed outlet for the SWAT model was placed just above the confluence of Canaseraga Creek with the Genesee River. The model resulted in 68 subbasins and 3,063 HRUs.

Source Inputs

The presence of sources of sediment and nutrients in Canaseraga Creek watershed not inherently built into the SWAT model necessitated their manual input.

These included crop management practices, point sources, confined animal feeding operations, and groundwater phosphorus concentration.

Crop Data

The New York State 2010 Cropland Data Layer (CDL) was used to determine the percent distribution of crops in Canaseraga Creek watershed (USDA NASS 2010). The distribution was 34% corn, 18% alfalfa, 16% pasture/grass, 11% shrubland, 8% soybean, 4% winter wheat, 3% range grass, 2% oats, 1% dry beans, and 3% other. This distribution was used to split the SWAT generic row crop land use into specific crop type subclasses.

Crop rotation and fertilization was based on data provided by the Genesee County Soil and Water Conservation District (personal communication: George Squires, Genesee County SWCD) and the 2010 Cornell Guide for Integrated Field Crop Management (CCE 2010). The first year of crop rotation was determined by where the cover crop aligned with the 2010 CDL. Spring tillage was assumed to occur in the first half of May due to a 'wet' spring in 2011, while fall tillage occurred in mid-October depending on crop type. A high-nutrient starter fertilizer was applied to agricultural fields in early May.

Point Sources

The seven WWTPs in Canaseraga Creek watershed were placed into CCSWAT as discharge and P inputs in their own subbasin using a GIS layer and field knowledge of the discharge location. Discharge data for the WWTPs was obtained from the USEPA Envirofacts NPDES database (USEPA 2011) or from personal communications with the WWTP operators (personal communications: Ron Macomber, Village of Nunda Wastewater Superintendent; Paul Lampere, Groveland Correctional Facility Sewage Treatment Plant Operator). The average discharge was used to calculate P load from each facility, which was then input into the model. Nutrient concentration was measured from a discharge pipe sample from each facility, which was used as a constant value to calculate annual load.

Point source inputs of phosphorus must be in the form of mineral and/or organic P (Arnold *et al.* 2011) for the QUAL2E module within the SWAT model. QUAL2E assumes two forms of phosphorus- mineral P (inorganic, such as SRP or orthophosphate) and organic P (all other forms of phosphorus except SRP) (personal communication: Dr. James Almendinger, St. Croix Watershed Research Station, Science Museum of Minnesota). Since these two fractions can be summed to get total phosphorus, results from sampling were used as inputs by using SRP as mineral P and the difference of TP and SRP as organic P. The mineral and organic P point source loads were then calculated using concentration and average discharge.

Confined Animal Feeding Operations

The nine confined animal feeding operations (CAFOs) are a nonpoint source of nutrients and sediment to Canaseraga Creek and were incorporated into CCSWAT by assignment to their respective subbasin (Table 4). The amount of manure produced by each CAFO (kg manure/d) was calculated based on the number and type of animals and a constant amount of manure produced per animal per day (ASAE 2003, 2005) spread on corn, alfalfa, hay, soybean, generic agriculture, and/or winter wheat

HRUs. The manure application rate for each CAFO (total amount of manure produced at each CAFO divided by total area used for spreading) varied based on the area of HRUs in the subbasin where the CAFO was located and was applied to the surface soil layer with a frequency of 30 days. The manure applied in this manner was independent of row crop fertilization practices in order to separate the impacts of row crop fertilization from CAFO manure production.

Groundwater Phosphorus Concentration

Groundwater TP concentration in CCSWAT was set to 20 µg P/L in order to simulate groundwater phosphorus. Observed TP concentrations in 16 southern New York wells in and near the Genesee River basin had an average concentration of 22.1 µg P/L and a range of 0.7-162.7 µg P/L. Additionally, the USGS sampled SRP in wells in the Genesee River basin and obtained a range of 6 - 111 µg P/L, with a median of 18 µg P/L (Reddy 2012). To obtain the current calibration, groundwater phosphorus was changed in the Mill Creek and Shaker’s Crossing subbasins to 3 and 35 µg P/L, respectively.

Septic Systems

If septic systems are activated in an HRU in the SWAT model, the entire HRU is modeled as having septic systems (personal communication: Dr. Raghavan Srinivasan, Texas Agricultural Experiment Station, Blackland Research Center). Thus, septic systems were activated only in urban HRUs outside of a subbasin with a WWTP. Active septic systems were applied to all HRUs with the ‘urban’ description except for subbasins 1, 2, 3, 17, 22, 26, 30, 33, 34, 36, 41, 46, and 61, which are sewered areas. The septic system type was designated as 'septic tank with conventional drainfield', which is most accurate for western NY homes.

Ponds and Wetlands

In order to improve CCSWAT in the Twomile and Mill Creek subwatersheds, a pond was simulated in subbasin 41 and a wetland was simulated in subbasin 31. The Twomile Creek subbasin where the wetland was simulated is a very flat (the 'Groveland Flats' area), drained area that was thought to act like a wetland hydrologically. In the Mill Creek subbasin, a marl pond (herein named 'Wayland Pond') receives tributary water and effluent from the Wayland WWTP, which is a significant source of nutrients (Table 7).

Calibration and Validation

After model setup, the model was calibrated and validated. The Canaseraga Creek SWAT model was calibrated for flow, TSS and TP load at the Shaker's Crossing and Dansville USGS sites (subbasins 2 and 40). The calibration period at the USGS sites for water was June 2010 through April 2012, while TSS and TP loads were calibrated for the period of August 2010 through January 2012. Tributary sites were calibrated for flow from February 2011 to April 2012 and for TSS and TP loads from February 2011 to January 2012. The model was validated for flow for the time period January to December 2003 at Shaker's Crossing. While some CCSWAT parameters were applied to the whole model, some were changed for specific subbasins (e.g. CH_N2, manning's N for the main channel). A comprehensive list is provided in Appendix C.

Calibration consisted of calculating percent bias (PBIAS) of the model output to USGS data, Nash-Sutcliffe (NS) efficiency, correlation coefficient (r^2) of modeled versus USGS discharge, and visual distribution of peaks (Moriasi *et al.* 2007). The PBIAS metric measures the magnitude of difference between modeled and actual data with a positive value indicating model overprediction and negative values indicating model underprediction. A PBIAS within 10% was acceptable for water calibration, 15% for TSS and 25% for TP with an ideal goal of 0.0% (Moriasi *et al.* 2007). The Nash-Sutcliffe model efficiency coefficient measures how closely the model variance compares to the observed data variance for a given period of time:

$$E = 1 - \frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}$$

where Y^{obs} is observed data, Y^{sim} is modeled data (SWAT output) and Y^{mean} is the average of observed data (Moriasi *et al.* 2007). The scale is from $-\infty$ to 1, where 1 is a perfect simulation of actual data and 0 is a simulation that reflects the mean of real data, while more negative numbers indicate that the mean of the real data is a better predictor. A NS>0.75 is considered a very good simulation of observed data (Moriasi *et al.* 2007). The correlation coefficient (range of -1 to 1) of modeled versus observed data quantifies the strength of the relationship; an $r^2>0.7$ was considered very good.

Water Balance

Several surface runoff, soil, and groundwater parameters were changed, most importantly ESCO, EPCO, GWDELAY, and ALPHABF (Table 8, Appendix C). Curve number was decreased by 20%, which is consistent with other western NY

SWAT models for Black Creek and Oak Orchard (Pettenski 2012; Richards *et al.* 2010; Winslow 2012) and is within the range of other published SWAT models as reported by Richards *et al.* (2010). The method used for potential evapotranspiration was Hargreaves, which is also consistent with other models for nearby watersheds. A deficit of water was observed at all calibration sites, so a global 30% reduction in soil available water content (SOL_AWC) was used to increase flows within acceptable ranges. For the calibration period June 2010 through April 2012, the model predicted monthly flow at Shaker's Crossing with a very good rating for NS (0.76), PBIAS (0.7%), and r^2 (0.76) (Table 9a). Flow calibration results at the Dansville USGS site were also good, with NS = 0.70, PBIAS = -8.8%, and r^2 = 0.74 (Table 9a). The validation period January – December 2003 was also very good at Shaker's Crossing, with NS = 0.79, PBIAS = -3.7%, and r^2 = 0.81.

Sediment and Phosphorus Loading Calibration

The model was also calibrated for TSS and TP loss simultaneously at Shaker's Crossing and Dansville from August 2010 through January 2012. The model predicted sediment loss at Shaker's Crossing with a good NS (0.70), very good PBIAS (-0.7%), and r^2 (0.70) (Table 9a). Total phosphorus prediction had a very good NS (0.82), PBIAS (–2.7%), and r^2 (0.83). The USGS site at Dansville was also calibrated to similarly high standards (Table 9a).

To improve TSS and TP prediction at non-USGS sites, some parameters were changed in specific subbasins (Appendix C). Examples of parameters changed by subbasin include sediment routing method, Manning's 'N' and hydrologic conductivity in the main channel. All non-USGS sites had very good PBIAS ratings for TSS (±15%), ranging from -7.5% to +9.4% (Table 9b). Percent bias for TP had a wider range (-24.6% to +22.3%) than TSS but were still within the very good guideline of ±25% (Table 9b).

Average monthly phosphorus concentration of model output was calculated by converting model TP output from kg to µg, then dividing by discharge (L) to give µg P/L. To attain a more realistic comparison between observed and simulated data, and to eliminate any bias due to observed samples not being representative of average monthly concentrations, observed concentrations were weighted by flow. The CCSWAT predicted the average TP concentration at Shaker's Crossing within 0.7% (TP observed average: 100.3µg P/L; modeled average 101.0 µg P/L; Table 9a). Average TP concentration PBIAS was high at Mill Creek (20.7%) and Dansville (13.9%) but low at Twomile Creek (-24.2%). The TP concentrations at the other two calibration sites (Stony Brook and Buck Run Creek) were within 10% (Table 9b).

Phosphorus Loading Allocation

To determine the major sources of phosphorus loss from Canaseraga Creek watershed, CCSWAT simulated the losses of P from agricultural crops, tile drains, farm animals (CAFOs), stream bank erosion, wetlands, groundwater, forest, urban runoff, sewage treatment plants, and septic systems.

Phosphorus loss from CAFOs was the difference of the base model's phosphorus load and a scenario where all CAFO manure applications were removed, agricultural crop P loss was the difference of the base model and a scenario where all agricultural crops (including hay and pasture) were converted to forest; phosphorus from CAFOs was also subtracted to avoid redundancy. A scenario was run with 10.0% tile drainage (personal communication; Larry Geohring, Cornell University) added, and the difference of the tile drain scenario and the base model yielded the contribution of phosphorus from tile drains.

Phosphorus from wetlands, forests, and groundwater was output directly from CCSWAT. Stream bank P erosion was the difference of a base model run and a run where channel cover was increased, and Manning's N value was increased by 50%. The phosphorus loss from urban runoff was the difference in P output from the calibrated model and the output from a simulation where all urban land was converted to forest. Phosphorus from septic systems was calculated separately by removing them from the model and subtracting the output from the base model. The contribution of phosphorus from wastewater treatment plants was determined by the difference of a simulation that removed all WWTPs and the base model. Since additional data was available, an additional P allocation table was produced for comparison (Appendix D).

Model Simulations

Scenarios were based on several different categories: natural forested simulation, agricultural BMPs, wastewater treatment options, and CAFO management. Percent reduction in P load, TP concentration, and TSS load versus the base model at Shaker's Crossing was determined from these scenarios.

Natural Forested Scenario

Background levels of phosphorus and sediment were determined by simulating a fully forested watershed. All agricultural and urban land uses were converted to ‘Forest-Mixed’ (FRST) with 100-year maturity, all point sources were removed, and all septic was set to inactive. This simulated the removal of all anthropogenic sources and impacts. Existing wetlands and forest were unchanged.

Wastewater Treatment Options

To determine the impact of removing all WWTPs in the watershed, tertiary treatment with chemical addition and two-stage filtration was simulated using a concentration of 10 µg P/L (USEPA 2007). In a second scenario, all WWTPs were removed from CCSWAT. Separately, all septic systems were deactivated in order to determine their impact.

Agricultural Best Management Practices

The Canaseraga Creek SWAT model was used to simulate implementation of various agricultural BMPs. Realistic BMPs were selected, such as no till/conservation tillage, grassed waterways, contour farming, terrace farming, filter strips, strip cropping, cover cropping, and retiring agricultural land (converted to forest). Nutrient management scenarios that reduced fertilizer application by 25, 50, 75, and 100% were run; this reduction did not change manure applications from CAFOs. Manure application from CAFOs was treated separately.

CAFO Management

To determine the impact of manure application on agricultural fields by CAFOs, manure application from all farms was completely removed. This simulated manure storage practices that eliminated runoff from agricultural fields where manure was spread.

Stream Bank Stabilization

Stream bank stabilization is the implementation of vegetation or structures to protect stream banks from erosion. To simulate this in the CCSWAT model, several parameters were changed, such as increasing vegetative cover (CH_COV2) and increasing Manning's stream roughness coefficient, 'N', (CH_N2) by 50%.

Concentration Target Scenarios

Using the results of each scenario individually, combinations of the most effective scenarios and BMPs were simulated in order to reach TP concentration targets of 20, 45 and 65 µg P/L at Shaker's Crossing (6NYCRR §703.2, Smith *et al.* 2007). The target of 45 µg P/L was used as a moderate value between 20 and 65 µg P/L. Scenarios primarily targeted agricultural runoff by utilizing grassed waterways and point source inputs by upgrading WWTPs to tertiary treatment. The effect of implementing BMPs in just the two most impacted tributaries (Buck Run and Twomile Creeks) or areas (Groveland Flats) was also determined. The results of these different management scenarios and combinations were used to determine the most effective way or ways to reach water quality targets.

Results

Discharge

Discharge (m^3/s) and stream depth (m) were regressed in order to build discharge rating curves for each non-USGS site. In general, very good relationships were observed at Canaseraga Creek at Faulkner Road ($r^2 = 0.95$, Fig. 7), Stony Brook ($r^2 = 0.93$), Canaseraga Creek at Pioneer Road ($r^2 = 0.94$), Twomile Creek ($r^2 = 0.95$), and Buck Run Creek ($r^2 = 0.99$). The curve for Mill Creek had the weakest relationship ($r^2 = 0.91$; Fig. 7).

Average Annual Nutrient Concentration

Average annual main stem and tributary concentration of all analytes (TP, SRP, TSS, TN, nitrate, and TC) generally increased downstream (Fig. 8). Total phosphorus concentration in the main stem was lowest in the upstream reaches from Faulkner Road to Dansville (<50 µg P/L) and increased downstream to Pioneer Road and at Shaker's Crossing, where average TP concentration was over 100 µg P/L. Two tributaries (Buck Run and Twomile Creeks) had the highest TP concentrations of all sites (>130 µg P/L; Fig. 8), while Stony Brook was the lowest (21.0 µg P/L). Soluble reactive phosphorus was low in the main stem from Faulkner Road to Pioneer Road (<10 µg P/L). Downstream at Shaker's Crossing, SRP was the highest of all main stem sites (23.4 µg P/L). Between main stem sites Pioneer Road and Shaker's Crossing lie the Twomile Creek (17.4 µg P/L) and Buck Run Creek (59.3 µg P/L) tributaries, which were higher in SRP concentration than upstream tributaries Mill

Creek and Stony Brook (<6 µg P/L). The high concentrations of TP and SRP at Twomile and Buck Run Creeks suggest that they are sources of phosphorus to Canaseraga Creek.

Total nitrogen in the main stem increased from 0.89 mg N/L at Faulkner Road to 1.56 mg N/L at Shaker's Crossing, while total nitrogen in the tributaries was similar to main stem sites with the exception of Twomile and Buck Run Creeks. These two creeks had the highest average TN concentration (>2.00 mg N/L) of all sites. This trend of increasing concentration is similar in the main stem and tributaries for nitrate, except Twomile Creek alone had the highest nitrate concentration (1.74 mg N/L).

Total suspended solids concentrations in the main stem were lowest at Faulkner Road (21.7 mg/L) and elevated at downstream main stem sites Dansville (57.4 mg/L) and Pioneer Road (59.3 mg/L); Shaker's Crossing had the highest average TSS concentration (100.5 mg/L). Total suspended solids in the tributaries were highest at Buck Run and Twomile Creeks (>55 mg/L).

Total coliform bacteria abundance was elevated in the main stem at Pioneer Road (6,022 CFU/100 mL) and high at the outlet (Shaker's Crossing: 9,666 CFU/100 mL; Fig. 8). The highest average bacterial abundance was observed at two tributary sites (Twomile and Buck Run Creeks, >12,000 CFU/100 mL).

Conclusions from Average Annual Nutrient Concentrations

Concentrations of all analytes generally increased from the main stem site at Faulkner Road to the main stem site at Shaker's Crossing. Buck Run and Twomile

Creeks, which were high in TP, SRP, TN, and coliform bacteria, are responsible for the major increases observed on the main stem of Canaseraga Creek between Pioneer Road and Shaker's Crossing. Both of these tributaries contain agricultural practices, such as dairy farms and corn cultivation that appear to be the source, but were further investigated using segment analysis. Also noteworthy of the increase in nutrients at Shaker's Crossing is the close upstream proximity of the Mt. Morris WWTP, a significant source of all analytes.

The increase in TSS concentration along the main stem from Faulkner Road to Dansville suggests that erosion along the main stem is occurring, especially considering the low average TSS concentration at the Stony Brook tributary. Downstream, TSS concentration rose from Pioneer Road to Shaker's Crossing, which could also indicate main stem erosion since the two monitored tributaries (Twomile and Buck Run Creeks) between these two main stem sites had average TSS concentrations similar to the main stem at Pioneer Road.

Annual Sediment and Nutrient Loadings

Annual sediment and nutrient loads were calculated at each main stem (Faulkner Road, Dansville, Pioneer Road and Shaker's Crossing) and tributary (Stony Brook, Mill Creek, Twomile Creek and Buck Run Creek) routine monitoring site using observed concentration multiplied by predicted daily discharge (Table 6, Fig. 5). Loadings of TP, TN, nitrate, TSS, and total coliform bacteria increased moving downstream in the main stem, from Faulkner Road to Shaker's Crossing (Table 10; Fig. 9). Soluble reactive phosphorus loading decreased in the main stem from

Faulkner Road (0.7 MT/yr) to Dansville (0.3 MT/yr) but increased dramatically at each successive downstream main stem site, to a high of 9.9 MT/yr at Shaker's Crossing. Shaker's Crossing, the furthest downstream main stem site, had the highest annual loads for all analytes (Table 10). A large increase in all loadings was observed between main stem sites Pioneer Road and Shaker's Crossing. Higher loadings of TN, nitrate, and coliform bacteria from Twomile Creek suggest that it is a partial source to Canaseraga Creek (Fig. 9). Upstream from Pioneer Road, loadings of all analytes were comparatively low, especially at the Stony Brook and Mill Creek tributaries. The low loadings in the upstream sections of Canaseraga Creek indicate that the nutrient sources upstream from Pioneer Road are relatively minor.

Areal Loadings

Areal loadings were calculated by dividing the total annual load for a segment by the segment area in order to normalize the results for easier comparison. To calculate load for a segment of the main stem, the upstream load was subtracted from the downstream load. The upstream area was also subtracted from the downstream area for this calculation. This normalization gives loading for each segment in terms of mass units (kg) per land area (ha), so that each site's contribution is adjusted for its size. Negative areal loads indicate that a decrease in loading was observed in that segment, possibly due to sedimentation.

Areal loads of TP (2.4 kg/ha/yr), SRP (0.6 kg/ha/yr), TSS (1,254 kg/ha/yr), TN (17.6 kg/ha/yr), and TC (6.4E+11 CFU/ha/yr) were highest at the Buck Run Creek tributary (Fig. 10, Table 11). Buck Run Creek accounts for only 2% of the total

Canaseraga Creek watershed area but contributes a substantial amount of sediment and nutrients per unit area. Twomile Creek had the second highest areal TC (4.9E+11 CHU/ha/yr) load and elevated areal loads of all other analytes, which paralleled the high loadings observed at the main stem site at Pioneer Road. Main stem site Pioneer Road had the highest TN (14.3 kg/ha/yr), nitrate (11.0 kg/ha/yr) and coliform bacteria (4.6E+11 CFU/ha/ye) areal loads of all main stem sites. A negative areal SRP load was observed at Dansville (-0.03 kg/ha/yr), which indicates that this segment is a sink for SRP (Table 11). The high loadings observed at Buck Run and Twomile Creeks contributed to increases in areal loadings of TP, SRP, and TSS in the main stem segment from Pioneer Road to Shaker's Crossing. The lower TN, nitrate, and coliform loadings at Shaker's Crossing indicate that the main stem segment from Pioneer Road to Shaker's Crossing is acting as a nutrient, sediment, and bacterial sink. The flat topography allows for settling of particulates and biologic uptake of nutrients. The decrease in bacterial abundance indicates that die-off is occurring as the organisms are transported downstream away from their source.

Monthly Loadings

Loadings were highest in the late winter and spring months (February to May), which was heavily influenced by snowmelt runoff (Figs. 11-16). The summer months (June to September) had much lower loadings due to less runoff caused by increased canopy cover and plant uptake. Less rainfall from June through July (Fig. 17) is also another cause of the lower loadings. Nitrogen (TN and nitrate) loadings were also elevated in the late fall to early winter months (October – January; Figs. 13

and 14). Besides one large event in November, precipitation was low in this time period, indicating that the elevated nitrogen was caused by increased groundwater recharge as a result of decreased uptake by plants. Bacterial loadings had a less distinct trend, with the highest loads observed in May (Fig. 16). High values were observed in other months such as in November at Twomile Creek, Pioneer Road, and Shaker's Crossing. This high value amidst other sites with low loadings at that time suggests that the agricultural land use in those areas is the cause of increased bacterial loading. Also, the consistently high bacterial loadings at Shaker's Crossing when all others are low (such as in the summer and winter months) suggest that the Mt. Morris WWTP (Fig. 6) is contributing bacteria during low flows and throughout the winter.

Wastewater Treatment Plant Sampling by Location

Canaseraga Wastewater Treatment Facility, 21 June 2011

The WWTP for the Village of Canaseraga, NY, is located in the upper reaches of Canaseraga Creek along the main stem (Fig. 6). The WWTP is allowed to discharge 379 m^3/d (100,000 GPD) but on average discharges 146 m^3/d (38,571 GPD; Table 7a) into Canaseraga Creek. The effluent from the Canaseraga WWTP had high TP (3,573.3 µg P/L), SRP (3, 211.7 µg P/L), TN (5.72 mg N/L) and nitrate (4.80 mg N/L) concentrations. Using the daily average discharge and effluent P concentrations resulted in an estimated daily TP and SRP load of 0.5 kg P/d (Table 7b). Total suspended solids were very low (0.6 mg/L), and TC were not detectable in the effluent. Wilcoxon test results indicated that samples taken ~1 m below the WWTP were not statistically greater than those taken ~ 1 m above in SRP, nitrate, or TC

(Table 7). However, there were significant but not drastic increases in TP, TN, and TSS. Total nitrogen increased 6.3% (from 0.64 ± 0.01 upstream to 0.68 ± 0.02 downstream), TP increased 27.2% (from 20.2 ± 1.0 upstream to 25.7 ± 2.2 downstream), and TSS increased 141.2% (from 1.7 ± 0.4 upstream to 4.1 ± 1.6 downstream). The fact that there was no significant difference between above and below samples for other analytes could be due to the discharge pipe design or better treatment.

The discharge pipe is perforated and runs across the width of the stream and might dilute effluent more than a standard outfall pipe. Low flows are another cause, since the facility does not always discharge at full capacity (personal communication: Duane Gates, Canaseraga Sewer Plant Supervisor). Also, noteworthy of the Canaseraga WWTP is its modern sequencing batch reactor design. The process includes aeration, removal of solids, sludge beds with vegetation, sand filters, and finally ultraviolet light disinfection. The purpose of the sludge beds is to collect the sludge that is not removed mechanically and allow the effluent to infiltrate into the soil and be bioremediated by vegetation.

Dansville Wastewater Treatment Plant, 26 July 2011

The Dansville WWTP is located downstream from the routine sampling location at Dansville (Fig. 6), and is the largest WWTP in Canaseraga Creek watershed. The effluent pipe is located on the opposite bank from the plant and empties on top of the bank where effluent trickles into the stream at a limit of 5,678

m^3/d (1,500,000 GPD) (Fig. 18, Table 7a). The average discharge for the Dansville WWTP is 5,209 m^3/d (1,376,190 GPD; Table 7a).

The Dansville WWTP was sampled on 26 July 2011 ~30 m downstream from the bank where the effluent is discharged. Effluent from the Dansville WWTP had high TP (725.6 µg P/L), SRP (224.8 µg P/L), TN (10.16 mg N/L), nitrate (9.64 mg N/L), and total coliform bacteria (50,000 CFU/100 ml) but low TSS (6.7 mg/L; Table 7a). Estimated daily TP loading to Canaseraga Creek is 3.3 kg P/d, while SRP is 1.0 kg P/d (Table 7b). Wilcoxon test results indicated TP, SRP, TN, nitrate, and TC to be significantly higher below the discharge point (Table 7). Total phosphorus increased 349% from 57.9 ± 1.0 to 260.0 ± 12.4 µg P/L, while SRP increased 1,286% from 9.6 ± 0.4 to 133.1 ± 3.9 µg P/L. Total nitrogen and nitrate increased by 214 and 286%, respectively. Total coliforms increased 51% from 18,800 ± 1,855 to 28,400 ± 2,482 CFU/100 mL. Total suspended solids were not significantly greater downstream from the Dansville WWTP when compared to the upstream site.

Nunda Village Sewage Treatment Plant, 12 July 2011

The Nunda WWTP drains into a small manmade ditch, which runs a short distance before emptying into Keshequa Creek at an average rate of 386 m^3/d (102,000 GPD) (Figs. 6, 19; Table 7a). The effluent from the Nunda WWTP was high in TP (3,653.8 µg P/L), SRP (2,878.8 µg P/L), TN (20.84 mg N/L), nitrate (18.81 mg N/L), and coliform bacteria (18,000 CFU/100 mL), but low in TSS (2.1 mg/L; Table 7). Daily TP and SRP loading from the Nunda WWTP were approximately 1.4 kg P/d and 1.1 kg P/d, respectively (Table 7b). A Wilcoxon test determined a significant increase in analyte concentration medians between replicate samples taken upstream versus ~20 m downstream for TP, SRP, TN, nitrate, and TC (Table 7). Total phosphorus increased 2,021% from 12.8 ± 0.8 to 271.5 ± 63.5 µg P/L, and SRP increased drastically by 6,671% from 3.8 ± 0.2 to 257.3 ± 63.2 µg P/L. The increases in TN (1.12 ± 0.01 to 2.54 ± 0.34 mg N/L, a 127% increase), and nitrate (0.90 ± 0.00 to 2.30 ± 0.32 mg N/L, a 153% increase) were not as high as with phosphorus. Total coliforms were high above but still increased by 29% below the WWTP outfall (10,600 ± 808 to 13,680 ± 1,105 CFU/100 mL)

Groveland Station Wastewater Treatment Facility, 19 July 2011

The Groveland Station WWTP drains directly into Canaseraga Creek at a maximum rate of 246 m^3/d (65,000 GPD) but discharges an average of 32 m^3/d (8,452 GPD) and is the smallest WWTP in Canaseraga Creek watershed (Fig. 6, Table 7a). The effluent from the Groveland Station WWTP was very high in TP (6,426.5 µg P/L) and SRP (5,618.8 µg P/L), high in TN (5.63 mg N/L), nitrate (3.58 mg N/L), and total coliform bacteria (20,100 CFU/100 mL), but low in TSS (4.2 mg/L; Table 7a). The loading of phosphorus from the Groveland Station WWTP was the lowest of all WWTPs due to the low average daily discharge (TP: 0.2 kg P/d and SRP: 0.2 kg P/d; Table 7b). Samples taken ~7 m below the discharge point were determined to be significantly higher in TP, SRP, TN, and TSS than those taken above (Table 7). Total phosphorus increased 41% from 24.4 ± 1.0 to 34.4 ± 1.4 µg P/L, while SRP increased more drastically than TP, with downstream samples being 192% higher (from 5.2 ± 0.7 to 15.2 ± 2.7 µg P/L).

Wayland Village Sewage Treatment Plant, 9 August 2011.

The Wayland WWTP drains into a small creek, which later empties into Wayland Pond and eventually joins Mill Creek (Fig. 6). The maximum regulated flow is 1,325 m^3/d (350,000 GPD), but the average discharge is 668 m^3/d (176,486 GPD; Table 7a). The Wayland effluent contained high concentrations of TP (3,292.5 µg P/L), SRP (1,542.3 µg P/L), TN (23.09 mg N/L), nitrate (21.47 mg N/L), and total coliform bacteria (50,000 CFU/100 mL; Table 7a). However, TSS were low (5.3 mg/L). Estimated daily P loadings were moderately high, with approximate losses of 2.1 kg P/d and 1.0 kg P/d for TP and SRP, respectively (Table 7b). Concentrations of TP, SRP, TN, nitrate, and total coliform bacteria in the creek were significantly higher ~ 118 m below the effluent pipe than above (Table 7a). Total phosphorus increased by 4,514% (from 35.2 ± 7.1 to 1,624.3 ± 90.5 µg P/L) and SRP increased even more dramatically by 18,559% (from 7.5 ± 0.4 to 1,399.4 ± 33.5 µg P/L). Total nitrogen increased from 1.84 ± 0.06 to 5.47 ± 0.11 mg N/L, an increase of 197%, while nitrate increased by 227% (from 1.62 ± 0.03 to 5.29 ± 0.10 mg N/L). Total coliform bacteria were high above the WWTP but increased by 232% downstream of the effluent (from 14,440 ± 2,024 to 48,000 ± 7,899 CFU/100 ml).

Mt. Morris Wastewater Treatment Facility, 14 December 2011

The Mt. Morris WWTP has a maximum allowable discharge of 3,271 m^3/d (864,000 GPD) but discharges 1,545 m^3/d (408,238 GPD; Table 7a) on average. The effluent from the Mt. Morris WWTP was very high in phosphorus (TP: 3,565.8 µg P/L; SRP: 2,748.2 µg P/L), nitrogen (TN: 32.66 mg N/L; nitrate: 25.18 mg N/L), and extremely high in total coliforms (154,000 CFU/100 mL; Table 7a). Total suspended solids were elevated (21.5 mg/L). Daily phosphorus loading estimates from the Mt. Morris WWTP were the highest of all WWTPs in Canaseraga Creek watershed (TP: 5.4 kg P/d, SRP: 4.2 kg P/d; Table 7b). Wilcoxon test results indicated significant differences in all analytes measured, with downstream samples (~10 m downstream from the discharge point) being higher than upstream. Total phosphorus increased by 2,577% (from 18.4 ± 0.2 to 492.6 ± 26.8 µg P/L), while SRP increased by even more (8,445%, from 4.2 ± 0.2 to 358.9 ± 20.2 µg P/L). Total nitrogen increased from 1.57 ± 0.03 to 4.38 ± 0.20 mg N/L, an increase of 179%. Nitrate had a similar trend, wherein an increase of 123% was observed (from 1.45 ± 0.02 to 3.23 ± 0.11 mg N/L). Total suspended solids increased by 66%, from 7.1 ± 0.3 to 11.8 ± 0.4 mg/L downstream of the WWTP. Total coliform bacteria increased by 2,259%, from 2,340 ± 169 to 55,200 ± 5,678 CFU/100 mL.

Groveland Correctional Facility, 21 February 2012

The Groveland Correctional Facility in Sonyea, NY, has its own sewage treatment plant that is allowed to discharge 3,028 m^3/d (800,000 GPD) but discharges 1,264 m^3/d (334,000 GPD) on average (Fig. 6, Table 7a). The effluent from this facility had high concentrations of phosphorus (TP: 3,487.4 µg P/L; SRP: 3,487.4 µg P/L) and nitrogen (TN: 18.76 mg N/L; nitrate: 16.88 mg N/L; Table 7a). However, TSS (14.3 mg/L) and coliforms (2,100 CFU/100 mL) were low. Daily phosphorus loadings from the Groveland Correctional Facility were the second highest in Canaseraga Creek watershed of all WWTPs (TP: 4.4 kg P/d, SRP: 4.4 kg P/d; Table

7b). Samples were taken 1 m upstream and ~10 m downstream from the discharge point. Wilcoxon test results indicated that all measured analyte mean concentrations below the discharge point were significantly greater than the above (Table 7a). There were very large percentage increases in total phosphorus (from 4.9 ± 0.3 to 2,973.7 ± 17.9 µg P/L, 60,588%), SRP (from 0.8 ± 0.2 to 2,812 ± 76.0 µg P/L, 351,438%), TN (from 1.25 ± 0.02 to 18.37 ± 0.13 mg N/L, 1,370%), nitrate (from 0.99 ± 0.02 to 16.43 ± 0.39 mg N/L, 1,560%), TSS (from 3.4 ± 0.2 to 47.2 ± 7.5 mg/L, 1,288%), and total coliform bacteria (from 320 ± 111 to 1,380 ± 66 CFU/100 mL, 331%).

Chronological Account of Stressed Stream Analysis

Initial Sampling (8 February 2011)

Initially, 13 locations were sampled under nonevent conditions during a scoping visit to determine which sites to choose for routine monitoring (Fig. 4). Shaker's Crossing, the farthest downstream main stem site, had the highest TP concentration (50.9 µg P/L) and Stony Brook, which flows through Stony Brook State Park, had the lowest (4.3 µg P/L; Fig. 20). The second highest value (46.4 µg P/L) was observed at Buck Run Creek, which passes through several acres of agricultural fields and one large CAFO (Fig. 3). The third highest TP concentration was at the furthest upstream main stem site, Faulkner Road (21.7 µg P/L); TP concentration decreased at the next downstream main stem site (Dansville, 12.4 µg P/L).

Soluble reactive phosphorus ranged from non-detectable to 29.9 µg P/L

(Fig. 20). Buck Run Creek had the highest value for SRP (29.9 µg P/L) with Shaker's Crossing having the second highest (22.2 µg P/L). This small tributary with such a high nutrient value suggests a phosphorus source upstream of the sampling site. Further sampling was conducted to discover this source on 15 March 2011 (discussed later under Buck Run Creek Segment Analysis). The third highest SRP concentration on 8 February 2011 was at Faulkner Road (14.0 µg P/L). The two lowest values (non-detectable; P<0.5 µg/L) for SRP were at main stem sites- Dansville and the Dansville USGS site nearby.

The furthest downstream main stem site at Shaker's Crossing had the highest value for TN (1.64 mg N/L), while the most upstream main stem site at Faulkner Road had the lowest (0.56 mg N/L; Fig. 21). Nitrate, however, was highest at the middle main stem site at Pioneer Road (1.30 mg N/L), while the lowest nitrate concentration (0.48 mg N/L; Fig. 21) was upstream at Faulkner Road. There was a large increase in TN and nitrate concentration from Faulkner Road to the next downstream main stem sites, after which TN and nitrate concentrations became more consistent until Pioneer Road (TN, 1.46 mg N/L; nitrate, 1.30 mg N/L). Shaker's Crossing had the highest TN value but the second lowest nitrate value (0.59 mg N/L).

Total suspended solids were highest at Dansville (15.8 mg/L) and lowest at Stony Brook (2.0 mg/L) (Fig. 22). The lower values seen at Shaker's Crossing (7.7 mg/L) and Pioneer Road (8.0 mg/L), as compared to the Dansville site (15.8 mg/L), could be due to decreased water velocity. Since downstream reaches of Canaseraga Creek (moving from Dansville to Shaker's Crossing) level out into the Groveland

Flats area (Fig. 2), the slower water would cause suspended solids to settle. In general, there was no clear trend for TSS downstream of Faulkner Road (4.9 mg/L), which had the lowest concentration of main stem sites and the second lowest value of all sites. Total coliforms were detected at three sites: Shaker's Crossing (3,600 CFU/ 100 mL), Pioneer Road (1,600 CFU/ 100 mL), and Keshequa Creek (200 CFU/ 100 mL; Fig. 22).

Conclusions from Initial Sampling, 8 February 2011

Shaker's Crossing had an elevated SRP concentration, and the highest TP, TN and coliform concentrations. Likely sources are the Mt. Morris WWTP (Fig. 6, Table 7) and/or the nearby Buck Run Creek tributary, which had the highest SRP (29.9 μg P/L) concentration and elevated TP (46.4 μg P/L; Fig. 20) and TN (1.15 mg N/L; Fig. 21). The source of high nutrients at Buck Run Creek may be related to a large CAFO upstream from the sampling point (Mt. Morris Dairy Farms, Inc.; Fig. 3, Table 4). Downstream from Faulkner Road, Canaseraga Creek runs through a steep gorge, where main stem erosion likely accounts for the high total suspended solids at Dansville (Fig. 23).

High nitrate concentrations made up the majority of TN, especially at forested upstream sites. Due to the lack of other potential sources, groundwater was likely a major source of N. Moving downstream, the higher TN values observed at main stem sites Pioneer Road and Shaker's Crossing reflect sources such as WWTPs, agriculture, and tributary contribution.

Buck Run Creek

Stressed Stream Analysis, 15 March 2011

Potential sources of TP in Buck Run Creek were investigated because of elevated TP levels on 18 February 2011 (1,631.2 µg P/L). A segment analysis was performed under nonevent conditions on five sites along Buck Run Creek. One large CAFO (Mt. Morris Dairy Farms, Inc.) was found within the subbasin between sites 4 and 3 (water flows from site 5 to site 1; Fig. 24). The CAFO has 1,430 dairy cows and 2,050 acres of land (829.6 ha; Table 4).

Both TP and SRP were elevated at sites 1 to 3 and markedly lower at sites 3 and 4 (Fig. 25). The largest percentage increase between successive sites for TP and SRP (586.7%, 551.7%, respectively) occurred between site 4 (TP: 21.1 µg P/L; SRP: 14.5 µg P/L) and site 3 (TP: 144.9 µg P/L; SRP: 94.5 µg P/L). Total nitrogen displayed a similar pattern, with the largest percentage increase (208.5%) occurring between site 4 (0.59 mg N/L) and site 3 (1.82 mg N/L; Fig. 25). Site 5 had a low nitrate concentration (0.10 mg N/L) but increased at site 4 (0.32 mg N/L) and site 3 (0.92 mg N/L), a 187.5% increase. Nitrate concentration at downstream Buck Run Creek sites remained high (site 2: 0.79 mg N/L; site 1: 0.97 mg N/L).

While TSS were not very high (0.8 to 3.8 mg/L), a noticeable increase was visible between sites 4 and 3 that concurs with phosphorus and nitrogen patterns (Fig. 25). The only analyte that was markedly higher upstream than downstream was total coliforms, which were highest at site 5 - the furthest upstream (Fig. 25). The high coliforms could be due to a pond upstream from the site which connects by a roadside ditch.

Conclusions from Buck Run Creek Segment Analysis, 15 March 2011

The data suggest that the CAFO between sites 3 and 4 is a source of TP, SRP, TN, nitrate, and TSS and thus is the nutrient source to Buck Run Creek. A possible explanation for the high nutrient concentrations observed is the collection of retention ponds that drain directly into Buck Run Creek (Fig. 26). The ponds lie in a small valley created by sloping topography, which inevitably receives runoff from the surrounding fields and dairy cow barns. These retention ponds are collecting nutrient and manure runoff from the nearby fields and barns and then draining into Buck Run Creek. Cutting off the flow from the ponds to the creek would be an effective way to cease their contribution. Alternatively, decreasing the amount of runoff by using management practices such as conservation tillage and cover crops would decrease the amount of nutrients transported from the farm to the creek.

Buck Run Creek Segment Analysis, 10 May 2011

Buck Run Creek was sampled again on 10 May 2011 under nonevent conditions at sites 3 and 4 and at a tributary upstream from the CAFO (Fig. 24). The purpose was to determine if the tributary was acting as a source of nutrients to Buck Run Creek. Total phosphorus was high downstream from the CAFO at site 3 (526.1 µg P/L) but lower upstream from the CAFO at site 4 (28.3 µg P/L) and lower at the tributary between those sites (49.6 µg P/L; Fig. 27). Soluble reactive phosphorus followed the same pattern (site 3: 195.8 µg P/L; site 4: 16.5 µg P/L; tributary: 22.1 µg P/L; Fig. 27). Total nitrogen was distinctly higher downstream from the CAFO at site 3 (4.80 mg N/L) than at either site 4 or the tributary (0.67 and 0.56 mg N/L, respectively; Fig. 27). Nitrate was quite different, however, with non-detectable concentrations at site 3, 0.39 mg N/L at site 4, and 0.01 mg N/L in the tributary between them (Fig. 27). The elevated nitrate at site 4 could be due to the presence of several small ponds upstream from the site.

Total suspended solids were generally low at all sites, although higher than on the previous sampling date (site 3: 8.0 mg/L; site 4: 2.8 mg/L; tributary: 5.9 mg/L) (Fig. 27). Total coliforms were elevated at all sites, with the highest occurring in the tributary (2,000 CFU/100 mL), followed by site 3 (1,600 CFU/100 mL) and site 4 (1,000 CFU/100 mL; Fig. 27).

Conclusions from Buck Run Creek Segment Analysis, 10 May 2011.

The much higher phosphorus values for site 3 compared to the two upstream sites (site 4 and the tributary) again suggest that there is a source of phosphorus between them and that it is not the tributary. The very high total nitrogen value for site 3 and the low values for site 4 and the tributary suggest that there is a major source of nitrogen between the sites, concurring with the previous segment analysis and ruling out the tributary as a nitrogen input. Nitrate, however, was very low for all sites. Nitrate was highest at site 4 (upstream of the CAFO) but was similar to previous findings (0.39 mg N/L vs. 0.32 mg N/L). The non-detectable nitrate concentration and the high total nitrogen concentration at site 3 suggest that the source of nitrogen is occurring almost entirely in the organic fraction, indicating animal waste. Total suspended solids were higher at site 3 than at the tributary or site 4, again suggesting a source. The high number of total coliform bacteria in the tributary could be due to close proximity with manure since the tributary runs through a cultivated field. The results of this additional investigation indicate the CAFO (Mt. Morris Dairy Farms, Inc.) as a source of TP, SRP, TN, and TSS to Buck Run Creek.

Twomile Creek

Stressed Stream Analysis, 5 April 2011

Persistent high concentrations of TP (261.2 and 244.6 µg P/L on 18 February and 15 March 2011, respectively) and TSS (138.0 and 126.0 mg/L on 18 February and 15 March 2011, respectively) in Twomile Creek suggested that there are sources upstream of the routine site (Fig. 28). This tributary is dominated by deciduous and mixed forest, with patches of agriculture (mostly corn and hay) in its steeper upstream reaches (Fig. 3). Near the confluence with Canaseraga Creek (between site 1 and the routine Twomile Creek site), Twomile Creek becomes very flat and is joined by two ditches with extensive drainage networks through agricultural fields (i.e., the Groveland Flats, Fig. 2) and Bradner Creek. Agricultural areas tend to be close to or bordering the channel of Twomile Creek and its sub-tributaries. Additionally, a CAFO (Sparta Farms, Table 4) with 2,555 dairy cows is located along Twomile Creek just before the confluence with Canaseraga Creek (between site 1 and the routine site). In order to determine the location of nutrient sources, a segment analysis was performed on seven locations along Twomile Creek in addition to the routine weekly sample during event conditions on 5 April 2011 (Fig. 28).

Phosphorus concentrations started low at upstream site 7, with no detectable SRP and relatively low TP (14.5 µg P/L, Fig. 29a). At site 6, a jump in both TP and

SRP concentrations was seen (76.7 and 29.2 µg P/L, respectively) with SRP being the highest of all sites. Site 6 is just downstream from a small farm with cattle barns and from several corn fields and ponds. Total phosphorus, however, did not surpass the level seen at site 6 until site 1, when it reached 108.6 µg P/L. Both measures of phosphorus increased between site 1 and the routine site, which includes a CAFO, the discharge from drainage ditches and Bradner Creek (TP: 153.2 µg P/L; SRP: 21.3 µg P/L).

Nitrogen followed a similar pattern with a noticeable increase between sites 7 and 6 (Fig. 29b). Site 7 had 0.34 mg N/L of TN and no detectable nitrate. At site 6, TN increased to 0.74 mg N/L; nitrate was 0.17 mg N/L. These levels remained relatively consistent until site 1, where concentrations were slightly higher (TN: 0.87 mg N/L; nitrate: 0.28 mg N/L). The most notable increase in TN and nitrate was between site 1 and the routine sampling site, which had 1.60 mg N/L of TN and 0.92 mg N/L of nitrate (an increase of 83.9% and 228.6%, respectively). Between the routine sampling site and site 1, there is a CAFO and the Groveland Flats area.

Total suspended solids for the seven Twomile Creek sites were quite low (highest at site 1: 35.7 mg/L) when compared to the routine site (107.3 mg/L; Fig. 29c). Total coliform bacteria counts followed a generally opposite trend from the other analytes (Fig. 29d). There were no bacteria found at site 7, but the next site (site 6) had the most of all sites on this date (34,000 CFU/100 mL), which was downstream from a small farm. Total coliform abundance then decreased from site 5 (14,000 CFU/100 mL) to site 2 (4,300 CFU/100 mL). As with other analytes, an increase from site 2 to site 1 (10,000 CFU/100 mL) was observed. Total coliform abundance decreased slightly from site 1 to the routine site (8,700 CFU/100 mL).

Conclusions from Twomile Creek Segment Analysis, 5 April 2011

The Twomile Creek segment analysis had relatively low nutrient concentrations in its headwaters at site 7 (Fig. 28). Moving downstream, concentrations (especially coliform bacteria) increased at site 6 due to manure runoff from a small cattle farming operation with animal barns, corn fields, and several ponds. After site 6, concentrations decreased and were relatively stable until site 1, where increases in TP, TN, TSS, and coliforms were observed. The area between sites 2 and 4 is characterized by patches of cultivated fields with some forested areas between them. After site 2, Twomile Creek enters Sonyea State Forest, in which the creek becomes steep (approx. 15.9 m/km) and enters a small gorge (Fig. 30). This section is a potential cause of elevated nutrients at site 1 due to the increased erosive force of the creek caused by the elevation gradient. Also, there is a tributary that drains corn and soybean fields that enters Twomile Creek between sites 2 and 1. However, TP, TN, nitrate, and TSS all increased distinctly downstream at the routine Twomile Creek site, indicating that these upstream areas are not the major sources of nutrients to Twomile Creek. Downstream from site 1, Twomile Creek passes Sparta Farms and is joined by the agricultural drainage ditches from the Groveland Flats and Bradner Creek. The most noticeable increases were in TP, TSS, TN, and nitrate. Further investigation is required on these other waterways to determine the source of the increased nutrient concentrations observed between site 1 and the routine site.

Groveland Flats Investigation

24 May 2011 (Twomile Creek subwatershed)

The 5 April 2011 trip suggested that there were nutrient inputs coming from ditches draining cultivated fields (the Groveland Flats area) and/or from Bradner Creek, a tributary of Twomile Creek (Fig. 31). The two ditches (A and B) drain a large area of cultivated fields (mostly corn). The fields also run along Bradner Creek. There is a CAFO (Sparta Farms, Table 4) along Twomile Creek between the segment analysis site (Twomile 1) and the routine sampling site at Twomile Creek (Fig. 31). Notably, the fields draining to the ditches were flooded at the time of this sampling (event conditions).

Total phosphorus was lowest at Twomile 1 (93.9 µg P/L), highest in Bradner Creek (214.6 µg P/L) and also high in both ditches (ditch A: 169.4 µg P/L; ditch B: 171.0 µg P/L; Fig. 32). Soluble reactive phosphorus was lowest at Twomile 1 (20.2 µg P/L) and highest at Ditch A (56.7 µg P/L; Fig. 32).

Total nitrogen was extremely high at Ditch B (35.63 mg N/L), the next highest was at Bradner Creek (2.96 mg N/L), and the lowest was at Twomile 1 (0.85 mg N/L; Fig. 33). Nitrate followed a similar pattern with Ditch B having a much higher value than the rest of the sites (31.20 mg N/L), the next highest at Bradner Creek (1.78 mg N/L), and the lowest at Twomile 1 (0.13 mg N/L) (Fig. 33).

Total suspended solids were lowest at Ditch B (14.0 mg/L) and highest at the routine Twomile Creek site (91.0 mg/L). Bradner Creek had the second highest TSS concentration (84.0 mg/L; Fig. 34). Total coliform abundance was also lowest at

Ditch B (8,900 CFU/100 mL) but highest at Ditch A (60,000 CFU/100 mL), with Twomile 1 being a close second (58,000 CFU/100 mL; Fig. 34). Bradner Creek and the Twomile routine site were similarly high in total coliform abundance (38,000 CFU/100 mL).

Conclusions from Groveland Flats Investigation, 24 May 2011

The analysis indicates that Bradner Creek and the two ditches contribute high concentrations of TP and TN to Twomile Creek during event conditions. Since ditch B is not connected to Bradner Creek, it serves as a source of nutrients to Ditch A, which connects to Twomile Creek (Fig. 31). The cause of high nitrogen and total coliform concentrations is fertilizer and manure runoff from the surrounding corn fields from a recent storm that left the fields flooded during the time of sampling. The lack of both cover on the fields and a buffer zone between the fields and the ditches also contributes to high TSS concentrations because there is no barrier to prevent runoff from scouring the fields and emptying into the ditches. The cause of the much lower TSS at Ditch B compared to the other sites is settling since the flow in Ditch B is very slow or stagnant, while Ditch A and Bradner Creek move at a rate of approximately 0.40 and 0.32 m/s, respectively, and were consequently higher in TSS concentration.

Further Investigation of the Groveland Flats Area

Samples were collected at the same locations four more times (14 June, 7 September, 28 September 2011, and 1 May 2012; Fig. 31) in order to better understand the movement of nutrients flowing through the area. The June sampling date represented nonevent conditions, causing Ditch B to be dry, while the September and May sampling dates represented event conditions. Using several dates for these locations elucidated some patterns.

Total phosphorus concentrations were highest at the two ditches (Ditch A average = 166.1 µg P/L; Ditch B average = 794.3 µg P/L) and lowest at Twomile 1 (average = 42.9 µg P/L) and Bradner Creek (average = 86.6 µg P/L; Fig. 35). The routine Twomile Creek site had concentrations between these extremes (average = 123.1 µg P/L). Soluble reactive phosphorus was highest at Ditch B (average = 104.4 µg P/L), which overshadowed the other sites (averages= Ditch A: 21.2 µg P/L; Twomile 1: 11.3 µg P/L; Bradner Creek: 18.9 µg P/L; Twomile Creek routine: 19.4 µg P/L; Fig. 35).

Nitrogen concentrations showed different trends than phosphorus. Ditch B had the highest average concentration for TN and nitrate because of the extremely high concentrations observed on 24 May 2011 and 1 May 2012 (averages= TN: 20.25 mg N/L; nitrate: 14.20 mg N/L; Fig. 35). On other dates, Ditch B had high, though not as extreme, concentrations of TN, whereas nitrate was very low for this site. For TN, Bradner Creek averaged the next highest (1.95 mg N/L) followed by Ditch A (1.82 mg N/L). Twomile 1 had the lowest TN concentration on average (0.56 mg N/L). The average TN concentration at the routine Twomile Creek site was most similar to Ditch A (1.53 mg N/L). Nitrate was very low at Ditch B with the exception of the May samples, indicating that nitrate concentration at Ditch B is almost entirely event driven (Fig. 35). Nitrate was consistently low at Twomile 1 (average = 0.18 mg N/L).

Ditch A also had a low nitrate concentration (average = 0.51 mg N/L). Bradner Creek had a high average nitrate concentration (1.16 mg N/L), which may have played a part in the elevated average concentration at the routine Twomile Creek site (0.76 mg N/L).

Total suspended solids displayed a distinct trend with the ditches having the highest values (averages= Ditch A: 96.5 mg/L; Ditch B: 109.5 mg/L), followed by the routine site (average = 69.8 mg/L; Fig. 35). Twomile 1 had the lowest value (average = 19.4 mg/L) and Bradner Creek was moderately high (average = 38.8 mg/L). Total coliform bacteria were highest at Ditch A (average = 47,920 CFU/100 mL), which was almost twice as high as the next site's average (Twomile Creek routine: 26,580 CFU/100 mL; Fig. 35). The bacteria source to Ditch A is manure application on the surrounding corn fields, which flood directly into the ditch during events. Twomile 1 was similar to the routine site in total coliform abundance (average = 22,860 CFU/100 mL), while Bradner Creek and Ditch B were relatively similar (averages= Bradner Creek: 19,900 CFU/100 mL; Ditch B: 15,100 CFU/100 mL).

Conclusions from Groveland Flats Sampling

The results from these sampling dates suggest the ditches draining the Groveland Flats and Sparta Farms are sources of TP, TN, TSS, and TC to Twomile Creek, especially during event conditions. The soluble portion of phosphorus was highest at Ditch B, which drains south to Ditch A (Fig. 31), which was similar in SRP to Bradner Creek and the routine Twomile Creek site. The very high nitrogen concentrations on the two May dates at Ditch B indicate that the ditch system is driven by precipitation, which causes sediment and nutrients to run off unimpeded into the ditch network. Bradner Creek was consistently high in TN and nitrate and is acting as a source of nitrogen to Twomile Creek. Total suspended solids and total coliform bacteria were highest at Ditch A, suggesting that it is the largest source of TSS and TC to Twomile Creek of these sites. No observed flow (water was stagnant) at Ditch B contributed to the lower TSS concentrations, while Ditch A (0.40 m/s) and Bradner Creek (0.32 m/s) had elevated TSS due to faster velocities, which kept sediment suspended in the water. Twomile 1 (Fig. 31), being upstream from Sparta Farms and the Groveland Flats, was determined not to be a source of TP, SRP, TN, nitrate, or TSS because of the lower concentrations observed at that site. The elevated total coliform abundance at Twomile 1 could be due to upstream agricultural activities and is discussed separately.

The observation that Twomile 1 was low in nutrient concentrations when compared to the other sites provides additional evidence that the upstream forested reaches of Twomile Creek are not causing the elevated concentrations at the routine Twomile Creek site. This investigation also provided additional evidence that the Groveland Flats (Fig. 2), which is almost entirely corn fields, contribute high concentrations of all analytes except SRP. The low SRP concentrations (except at Ditch B) and high TSS concentrations can indicate that phosphorus was binding to sediment. Low SRP concentrations can also indicate uptake by plants. The purpose of the ditch network in the Groveland Flats area is to drain the naturally low-lying land, which tends to flood frequently, for farming. Since there is a network of ditches that drain these flood-prone fields, runoff is able to take a more direct route from the field to the ditch, with little impediment from riparian buffers or cover crops. Accordingly, the ditches move not just excess water out of the Flats but sediment and nutrients as well.

Since the purpose of the ditches is to drain the fields for agriculture, management goals should focus on mitigating the effect of cultivation on the ditch water quality. The addition of buffer strips/zones is a simple solution that could prevent sediment and nutrients from entering the ditches. Contour cropping, cover crops, and conservation tillage are other common best management practices. A more sophisticated approach to reduce sediment and sediment-bound phosphorus loss from Twomile Creek would be the installation of settling basins or other structures to capture sediment before being transported into Canaseraga Creek.

Groveland Flats Investigation on Bradner Creek, 7 September 2011

Bradner Creek originates in steep, forested terrain upstream from the Groveland Flats and flows northward into the flats area before joining Twomile Creek (Fig. 36). Bradner Creek was targeted to investigate nutrient concentrations upstream versus downstream from the Groveland Flats. Samples were taken just upstream of the flats (sites 1 and 2), in the flats (site 3), and further downstream from the flats (site 4) on 7 September 2011 during event conditions (Fig. 36). The farthest downstream sample (site 4) is the same location previously mentioned in the Groveland Flats Investigation (Fig. 31).

Total phosphorus in Bradner Creek was similar at the two upstream sites (site 1: 34.2 µg P/L; site 2: 30.2 µg P/L) but increased by 137% at site 3 (71.7 µg P/L; Fig. 36). At downstream site 4, TP was lower (63.7 µg P/L). Soluble reactive phosphorus was similar at all sites, ranging from 20.2-24.0 µg P/L (Fig. 36).

Total nitrogen was highest at site 1 (1.83 mg N/L) and decreased steadily throughout remaining sites to reach 1.32 mg N/L at Bradner Creek site 4 (Fig. 37). This trend is similar for nitrate, which began at 1.57 mg N/L at site 1 and ended at 0.75 mg N/L at site 4 (Fig. 37).

Total coliform bacteria were present at the two upstream sites (site 1: 7,400 CFU/100 mL; site 2: 6,800 CFU/100 mL) but increased by 429% at site 3 (36,000 CFU/100 mL; Fig. 37). Downstream at site 4 (12,300 CFU/100 mL), coliforms were 66% lower than at site 3.

Total suspended solids were lowest at the two upstream sites (4.7 mg/L) and increased by 483% at site 3 (27.4 mg/L; Fig. 36). Downstream, TSS decreased by 48% (14.3 mg/L).

Conclusions from Groveland Flats Investigation on Bradner Creek, 7 September 2011

The data from this investigation provide evidence that the Groveland Flats area is a considerable source of TP, TSS, and coliform bacteria to Bradner Creek. Concentrations of these analytes were lower upstream from the Groveland Flats at Bradner Creek sites 1 and 2 due to the stream's origin in mainly forested terrain. Total phosphorus, TSS, and bacteria increased downstream due to the heavy agricultural (corn) activity and lack of buffer zones between the fields and the stream. The vast, flat corn fields are prone to erosion due to reduced soil cover and tendency to flood, as evidenced by the 483.0% increase in TSS concentration between sites 2 and 3. There is also little to no barrier between the fields and streams/ditches. A vegetative buffer zone would aid in slowing runoff from fields and capturing sediment before it enters a waterway by providing a barrier. The decreases in analytes between site 3 and the downstream site can be partially explained by the very flat topography beginning after site 1, which causes sediment and sediment-bound nutrients to settle. Other causes of the nutrient decrease are plant uptake, since the area is primarily in agricultural use, and dilution of nutrients.

Twomile Creek Segment Analysis, 1 May 2012

Eight samples were taken between Twomile Creek segment analysis sites 1 and 2 under event conditions due to the increases in nutrient concentrations observed on 5 April 2011 (Fig. 38). Tributary site D was taken because it was the only accessible forested watershed. Samples were also taken at Ditch A, Ditch B, Bradner Creek, and the routine Twomile Creek site in order to isolate the effects of nutrient sources upstream from Twomile Creek site 1 from the ditches, Bradner Creek, and Sparta Farms. Notably, Ditch B was stagnant.

Total phosphorus at Twomile Creek site 2 (82.0 µg P/L) was much higher than SRP (7.8 µg P/L; Fig. 38). Nearby tributary sites A (TP: 291.6 µg P/L; SRP: 67.2 µg P/L) and B (TP: 113.2 µg P/L; SRP: 40.2 µg P/L) were elevated due to retention ponds, cattle farms, and corn fields (Fig. 39). Tributary site C (TP: 34.1 µg P/L; SRP: 1.5 µg P/L) was lowest in phosphorus of the upstream stream segments near Twomile

Creek site 2. Downstream at Twomile Creek site 1, phosphorus (TP: 76.0 µg P/L; SRP: 7.7 µg P/L) was lower than at site 2, indicating that dilution from tributaries was occurring. Tributary site E (TP: 70.5 µg P/L; SRP: 18.9 µg P/L) and site F (TP: 60.5 µg P/L; SRP: 17.6 µg P/L) lie along a small stream with hay, soybean, and forested land uses, which joins the stream from site A before entering Twomile Creek upstream from site 1. Tributary D (TP: 28.1 µg P/L; SRP: 5.8 µg P/L), flowing from the forest, had low phosphorus concentrations. Compared to Twomile Creek site 1, both ditches along with Bradner Creek and the routine Twomile Creek site (TP: 137.7 µg P/L; SRP: 18.5 µg P/L) were higher in phosphorus concentration (Fig. 38).

Nitrogen at upstream Twomile Creek site 2 (TN: 1.47 mg N/L; nitrate: 0.84 mg N/L) was elevated (Fig. 40). Nearby tributary B (TN: 2.41 mg N/L; nitrate: 1.38 mg N/L) was much higher in nitrogen concentration, while tributary C (TN: 1.27 mg N/L; nitrate: 0.87 mg N/L) was lower. The cause of elevated nitrogen at tributary site B is the collection of ponds at a small cattle farm (Fig. 39). Nitrogen was by far the highest of Twomile Creek sites at tributary site A (TN: 15.26 mg N/L; nitrate: 12.67 mg N/L), which originates in a pond and flows through a corn field (Fig. 39). Downstream along the main stem of Twomile Creek, nitrogen was lower at site 1 (TN: 1.28 mg N/L; nitrate: 0.72 mg N/L) than at site 2 due to dilution from sites D (TN: 0.38 mg N/L; nitrate: ND), E (TN: 1.02 mg N/L; nitrate: 0.14 mg N/L), and F (TN: 0.90 mg N/L; nitrate: 0.69 mg N/L). Nitrogen increased downstream from Twomile Creek site 1 at the routine Twomile Creek site (TN: 1.65 mg N/L; nitrate: 0.90 mg N/L) due to contributions from Ditch A (TN: 1.82 mg N/L; nitrate: 0.98 mg

N/L) and Bradner Creek (TN: 1.62 mg N/L; nitrate: 1.03 mg N/L; Fig. 40). Ditch B was very high in nitrogen (TN: 35.63 mg N/L; nitrate: 25.60 mg N/L) but was not flowing.

Total suspended solids were elevated in the main stem of Twomile Creek at site 2 (36.8 mg/L) but lower at tributary sites B, C, D, E, and F (Fig. 38). Tributary A (52.3 mg/L) had the highest TSS concentration of all Twomile Creek tributary sites, which was also higher than the downstream main stem site 1 (41.5 mg/L). Compared to Twomile Creek site 1, the ditch samples and Bradner Creek were higher in TSS concentration, which contributed to high TSS at the Twomile Creek routine site (80.3 mg/L; Fig. 38).

Total coliform bacteria were elevated at most sites on this sampling date. Twomile Creek site 2 (27,900 CFU/100 mL) was high in bacteria, but tributary site A (100,000 CFU/100 mL) was even higher as a result of the corn fields and cattle farm upstream (Fig. 40). Tributaries B (21,800 CFU/100 mL) and C (20,200 CFU/100 mL) were elevated and also have some agricultural areas upstream from the sampling locations, including retention ponds, cattle barns, and corn fields. Twomile Creek site 1 (20,800 CFU/100 mL) was lower in total coliforms than upstream site 2, due to the lower bacterial abundances observed at tributary sites E (19,500 CFU/100 mL), F (12,000 CFU/100 mL), and D (3,000 CFU/100 mL). An increase in coliform bacteria was observed between Twomile Creek site 1 and the routine Twomile Creek site (33,500 CFU/100 mL), which is due to the ditches, Bradner Creek, and Sparta Farms (Fig. 40).

Conclusions from Twomile Creek Segment Analysis, 1 May 2012

This segment analysis provided insight into source areas in Twomile Creek between sites 1 and 2. Tributary A was very high in phosphorus, nitrogen, bacteria, and TSS while tributaries B, A, E, and F were high in phosphorus. These samples indicate that agricultural practices along these small streams have the potential to impact water quality in Twomile Creek. However, on this date, no large increase of TP, SRP, TN, nitrate, or TC was observed between sites 1 and 2, suggesting that there was dilution occurring in Twomile Creek, mitigating the effects of high tributary concentrations. An increase of 12.8% in TSS concentration between Twomile Creek sites 1 and 2 indicates that the steep topography and Tributary A are minor sediment contributors when compared to the 93.5% increase in TSS between site 1 and the Twomile Creek routine site (Fig. 38). Increases in all analyte concentrations between site 1 and the routine site further support the conclusion that the upstream nutrient sources to Twomile Creek are minor compared to the two ditches, Bradner Creek, and Sparta Farms.

Mill Creek

Mill Creek Segment Analysis, 16 August 2011

Mill Creek subwatershed was chosen for segment analysis because of its large area, mixture of land uses, and consistently moderate nutrient concentrations. The Mill Creek subwatershed is located in the southeastern corner of Canaseraga Creek watershed (Figs. 3, 4 and 41). The land uses in this subwatershed are primarily deciduous forest, followed by agriculture (corn and hay), with some residential-including part of Dansville and all of Wayland (including the Wayland WWTP). Mill Creek undergoes a steep elevation drop in its middle reach (between sites MC 7 and MC 6) and flattens out at Dansville. This segment analysis included 11 main stem sites and three tributary sites (MC 4, MC 5, MC 14) in addition to the routine Mill Creek site during nonevent conditions. Site MC 8 was hidden by a wooded area off the road and was unable to be located for sampling.

Total phosphorus in Mill Creek at site MC 15 was 17.5 µg P/L and decreased slightly at subsequent main stem sites until site MC 10, where TP rose to 17.5 µg P/L, similar to site 15 (Fig. 41). There was an 80.0% increase in TP from site MC 10 to site MC 9 (31.5 µg P/L) and a 51.1% increase in SRP (site MC 10: 4.7 µg P/L; site MC 9: 7.1 µg P/L). Between sites MC 10 and MC 9, several ditches join Mill Creek from nearby corn fields which include a small pond.

Soluble reactive phosphorus decreased after site MC 15 (11.2 µg P/L) and remained low until site MC 7 (TP: 87.2 µg P/L; SRP: 18.2 µg P/L), where TP and SRP concentrations increased from site MC 9 (TP: 176.8% increase; SRP: 156.3% increase; Fig. 41). The reach from site MC 9 to site MC 7 includes a tributary flowing from the Village of Wayland, which contains sewage treatment plant effluent. Samples taken on 9 August 2011 below the Wayland WWTP were significantly higher in concentration than those taken above, in all analytes except TSS (Table 7a). A 23.3% increase in TP was observed from site MC 7 to site MC 6 (107.5 µg P/L), which coincides with the presence of a gorge that begins at site 7 and extends just past site MC 6 (Fig. 42). Phosphorus concentration remained consistently high in the main stem of Mill Creek after this location, reaching a TP maximum at site MC 3 (111.3 µg P/L) and SRP maximum at site MC 6 (19.3 µg P/L). Downstream, TP and SRP decreased slightly at the routine site (TP: 93.2; SRP: 17.4 µg P/L). Sites MC 4 and MC 5, taken from the Little Mill Creek tributary, were lower in TP and SRP than nearby main stem sites.

Nitrogen was lowest at main stem site MC 15 (TN: 0.53 mg N/L; nitrate: 0.37 mg N/L) and generally increased throughout the main stem to site MC 10 (TN: 1.58 mg N/L; nitrate: 1.39 mg N/L; Fig. 43), possibly due to agricultural activities closely situated to the creek or to groundwater recharge containing nitrate. Total nitrogen and nitrate then decreased farther down the main stem from site MC 9 to site MC 7 (TN: 1.07 mg N/L; nitrate: 0.47 mg N/L), a 34.4% and 63.6% decrease respectively. Dilution and/or plant uptake from the tributaries between these sites is suspected as the cause of the nitrogen decrease. Mill Creek runs through a small forested wetland upstream from site MC 7, which likely is responsible for nitrogen uptake by vegetation (Coveney *et al.* 2002, Fennessy *et al.* 2008, Richardson *et al.* 2011). After site MC 7, nitrogen remained relatively consistent throughout Mill Creek. The Little Mill Creek tributary sites MC 5 and MC 4 had slightly higher nitrogen concentrations than nearby main stem sites, but since lower concentrations were observed downstream at site 3 (TN: 1.11 mg N/L; nitrate: 0.51 mg N/L) this tributary was not a suspected nitrogen source.

Total suspended solids in Mill Creek subwatershed were generally low at the upstream sites (Fig. 44). Site MC 15 had the lowest concentration (2.0 mg/L) of all sites, which slowly rose in concentration until site MC 7 (16.5 mg/L). Site MC 6 had a much higher TSS concentration (50.0 mg/L) than site MC 7, a 203.0% increase. This is attributed to stream bank erosion, since the increase occurs in the section where Mill Creek enters a gorge. In fact, this reach has been found to be the largest sediment source to Mill Creek (Mansue *et al.* 1991; Fig. 42). Main stem site MC 3 had the highest TSS concentration of all sites (69.7 mg/L), which is also due to the steep topography which ends between sites 6 and 3. The Little Mill Creek tributary sites MC 5 and MC 4, which were low in TSS (5.3 and 12.0 mg/L), join Mill Creek just downstream from main stem site MC 3. Total suspended solids steadily decreased in the main stem from site MC 3 to the routine site (45.3 mg/L), which was due to dilution from Little Mill Creek and settling since the topography becomes much more flat in this section.

Total coliform bacteria were detected at site MC 15 (4,300 CFU/100 mL), the furthest upstream site (Fig. 44). A generally increasing trend was observed along Mill Creek to a high of 20,000 CFU/100 mL at main stem sites MC 3 and MC 1. There was a 37.5% increase in coliform bacteria abundance from site MC 9 to site MC 7 (8,800 to 12,100 CFU/100 mL) due to the Wayland WWTP, which is a significant source of TP, SRP, TN, nitrate, and total coliform bacteria (Table 7a). The two sites on Little Mill Creek were comparatively low in total coliform bacteria (site MC 5: 4,500 CFU/100 mL; site MC 4: 5,000 CFU/100 mL). Site MC 2 (12,000 CFU/100 mL) had a much lower total coliform abundance than site MC 3, which is from dilution from Little Mill Creek. Downstream at main stem site MC 1, bacterial abundance increased by 66.7% from site MC 2. The segment from site MC 2 to site MC 1 includes several residences and a golf course. The number of coliform bacteria at the routine sampling site (11,700 CFU/100 mL) was much lower than site MC 1, possibly due to shading from increased canopy cover.

Conclusions from Mill Creek Segment Analysis, 16 August 2011

This segment analysis found no major nutrient or sediment sources upstream from site MC 11, which includes Loon Lake. The tributary Little Mill Creek (sites MC 4 and MC 5) was also determined not to be a source of any analytes to Mill Creek. High concentrations of TP, SRP, and coliform bacteria were observed downstream at site MC 7, downstream from where the Wayland WWTP effluent stream joins Mill Creek. The Wayland WWTP was sampled on 9 August 2011 and determined to be a significant source of all analytes except TSS (Table 7a). The gorge, beginning at site MC 7 and extending just downstream from site MC 6, was a source of TP and TSS. This observation agrees with past findings that identified this reach as a major sediment source (Mansue *et al.* 1991). The decrease in TSS and TP downstream from site MC 3 is due to settling, since the topography in that area is much flatter than upstream. Bacterial abundance increased distinctly downstream from the confluence with the Wayland WWTP effluent stream, but the highest values were observed in the village of Dansville. Notably, the highest concentrations of coliform bacteria were observed downstream from a golf course (site MC 1), a residential area (site MC 2), and an auto-auction parking lot (Site MC 3).

Mill Creek Segment Analysis, 31 August 2011

Due to the results from prior segment analysis, further investigation of Mill Creek's upstream tributaries was conducted under nonevent conditions. The sampling date included main stem site MC 8, which was located with help from local citizens. Phosphorus on this sampling date (Fig. 45) was generally low in the upstream reaches of Mill Creek, from main stem site MC 12 to site MC 9, despite the elevated concentrations observed in some tributaries (e.g., sites A-1, A-3, and A-4). An increase in phosphorus was observed from site MC 9 (TP: 10.6 µg P/L; SRP: 3.8 µg P/L) to site MC 8 (TP: 22.6 µg P/L; SRP: 4.6 µg P/L) and to a lesser extent at site MC 7 (TP: 28.1 µg P/L; SRP: 6.8 µg P/L; Fig. 45). After site MC 8, a tributary enters Mill Creek that flows from the Village of Wayland WWTP (Table 7), which accounts for the high TP concentrations at tributary sites A-6 (1,326.9 µg P/L) and A-8 (168.0 µg P/L; Fig. 45). Phosphorus site MC 6 (TP: 28.8 µg P/L; SRP: 6.4 µg P/L) was similar to site MC 7. The routine site had lower phosphorus concentrations (TP: 13.5 µg P/L; SRP: 3.7 µg P/L), mostly due to dilution from tributaries. The increases in phosphorus concentration in the upstream portions of Mill Creek on this sampling date are likely due to inputs by small tributaries such as sites A-1, A-3, and A-4.

Nitrogen in Mill Creek was similar at main stem sites. Site MC 10 had the highest TN concentration (1.43 mg N/L) of main stem sites (Fig. 46). Although some tributaries had high nitrogen values (e.g. A-1, A-3), a decrease in nitrogen was observed from site MC 10 to site MC 9 (1.14 mg N/L). Total nitrogen again decreased at site MC 8 (0.98 mg N/L) but increased at site MC 7 (1.18 mg N/L) due to the effluent stream from Wayland WWTP, which is a significant source of TN and nitrate (Table 7a). There was a small decrease in TN concentration throughout the stream, with the routine site having 0.95 mg N/L. Nitrate followed a very similar pattern, ending at 0.75 mg N/L at the routine site.

Total suspended solids were generally low, due to nonevent conditions. Several tributaries were high in TSS (A-1: 16.0 mg/L; A-3: 24.3 mg/L; A-4: 12.0 mg/L; Fig. 47) compared to other sites on this date. However, this only accounted for an 8.8% increase in TSS concentration from main stem sites MC 10 (5.7 mg/L) to MC 9 (6.2 mg/L). A 148.6% increase was observed from site MC 8 (3.7 mg/L) to site MC 7 (9.2 mg/L), between which an entering tributary had the highest TSS concentration of all sites (A-8: 26.8 mg/L; Fig. 47). This tributary, site A-8, takes a very straight course through forests and wetlands from Wayland Pond. The channelization of the tributary and of Mill Creek in this section appears to be a remnant from an old railroad. Upstream from Wayland Pond at site A-6 (17.5 mg/L), TSS were lower than at A-8, indicating that the pond and the wetland areas are contributing TSS to this tributary. Site A-6 was taken downstream from the Wayland WWTP, which is not a significant source of TSS. Therefore, sources of TSS exist upstream from the Wayland WWTP. Site MC 6 had the highest TSS of all main stem sites (15.8 mg/L) due to the gorge in the segment downstream from site MC 7 extending just past site MC 6. The flattening of terrain after site MC 6 probably accounts for the decrease at the routine site (4.5 mg/L).

Total coliform bacteria were, in general, low in main stem sites and higher in tributaries. Tributary sites A-4 (22,000 CFU/100 mL) and A-6 (34,000 CFU/100 mL) had the highest number of coliform bacteria due to their connection to corn fields where any manure application can easily spread into these ditches (Fig. 47). A pattern similar to other analytes was observed, where site MC 9 (1,700 CFU/100 mL) had a lower number of coliform bacteria than site MC 8 (4,200 CFU/100 mL). Site MC 7 (4,600 CFU/100 mL) had a similar number of coliform bacteria as site MC 8, suggesting that the effluent stream from the Wayland WWTP contributed minimally to total coliform abundance. The minimal contribution from the WWTP can be explained by the decrease in bacteria from site A-6 (34,000 CFU/100 mL) to site A-8 (7,100 CFU/100 mL), between which are Wayland Pond and forested wetlands. Total coliforms were much lower downstream at site MC 6 (1,000 CFU/100 mL), and only slightly higher downstream near the outlet (2,400 CFU/100 mL; Fig. 47).

Conclusions from Mill Creek Segment Analysis, 31 August 2011

Although this segment analysis occurred under nonevent conditions, some patterns did develop. Increases in analytes from site MC 8 to site MC 7 indicate that the effluent stream from Wayland WWTP between these sites is a source of TP, SRP, TN, TSS, and total coliform bacteria. Concentrations of all analytes except TSS decreased from site A-6 (just downstream from the WWTP) to site A-8 (downstream from Wayland Pond and wetland areas). Even though decreases in analytes were observed in the area between sites A-6 and A-8 (e.g. TP: site A-6, 1,326.9 µg P/L; site A-8, 168.0 µg P/L), the resulting effluent stream was still determined to be a source to Mill Creek. The large decrease in nutrient concentrations from site A-6 to site A-8 can be attributed to Wayland Pond and wetland areas between them, which provide nutrient uptake and dilution. The other tributary coming from the vicinity of Wayland between main stem sites MC 9 and MC 8 was not sampled because it was overgrown with vegetation and was not visible.

Mill Creek Segment Analysis, 23 April 2012

Mill Creek was revisited under event conditions in order to further investigate the steep gorge in its middle section, as well as tributary inputs. Of special interest was the stream flowing from the Village of Wayland, which carries WWTP effluent and is a significant source of TP, SRP, TN, nitrate, and total coliform bacteria (Table 7), and another tributary coming from the Wayland area.

The small tributary originating north of the Village of Wayland was low in phosphorus from its beginning near site A-6-6 (TP: 14.6 µg P/L; SRP: 5.0 µg P/L) to site A-6-2, where it was dry (Fig. 48). Field investigation of the area around site A-6-2 revealed that it was in fact not flowing; it was later discovered that this stream is usually dry or is diverted outside the watershed, possibly due to an old spillway connected to Hemlock Lake (personal communication: Terry Fairbrother, Village of Wayland Highway Superintendant and Public Works Supervisor). Phosphorus was high at site A-6-1 (TP: 461.0 µg P/L; SRP: 20.6 µg P/L) due to stormwater runoff (personal communication: Terry Fairbrother, Village of Wayland Highway Superintendant and Public Works Supervisor). The Wayland WWTP caused increased phosphorus concentrations downstream at site A-6 (TP: 574.9 µg P/L, SRP: 574.9 µg P/L), while Wayland Pond and wetland areas caused decreases in phosphorus downstream at site A-8 (TP: 122.4 µg P/L; SRP: 12.6 µg P/L), due to dilution and possibly biological uptake.

Main stem site MC 9 (TP: 23.0 µg P/L; SRP: 5.7 µg P/L) was the furthest upstream main stem site sampled on this date. Downstream at main stem site MC 8 (TP: 21.3 µg P/L; SRP: 5.3 µg P/L), there was a decrease in phosphorus despite the high concentrations observed at tributary site A-5 (TP: 132.4 µg P/L; SRP: 18.3 µg P/L; Fig. 48), which could be due to a wetland area or dilution from the main stem. Main stem site 7-1 (TP: 44.1 µg P/L; SRP: 7.4 µg P/L) is downstream from the confluence of site MC-8 (main stem) and A-8 (Wayland WWTP effluent stream). Since no other tributaries join between these segments, these samples provide evidence that the effluent stream from Wayland (site A-8) contributes phosphorus.

Downstream, tributary sites A-4 and A-2 (Fig. 49) enter the main stem and contribute phosphorus to Mill Creek due to runoff from cattle farms. Between main stem sites MC 7 (TP: 47.0 µg P/L; SRP: 20.7 µg P/L) and MC 6 (TP: 71.7 µg P/L; SRP: 7.0 µg P/L), there was a 52.6% increase in TP concentration but a 66.2% decrease in SRP. This TP increase coincides with the gorge feature in this area (Fig. 42). Downstream at the outlet (Mill Creek routine site; TP: 86.2 µg P/L; SRP: 3.9 µg P/L), TP was high due to main stem site MC 3, which had the highest TP (101.9 µg P/L) concentration. Site MC 3 is influenced by the gorge, which terminates upstream from the site. Little Mill Creek provided dilution into Mill Creek because it had lower phosphorus concentrations (site MC 4, TP: 47.0 µg P/L; SRP: 3.0 µg P/L).

Nitrogen on this sampling date was high in the tributary north of the Village of Wayland (e.g. site A-6-3, TN: 5.45 mg N/L; nitrate: 5.05 mg N/L) but was much lower at site A-6-1 (TN: 1.25 mg N/L; nitrate: 0.51 mg N/L) after the tributary went dry upstream at site A-6-2 (Fig. 50). Downstream from the Wayland WWTP, nitrogen was very high at site A-6 (TN: 5.15 mg N/L; nitrate: 4.94 mg N/L) but was considerably decreased at site A-8 (TN: 1.33 mg N/L; nitrate: 0.03 mg N/L) after it flowed through Wayland Pond and wetlands. A decrease in nitrogen was observed between main stem sites MC 9 and MC 8 (TN: 1.12 mg N/L; nitrate: 0.71 mg N/L) due to dilution as the creek enters pooled water in a wetland area along the main stem in that segment. At main stem site MC 7-1 (TN: 1.17 mg N/L; nitrate: 0.55 mg N/L), TN was slightly higher than site MC 9 while nitrate was lower due to site A-8. Downstream along the main stem, nitrogen decreased and remained relatively low until the routine Mill Creek outlet site (TN: 1.08 mg N/L; nitrate: 0.62 mg N/L; Fig. 51).

Total suspended solids were low in the Wayland tributary before it disappears at site A-6-2 but were very high at site A-6-1 (154.0 mg/L), where the stream emerges from the ground as a stormwater discharge pipe (Fig. 48). Downstream at site A-6 (4.5 mg/L), TSS were much reduced due to dilution from the Wayland WWTP and settling. After the stream flowed through Wayland Pond and wetland areas to site A-8 (10.1 mg/L), TSS were over twice as high as upstream site A-6, indicating that this area contributes sediment. Site A-5 was high in TSS (56.3 mg/L) but was diluted by main stem site MC 9 (9.5 mg/L) and the wetlands downstream from both sites, after which TSS decreased at main stem site MC 8 (3.4 mg/L). Total suspended solids remained relatively low until a very large increase of 449.4% was observed in the main stem between sites MC 7 and MC 6 (42.3 mg/L) primarily due to the gorge-like topography between those sites (Figs. 42, 49). Tributary A-2 (28.9 mg/L) was observed to be a secondary TSS source. Downstream at the routine Mill Creek site (60.4 mg/L), TSS were lower in part due to dilution from Little Mill Creek (34.6 mg/L).

Total coliform bacteria were very high in the Wayland tributary at site A-6-1 (16,400 CFU/100 mL) due to stormwater runoff from the Village of Wayland (Fig. 50) but were actually lower downstream from the Wayland WWTP at site A-6 (10,600 CFU/100 mL). As observed with other analytes, decreases were observed between site A-6 and site A-8 (400 CFU/100 mL) and between sites MC 9 (2,700 CFU/100 mL) and MC 8 (1,000 CFU/100 mL; Fig. 50); both segments include wetland areas. Bacterial abundance increased by 142.9% between sites MC 7-1 (1,400 CFU/100 mL) and MC 7 (3,400 CFU/100 mL) due to a cattle farm upstream from tributary site A-4 (17,100 CFU/100 mL; Fig. 52), and by 32.4% between sites MC 7 and MC 6 (4,500 CFU/100 mL) due to a cow pasture upstream from site A-2 (12,600 CFU/100 mL; Fig. 51). Downstream in the main stem, total coliform bacteria abundance decreased at site MC 3 (3,300 CFU/100 mL) and the routine Mill Creek outlet site (2,000 CFU/100 mL), partially due to dilution from Little Mill Creek (site MC 4: 2,800 CFU/100 mL).

Conclusions from Mill Creek Segment Analysis, 23 April 2012.

This sampling date displayed the importance of wetland areas in the Mill Creek subwatershed in reducing nutrient concentrations (TP, SRP, TN, nitrate, total coliforms) especially in the Wayland tributary, which receives WWTP effluent and stormwater runoff. Samples taken on this date also provide further evidence that the gorge feature beginning after site MC 7 (Fig. 42) and ending upstream from site MC 3 is a major source of sediment in the Mill Creek subwatershed, which was also concluded by the USGS (Mansue *et al.* 1991). Tributary sites A-4 and A-2 were determined to be sources of TP, SRP, TSS, and coliform bacteria (Figs. 49, 51, and 52). Site A-4 was downstream from a cattle farm through which the stream flows, while site A-2 was directly downstream from a cow pasture. Dilution from the main stem and other tributaries (especially Little Mill Creek, site MC 4) mitigates the effect of these sources in the Mill Creek subwatershed.

Mud Creek Segment Analysis, 21 September 2011

Mud Creek lies between the routine Dansville and Pioneer Road main stem sites, where increases in TP, SRP, and total coliform bacteria were observed (Figs. 4 and 53). Mud Creek was targeted for segment analysis to determine if it was contributing to the increase in these analytes. It flows directly through a residential area and then continues through a mixture of forested and cultivated land before joining with Canaseraga Creek. This segment analysis was taken at six locations along the main stem of Mud Creek during nonevent conditions in order to determine if it is contributing to the increase in TP, SRP, and coliform bacteria observed in Canaseraga Creek between Dansville and Pioneer Road.

Total phosphorus was low in the upstream portion of Mud Creek at sites 1-3, which transitions abruptly from a forested to a dense residential land use at site 2 (Fig. 54). A marked increase was seen at site 4 (22.7 µg P/L) when compared to upstream site 3 (6.3 µg P/L, 260.3% increase). The creek between sites 3 and 4 is bordered by a public park consisting mostly of baseball fields on one side and residential suburban development on the other side. A very high TP value was observed (102.4 µg P/L, 351.1% increase) at site 5, which was downstream from several small tributaries originating in corn and hay fields that run through steep slopes before joining Mud Creek. Site 6 (20.7 µg P/L) was 79.8% lower in TP concentration than site 5, which could be due to dilution from forested streams, sedimentation, or biological uptake. The soluble portion of phosphorus was very low at all sites (<9 µg P/L) and followed the same trend as TP but with much lower concentrations.

Total nitrogen began in moderate concentration at site 1 (1.01 mg N/L) and decreased slightly at each successive site moving downstream to a low at site 5 (0.69 mg N/L; Fig. 55). Total nitrogen at site 6, however, sharply increased to the highest value for all sites (1.61 mg N/L, 133.3% increase). Nitrate followed this same pattern: a moderate value at site 1 (0.91 mg N/L), successive decreases with a low at site 5 (0.37 mg N/L), and a high at site 6 (1.43 mg N/L, 286.5% increase). The increase in nitrogen is likely due to corn fields that surround Mud Creek downstream from site 5 or from tributary input (Fig. 56).

Total suspended solids closely paralleled the trend observed in TP values (r^2 = 0.95; Figs. 57 and 58). Sites 1-3 had very low TSS values, which slightly increased at site 4 (8.3 mg/L), and reached a high at site 5 (23.4 mg/L). Site 6 also had a lower TSS value (6.3 mg/L) than the previous upstream site, as in TP. The increase in TSS is due to tributaries that drain agricultural fields and then flow through steep terrain before joining Mud Creek. The lower value at site 6 is due to sedimentation and dilution from tributaries that drain hay fields, forest, and low density residential land (Fig. 56).

Total coliform bacteria had an increasing trend beginning at site 1 (4,800 CFU/100 mL) and reaching a high a site 4 (19,000 CFU/100 mL; Fig. 59). Total coliforms then decreased downstream at site 5 (7,500 CFU/100 mL), and again at site 6 (2,300 CFU/100 mL). The increasing trend to site 4 coincides with increasing urban development, while the decreases at sites 5 and 6 coincide with less urban development (Fig. 60). Also, site 5 is influenced by tributary dilution, whereas other sites have no tributary input.

Mud Creek Segment Analysis Conclusions, 21 September 2011

The high values of TP and TSS at site 5 could be attributed to flow from several small tributaries that originate in corn and hay fields and run through very steep terrain before joining Mud Creek. The low values of TP and TSS seen downstream at site 6, however, suggest that some sediment settled between the sites or dilution from other tributaries occurred. The nitrogen source between sites 5 and 6 is likely due to land use between these sites, which is mostly forest and hay fields but does include some corn fields. Also, several small several streams join Mud Creek in this segment that originate in flat hay fields and low density residential areas and then become steep before the confluence. Coliform bacteria in Mud Creek were highest in the residential part of Dansville, NY, and decreased moving downstream, which suggests anthropogenic sources. The sedimentation of TP and TSS in Mud Creek during nonevent periods suggests that the creek will become a source during event periods when high flows flush these nutrients out of the tributary and into Canaseraga Creek.

Main Stem Segment Analysis, 28 September 2011

Seven segment analysis sites were sampled along with eight routine sampling locations in order to observe nutrient concentrations along the main stem during a moderate event (Fig. 61). Also, this segment analysis was conducted to guide further sampling efforts.

Total phosphorus was detected at moderately low levels in the furthest upstream main stem site at Faulkner Road (22.4 µg P/L; Fig. 61). The routine Mill Creek tributary site had an elevated TP concentration (30.9 µg P/L) compared to the main stem sites upstream (Dansville, 8.4 µg P/L) and downstream (SSA site 1, 17.4 µg P/L) from its confluence. Low TP concentrations in the main stem were observed until SSA site 2 (26.9 µg P/L). Site 2 was located downstream from the Dansville WWTP, a significant source of all analytes except TSS (Table 7). A decrease in TP concentration was observed at SSA site 3 (19.9 µg P/L), which coincided with a decrease in TSS and indicates that settling occurred. The Groveland Flats area begins between SSA sites 3 and 2. After SSA site 3, TP concentrations continued to rise until SSA site 5 (26.5 µg P/L). The segment from SSA sites 3 to 5 is very straight, flat and bordered on the west side by thinly buffered corn fields and by forest, hay, corn, and low density residential land uses on the east. The east side receives a multitude of small tributaries that drain steep forested slopes with patches of agricultural activity. After SSA site 5, there was a 59.2% increase in TP concentration at Pioneer Road (42.2 µg P/L), which is downstream of the Groveland Station WWTP - a significant TP source (Table 7). After Pioneer Road, TP concentrations were lower at SSA sites 6 and 7 (30.0 and 38.2 µg P/L, respectively). Segment analysis site 6 was sampled just downstream from Twomile Creek's (113.5 µg P/L) confluence with Canaseraga Creek, but may have been low due to slow moving water causing sedimentation. Downstream at SSA site 7, a low TP concentration was observed due to dilution from Keshequa Creek (not sampled on this date), which was found to be low in nutrients through prior sampling. Total phosphorus rose to 61.8 µg P/L at Shaker's Crossing, which had the second highest TP concentration due to a combination of corn farming along the main stem, influence from Buck Run Creek (58.8 µg P/L), and from the Mt. Morris WWTP. The Mt. Morris WWTP was identified as a significant source of all analytes to Canaseraga Creek (Table 7).

Soluble reactive phosphorus was detected at Faulkner Road (17.6 µg P/L; Fig. 61) but not at the next downstream main stem site at Dansville nor at the Stony Brook tributary between them. Downstream from the Dansville WWTP, SSA site 2 (12.6 µg P/L) had a higher SRP concentration than SSA site 1 (3.5 µg P/L), which was upstream. Soluble reactive phosphorus decreased successively at SSA sites 3 (9.4 µg P/L), 4 (6.3 µg P/L), and 5 (4.7 µg P/L), opposite to the trend for TP and TSS. The increasing TP and TSS concentrations and decreasing SRP concentrations at these sites indicate that phosphorus is being bound to sediment or utilized by vegetation. The Twomile Creek tributary had a relatively low SRP concentration (20.4 µg P/L) compared to TP concentration, again suggesting that phosphorus was being held by sediment. Main stem SSA site 6 was lower (4.6 µg P/L) in SRP concentration than Twomile Creek and Pioneer Road (7.1 µg P/L). A large increase (200.9%) was observed between main stem SSA site 7 (10.9 µg P/L) and Shaker's Crossing (32.8 µg P/L), which included Buck Run Creek (the highest in SRP: 47.4 µg P/L) and the Mt. Morris WWTP effluent.

Nitrogen values were low in the upstream reaches of Canaseraga Creek at Faulkner Road (TN: 0.63 mg N/L; nitrate: 0.51 mg N/L), slightly increasing at Dansville (TN: 0.81 mg N/L; nitrate: 0.67 mg N/L; Fig. 62). Nitrogen was lower at SSA site 1 (TN: 0.67 mg N/L; nitrate: 0.59 mg N/L) but increased by 50.7% for TN and 47.5% for nitrate at SSA site 2 (TN: 1.01 mg N/L; nitrate: 0.87 mg N/L), which was taken a short distance downstream of the Dansville WWTP (whereas SSA site 1 was upstream). The value observed at SSA site 2 remained consistent throughout the main stem (and Twomile Creek), ending at Shaker's Crossing (TN: 1.00 mg N/L; nitrate: 0.81 mg N/L). Buck Run Creek had the lowest TN concentration of all sites (0.56 mg N/L), while Twomile Creek had the lowest nitrate concentration (0.19 mg N/L).

Total suspended solids were generally low at all sites on this sampling date but were elevated at Twomile Creek (30.3 mg/L), Canaseraga Creek at Pioneer Road (19.7 mg/L), SSA site 7 (15.7 mg/L), and Shaker's Crossing (19.0 mg/L; Fig. 63). Also, an increasing trend was observed from SSA site 3 (2.1 mg/L) to Pioneer Road (19.7 mg/L), which suggests that main stem erosion and cumulative effects from many small tributaries are occurring. The high TSS concentration at Twomile Creek is a result of the heavy corn farming and hydrologic modification in that subwatershed, and is discussed under previous sections (Twomile Creek Segment Analysis). The decrease in TSS at SSA site 6, just downstream from Twomile Creek, is due to rapid settling of sediment due to the slow current, and to dilution from Canaseraga Creek. Dilution also occurs downstream from Keshequa Creek, which accounts for the slightly lower TSS at SSA site 7. In the segment downstream from SSA site 7 to Shaker's Crossing, the stream meanders greatly, has poor riparian buffer, and is downstream from the Mt. Morris WWTP effluent pipe- a significant TSS source (Table 7a).

Total coliform bacteria were generally low (<6,000 CFU/100 mL) in the upstream sites from Faulkner Road to SSA site 1 (Fig. 63). It was not until SSA site 2 (9,400 CFU/100 mL), below the Dansville WWTP, that a noticeable increase (129%) in coliform abundance occurred in the main stem. Total coliform abundance was variable until Pioneer Road (34,000 CFU/100 mL), which was 127% higher than upstream SSA site 5 (15,000 CFU/100 mL). Pioneer Road had the second highest coliform abundance and is located just downstream of the Groveland Station WWTP.

There was a sharp decline in coliform abundance downstream at site 6 (10,200 CFU/100 mL) and again at SSA site 7 (3,400 CFU/100 mL), the lowest value of all sites. Shaker's Crossing (11,700 CFU/100 mL) had an elevated bacterial abundance, possibly due to the Mt. Morris WWTP and influence from Buck Run Creek, which had the highest total coliform abundance of all sites (46,000 CFU/100 mL).

Conclusions from Main Stem Segment Analysis, 28 September 2011

The increase in TP, TN, nitrate, and coliform bacteria between sites 1 and 2 (Figs. 61-63) can be attributed to the Dansville WWTP (Fig. 6, Table 7a), which was shown to be a significant source of TP, SRP, TN, nitrate, and total coliform bacteria on 26 July 2011. Similarly for the TP increase from SSA site 5 to Pioneer Road, the Groveland Station WWTP was shown to be a significant source of TP, SRP, TN, and TSS on 19 July 2011 (Fig. 6, Table 7a). The increase in TP, SRP, and coliform bacteria from SSA site 7 to Shaker's Crossing is influenced by high concentrations from Buck Run Creek and from the Mt. Morris WWTP, which empties directly into Canaseraga Creek just upstream from Shaker's Crossing and is a significant source of all analytes (TP, SRP, TN, nitrate, TSS, and TC; 14 December 2011).

Sugar Creek Segment Analysis, 5 October 2011

The Sugar Creek tributary joins Canaseraga Creek downstream of the Village of Canaseraga and before Dansville (Fig. 64). It runs about 18 km through steep, mostly forested terrain, including state wildlife areas. This tributary is the only other major tributary besides Stony Brook that enters Canaseraga Creek between the Faulkner Road and Dansville main stem sites. Seven sites (site 6 was unattainable) were sampled during nonevent conditions in order to determine if Sugar Creek was acting as a source of TSS and nutrients to Canaseraga Creek (Fig. 63).

Total phosphorus in Sugar Creek was highest in the most upstream reaches and decreased moving downstream (Fig. 65). Site 8 (furthest upstream) had the highest concentration of TP (25.1 µg P/L), which decreased at site 7 (15.5 µg P/L), then increased again at site 5 (22.1 µg P/L). This upstream section contains several farms with surrounding hay, pasture, and corn fields. Soluble reactive phosphorus rose from site 8 (6.5 µg P/L) to a high at site 5 (10.2 µg P/L; Fig. 65). After site 5, TP and SRP concentrations decreased dramatically at site 4 (TP: 9.3 µg P/L; SRP: 2.8 µg P/L), then remained relatively consistent throughout Sugar Creek to site 1 (TP: 7.9 µg P/L; SRP: 1.8 µg P/L). The segment between sites 5 and 4 becomes very steep and entirely forested. The lack of nutrient sources in the forested section combined with tributary dilution accounts for the decrease in phosphorus concentrations.

Nitrogen was quite variable in Sugar Creek, and trends for TN and nitrate were similar (Fig. 66). Starting at site 8, TN was low and nitrate was the lowest of all sites (TN: 0.64 mg N/L; nitrate: 0.24 mg N/L). Nitrogen increased at site 7 (TN: 0.93 mg N/L; nitrate: 0.72 mg N/L), which was downstream from some hay and corn fields. Nitrogen concentration decreased at sites 5 (TN: 0.61 mg N/L; nitrate: 0.41 mg N/L) and 4 (TN: 0.38 mg N/L; nitrate: 0.31 mg N/L), in which there was an end to agricultural practices and the beginning of mostly forested land use. Site 3 had a higher TN concentration (0.61 mg N/L) and similar nitrate concentration as the previous site (0.32 mg N/L). Between sites 3 and 2 (TN: 1.14 mg N/L; nitrate: 0.95

mg N/L) are corn and soybean fields situated close to the stream (Fig. 67), where a large increase was observed; a slight increase at site 1 (TN: 1.20 mg N/L; nitrate: 1.14 mg N/L; Fig. 66) was also observed.

Since sampling occurred under nonevent conditions, TSS were low at all sites, with a high of 2.4 mg/L at site 3 (Fig. 68). Total suspended solids decreased from site 8 (2.1 mg/L) to site 4 (1.1 mg/L), where the creek becomes mostly forested. A large increase was observed at site 3, which was adjacent to a hay field with little riparian buffer (Fig. 69). A sharp decrease in TSS concentration was observed at sites 2 and 1 (0.6 and 0.7 mg/L, respectively). The section between sites 2 and 1 contains some agricultural fields but with forested buffer zones.

Total coliform bacteria were high at site 8 (8,000 CFU/100 mL) due to being directly downstream from cattle barns and hay fields. Bacterial abundance was much lower at site 7 (2,700 CFU/100 mL), which was mostly forested, and highest at site 5 (8,200 CFU/100 mL; Fig. 70). Site 5 was downstream from several corn and hay fields as well as a cattle farming operation. After site 5, coliform bacteria sharply decreased at site 4 (1,600 CFU/100 mL) and increased at the next two sites (site 3: 2,300 CFU/100 mL; site 2: 3,100 CFU/100 mL). Along this segment, the stream has riparian buffer zones next to hay, soybean, and corn fields along with cattle barns. Site 1 (1,700 CFU/100 mL) was the second lowest in total coliform abundance (after site 4).

Sugar Creek Segment Analysis Conclusions, 5 October 2011

Even though sampling occurred under baseline conditions, some patterns did arise. The relatively high values of TP (when compared to other sites on this date) at sites 8, 7, and 5 corresponded to similarly high values of TSS and land uses of hay, corn, and pasture located close to the creek. Also, sites 8 and 5 were highest in TP and total coliform bacteria. All analytes decreased from site 5 to site 4, which is due to the ~6-km course the creek takes through an almost entirely forested area with few tributaries joining in that segment. Nitrogen (TN and nitrate) was highest at the downstream sites of Sugar Creek, which is likely from agricultural influence, as the creek and some small tributaries run in and near crop fields. The ultimately low concentrations of analytes observed in Sugar Creek indicate that it is a minor nutrient source to Canaseraga Creek.

CAFO Sampling by Location

Merrimac Farms, 7 December 2011

Merrimac Farms contains about 660 dairy cattle and is located near the northern border of Canaseraga Creek watershed at the head of a small tributary that drains into Canaseraga Creek just downstream of the Shaker's Crossing site (Fig. 71, Table 4). Samples were taken downstream from the farm and on a nearby tributary without a CAFO for comparison because samples upstream from the CAFO were unable to be taken. Samples at sites MF 1-3 were taken near the CAFO, while samples at sites MF T, A, and B were taken on the tributary.

The site MF 1 sample was taken from a ditch that drained fields adjacent to the farm, while the site MF 2 sample was taken directly downstream from the farm.

Both were high in TP (MF 1 230.2: µg P/L; MF 2: 237.7 µg P/L), as was MF 3, which was downstream (170.3 µg P/L; Fig. 71). Site MF 3 was 26% lower than site MF 2, which was upstream. Tributary site MF A was high in TP (87.4 µg P/L), but MF B was quite low (13.0 µg P/L). Downstream from their convergence, the TP concentration was between these values (48.3 µg P/L). Concentrations of SRP followed a similar pattern, with MF 1 and 2 having high concentrations (93.4 and 91.5 µg P/L, respectively), and MF 3 having a 26% lower concentration (67.5 µg P/L) than MF 2. Tributary sites had lower SRP concentrations than the farm sites (MF A: 51.3 µg P/L; MF B: 1.4 µg P/L; MF T: 26.7 µg P/L).

Total nitrogen near the farm was highest at site MF 1 (8.43 mg N/L), lower at site MF 2 (7.19 mg N/L), and 9.7% lower downstream at MF 3 (6.49 mg N/L; Fig. 72). Total nitrogen concentrations in the tributary were variable. Site MF B had the lowest TN concentration (0.56 mg N/L), MF A was higher (3.88 mg N/L), and much higher downstream at MF T (7.02 mg N/L). This same trend was observed with nitrate concentrations. Near the farm, nitrate was highest at MF 1 (7.25 mg N/L), followed by MF 2 (6.47 mg N/L), and MF 3 (1.24 mg N/L). Tributary site MF B was lowest in nitrate (0.05 mg N/L), MF A was much higher (3.12 mg N/L), and MF T was higher still (6.06 mg N/L).

Sites downstream from the CAFO were all similarly low in TSS (MF 1: 6.4 mg/L; MF 2: 7.9 mg/L; MF 3: 8.0 mg/L; Fig. 71). Total suspended solids concentrations were more variable at tributary sites. Site MF B had the lowest concentration (1.4 mg/L), while MF A (17.4 mg/L) had the highest. Downstream at MF T (5.1 mg/L), TSS concentration was between MF A and MF B.

Total coliform bacteria were highest at the farm sites (Fig. 72), with MF 1 having a lower value (7,700 CFU/100 mL) than MF 2 (9,300 CFU/100 mL) and MF 3 (9,900 CFU/100 mL; Fig. 72). Tributary sites MF A (1,200 CFU/100 mL) and MF B (3,400 CFU/100 mL) were lower than MF T (8,700 CFU/100 mL).

Merrimac Farms Conclusions

The tributary site MF A was considerably higher in TP, SRP, TN, and nitrate than MF B, which was most likely due to some agricultural influence. However, site MF A was lower compared to the CAFO sites (48.7% lower in TP and 24.0% lower in SRP than site MF 3). Some agricultural practices (hay, corn fields) upstream from site MF A are potential causes of the elevated nutrient concentrations observed, but to a lesser extent than was observed at the CAFO sites. From the observation that the tributary sites not draining the CAFO (MF A, B, T) were lower in TP and SRP than those draining the CAFO (MF 1-3), it can be concluded that Merrimac Farms is a source of TP and SRP. Total nitrogen and nitrate were high at all farm sites but also high at MF T and elevated at MF A, which indicates that nitrogen sources are not limited to the area surrounding the CAFO. Nitrogen sources could be attributed to manure or fertilizer spreading on hay fields upstream and downstream from tributary site MF A.

Edgewood Farms 26 October 2011

Edgewood Farms has about 1,140 cows and is situated close to the northeastern boarder of Canaseraga Creek watershed, just upstream from the Pioneer Road site (Fig. 73, Table 4). Samples were taken during event conditions at five locations along the stream network that drains from the CAFO to determine if it was contributing to the increase of TP and coliform bacteria observed between Dansville and Pioneer Road. Since the farm lies at the very headwaters of this small stream, the only upstream sample able to be taken was at site A. Site A served as a surrogate sample for the two inaccessible streams, due to their similar land uses of corn, hay and alfalfa. Samples were taken at sites D and E for comparison. The purpose of this investigation was to determine if Edgewood farms is impacting stream water quality.

Total phosphorus upstream from the CAFO at site A was moderate (60.5 µg P/L, Fig. 73). Downstream from the CAFO and after the confluence of the three tributaries at site 1 (80.1 µg P/L), TP was 32.4% higher. Total phosphorus was lower at site D (50.4 µg P/L), and much lower at site E (16.7 µg P/L). Downstream at site 2 (57.9 µg P/L), TP decreased by 27.7% when compared to site 1. Soluble reactive phosphorus concentrations had a similar trend, with site A having a moderately low amount (39.1 µg P/L) when compared to site 1 (78.1 µg P/L). Sites D (21.7 µg P/L) and E (8.4 µg P/L) had the lowest SRP concentrations. Site 2 (57.7 µg P/L) was 26.1% lower than site 1. Total suspended solids were very low at all sites, and no clear trend was observed.

Total nitrogen was lowest at site A (2.28 mg N/L, Fig. 74). Downstream at site 1 (7.58 mg N/L), TN increased by 232.5%. Site D had the highest TN concentration

(9.91 mg N/L), while site E was the second lowest (3.76 mg N/L). Site 2 was slightly higher in TN concentration than site 1 (7.68 mg N/L). Nitrate increased by 95.5% from site A (1.79 mg N/L) to site 1 (3.50 mg N/L). Site D had the highest nitrate concentration (7.39 mg N/L), but site E had a much lower concentration (2.58 mg N/L). Nitrate concentration was slightly higher downstream at site 2 (3.81 mg N/L) than at site 1.

Total coliform bacteria were highest at sites A (9,000 CFU/100 mL) and D (9,400 CFU/100 mL, Fig. 74). Site 1(2,400 CFU/100 mL) was much lower than site A, and site 2 was lower still (1,600 CFU/100 mL).

Edgewood Farms Conclusions

Site A was used as a surrogate for water quality in the two streams that originate inside agricultural fields and were inaccessible. The concentration of TP and SRP was higher at site 1 than at site A, indicating that the CAFO is a source of phosphorus. The two small branches at sites D and E were lower in both measures of phosphorus, although to different extents. The decrease in phosphorus from site 1 to site 2 is mainly due to dilution from other tributaries (sites D and E). Also, the segment between sites 1 and 2 is mostly forested, which was not acting as a source of phosphorus.

Total nitrogen and nitrate were both lowest at site A, and the higher concentration at site 1 indicates that the CAFO could be a nitrogen source. However, the high concentrations of nitrogen at site D indicate that there are other sources in the area. Orthoimagery revealed that a small pond upstream from site D that is bordered by a soybean field is the likely source of nutrients (Fig. 75). Site E was also elevated possibly due to nearby corn fields, and there was no decrease in nitrogen observed from sites 1 to 2 as there was with phosphorus. These results indicate that the CAFO could be a source of nitrogen, but other sources also exist. Total coliform bacteria were highest in the upstream reaches of this tributary network, and decreased going downstream. These results indicate that there are bacteria present upstream from the CAFO, indicating manure transport from upstream hay and corn fields into the stream at site A. The decrease in coliform bacteria downstream at site 1 indicates that the two streams coming from fields next to the CAFO were not contributing more bacteria to the stream on this date.

Erosion Inventory

An inventory of erodible areas was conducted on a reference segment of Canaseraga Creek upstream from the Faulkner Road main stem site and on an area suspected to have excessive erosion between the Dansville and Pioneer Road main stem sites (Groveland Flats site; Figs. 2 and 76, Appendix E). The reference site was characterized by shallow waters with mainly forested and rural residential land uses and forested or meadow/field riparian zones. The major cause of erosion was from bends in the river. The Groveland Flats site was located downstream from the Village of Dansville and ended approximately 2.5 km upstream from the Pioneer Road site (Fig. 76). The Groveland Flats site was characterized by deeper waters with riparian buffered agricultural fields and straight flow paths.

The lengths of erodible banks in the reference site were, on average, an order of magnitude shorter (24.5 m) than at the Groveland Flats site (222.6 m; Table 12). The average score of 24 at the reference site was also much lower than at the Groveland Flats site (39) (Table 12). The score range at the reference site (range: 19-30) was less variable than at the Groveland Flats site (range: 22-60), which only had one score under 30 (Table 12). Since higher scores indicate higher degrees of erosion, the Groveland Flats sites were determined to be almost uniformly more eroded than reference sites. Further descriptions of the most eroded sites in each segment are provided in Appendix E, Table E1. The longer stretches of erodible banks and agricultural fields with either < 20 m riparian buffer (6 sites, 69.0% of measured bank length) or > 20 m riparian buffer (5 sites, 23.9% of measured bank length) were major factors in the higher scores at the Groveland Flats site. Only three sites in the Groveland Flats segment had forest or meadow riparian zones; all sites in the reference segment had forest or meadow riparian buffers. Ultimately, the percentage of erodible banks measured was 7.7% at the reference site and 54.6% at the Groveland Flats site, indicating that the downstream areas of Canaseraga Creek are more susceptible to stream bank erosion than upstream segments (Table 12).

SWAT Model

Model Performance

The model was calibrated for discharge, TSS, and TP at Shaker's Crossing (outlet USGS monitoring site) and Dansville (upstream USGS site) for the calibration periods of June 2010 – January 2012 for water and August 2010 – January 2012 for

TSS and TP. Additionally, PBIAS was calculated for four other tributary monitoring sites for the sampling period February 2011 – January 2012 to enhance the model's predictions. All locations were within the 'very good' PBIAS guidelines set by Moriasi *et al.* (2007) for TSS (±15%) and TP (±25%; Table 9). The successful prediction of TSS load, TP load and flow weighted TP concentration at two main stem USGS locations as well as at four tributary locations indicates a strong model calibration.

In the main stem, TSS loads were overpredicted at Dansville by 1.9% and underpredicted at Shaker's Crossing by -0.7% (Table 9a). Total phosphorus loads were underpredicted at Dansville (-14.4%) and Shaker's Crossing (-2.7%), while TP concentrations were overpredicted by 13.9% at Dansville and by 0.7% at Shaker's Crossing.

Model predictions in the Stony Brook and Mill Creek tributaries slightly overpredicted TSS loadings (6.1% and 9.4%, respectively), while TSS loading was underpredicted at Twomile and Buck Run Creeks (-7.5% and -3.5%, respectively; Table 9b). Total phosphorus loads were underpredicted at Stony Brook (-24.6%), Mill Creek (-5.7%), and Buck Run (-1.6%), but overpredicted at Twomile Creek (22.3%; Table 9b). Flow-weighted TP concentrations were within ±25% at all tributary sites, with model overpredictions occurring at Stony Brook (9.6%), Mill Creek (20.7%) and Buck Run (5.1%). The only tributary site to underpredict TP concentration was Twomile Creek (-24.2%; Table 9b).

Phosphorus Loading Allocation

After calibration, the Canaseraga Creek SWAT model was used to allocate and quantify various sources of phosphorus in kg/yr for the period February 2011 – January 2012. Major categories of sources were agricultural, natural, and wastewater/urban. Agriculture accounted for 59.6% of the phosphorus load, the majority of which came from crops (35.6%, 20,677 kg TP/yr), followed by CAFO manure applications (14.5%, 8,383 kg TP/yr), and tile drainage (9.5%, 5,521 kg TP/yr; Table 13). The natural sources together made up approximately 22% of the TP load, with groundwater (17.8%, 10,326 kg TP/yr) comprising the most, followed by stream bank erosion (4.5%, 2,606 kg TP/yr), forests (1.0%, 557 kg TP/yr), and wetlands (0.0%, 0.5 kg TP/yr; Table 13). The wastewater/urban sources accounted for about 17% of the total allocated load, mostly coming from sewage treatment plants (9.6%, 5,584 kg TP/yr). Septic systems (6.0%, 3,506 kg TP/yr) and urban runoff (1.5%, 855 kg TP/yr) were relatively minor sources (Table 13).

SWAT Model Management Scenarios

Several management scenarios were simulated with CCSWAT, including agricultural BMPs, CAFO manure mitigation, upgrading or removing WWTPs, and tributary remediation. In addition, combinations of the most effective management scenarios were utilized in order to reach water quality goals of 20, 45, and 65 µg P/L. The completely forested scenario provided a TP concentration of 33.5 µg P/L at Shaker's Crossing, which is the absolute minimum TP concentration that Canaseraga Creek is capable of (Table 14). As such, the 20 µg P/L proposed water quality standard was determined to be unattainable for Canaseraga Creek, and the focus of management scenarios concentrated on the 45 and 65 µg P/L targets. Management scenarios were compared to the calibrated base model output to calculate percent reduction for P load, TP concentration, and TSS load.

At Shaker's Crossing, the most effective agricultural BMP for phosphorus loading was grassed waterways, which reduced phosphorus load by 44.8% to 69.9 µg P/L (Table 14). The grassed waterways BMP was even more effective than the complete removal of agricultural crops from the watershed ('No Agricultural Crops'), which reduced phosphorus loading by 34.8% to 81.6 µg P/L. The next highest reductions of phosphorus loadings were observed with the terracing (37.8%, 75.0 µg P/L), cover crops (rye, 31.2%, 82.8 µg P/L), and contouring (30.1%, 80.8 µg P/L) BMPs.

Removing point sources (WWTPs) in Canaseraga Creek watershed resulted in a 9.4% reduction of P load and a TP concentration of 83.9 µg P/L (Table 14). However, upgrading all WWTPs to tertiary treatment (simulated by calculating P load with 10 µg P/L in the effluent, USEPA 2007) produced a similar 9.4% P load reduction and TP concentration of 84.0 µg P/L (Table 14). Due to the similarities between upgrading WWTPs and entirely removing them, the upgrade option was determined to be the most realistic and was used in subsequent combination management scenarios.

For TSS loading at Shaker's Crossing, the best BMP was streambank stabilization (49.4% TSS load reduction). The only other reductions in TSS loading over 10% were observed in the forested (28.1%), no septic (14.2%), and no agricultural crops (13.8%) simulations (Table 14). Higher percent reductions in TSS loading (range = 23.0 to 79.4%) were observed at the Dansville location for various agricultural BMPs but streambank stabilization yielded a lower percent reduction (20.5%, Table 14), suggesting that the upstream reaches of Canaseraga Creek receive more TSS losses from surface runoff than from streambank erosion. The observation that Shaker's Crossing experienced a greater TSS load reduction (49.4%) from streambank stabilization than Dansville (20.5%) provides evidence that streambank erosion is a larger component of sediment losses in the downstream reaches of Canaseraga Creek when compared to the upstream reaches. This observation agrees with data taken from an erosion study, where 54.6% of a 5.71 km segment between Dansville and Shaker's Crossing was determined to be highly erodible, compared to 7.7% of a 4.49 km segment upstream from Dansville (Table 12). Further evidence of increased in-stream sediment loss is the low TSS loading percent reductions for all agricultural BMPs at Shaker's Crossing (range = 1.0 to 6.5%) when compared to the previously mentioned high TSS load reductions at Dansville for the same BMP scenarios.

It is also important to note that the streambank stabilization scenario resulted in a 49.4% reduction in TSS load but only a 4.4% reduction in TP load at Shaker's Crossing (Dansville load reductions: 4.9% TP and 20.5% TSS). Similar results were reported by Tuppad *et al.* (2010), who concluded that this unexpected result was a product of the equations used in SWAT. Regressions of TP versus TSS at Shaker's

Crossing and Dansville resulted in strong relationships, with r^2 values of 0.75 and 0.92, respectively. Using the regression equation for Shaker's Crossing to calculate the expected TP concentration from the modeled TSS concentration yielded a result of 83.7 µg P/L, a 19.7% reduction of TP concentrations when compared to the base model concentration of 104.3 µg P/L.

45 µg P/L Target Scenarios

Combining grassed waterways in the entire watershed with upgrading sewage treatment plants resulted in a 54.1% reduction in phosphorus load and a concentration of 49.7 µg P/L (Table 14). Combining additional BMPs had a very minimal effect on TP loading and concentration. For example, when upgraded WWTPs and grassed waterways were combined with the removal of CAFO manure applications, terracing, contouring, and filter strips (45 Target Scenario 1), the P load reduction was 55.2% with a TP concentration of 48.4 µg P/L (Table 14). This suggests that the most effective BMP will have the greatest effect, and additional BMPs are in essence redundant when applied at the same time. In this manner, the 45 µg P/L target was not reached with the model.

65 µg P/L Target Scenarios

In addition to the above scenarios, other simulations were run that reached the less stringent 65 µg P/L target at Shaker's Crossing, primarily tertiary WWTPs combined with either terracing (54.8 µg P/L) or contouring (60.6 µg P/L) in the whole watershed (Table 14). The multitude of scenarios that simulated a TP concentration below 65 μg P/L indicates that this water quality target is a reasonably attainable maximum for Canaseraga Creek.

Tributary Remediation Scenarios

In addition to a whole watershed approach, the two most impacted tributaries (Buck Run Creek and Twomile Creek) were remediated in order to determine their effect on downstream loadings. One intensive scenario (Tributary Remediation 1) was run that implemented grassed waterways, terracing, and a 50% reduction in manure application rates in the two tributaries, which resulted in a 12.8% reduction of phosphorus load, a TP concentration of 95.2 μg P/L, and a TSS reduction of 0.2% at Shaker's Crossing (Table 14). In the targeted tributaries, loadings and TP concentrations were much more reduced, with Twomile Creek having reductions of 68.3%, 74.1%, and 97.0% in P load, TP concentration (29.2 μg P/L) and TSS load, respectively (Table 14b). Buck Run Creek had even higher reductions of P load (93.1%), TP concentration (89.3%, 23.4 μg P/L), and TSS load (98.0%; Table 14b). As discussed previously, the effects were similar when compared to a simulation that implemented just grassed waterways in these two tributaries (Tributary Remediation 2; Table 14b).

An attempt was also made to simulate the effect of implementing BMPs in just Buck Run and Twomile Creeks as well as the Groveland Flats area. Upgraded WWTPs were combined with grassed waterways in just these impacted areas, as well as stream bank stabilization in the main stem downstream from Dansville to the outlet (Tributary Remediation 3). The result was quite striking, with reductions of 27.2%, 31.4% (71.6 µg P/L), and 18.7% in TP load, TP concentration, and TSS load, respectively, at Shaker's Crossing (Table 14a). While this scenario did not achieve the target of 65 µg P/L, it came close and indicates that targeting BMPs in only impacted areas has the greatest effect in terms of area versus reduction. Also, it is probable that the actual concentration would tend to be lower than the model predicted due to the disconnection between TSS and TP loading within the channel. For example, if the Tributary Remediation 3 scenario is run without streambank stabilization (upgraded WWTPs and grassed waterways in Buck Run, Twomile Creek, and Groveland Flats), the reduction of TP is 26.7% and TSS is 0.3% at Shaker's Crossing with a TP concentration of 71.8 µg P/L. Adding in streambank stabilization caused a mere 0.5% additional TP load reduction (0.2 µg P/L less), but reduced TSS by a further 18.4%. The conclusion that TP would be lower was based on the strong regression of TP and TSS at Shaker's Crossing ($r^2 = 0.75$; Fig. 77) and similar findings by this study (this section and SWAT Model Limitations) and Tuppad *et al.* (2010).

Nutrient Biotic Index

Nutrient Biotic Index Quality Control and Identification Results

Identifications were carried to lowest taxonomic order possible. However, some specimens were damaged, immature, or female, which led to the inability to identify to genus or species. Especially with Elmidae adults and Chironomidae and Hydropsyche larvae, it was decided that a more confident (and accurate) genus level identification was preferable over a questionable species level identification (personal communication: Peter Lent, retired NYSDEC Biologist; Gary Neuderfer, Adjunct

Lecturer and retired NYSDEC Biologist). A further consideration with Coleoptera individuals of the Elmidae family is the lack of species level taxonomic keys for larvae, which outnumbered adults in the Buck Run Creek sample (e.g., 5 adults and 20 larvae in the Elmidae family, Table 15). For example at Stony Brook, an adult Coleoptera Elmidae specimen was determined to be in the genus *Optioservus* instead of the initial identification of *Stenelmis*, and was then identified to species (O. *fastiditus*), and placed in a separate vial. The final taxonomic review between an experienced taxonomist (Peter Lent, retired NYSDEC Biologist) and the author revealed 100% agreement on identifications.

Black Creek watershed NBI (Bigelow Creek at South Byron, NY)

Bigelow Creek (Fig. 3 in Winslow 2012, Table 6) is a small tributary (2,616 ha) of Black Creek with agriculture comprising 82% of the land use. The average discharge ranged from 30,860 m^3/d during baseflow conditions to 90,418 m^3/d during events. Stream substrate was rocky with silt underlain, and an agricultural field was adjacent to the site. The presence of a buffer zone provided some canopy cover to Bigelow Creek.

Shannon-Wiener diversity (D = 3.3) and taxa richness (R = 14) were moderate, suggesting a relatively stable macroinvertebrate community structure (Table 16). The Bigelow Creek macroinvertebrate sample totaled 100 specimens; however, 8 had no NBI scores and were not used in the NBI calculation. Both NBI scores indicated mesotrophy (NBI-P: 5.5, NBI-N: 5.6, Table 5). The short-term average stream TP concentrations in summer 2010, summer 2011, and the long-term average NO_3+NO_2 concentration were 0.25, 0.40 and 0.75 mg NO_3+NO_2-N/L, respectively, while total phosphorus concentrations were 69.8, 79.8, and 114.5 µg P/L, respectively (Table 5). The long-term total nitrogen concentration was 1.42 mg N/L (Table 5).

Oatka Creek NBI (Oatka Creek at Garbutt, NY)

Oatka Creek (Fig. 2 in Pettenski 2012, Table 6) is a larger tributary (55,700 ha) of the Genesee River watershed with flows ranging from 107,649 – 3,914,520 m^3/d. Agriculture (73.8%) and forest (21.6%) are the major land uses. The substrate at the sampling site, Garbutt, NY, was rocky with significant growth of filamentous algae and had riparian zones on either side, which provided some canopy cover.

The macroinvertebrate sample totaled 100 specimens (Table 17), but 10 had no NBI scores and were not used for NBI calculation. Diversity (D = 4.5) and taxa richness (R = 23) were high, suggesting a more stable and diverse macroinvertebrate community than Bigelow Creek. The NBI-P and NBI-N scores of 5.9 and 5.2 indicated mesotrophic stream conditions (Table 5). Measured stream concentrations of TP were 24.5 µg P/L (short-term 2010, n= 15), 36.6 µg P/L (short-term 2011, n= 2), and 41.3 µg P/L (long-term average), while NO_3+NO_2-N concentrations were 1.70 mg N/L (short-term 2010), 2.15 mg N/L (short-term 2011), and 2.07 mg NO_3-N/L (long-term average; Table 5). The long-term average TN concentration was 2.52 mg N/L (Table 5).

Stony Brook NBI (Canaseraga Creek)

The Stony Brook site (Fig. 3, Table 6) is one two sites sampled in the Canaseraga watershed. Stony Brook is an upland site with a wide riffle habitat and is a relatively small tributary (5,491 ha of the Canaseraga Creek watershed) with flows ranging from 27,173 to 1,012,401 m^3/d. Forest (49.4%) and agriculture (45.5%) and are the major land uses. A total of 102 specimens were identified in the Stony Brook sample (Table 18), but 18 had no score and were not used in NBI calculations. Diversity values using genera were low and very similar to Buck Run with values of 3.2 for Stony Brook (n= 93) and 3.2 for Buck Run Creek (n= 92). The low diversity values are likely due to the identification only to the genus level. Nutrient biotic index scores were in the oligotrophic range at Stony Brook (NBI-P: 5.0, NBI-N: 4.5). The average (n= 14) short-term TP concentration of samples taken between 17 May 2011 and 23 August 2011 was 13.9 µg P/L at Stony Brook, while the long-term average was 21.0 µg P/L (Table 5). Stony Brook had the lowest TP concentrations of all macroinvertebrate sampling sites. Total nitrogen concentrations were 1.31 mg N/L (short-term) and 1.18 mg N/L (long-term; Table 5).

Buck Run Creek NBI (Canaseraga Creek)

The Buck Run site (Fig. 3, Table 6) is the second of two sites sampled in the Canaseraga Creek watershed. Upstream, there was more riparian cover as the land became more forested, but this subwatershed is overall dominated by agriculture (76.4%). Canaseraga Creek is the largest tributary of the Genesee River, while Buck Run is relatively small (1,751 ha of the Canaseraga Creek watershed) with flows ranging from 13 to 946,446 m^3/d. The Buck Run Creek site was taken in a narrow riffle zone upstream from the bridge on NYS Route 36/ Main Street/ Sonyea Road that crosses Buck Run Creek in Mt. Morris, NY (Table 6). The site was bordered by a bus garage on one side and a residence on the other, and had some riparian vegetation.

The Buck Run Creek sample had 97 specimens (Table 15), 17 of which had no score and were omitted from NBI calculations. The diversity value (3.2) for Buck Run Creek was derived from genera data and was the same as Stony Brook (3.2). Nutrient biotic index scores were in the eutrophic (NBI-P: 6.1) and mesotrophic (NBI-N: 5.4) ranges at Buck Run Creek. The short-term average (n= 14) TP concentration of samples taken between 17 May 2011 and 23 August 2011 was 62.3 µg P/L at Buck Run Creek, while the long-term average TP concentration was 150.5 µg P/L (Table 5). Nitrate concentrations were similar at Stony Brook and Buck Run Creek with a long-term average of about 1.00 mg NO_3+NO_2-N/L, but the short and long-term TN averages were much higher at Buck Run Creek (1.97 and 2.03 mg N/L, respectively; Table 5).

Discussion

To determine impacts on water quality in a watershed, a spatially and temporally diverse sampling protocol should be used. In this study on the Canaseraga Creek watershed, weekly chemistry samples and discharge measurements were taken at four main stem and four tributary sites for one year. Additionally, the process of segment analysis was used to determine the location and severity of point and nonpoint sources of TP, SRP, TN, nitrate, TSS, and total coliform bacteria. Sampling results were used to calibrate a Soil and Water Assessment Tool (SWAT) model for the Canaseraga Creek watershed (CCSWAT) at these eight monitoring points. The calibrated and validated CCSWAT model was then used to simulate a completely forested natural condition, which determined the minimum attainable TP concentration for Canaseraga Creek watershed (33.5 μg P/L, Table 14a). Several management simulations were run with the CCSWAT model in order to determine an appropriate water quality target goal.

Water Quality Targets

With increasing pressure on streams from anthropogenic activities, nutrient criteria for the protection of aquatic life in flowing waters should be set. New York State's current standard for phosphorus and nitrogen in surface waters is narrative, stating that P and N concentrations shall be, "None in amounts that will result in the growths of algae, weeds and slimes that will impair the waters for their best usages" (6NYCRR §703.2). Since the narrative standard lacks a definitive nutrient value, current regulations will not protect water bodies from water quality degradation due to excessive phosphorus. Therefore, a guidance value of 20 µg P/L has been suggested for lakes but does not have the force of regulation (NYSDEC 1998). This guidance value is often viewed as unrealistically low for streams, as evidenced by the CCSWAT model simulation of completely natural conditions and by other models' simulation of 'natural' conditions (Black Creek/ BCSWAT: 36.2 µg P/L, Winslow 2012; Oatka Creek/ OCSWAT: 22.9 µg P/L, Pettenski 2012). Determining 'natural' nutrient concentrations is an important step in developing a nutrient standard because it provides a reference condition to which nutrient standards can be compared. Concentrations below natural conditions are unrealistic and unaccommodating to human influence. In fact, the 25th percentile of 150 streams over 10 years in level III ecoregion 83 (where the Genesee River Basin is located) was 24.13 µg P/L, while a value of 33 µg P/L was suggested for the greater area covered by aggregate ecoregion VII (USEPA 2000b). These values are meant to approximate reference conditions, and therefore are proactive in protecting aquatic life (USEPA 2000b). A similar value of 30 µg P/L was reported by Smith *et al.* (2003) for ecoregion VII using similar methods as USEPA (2000b) and by Smith and Tran (2010) using macroinvertebrates and diatoms. Dodds *et al.* (1997) also proposed a TP concentration of 30 µg P/L to control chlorophyll a in streams.

To set a more achievable and realistic water quality target for streams, New York State used benthic macroinvertebrate and water chemistry data to determine a TP water quality target of 65 µg P/L that would protect aquatic life from impairment due to high nutrient concentrations (Smith *et al.* 2007). This value represents a threshold above which aquatic life in wadeable flowing waters will become impaired due to excessive nutrients. As a logical median value between the proposed 20 and 65 µg P/L targets, a TP concentration of 45 µg P/L was also considered.

The 65 µg P/L water quality target is lower than the 100 µg P/L state-wide phosphorus standards in states such as NJ, NM, AR, and ND (USEPA 2003). Other states (VT, IL, OK, UT, WA, OR, AK) have varying phosphorus nutrient standards for specific streams and rivers (USEPA 2003). However, the proposed NY standard of 65 µg P/L is meant to protect aquatic life in wadeable flowing waters by being proactive instead of reactive (Smith *et al.* 2007). It was determined that concentrations of phosphorus above this threshold will begin to impair the integrity of biological communities within the stream, shifting the trophic state from mesotrophic to eutrophic (Smith *et al.* 2007). In a second study focused on large rivers, Smith and Tran (2010) proposed a TP guidance value of 30 g P/L. They concluded that shifts in biological communities can occur at low nutrient concentrations, while water quality impairment will occur at higher concentrations (Smith and Tran 2010). Since the CCSWAT model simulated a TP concentration of 33.5 µg P/L under completely forested conditions, any proposed water quality targets under this value were ruled out as impossible. Instead, the 45- and 65-µg P/L targets were considered as being the most realistic goals for the Canaseraga Creek watershed.

In the Canaseraga Creek watershed, four sites exceed the proposed TP target of 65-µg P/L threshold for aquatic life protection (Smith *et al.* 2007) in observed samples: two tributaries (Twomile and Buck Run Creeks) and two main stem sites

(Pioneer Road and Shaker's Crossing; Fig. 8). At three sites (Twomile Creek, Buck Run Creek, and Shaker's Crossing), phosphorus concentration exceeds the 100 µg P/L standard adopted state-wide by several aforementioned states. Using the calibrated CCSWAT model, a management simulation that combined upgraded WWTPs with grassed waterways in just these impacted areas (Twomile Creek, Buck Run Creek, and the Groveland Flats area) and stream bank stabilization in the main stem from Dansville to the outlet resulted in a TP concentration of 71.6 µg P/L at Shaker's Crossing (Tributary Remediation 3, Table 14a). Management efforts in the whole watershed would reduce the TP concentration under 65 µg P/L and just above 45 µg P/L at Shaker's Crossing (e.g., tertiary WWTPs + grassed waterways, 49.7 µg P/L; Table 14a). While the implementation of one or more BMPs to every farm in the whole watershed might not be realistic, the results of the CCSWAT simulations that target the most impacted areas indicate that concentrations of 65 µg P/L are attainable in the Canaseraga Creek watershed. Including other impacted areas in this management regime would bring the concentration below 65 µg P/L. The 45 µg P/L target was slightly exceeded and was considered the result of an ideal management situation. Therefore, based on the CCSWAT model results, the most feasible water quality target for Canaseraga Creek is 65 µg P/L at the outlet (Shaker's Crossing). This target TP concentration could be met by implementing a variety of BMPs in either the whole watershed or in selected areas. Furthermore, model results provided evidence that stream bank stabilization would have a larger impact on TP concentration than the model predicted, resulting in an estimated TP concentration of

83.7 µg P/L (see ‘SWAT Model Management Scenarios’ and ‘SWAT Model Limitations’).

Canaseraga Creek Compared To Other Lake Ontario Tributaries

Comparing Canaseraga Creek to other Lake Ontario tributaries on an areal basis serves to put the loadings in perspective. Areal loads allow comparison of watersheds of different sizes by normalizing load by area. Forested watersheds have a relatively low areal TP load (Bobolink Creek, 0.01 kg P/ha/yr; First Creek, 0.10 kg P/ha/yr; Clark Creek, 0.21 kg P/ha/yr) when compared to mixed agricultural and forested watersheds (Salmon River, 0.23 kg P/ha/yr; Oatka Creek, 0.26 kg P/ha/yr; Black Creek, 0.33 kg P/ha/yr; Makarewicz *et al.* 2012). Agriculturally dominated watersheds have the highest areal TP loads (Golden Hill Creek, 0.88 kg P/ha/yr; Oak Orchard, 1.04 kg P/ha/yr; Wolcott Creek, 1.37 kg P/ha/yr; Makarewicz *et al.* 2012). Suburban watershed Buttonwook Creek (0.57 kg P/ha/yr) and mixed suburban/agricultural watershed Johnson Creek (0.54 kg P/ha/yr; Makarewicz *et al.* 2012) have areal TP losses between the agricultural/forested and the dominantly agricultural watersheds. Canaseraga Creek (0.7 kg P/ha/yr) compares closely to the lower end of the mostly agricultural watersheds but is higher than the suburban and suburban/agricultural watersheds, which indicates that anthropogenic sources are apparent from municipalities and from farming practices. Other agricultural Genesee River subbasins such as Black Creek (0.33 kg P/ha/yr; Winslow 2012) and Oatka Creek (0.26 kg P/ha/yr; Pettenski 2012) had lower loadings than Canaseraga Creek while the Upper Genesee River had a higher annual areal load (0.90 kg P/ha/yr, Makarewicz *et al.* 2013). Canaseraga Creek and the Genesee River (0.64 kg P/ha/yr; Makarewicz *et al.* 2012) are similar in areal TP loading, which is in part due to their similarity in land uses. Canaseraga Creek has a mixed forest (44.4%)/agricultural (46.8%) land use, some urban areas (5.7%) such as the Villages of Dansville and Mt. Morris, and seven WWTPs (Table 7). The mixture of land uses and point sources explains the high areal load in Canaseraga Creek watershed, despite the large percentage of forested land.

Tributaries such as Buck Run and Twomile Creeks (2.4 and 0.6 kg P/ha/yr, respectively) and main stem segments from Dansville to Pioneer Road (0.8 kg P/ha/yr) and Pioneer Road to Shaker's Crossing (1.0 kg P/ha/yr) have high areal TP loadings, which coincides with a prevalence of agricultural activity, CAFO operations, and WWTPs (Table 11). Tributaries Mill Creek and Stony Brook (each 0.2 kg P/ha/yr; Table 11) and main stem segments from headwaters to Faulkner Road and from Faulkner Road to Dansville (0.3 and 0.4 kg P/ha/yr, respectively) were similar to forested and mixed forest/agricultural watersheds. A distinct trend is visible in the Canaseraga Creek watershed where upstream segments Faulkner Road, Stony Brook, Dansville, and Mill Creek have lower loadings that correspond to forest and mixed forest/agricultural land uses. Downstream segments Pioneer Road, Twomile Creek, and Buck Run all had elevated areal TP loadings that were indicative of agricultural influence. The areal TP loading from the whole Canaseraga Creek watershed is similar to watersheds with heavy agricultural and/or suburban land uses when compared to other Lake Ontario tributaries.

SWAT Model Limitations

Any hydrologic computer model has limitations, problems, and/or deficiencies that are the result of highly variable environments, our understanding of these environments, and computer technology. The SWAT model suffers from several of these deficiencies, but its robust nature due to the ability to incorporate a myriad of datasets, variables, and user-defined inputs allow watershed modelers and managers to have confidence in simulations using SWAT.

The data inputs to the SWAT model can be a limitation due to data availability and spatial scale. The use of temperature and precipitation gauges instead of radar data has the potential to omit localized precipitation events, especially if few gauges are available in or near the watershed. Special adaptations have been made that successfully used radar precipitation data in the SWAT model (Jayakrishnan *et al.* 2005), which have more spatial and temporal resolution. Also, fertilization regimes, manure applications, and point sources must be put into the model by the user, which may be difficult to obtain and are time intensive. Having firsthand knowledge of the watershed being modeled and access to the information required to properly incorporate all major source inputs is essential. Additionally, some knowledge of the major equations used by SWAT is important to understand how the model works, which parameters to change for calibration, and what they mean. In a complex model such as SWAT, this is no easy task.

Other limitations to the SWAT model are deficiencies within the model equations and coding. A disconnect exists in the relationship between phosphorus and sediment in the SWAT model equations for channel nutrient transport (Tuppad *et al.* 2010), which were adapted from the QUAL2E model (Brown and Barnwell 1987). The QUAL2E equations are only affected by peak flows and are unaffected by channel cover and channel erodibility (Tuppad *et al.* 2010). This was most acutely apparent in the CCSWAT model with the stream bank stabilization management scenario, which reduced sediment load by 49.4% at Shaker's Crossing and 20.5% at Dansville, but only reduced TP load by 4.4% and 4.9%, respectively (Table 14a). Since one of the fractions of TP includes particulate bound phosphorus, it is dubious that a reduction of nearly 50% in TSS resulted in a TP reduction of less than 5%. A regression of observed TP versus TSS (n= 77) concentrations at the Shaker's Crossing USGS site revealed a strong relationship with an r^2 value of 0.75 (Fig. 77). Using the regression equation to predict phosphorus concentration from a calculated SWAT TSS concentration for the stream bank stabilization scenario yielded a result of 83.7 µg P/L at Shaker's Crossing, a 19.7% reduction of TP concentration when compared to the base model concentration of 104.3 µg P/L. This disconnect in the model between TSS and TP losses from stream bank erosion indicates that the stabilization of stream banks could in reality reduce TP concentrations at Shaker's Crossing to below the 45 and 65 µg P/L targets when combined with other management practices.

The SWAT model is also limited by the changes required to calibrate the model, as with curve number. The CCSWAT model reduced curve number (CN2) by 20%, which is consistent with models from nearby watersheds such as Oatka Creek (-23%; Pettenski 2012), Black Creek (-25%; Winslow 2012), and Oak Orchard Creek (-23%;

Richards *et al.* 2010). The value used for CCSWAT was within the range of reported curve numbers from published SWAT papers cited in Richards *et al.* (2010), who interpreted the large reduction in curve numbers "…to be due to the presence of flat and internally drained topography at watershed scales." Many other parameters were changed from default values within the model, such as the baseflow alpha factor (ALPHA_BF) and Mannings N for the main channel (CH_N2; Appendix C). It was suspected that some default values (e.g., CH_N2) were not accurate for the streams in the Canaseraga Creek watershed due to the SWAT model's origin in Texas, where the default values might be more appropriate.

Additionally, since only sites with water chemistry and flow data were calibrated, confidence in the simulation of other subwatersheds is somewhat lessened due to the broader spatial area included in the next downstream calibration site. However, multiple calibration sites serve to enhance the model's predictions and therefore the current CCSWAT model should be viewed as an improvement upon a comparable model with only one calibration site. Furthermore, confidence in the CCSWAT model was gained through the use of rigorous calibration criteria at multiple sites and successful flow validation.

Load Allocations Using SWAT

The CCSWAT model was used to partition the various sources of phosphorus to Canaseraga Creek (Table 13). By allocating the amount of P from each source, comparisons were made of the relative extent each source contributes to the watershed. Once all sources were identified and quantified, they were prioritized by magnitude. The sources that contributed the most P to Canaseraga Creek were targeted with BMPs using the CCSWAT model.

Three general groups of sources were identified: agricultural, natural, and urban/sewage treatment. Agricultural activities comprised of agricultural crops (35.6%, 20,677 kg P/yr), CAFO animals (14.5%, 8,383 kg P/yr), and tile drains (9.5%, 5,521 kg P/yr; Table 13) contributed the most P (59.6%, 34,581 kg P/yr) to the CCSWAT model. Natural sources contributed 23.3% (13,489.5 kg P/yr) of the P, of which groundwater was the largest source (17.8%, 10,326 kg P/yr), followed by stream bank erosion (4.5 %, 2,606 kg P/yr), forest (1.0%, 557 kg P/yr), and wetlands (0.5 kg P/yr, 0.0%; Table 13). Wastewater treatment (9.6%, 5,584 kg P/yr), septic systems (6.0%, 3,506 kg P/yr), and urban runoff (1.5%, 855 kg P/yr) sources contributed 17.1% (9,945 kg P/yr) collectively (Table 13).

These loading allocations indicate that agricultural crops and CAFO animals are crucial components of P loading to Canaseraga Creek. Also, seven WWTPs treatment plants contributed nearly 10% of the P load, which indicates an acute source that was targeted for remediation. It was for these reasons that the focus of BMP simulations was on agriculture coupled with upgraded WWTPs.

Sources and Sinks of Pollutants from Subbasins

Through sampling, segment analysis, field investigation, and utilization of the CCSWAT model, it was apparent that agricultural sources were a major source of nutrients, sediment, and bacteria to Canaseraga Creek. To explore the issue, an investigative framework was developed to assess and prioritize sources in each main stem segment (Faulkner Road to Dansville including Stony Brook, Dansville to Pioneer Road including Mill Creek, and Pioneer Road to Shaker's Crossing including Twomile and Buck Run Creeks). Calculated areal loadings at each routine monitoring site were used to prioritize each site by severity, while segment analysis allowed for the identification of key source areas that help explain loadings in the reach. The CCSWAT model was used to recommend effective and feasible BMPs to reduce sediment and nutrient losses to Canaseraga Creek and to help remediate water quality to reach a target TP concentration.

Main Stem of Canaseraga Creek: Headwaters to Faulkner Road Segment

The 'headwaters to Faulkner Road' segment (15,100 ha; Fig. 4) is the farthest upstream main stem Canaseraga Creek reach. Land use in this segment is largely forested (80%), containing the Rattlesnake Hill State Wildlife Management Area, Ossian State Forest, and Canaseraga State Forest, followed by agriculture (17.6%) and urban (mainly the Village of Canaseraga; 1.7%) uses (Fig. 3). The Village of Canaseraga has one small WWTP that discharges directly into Canaseraga Creek (Fig. 6, Table 7a) above the sampling site at Faulkner Road. No CAFOs are known to exist upstream from Faulkner Road.

While the Village of Canaseraga WWTP was a statistically significant source of TP, TN, and TSS, the concentrations below the effluent pipe were relatively low (average TP: 25.7 ± 2.2 µg P/L) when compared to other WWTP samples (e.g., below Nunda WWTP average TP: 271.5 ± 63.5 µg P/L; Table 7a). The lower concentrations observed may be due to the sequencing batch reactor design, which uses activated sludge, bioremediation of solids using reed beds and ultraviolet light disinfection of effluent. Also, the design of the discharge pipe, which is perforated and runs across the bottom of the stream, may play a role in reducing the nutrient plume effect and aiding in dilution.

Areal loadings in the 'headwaters to Faulkner Road' segment were moderate (SRP: 0.04 kg/ha/yr, TC: 1.5E+11 CFU/ha/yr) to low (TP: 0.3 kg/ha/yr, TN: 5.2 kg/ha/yr, nitrate: 2.9 kg/ha/yr, TSS: 214 kg/ha/yr; Table 11, Fig. 10) when compared to other sites (Table 11, Fig. 10). In general, the average observed concentrations at the Faulkner Road site were not indicative of excessive contamination by the WWTP nor by agricultural activities (Fig. 8). For example, the average annual observed TP concentration at the Faulkner Road site was 34.5 μg P/L (Fig. 8), which was similar to the forested CCSWAT simulated concentration at the most downstream main stem site at Shaker's Crossing (33.5 μg P/L) but still higher than the simulated forested concentration at the upstream site at Dansville (13.5 μg P/L).

While no acute nutrient or sediment sources were observed upstream from Faulkner Road, this segment is receiving minor impairment from nonpoint agriculture and from the Canaseraga WWTP. For example, total phosphorus and sediment loading could be reduced in this segment by implementing BMPs such as grassed waterways (TP: 64.4%, TSS: 91.7% reduction), terracing (TP: 52.3%, TSS: 80.7% reduction), or contour farming (TP: 41.6%, TSS: 68.0% reduction) on crop fields and upgrading the Canaseraga WWTP (TP: 3.6%, TSS: 0% reduction, Table 19), but overall this area is not a priority for these actions. Considering water quality targets, this upstream segment of Canaseraga Creek already meets the proposed 45- and 65-μg P/L target TP concentrations and should be considered a low priority segment of Canaseraga Creek. However, attention to the preservation of forested areas in this segment is important to ensuring that good water quality persists.

Main Stem of Canaseraga Creek: Faulkner Road to Dansville Segment

(Including the Stony Brook and Sugar Creek tributaries; Fig. 4)

The main stem segment between Faulkner Road and Dansville (13,908 ha) includes the Sugar Creek and Stony Brook tributaries (Fig. 4) and has two CAFO operations (Wilson Dairy and Sheep Farms and R. Schramm Ent.; Table 4, Fig. 3). There are no WWTPs in this segment of Canaseraga Creek.

Sugar Creek Subwatershed

The Sugar Creek tributary lies downstream from the main stem Faulkner Road site and upstream from the Stony Brook tributary (Fig. 4). The stream flows through part of the Rattlesnake Hill State Wildlife Management Area and several agricultural areas, which are often adjacent to the stream (Figs. 67 and 69). Segment analysis indicated minor sources of TSS, TN, and nitrate due to several agricultural and hay fields observed bordering the stream (Figs. 64 to 70 and 78). The large forested section between segment analysis sites 5 and 4 was attributed to a large decrease in all analytes. Our results and Welsch's (1991) USDA manual suggest that agricultural impacts on water quality can be mitigated by forested stream corridors/ riparian buffer zones. In the Sugar Creek subwatershed, BMPs focusing on the protection and restoration of natural areas along the stream should be adopted. Forested streams retain nutrients such as N and P (Valett et al. 2002, Sollins et al. 1980, Vitousek and Reiners 1975), and the removal of forests increases stream nutrients and major ion concentrations (Likens et al. 1970).

Although Sugar Creek is a minor nutrient source to Canaseraga Creek, installation of BMPs in agricultural areas would reduce sediment and nutrient losses from crop fields before they enter the stream via runoff (Makarewicz *et al.* 2009). For example, simulations with CCSWAT demonstrated that agricultural BMPs such as grassed waterways, terracing, and contouring were effective in reducing nutrient and sediment loads in the Canaseraga Creek watershed. In Sugar Creek for example, TP loadings were reduced by 77.5%, 66.8%, and 57.0% and TSS loadings by 98.2%, 88.6%, and 76.2% if grassed waterways, terracing, and contouring, respectively, were implemented on crop fields (Table 19).

Stony Brook Subwatershed

Stony Brook is a small (5,491 ha) tributary that lies between the Faulkner Road and Dansville main stem sites (Fig. 3). The land use is evenly split between forest (49.4%) and agriculture (45.5%) and includes the Stony Brook State Park. On an areal and total loading basis, Stony Brook delivers some of the lowest amounts of nutrients, sediment and bacteria to Canaseraga Creek (Tables 10 and 11). With the low loadings and the low measured annual average TP concentration (21.0 µg P/L), Stony Brook is not a major nutrient, sediment or bacterial source to Canaseraga Creek, already meets the 45- and 65-µg P/L proposed water quality targets, and is very close to meeting the 20-µg P/L guidance value for surface waters.

The low observed concentrations and areal loadings in the Stony Brook subwatershed suggest that the forested land use is mitigating any agricultural influence with many forested areas situated along the stream. The low observed average concentrations and loadings formed the basis to choose Stony Brook as a reference site for the NBI study (see 'Nutrient Biotic Index' in Methods section). Due to the low loadings, low concentrations, and considerable forested land use, the Stony Brook subwatershed was determined not to be a segment of Canaseraga Creek watershed requiring management.

The Faulkner Road to Dansville Main Stem Segment (Fig. 4)

This watershed (13,908 ha) of the main stem segment between Faulkner Road and Dansville includes the Sugar Creek and Stony Brook tributaries (Fig. 4). The land use, not including the Stony Brook tributary, is mostly forest (59.3%) with a large agricultural presence (35.5%, including CAFOs) and minor urban uses (rural residential, 3.2%). Average concentrations of TP (42.8 μg P/L), TN (1.19 mg N/L), nitrate (0.88 mg N/L), and TSS (57.4 mg/L) were higher at the downstream site at Dansville than at Faulkner Road (Fig. 8). Stream concentrations of TSS were distinctly higher than other analytes due to naturally occurring erosion resulting from the steep terrain and geology in portions of this segment (Fig. 23; Mansue *et al.* 1991). Moderate areal loadings of TP, TN, nitrate, and TSS (Table 11) were evident. A negative SRP loading (-0.03 kg/ha/yr) was observed, suggesting uptake by vegetation.

Although the Faulkner Road to Dansville segment of Canaseraga Creek is of low to moderate priority for remediation, simulated management practices using

CCSWAT indicate that water quality may be improved in this segment of the stream. For example, agricultural BMPs such as grassed waterways and terracing had larger reductions of TP load (59.8 and 52.7%, respectively) and lower TP concentrations (34.0 and 34.5 µg P/L, respectively) than upgrading WWTPs (2.2% TP load reduction, 53.0 µg P/L) or removing CAFO manure applications (5.3% TP load reduction, 54.7 µg P/L; Table 14a). These results indicate that the Canaseraga WWTP (upstream from the Faulkner Road to Dansville segment) and the two CAFOs within this segment are not major causes of nutrient loss when compared to agricultural fields. The more stringent proposed water quality goal of 45 µg P/L is possible with agricultural BMPs such as grassed waterways and terracing (Table 14a). As point of reference, but not being advocated, completely foresting this segment will reduce the current simulated TP concentration of 56.2 µg P/L at Dansville by 75.9% to 13.5 µg P/L (Table 14a).

The 45 µg P/L TP target is reasonable for this upstream reach (Faulkner Road to Dansville) when some agricultural BMPs are implemented, while the more lenient 65 µg P/L target TP concentration is the most feasible for the reaches downstream from Dansville. The idea of establishing two different water quality standards for Canaseraga Creek has the potential benefit of reducing upstream TP concentrations, which would remain elevated if a less strict standard was adopted for the whole watershed. Smith and Tran (2010) proposed water quality targets that would prevent changes in macroinvertebrate and algal communities due to increased nutrient concentrations. If nutrient concentrations continue to increase, water quality will more severely alter macroinvertebrate and algal communities, resulting in water quality impairment. By doing so, they propose a proactive rather than reactive standard. With two different water quality goals for Canaseraga Creek, changes in invertebrate communities in the Faulkner Road to Dansville segment would be buffered by capping the allowable TP concentration below current levels. Otherwise, TP concentrations in this section of Canaseraga Creek could actually increase to the detriment of aquatic life.

Main Stem of Canaseraga Creek: Dansville to Pioneer Road Segment

(Including the Mill Creek tributary)

The main stem segment between the Dansville and Pioneer Road (19,943 ha) sites includes the Village of Dansville and a portion of the Groveland Flats (Fig. 4). The Groveland Flats is an area of intensive corn production (Fig. 2) and hydrologic modification. Dominant land uses, excluding the Mill Creek subwatershed, are agriculture (59.2%) and forest (29.6%) with some urban uses (Village of Dansville and other rural residential, 11.2%). The Mill and Mud Creek tributaries are included in this segment, along with the three WWTPs in Dansville, Wayland, and Groveland Station (Fig. 6, Table 7) and one CAFO (Edgewood Farms) (Fig. 3, Table 4).

Mill Creek Subwatershed

Land use in the Mill Creek subwatershed (10,800 ha) is mostly agriculture (55.9%) followed by forest (35.6%). Areal loadings of TP (0.2 kg/ha/yr), SRP (0.02 kg/ha/yr), TN (6.1 kg/ha/yr), nitrate (4.8 kg/ha/yr), TSS (154 kg/ha/yr), and TC (1.2E+11 CFU/ha/yr) were low when compared to other Canaseraga Creek segments

(Table 11). Little Mill Creek (Fig. 4), a tributary to Mill Creek containing a drinking water supply for the Village of Dansville, had low nutrient, sediment, and bacteria concentrations. The source of an unnamed stream (Fig. 45) is a stormwater drainage pipe from the Village of Wayland that eventually receives the effluent from Wayland WWTP and continues to flow through wetlands and a pond ('Wayland Pond') before joining Mill Creek proper. The Wayland WWTP is a significant source of TP, SRP, TN, nitrate, and TC (Table 7a) while the stormwater pipe is a source of TP, SRP, TN TSS, and TC. However, the downstream effects of the Wayland WWTP and stormwater effluent pipe were mitigated due to biologic uptake and dilution as the tributary drains into Wayland Pond and a wetland area. Wetlands and ponds are known to reduce the high concentrations of nutrients and bacteria in a stream (Coveney *et al.* 2002, Fenessy *et al.* 2008, Richardson *et al.* 2011).

Within Mill Creek, the major source of sediment is associated with the steep terrain (Fig. 42) in the middle portion of Mill Creek between sites MC 7 and MC 6 (Fig. 44, Mansue *et al.* 1991). Also, a cattle farm (site A-4, Fig. 52) and a cow pasture (site A-2) were determined to be sources of TP, SRP, TSS, and total coliform bacteria (Figs. 49 and 51). The annual measured TP concentration (54.8 μg P/L) at Mill Creek meets the 65 μg P/L target (Fig. 8).

Since Mill Creek currently meets the proposed water quality targets, this tributary should be given a low to moderate priority similar to the Faulkner Road to Dansville segment. Management practices in the Mill Creek subwatershed should focus on the maintenance and protection of these forested, wetland, and pond areas in order to ensure that ecosystem services continue to naturally remediate water quality (e.g., Kline and Cahoon 2010, Richardson *et al.* 2011, Coveney *et al.* 2002). The ability of vegetated areas to utilize and retain N and P are well known (Vitousek and Reiners 1975, Odum 1969, Sollins *et al.* 1980, Valett *et al.* 2002). If these ecosystem services are lost, it would be difficult and costly to recreate their effects.

However, water quality may be improved via a few management practices. Simulations of implemented agricultural BMPs, such as grassed waterways and contour farming in Mill Creek subwatershed, would result in TP load reductions of 2.8% and 8.6%, respectively and TSS load reductions of 26.8% and 19.7%, respectively (Table 19). Upgrading the Wayland WWTP would have a larger effect on TP loading (30.0% reduction, Table 19) in Mill Creek, and would reduce the TP concentration to 36.8 μg P/L. Upgrading the Wayland WWTP to tertiary treatment (0.0032 kg P/d) would reduce the initial amount of nutrients being carried into the pond, wetland and forested areas in the unnamed stream and should result in lower TP concentrations downstream in Mill Creek. Agricultural BMPs should target areas such as sites A-4 and A-2 (Figs. 49 and 52), where there is no riparian buffer between crop fields and the small unnamed streams that run through them. In addition, preservation of natural areas within the Mill Creek subwatershed would ensure good long-term water quality. The wetlands, pond, and dilution combine to mitigate high tributary concentrations, especially the Wayland WWTP/stormwater effluent stream, to result in the low observed areal loadings.

Mud Creek Subwatershed

Mud Creek and adjacent subwatersheds are small, rural, steep watersheds with mixed agricultural and forested land uses highlighted by the CCSWAT model as 'hotspots' of TP load (Fig. 79). The Mud Creek tributary runs through a residential part of the Village of Dansville (Fig. 53), continues through forest and agricultural fields, and then drains into Canaseraga Creek. Large increases in concentration of TP (351.1%) and TSS (181.9%) between sites 4 and 5 (Figs. 54 and 57) were observed in Mud Creek during segment analysis sampling on 21 September 2011. The strong correlation between TP and TSS ($r^2 = 0.95$, Fig. 58) indicates that phosphorus was binding to sediment. Large increases of TN (133.3%) and nitrate (286.5%) were also observed between sites 5 and 6 (Fig. 55). The nutrient and sediment increases were a result of the many small tributaries that run through hay and cornfields before joining Mud Creek, as well as hay and cornfields bordering Mud Creek (Fig. 56). The steep upstream terrain of the tributaries was also believed to also be a cause of increased TSS. However, sediment and sediment-bound phosphorus were suspected to have been settling out in this tributary during sampling due to the flat terrain along the Mud Creek channel. This suggests that event periods later would flush these constituents out of Mud Creek and into Canaseraga Creek.

To reduce the amount of nutrients (TP load by 29.8% and TSS load by 49.5%) (Table 19) being transported into Mud Creek, riparian buffer zones could be implemented in segments where no buffer zone was visible (Fig. 56). Other simulated BMPs had even higher TP and TSS load reductions, including grassed waterways (TP: 71.6%; TSS: 94.8%), terracing (TP: 55.8%; TSS: 76.7%), and contouring (TP:

39.5%; TSS: 53.3%; Table 19). These BMPs are also applicable to the nearby subwatersheds that were highlighted by CCSWAT to be TP 'hotspots' (Fig. 79). Segment analysis and CCSWAT simulations indicate that Mud Creek is a source of nutrients and sediment to Canaseraga Creek in the Dansville to Pioneer Road main stem segment. The main source of elevated nutrients to Mud Creek- corn and hay fields -can be mitigated with the implementation of agricultural BMPs to reduce field runoff.

Dansville to Pioneer Road Main Stem Segment

Canaseraga Creek at Pioneer Road has an average annual TP concentration of 69.7 µg P/L (Fig. 8) and exceeded the 65 µg P/L proposed TP target. The main stem segment from Dansville to Pioneer Road is experiencing high nutrient concentrations and loadings (Figs. 8-10). Areal nitrate loading was the highest (11.0 kg/ha/yr); TN was the second highest (14.3 kg/ha/yr); and TP (0.8 kg/ha/yr), SRP (0.1 kg/ha/yr), TSS (583 kg/ha/yr), and TC (4.6E+11 CFU/ha/yr) were the third highest of all observed Canaseraga Creek segments (Table 11). The elevated nutrient concentrations and loads were caused by agricultural sources such as the Edgewood Farms CAFO, WWTPs in Dansville and Groveland, the Groveland Flats area, Mud Creek, and streambank erosion (Figs. 78 and 79). In general, CCSWAT simulations indicated that agricultural activities accounted for 59.6% of the allocated P load compared to 9.6% for WWTPs (Table 13).

Concentrated Animal Feeding Operations

Through segment analysis, Edgewood Farms (Table 4) was determined to be a source of TP and SRP on 26 October 2011 (Fig. 73). Nitrogen downstream from the CAFO was also elevated (Fig. 74), but results were inconclusive in pinpointing the area immediately surrounding the CAFO as a source. Orthoimagery revealed nearby agricultural areas such as soybean and hay fields, as well as a pond bordering the fields (Fig. 74), all acting as N sources. Elevated total coliform bacteria concentrations upstream from the CAFO suggested that manure runoff was entering the stream upstream from site A (Fig. 74). A forested stream segment in the area downstream from the CAFO resulted in a decrease in P, but concentrations were still elevated at site 2 (TP: 57.9, SRP: 57.7; Fig. 74).

Wastewater Treatment Plants

Within this segment of the Canaseraga Creek watershed are three WWTPs, including the largest (Dansville WWTP, average discharge of 5,209 m^3/d) and the smallest (Groveland Station WWTP, average discharge of 32 m^3/d). A third WWTP (Wayland WWTP) is located in the Village of Wayland within the Mill Creek subwatershed. All of these point sources are significant nutrient sources (Table 7a) with the Dansville and Groveland Station WWTPs discharging directly into Canaseraga Creek. For example, the daily TP and TC load from the Dansville WWTP are 3.3 kg P/d and 2.29E+12 CFU/d, respectively. Phosphorus loading from WWTPs accounts for 9.6% of the P load in Canaseraga Creek watershed (Table 13). Even so, upgrading the WWTPs to tertiary (10 µg P/L) plants reduced P load by 6.5% at Pioneer Road while CCSWAT simulations of agricultural BMP (grassed waterways:

32.0%, terracing: 25.5%, contouring: 19.2%) had a greater impact on water quality than WWTPs (Table 19).

Erosion

Total suspended solids levels were elevated in this segment (annual average concentration: 59.3 mg/L, areal segment load: 583 kg/ha/yr; Fig. 8, Table 11). An inventory of erosion conducted on a 5.71 km reach in the Dansville to Pioneer Road segment (‘Groveland Flats’ site; Fig. 76) concluded that 54.6% of the travelled distance was highly erodible, compared to 7.7% of the reference segment (upstream from the Faulkner Road site), and that a majority of the erosion was attributed to a close proximity to agricultural fields (69.0% of erodible areas were within 20 m of agricultural fields versus 0.0% at the reference site; Table 12). Another cause of increased erosion was the artificially straight channel in the Groveland Flats area (Allan and Castillo 2009). Others have observed similar effects of stream channeling. For example, Rousseau and Biron (2009) observed channel incision leading to bank failure in a straightened stream in southwestern Quebec.

Stream bank stabilization of the “erosion inventory study reach” in the ‘Groveland Flats’ reach reduced TSS load by only 2.0% (CCSWAT simulation) at Pioneer Road (Table 19). By extending the area targeted for stream bank stabilization to the whole main stem segment from Dansville to Pioneer Road, a 19.8% TSS load reduction was achieved (Table 19) and suggests that erosion in the main stem from Dansville to Pioneer Road is a large portion of the TSS load and is not limited to the immediate area surveyed in the field. In fact, the CCSWAT suggests a 14.3% TSS load reduction was observed at the outlet of Canaseraga Creek at Shaker's Crossing (Table 19) with the upstream stream bank stabilization, which resulted in a regressed TP concentration of 97.7 µg P/L (a 6.3% decrease from 104.3 µg P/L).

The restoration of riparian cover to the main stem of Canaseraga Creek would provide bank stability and a zone for nutrient uptake and sedimentation. Stream bank stabilization employs physical armoring (structural) such as stone riprap or vegetated cover (biotechnical) to reduce erosion. While structural stabilization techniques can be effective, they often result in lost habitat, reduced vegetative cover, and potential to increase stream velocities and shift erosion problems further downstream (Li and Eddleman 2002). Biotechnical stabilization utilizes natural vegetative cover to reduce erosion from the surface and provides subsurface cohesiveness (Li and Eddleman 2002). There is also the added ecological benefit of restoring lost habitat (Li and Eddleman 2002, Sudduth and Meyer 2006).

Agriculture

A portion of the Groveland Flats area is contained in this segment of Canaseraga Creek (Fig. 2). Repeated water sampling determined the Groveland Flats area and Bradner Creek to be sources of TP, TN, nitrate, TSS, and TC to Twomile Creek (Fig. 35). For example, TSS averaged 19.4 mg/L in Twomile Creek above the Groveland Flats and 69.8 mg/L at the routine Twomile Creek site downstream from the Groveland Flats (Fig. 35). Total suspended solids concentrations in the ditches (average = 96.5 mg/L and 109.5 mg/L; Fig. 35) that enter the creek from the Groveland Flats are undoubtedly a major source. Orthoimagery confirmed visual observations that all through the Groveland Flats area, there is either a very small or no riparian buffer zone between cornfields and the creek (Fig. 2, Table 12, Appendix E). A CCSWAT simulation of grassed waterways in only the Groveland Flats area resulted in a TP load reduction of 18.2% at Pioneer Road and 6.1% at Shaker's Crossing (Table 19), which corresponded to a 13.5% reduction in TP concentration at Shaker's Crossing (from 104.3 µg P/L to 90.2 µg P/L), underscoring the impact that the Groveland Flats area has on the whole watershed.

Since agricultural runoff was observed to be the primary source of nutrients and channel erosion was the major sediment source along the main stem of Canaseraga Creek in the Dansville to Pioneer Road segment, relevant BMPs to implement in this area include riparian buffer zones between the creek and crop fields, grassed waterways within crop fields, and stream bank stabilization along the main stem. Grassed waterways effectively control gully formation and control erosion by providing a vegetated flow path for crop field runoff (Chow *et al.* 1999, Hjelmfelt and Wang 1999, NYS Soil and Water Conservation Committee 2005) and can reduce runoff volume by increasing infiltration (Fiener and Auerswald 2003). Grassed waterways would likely be the most effective management practice in the Groveland Flats area, where runoff from cornfields flows directly into streams or ditches without a chance for sedimentation. Riparian buffer zones along stream banks offer sediment reduction via bank stability and nutrient reduction through biologic uptake as runoff is carried from crop fields to the stream (Lowrance *et al.* 1984, Polyakov *et al.* 2005, Newbold *et al.* 2010).

In summary, the elevated areal loadings observed in the Dansville to Pioneer Road segment are mainly due to nonpoint agricultural activity and are not limited to CAFOs. However, the large WWTP in Dansville is also a significant pollution point source with WWTPs, in general, accounting for 9.6% of P loading for the entire Creek (Table 13). Along the flat main stem segment, erosion is exacerbated by channel straightening and reduced riparian cover, while the Mill Creek tributary is a lesser contributor of nutrients and sediment. Mud Creek and an adjacent subwatershed were identified by CCSWAT as 'hotspots' or critical areas of P lost (Fig. 79). These small, rural, steep watersheds have mixed agricultural and forested land uses that would benefit from contour farming or terracing to mitigate runoff due to steep slopes.

Because of the large P reduction occurring with BMPs on crop lands in the Dansville to Pioneer Road segment (e.g., grassed waterways: 32.0%, terracing: 25.2%, Table 19), BMPs on cropped fields are suggested as priority management areas over other potential sources in this segment. The most effective BMP for P load reduction, grassed waterways, would be beneficial in the crop fields surrounding Canaseraga Creek in this segment, as well as in the fields of Edgewood Farms, a source of P. The restoration of riparian zones would also reduce nutrient and sediment loading. Structural or biotechnical stream bank stabilization techniques would reduce sediment loss from the main stem channel of this highly erodible segment.

Main Stem of Canaseraga Creek: Pioneer Road to Shaker's Crossing Segment

(Including the Twomile Creek and Buck Run Creek tributaries)

This main stem segment from the Pioneer Road site to the outlet site to the Genesee River at Shaker's Crossing (39,627 ha) includes the Buck Run Creek and Twomile Creek tributaries. The land use in this area, excluding Twomile and Buck Run Creeks, is dominantly agricultural (61.8%), followed by forest (30.4%) and urban (7.7%). There are a total of six CAFOs in this segment, with two being in the Twomile Creek subwatershed (T. Joseph Swyers and Sparta Farms, LP), one in the Buck Run Creek (Mt. Morris Dairy Farms, Inc.) subwatershed, one in the Keshequa Creek subwatershed (Roll-N-View), and two on the main stem (Merrimac Farms, Inc. and Hainsworth Calf Management, Inc.; Table 4, Fig. 3). In addition, three WWTPs occur in this segment: the Mt. Morris, Groveland Correctional Facility, and Nunda WWTPs (Fig. 6). The Mt. Morris and Groveland Correctional Facility WWTPs are the second and third largest WWTPs within the Canaseraga Creek watershed, respectively. Areal losses of TP (1.0 kg/ha/yr), SRP (0.2 kg/ha/yr), and TSS (998 kg/ha/yr) from the Pioneer Road to Shaker's Crossing main stem segment were the second highest of all monitored sites (Table 11).

Twomile Creek subwatershed

The Twomile Creek subwatershed (11,241 ha; Fig. 4) is mostly agricultural (57.9%), followed by forest (35.6%) and urban (rural residential, 5.6%) land uses and includes the Bradner Creek tributary (Fig. 4). Segment analysis results consistently yielded distinct increases in sediment, nutrient, and bacteria concentrations between Twomile Creek site 1 and the routine site across several dates (Figs. 29, 32 to 40). For example, the average TP concentration of four sampling dates at Twomile Creek site

1 (upstream from the Groveland Flats) was 42.9 µg P/L while the averages in Ditch A, Ditch B, and Bradner Creek (all draining the Groveland Flats) were 166.1 µg P/L, 794.3 µg P/L, and 86.6 µg P/L, respectively (Fig. 35). Bradner Creek and the ditches from the Groveland Flats join Twomile Creek between Twomile Creek site 1 and the Twomile Creek routine site (Fig. 28).

Agriculture within the Twomile Creek subwatershed is concentrated in the Groveland Flats area downstream from site 1 (Fig. 28), which includes the Sparta Farms CAFO. The Groveland Flats area, an area of intense corn production, was determined to be a source of TP, TSS, and coliform bacteria to Bradner Creek on 7 September 2011 (Figs. 36 and 37). Twomile Creek also had elevated loadings of TP (0.6 kg/ha/yr), SRP (0.1 kg/ha/yr), TN (12.7 kg/ha/yr), nitrate (9.1 kg/ha/yr), and total coliform bacteria (4.9E+11 CFU/ha/yr; Table 11, Fig. 10). Segment analysis provided abundant evidence that the elevated areal loadings observed in the Twomile Creek subwatershed were due to the extensive network of ditches that drain the intensely agricultural Groveland Flats area and the Sparta Farms CAFO (Fig. 78). Both CAFOs within Twomile Creek subwatershed were identified as 'hot spots' of TP load from the CCSWAT model simulation of current conditions (Fig. 79).

The annual average TP concentration at Twomile Creek (132.0 µg P/L) was twice as high as the proposed TP standard of 65 µg P/L (Fig. 8). A CCSWAT model simulation implementing grassed waterways in Twomile Creek resulted in a 64.3% reduction in P load and a TP concentration of 31.1 µg P/L (Table 14b).

Implementation of one BMP in this heavily impacted subwatershed would effectively remediate this tributary and would meet the TP water quality target of 45 μg P/L.

Currently, there are no obvious BMPs being used in the Groveland Flats area of Twomile Creek. The large reductions in P and TSS by the CCSWAT model when grassed waterways were simulated in Twomile Creek indicate an ideal BMP for this subwatershed. Grassed waterways provide a vegetated flow path for agricultural runoff to reduce gullying in fields, reduce runoff volume, reduce runoff velocity to enhance infiltration, and reduce sediment transport (Chow *et al.* 1999, Fiener and Auerswald 2003, NYS Soil and Water Conservation Committee 2005). This management practice should be extended to other areas within the Groveland Flats area that are not within the Twomile Creek subwatershed, such as portions of the main stem parallel to Bradner Creek, and downstream from the Pioneer Road sampling site.

Flood Gates and Pump Station on Twomile Creek

Just before Twomile Creek joins Canaseraga Creek, a pump station, consisting of cement walls that confine the stream to a narrow creek channel, exists at this study's routine Twomile Creek site. During high flows, a vertical gate is lowered to prevent backflow from Canaseraga Creek into Twomile Creek, and the pumps move water from Twomile Creek into Canaseraga Creek on the other side of the flood gate. This practice appears to be important for agricultural practices as well as transportation, as Flats Road/NYS Route 258 (which spans the length of the Flats area), which is in the Twomile Creek subbasin, has flooded as much as four times per year (personal communications: Donald Higgins, Livingston County Highway Superintendent and Duane Aycock, NYSDOT Resident Engineer). Since no records are known to exist and the pump was not observed in operation during regular sampling visits in the year of the study, the extent that this pump has on the hydrology of Twomile Creek and Canaseraga Creek is unknown. However, the pumping action could exacerbate water quality by moving water (and nutrients) out of Twomile Creek subbasin faster than would naturally occur.

Buck Run Creek subwatershed

Buck Run Creek is the smallest monitored tributary (1,751 ha) and is dominantly agricultural (76.4%) with some forest (18.0%) and urban land uses (rural residential and part of the Village of Mt. Morris, 5.6%). Buck Run Creek had the highest areal loadings of TP (2.4 kg/ha/yr), SRP (0.6 kg/ha/yr), TN (17.6 kg/ha/yr), TSS (1,254 kg/ha/yr), and total coliforms (3.8E+11 CFU/ha/yr) of all measured sites (Table 11, Fig. 10), which was also confirmed in the CCSWAT model (Fig. 79). Segment analysis results indicated that the Mt. Morris Dairy Farms, Inc. CAFO (Table 4) is a major source of TP, SRP, TN, and TSS to Buck Run Creek. Large increases in nutrient concentrations from site 4 to site 3, where the CAFO and several retention ponds lie (Fig. 26), were observed. It is suspected that the retention ponds are collecting runoff from the surrounding barns and lightly buffered fields and then flowing into Buck Run Creek. An indication of animal waste contamination was inferred from the low nitrate (inorganic) concentrations and high TN concentrations, which include organic forms of nitrogen (such as those found in animal waste).

Currently, Buck Run Creek's annual average TP concentration (150.5 µg P/L) greatly exceeds the proposed 65 µg P/L water quality standard (Fig. 8). However, with the implementation of one BMP, TP concentrations of 45 µg P/L could be achieved based on CCSWAT simulation. For example, implementation of grassed waterways to reduce runoff resulted in reductions of TP and TSS by 92.5% and 97.6%, respectively, and TP concentration by 88.5% to 25.1 µg P/L (Tributary Remediation 2, Table 14b). The large percent reductions of TP and TSS from the model combined with segment analysis results and field observations provide ample evidence that agricultural runoff from the Mt. Morris Dairy Farms CAFO is in fact the critical source of pollution to Buck Run Creek. While grassed waterways are effective in reducing agricultural runoff (Chow *et al.* 1999, Fiener and Auerswald 2003), other widely studied and effective BMPs such as riparian buffer zones (Lowrance *et al.* 1984, Newbold *et al.* 2010, Polyakov *et al.* 2005, Welsch 1991) and whole farm planning (Makarewicz *et al.* 2009) are applicable to this subwatershed. Knowing where to target BMPs is important for improving efficacy of remediation efforts by focusing resources to implement BMPs on a specific area, gaining the most benefit for the least effort. For example, Diebel *et al.* (2009) predicted that the implementation of riparian buffers in the 10% of watersheds with the highest P reduction potential would reduce P loss from all modeled watersheds by 20% in Wisconsin.

Keshequa Creek subwatershed

The large tributary Keshequa Creek (Fig. 4) has two WWTPs - the Nunda WWTP and Groveland Correctional Facility WWTP- that were identified as significant sources of all analytes except TSS at the Nunda plant (Table 7). For example, TP concentrations above the Nunda WWTP averaged 12.8 µg P/L, while downstream TP averaged 271.5 µg P/L (Table 7a). Even higher downstream concentrations were observed at the Groveland Correctional Facility WWTP (upstream TP: 4.9 µg P/L, downstream TP: 2,973.7 µg P/L; Table 7a). However, Keshequa Creek was not observed to be high in nutrient concentrations when sampled due to dilution from the high volume of the creek. But upgrades to these WWTPs would reduce the cumulative impact of these plants on downstream systems.

Pioneer Road to Shaker's Crossing Main Stem Segment

Areal losses of TP (1.0 kg/ha/yr), SRP (0.2 kg/ha/yr), and TSS (998 kg/ha/yr) from the Pioneer Road to Shaker's Crossing main stem segment were the second highest of all monitored sites (Table 11), while mass loading of TP was the highest (64.5 MT/yr; Table 10). The main causes were determined to be land use in the Twomile Creek and Buck Run Creek tributaries and WWTP effluent (Fig. 78). The comparatively high areal loadings for this main stem segment and the two tributaries it contains prioritize this segment of Canaseraga Creek above the others.

Wastewater Treatment Plants

The Mt. Morris WWTP is the second largest WWTP in the Canaseraga Creek watershed and discharges a short distance (~530 m) upstream from the Shaker's Crossing sampling site. The Mt. Morris WWTP is a significant source of all measured analytes (e.g., upstream TP average: 18.4 µg P/L, downstream TP average: 492.6 µg P/L; Table 7a) and had high estimated daily loadings (e.g., daily TP load of 5.4 kg/d; Table 7b). The high effluent volume discharge, high effluent concentrations, and close proximity to the Shaker's Crossing site combined to implicate this WWTP as a key nutrient, sediment, and bacteria source. A CCSWAT simulation that upgraded just the Mt. Morris, Nunda, and Groveland Correctional Facility WWTPs to tertiary treatment resulted in a 6.3% TP load reduction (Table 19) and a 13.7% TP concentration reduction to 90.0 µg P/L (from 104.3 µg P/L) at Shaker's Crossing. When compared to a scenario that simulated upgrading all the WWTPs in the whole Canaseraga Creek watershed (Shaker's Crossing: 9.4% TP load reduction, TP concentration of 84.0 µg P/L; Table 14a), the three WWTPs in the Pioneer Road to Shaker's Crossing segment account for a majority of the TP load and concentration reduction.

Canaseraga Creek Watershed: *Headwaters to Shaker's Crossing*

Several management options are viable for the Canaseraga Creek watershed. Stream bank stabilization (49.4% TSS load reduction), agricultural BMPs (e.g., grassed waterways, 44.8% TP load reduction), and upgrading WWTPs (9.4% TP load reduction) were effective CCSWAT model BMP simulations that would be useful to mitigate point and nonpoint source areas of pollution in all of the Canaseraga Creek subwatersheds (Table 14a). However, watershed scale BMP implementation may be impractical, as it applies the same BMP for large and small farms alike in the entire watershed. A more realistic approach is to target the most critical nutrient and sediment sources for BMP implementation. The implementation of just grassed waterways in Twomile and Buck Run Creeks alone (Tributary Remediation 2, Table 14) resulted in a 12.6% reduction in TP load at Shaker's Crossing and a TP concentration of 95.3 µg P/L (8.6% reduction, Table 14b). The targeting of a portion of the watershed was taken a step further by implementing the most effective agricultural BMP (grassed waterways) in the most impacted areas (Twomile Creek, Buck Run Creek and the Groveland Flats), stabilizing the erosion-prone stream banks from Dansville to the outlet, and upgrading all WWTPs to tertiary treatment (Tributary Remediation 3, Table 14a). This scenario had a striking effect on phosphorus and sediment loading at Shaker's Crossing (TP and TSS load reductions of 27.2% and 18.7%, respectively) and effectively reduced the TP concentration by 31.4% to 71.6 µg P/L from 104.3 µg P/L. Additionally, the TP reduction for the Tributary Remediation 3 scenario would be larger than the modeled result due to the previously observed model results for stream bank stabilization and the high observed correlation in chemistry samples (Fig. 77).

While the remediation of just two tributaries and a few selected areas does not reduce TP concentrations to below the proposed water quality target (65 µg P/L), it does indicate that these areas should be given the highest priority for remediation efforts. Other areas with similar impairments, such as the main stem area downstream from the Groveland Flats between the Pioneer Road and Shaker's Crossing sites, should be targeted for BMP implementation. The effectiveness of targeting critical source areas for BMP implementation in Canaseraga Creek is demonstrated by the

CCSWAT simulations and has been suggested by Diebel *et al.* (2009) as a realistic approach for watersheds in general.

In summary, the main stem segment from Pioneer Road to Shaker's Crossing is a priority segment for remedial efforts due to the high areal loadings observed in this section and at the two tributaries (Twomile and Buck Run Creeks) therein. Agricultural sources, such as the cornfield-dominated Groveland Flats/Sparta Farms area of Twomile Creek and Mt. Morris Dairy Farms on Buck Run Creek, are the largest source of P in this segment and in the entire Canaseraga Creek watershed (59.6%, Table 13). Upgrading WWTPs in all of Canaseraga Creek was effective in reducing TP loading by 9.4% and TP concentrations by 19.5% (from 104.3 μg P/L to 84.0 μg P/L at Shaker's Crossing; Table 14a). Upgrading just the three WWTPs in the Pioneer Road to Shaker's Crossing segment (the Nunda, Mt. Morris and Groveland Correctional Facility WWTPs) resulted in a 6.3% reduction in TP loading (Table 19) and a TP concentration reduction of 13.7% (from 104.3 μg P/L to 90.0 μg P/L) at Shaker's Crossing. Remediation of all these critical sources (Tributary Remediation 3) was simulated using the CCSWAT model, which resulted in a very effective reduction in P and TSS (Table 14a). However, the TP concentration did not quite reach the most appropriate proposed target of 65 μg P/L. This could be due to a deficiency in the stream-bank TP/TSS relationship within the SWAT model or an indication that further remedial efforts are required in more than in just these specified areas. If agricultural BMPs are implemented in more areas, the CCSWAT model has simulated that Canaseraga Creek can in fact reach the proposed TP concentration of 65 µg P/L (Table 14a).

Conclusions and Management Recommendations

With approximately 76.7% of its phosphorus load from anthropogenic sources (Table 13), the largest subbasin (88,578 ha) of the Genesee River, Canaseraga Creek, should be a high priority for water quality remediation. Reducing phosphorus loads from Canaseraga Creek into the Genesee River is an important step to reduce the impact that the Genesee River has on water quality in the nearshore zone of Lake Ontario. In general, nonpoint sources of agriculture were identified as the leading cause of phosphorus loss in Canaseraga Creek through segment analysis, determination of weekly and event water chemistry, and integration into the Soil and Water Assessment Tool (SWAT) model (Table 13).

The Canaseraga Creek watershed segments with the highest areal loadings were the Dansville to Pioneer Road main stem segment, Twomile Creek, Buck Run Creek, and the Pioneer Road to Shaker's Crossing main stem segments. Sources were investigated and identified by using the segment analysis sampling technique. Intensive agricultural areas such as the Groveland Flats and several CAFOs were identified as critical source areas (Fig. 78). Wastewater treatment plants were also determined to be significant point sources of nutrients, sediment, and bacteria (Table 7). The erosion-prone area along the main stem of Canaseraga Creek between Dansville and the Pioneer Road sampling site (Fig. 77) was considered a critical sediment source. By incorporating sampling results into SWAT, the Canaseraga Creek model (CCSWAT) was successfully calibrated, validated, and used to simulate various management scenarios. Total phosphorus concentrations of 45 and 65 μg P/L were considered as realistic water quality targets to reach by implementing various BMPs.

A simulated forested Canaseraga Creek watershed (CCSWAT) suggested an annual minimal stream TP concentration 33.5 μg P/L is potentially achievable (Table 14a). Of the various BMPs simulated throughout the whole watershed, grassed waterways were the most effective in reducing TP loading (44.8% reduction) and reducing TP concentration (69.9 μg P/L) at Shaker's Crossing. But grassed waterways by themselves did not reach either of the target (45 and 65 μg P/L) TP concentrations. Simulations combining grassed waterways with upgraded (tertiary) WWTPs resulted in a decreased P concentration of 49.7 μg P/L at Shaker's Crossing. This simulation suggested that 65 μg P/L is a realistic target concentration and that the 45 μg P/L target may be met with more stringent BMPs. The combined scenarios of grassed waterways in all agricultural lands and upgrades of all WWTPs within the watershed is a costly approach to an entire watershed. A less costly approach is to focus remediation to a smaller area known to deliver P to the streams. For example, by implementing grassed waterways in the impacted tributaries of Twomile and Buck Run Creeks and the Groveland Flats area, by implementing streambank stabilization in highly erodible main stem areas, and by upgrading WWTPs to tertiary treatment (Tributary Remediation 3, Table 14a), the CCSWAT model predicted a reduction in TP concentration from 104.3 μg P/L to 71.6 μg P/L (Table 14a). Although this scenario did reach even the less stringent 65 µg P/L regulatory standard, this scenario does provide an effective and discrete starting point for any remediation efforts.

The Canaseraga Creek watershed has water quality impairments that were mitigated using several management scenarios with the CCSWAT model. Through various combinations of management options, the CCSWAT model predicted that Canaseraga Creek is capable of reaching a target TP concentration of 65 µg P/L and that a target of 45 µg P/L is potentially possible with more rigorous efforts. Once these BMPs are implemented, the excessive loading of phosphorus and sediment from Canaseraga Creek into the Genesee River will be reduced. When combined with other remedial efforts in other watersheds, the overall impact of the Genesee River's tributaries will lessen and in turn the amount of sediment and nutrients delivered by the Genesee River to Lake Ontario will decrease. It is by this systematic approach that water quality can be improved in the Rochester area nearshore zone of Lake Ontario.

Nutrient Biotic Index

Their diversity, sensitivity to pollution, short life span, low mobility, food web interactions, and ease of collection make macroinvertebrates successful indicators of water quality (Bode *et al.* 2002, Smith *et al.* 2007). Their importance in multi-metric indices has been recognized by the USEPA, especially as secondary response variables that may aid in nutrient criteria development (USEPA 2000a). In fact, Smith *et al.* (2007) developed a Nutrient Biotic Index (NBI) using benthic macroinvertebrates from wadeable streams that determined trophic state based on the score, which is a result of optimal nutrient conditions specific for individual taxa.

The biologic approach to stream classification is paralleled by the chemical approach. Evaluating stream water quality using chemistry data is generally split into two methods: a maximum (‘threshold’) concentration above which biologic communities begin to experience changes and impairments (e.g., USEPA 1986, USEPA 2000b, Dodds *et al.*1997), and a trophic status system similar to that used for lakes (e.g., oligotrophic, mesotrophic, eutrophic), in which nutrient concentrations (TP and TN) represent some point along a gradient of nutrient pollution (e.g., Dodds *et al.* 1998, CCME 2004). While the single concentration threshold approach is easy to translate into nutrient criteria for states to regulate, it does not give an indication into stream trophic state. The trophic state approach allows watershed managers to classify the extent of nutrient pollution in a stream, enabling them to identify streams that are at a high risk of becoming impaired. Setting the boundary between mesotrophic and eutrophic as the point in which a stream becomes impaired (Smith *et al.* 2007) also incorporates the threshold approach.

This study evaluated the macroinvertebrate derived NBI-P and NBI-N determination of trophic status (Smith *et al.* 2007) with those derived from stream chemistry (e.g., Dodds *et al.* 1998). Four sites in three subbasins of the Genesee River were compared. Within the Canaseraga Creek watershed, two sites were sampled: a tributary with nutrient impairment (High P and high N, Buck Run Creek) and a tributary with no observed nutrient impairment (Low P and moderate N, Stony Brook;

Figs. 3 and 8, Table 5). A third stream, Bigelow Creek in the Black Creek watershed, has high phosphorus and low nitrate concentrations (Table 5b) and is listed as impaired on the NYS 303(d) list due to high phosphorus. The fourth macroinvertebrate sample was taken on Oatka Creek at Garbutt, NY, which has a high nitrate concentration but a low TP concentration (Table 5b).

Stony Brook

The Dodds *et al.* (1998) classification scheme based on stream phosphorus and nitrogen data was used to classify the stream's trophic status. Both the long and short-term average TP concentrations of stream water were < 25 µg P/L at Stony Brook, indicating oligotrophic conditions (Dodds *et al.* 1998; Table 5). Several 'threshold' type studies have proposed similar values that also indicate unpolluted conditions at Stony Brook (30 µg P/L, Smith and Tran 2010, Dodds *et al.* 1997, Stevenson *et al.* 2006; Table 5c). The low TP concentrations (Table 5b) at Stony Brook were expected, as annual and areal TP loads were the lowest of all measured sites within the Canaseraga Creek watershed (annual TP load: 1.0 MT/yr, areal TP load: 0.2 kg/ha/yr; Tables 10 and 11).

Again based on the Dodd et al (1998) classification, the short-term average TN (1.31 mg N/L) concentration and the annual average (1.18 mg N/L) indicated mesotrophy (Table 5). At Stony Brook both nitrate (NO_3+NO_2) concentrations (short and long-term averages) indicate a mesotrophic status for the stream. However, Dodds *et al.* (1997) and Dodds (2003) have suggested that TN is a better indicator of stream trophic state rather than just nitrate - a fraction of total nitrogen - as organic nitrogen levels may be high in watersheds with animal operations (e.g., CAFOs). At Stony Brook, TN (short-term average TN: 1.31 mg N/L, long-term average TN: 1.18 mg N/L) was higher than nitrate (short-term average nitrate: 1.07 mg N/L, long-term average nitrate: 0.92 mg N/L; Table 5). Based on the macroinvertebrate community composition and assigned tolerance values, both the NBI-P score of 5.0 and NBI-N score of 4.5 at Stony Brook indicated an oligotrophic condition of stream water.

Buck Run Creek

Nutrient Biotic Index derived trophic statuses based on macroinvertebrate composition at Buck Run Creek were indeed comparable to the classification scheme of Dodds *et al.* (1998), especially if long-term averages and total nitrogen are employed rather than short-term averages and nitrate. The long-term average TP concentration (150.5 µg P/L) at Buck Run Creek exceeded the suggested mesotrophic-eutrophic boundary value of 75 µg P/L (Dodds *et al.* 1998), the hyper-eutrophic value of 100 µg P/L (CCME 2004), and the criteria values of at least seven States (Table 5c), while the short-term average TP concentration (62.3 µg P/L) suggested mesotrophic conditions (Dodds *et al.* 1998). The elevated TP concentrations in the Buck Run watershed are a result of agricultural runoff from a CAFO, which coincide with high areal loadings (TP: 2.4 kg/ha/yr, TN: 17.6 kg/ha/yr; Table 11). The widely different results between the short and long-term average TP concentrations suggest that streams with inherently variable nonpoint source agricultural runoff might need a wider time frame from which to draw average nutrient concentrations.

The Buck Run Creek nitrogen data also suggest that nitrate may not be the best form of nitrogen to use in evaluating trophic conditions of streams (Dodds *et al.* 1997, Dodds and Welch 2000, Dodds 2003). Total nitrogen at Buck Run Creek was less variable than nitrate, with the short-term (TN: 1.97mg N/L) and long-term averages (TN: 2.03 mg N/L) both similar and indicating eutrophic conditions (Table 5). Nitrate concentrations (0.97 mg N/L) were approximately 50% of the long-term total nitrogen concentrations (2.03 mg N/L). We suspect this difference is due to the presence of organic forms of N (animal waste) from the upstream CAFO (e.g., segment analysis site 3 on 10 May 2011, downstream from CAFO TN: 4.80 mg N/L, nitrate: N.D.; Figs. 26 and 27). In an agriculturally impacted stream such as Buck Run Creek, the use of TN rather than nitrate will likely result in a more accurate assessment of overall water quality. Compared to literature TN concentrations, Buck Run Creek exceeded the TN mesotrophic-eutrophic boundary of 1.5 mg N/L (Dodds *et al.* 1998).

As with phosphorus, the period of time in which the average of stream N concentrations are taken impacts the ability to classify a stream's trophic state, especially when dissolved fractions are considered (e.g., short-term nitrate average: 1.44 mg N/L, long-term nitrate average: 0.97 mg N/L; Table 5). The NBI-P score indicated eutrophic conditions, while the NBI-N score indicated mesotrophy. The different trophic state due to the NBI-N may be to the assignment of tolerance values using nitrate (Smith *et al.* 2007) instead of TN.

The discrepancy between short term and annual averages must be addressed in order to improve trophic state predictions. While macroinvertebrate life cycles are a consideration for the use of the short-term (90-day) average to determine trophic state at the time of sampling, Buck Run Creek is an example where an individual macroinvertebrate sample (and its corresponding 90-day average nutrient concentration) may not accurately depict the actual conditions annually. Factors such as rainfall events, intensity of runoff, snowmelt versus rainfall events, whether or not manure is being spread and influencing the stream, and number of samples taken will influence the accuracy of a short-term average nutrient concentration at a given agriculturally impacted site. Potential solutions to this problem include taking more samples during the averaging period, ensuring that events are sampled, and/or extending the time period used for obtaining an average nutrient value.

Bigelow Creek in the Black Creek Watershed

Bigelow Creek is a small (2,616 ha), agricultural (82%) subwatershed in South Byron, NY, in the Black Creek watershed. Both the long-term average stream TP concentration of 114.5 µg P/L and the short-term 2011 average of 79.9 µg P/L indicated a eutrophic status of the stream water (Dodds *et al.* 1998; Table 5). The short-term 2010 average was in the mesotrophic range at 69.8 µg P/L, but close to the lower end of the eutrophic range of 75 µg P/L (Dodds *et al.* 1998; Table 5). The areal TP loading (1.1 kg/ha/yr) in Bigelow Creek was the highest of all Black Creek watershed sites, and was the observed to be primarily due to nonpoint agricultural runoff from pasture and row crop fields using field water chemistry sampling and

SWAT model simulations (Winslow 2012). The observed TP data at Bigelow Creek and Buck Run Creek indicate that an agriculturally impacted site's nutrient concentrations are not always well-represented when comparing short and long-term averages.

Compared to the other three sites, Bigelow Creek had the lowest nitrate concentrations of all sites (Table 5). However, the long-term nitrate average (0.75 mg N/L) in Bigelow Creek represented approximately one half of the TN annually (TN: 1.42 mg N/L, Winslow 2012). Considering mean nitrate, Bigelow Creek would be classified as barely mesotrophic using the Dodds *et al.* (1998) criteria. Again, the use of TN instead of nitrate more accurately depicts the amount of N in the stream, and includes organic forms of N which can be from agricultural manure applications (as observed in Buck Run Creek). If the TN data are used, the stream would be classified as mesotrophic. The macroinvertebrate derived NBI-P and NBI-N agreed with each other and indicated a mesotrophic status (Table 5). This NBI designation agrees well with the nitrogen classification scheme of Dodds et al (1998) but not with the P criteria for mesotrophy (Table 5). The long-term average TP for this site was 114.5 µg P/L, which is well into the eutrophic range of Dodds *et al*. (1998).

Oatka Creek at Garbutt, NY

Land use in the larger (55,700 ha) Oatka Creek site at Garbutt, NY is also predominantly agricultural (73.8%), but short and long-term stream TP concentrations were low and well within the mesotrophic range (between 25 and 75 µg P/L; Table 5). Of the four sites, the Oatka Creek site at Garbutt, NY, had the highest measured nitrate concentrations of all macroinvertebrate sampling sites (long-term average nitrate: 2.07 mg N/L) and made up 82% of the TN in Oatka Creek (long-term average TN: 2.52 mg N/L), indicating a eutrophic stream condition. Both the macroinvertebrate derived NBI-P (5.9) and NBI-N (5.2) scores at Oatka Creek suggested the stream was mesotrophic. The presence of numerous CAFOs and other agricultural areas were determined to be the leading causes of nitrogen in Oatka Creek (Pettenski 2012). The abundance of filamentous green algae at the Garbutt, NY, site on Oatka Creek also suggested persistent high nitrogen concentrations.

Nutrient Biotic Index Conclusions

The NBI trophic state predictions based on four macroinvertebrate samples were not always comparable (Smith *et al.* 2007) to the corresponding chemically-derived nutrient criteria as described by Dodds *et al.* (1998). In general though, macroinvertebrate and chemically derived predictions of trophic status agreed very well for phosphorus (Table 5b). The chemically derived Bigelow Creek predictions for the short-term period of 2011and long-term average (eutrophic) were not identical to macroinvertebrate derived trophic status (mesotrophy), as well as the short-term 2011 average (mesotrophic) for Buck Run Creek (NBI: eutrophic; Table 5b). It is interesting to note that the short-term average P concentration at Bigelow Creek for the year before would be classified as mesotrophic and agree with the macroinvertebrate prediction. The small number of water samples cannot be ruled out as the cause for the higher P concentration. Although a 2010 value is provided, it may not represent conditions in 2011, especially since the 2011 short-term concentration mimics the predicted trophic state from the long-term chemistry.

Another possibility is problems in taxonomy. While it is possible that NBI scores were variable due to inaccurate specimen identifications and inexperienced taxonomists, the quality control protocol minimized such variability and increased confidence in each samples' final identifications. The encountered variability is more likely due to tolerance values that may not fully depict each taxon's complete nutrient range, thus resulting in skewed or biased tolerance values. Also, each sample had some specimens that were omitted from NBI calculations due to the lack of a tolerance value. If there were more tolerance values that represented wider nutrient ranges for each taxon (and at different taxonomic levels), then the resulting NBI scores would presumably represent stream water chemistry more accurately.

We found very poor agreement between chemically-derived trophic status based on nitrate and macro-invertebrate trophic status. The chemical fraction of nutrients (e.g., total or dissolved) used for criteria development clearly affects the determination of trophic state. This is especially true for nitrogen. Even Smith *et al.* (2007) reported a weaker correlation for the NBI-N (r= 0.57) compared to the NBI-P (r= 0.68). This weaker correlation with nitrate and macroinvertebrate derived trophic status is related to the amount of organic nitrogen in the water. Nitrate does not consider organic nitrogen. Total nitrogen provides a better representation of the actual amount of nitrogen in the water (Dodds *et al.* 1997, Dodds and Welch 2000, Dodds 2003). As observed at Buck Run and Bigelow creeks, TN and nitrate concentrations can be very different (e.g., Buck Run Creek; annual TN average: 2.03 mg N/L, annual nitrate average: 0.97 mg N/L), which could potentially lead to mislabeling a stream as oligotrophic or mesotrophic when in fact eutrophic conditions are occurring. This becomes evident when CAFO operations exist in a watershed and the amount of organic nitrogen and potentially ammonia may be elevated. The USEPA routinely uses TN when proposing nutrient criteria values (USEPA 2000b). Developing the NBI for TN would be easier to relate to other studies, would potentially increase the accuracy of trophic state designations when compared to chemical data, and would therefore be more useful in setting nutrient criteria. However, setting a nutrient criteria value that is protective of water quality must also be reasonably attainable under current land use conditions.

Although Smith *et al.* (2007) collected chemistry data 4-10 times per year at each location, only the chemistry samples collected within the 90-day period, which suggests a smaller number of samples, preceding macroinvertebrate sampling were used to determine the NBI nutrient ranges for specimens. Such short-term averages could be quite different when compared to annual averages, especially in watersheds characterized by agricultural runoff such as Buck Run Creek and Bigelow Creek, where the NBI and chemistry classifications did not agree (Table 5). While a short-term average is appropriate for the conditions preceding a macroinvertebrate sample, it is not necessarily an accurate indicator of a stream's long-term chemistry; multiple short-term averages would likely be required to estimate overall stream water chemistry. Whatever time period is used for developing and then comparing to the

NBI, it is important that the NBI scores consistently predict the same trophic state as measured chemistry samples.

This study had mixed results. The NBI-P predicted trophic status reasonably well. However, the nutrient biotic index based on nitrate did not agree well with TN derived trophic status. The main reasons for the poor agreement are the use of nitrate instead of TN, the relatively low correlation between NBI scores and nitrate reported by Smith *et al.* (2007), and tolerance values that may not cover a wide range of nutrient concentrations for each taxon. Although improvements to the NBI-N could be made to include more samples and wider nutrient ranges to improve tolerance values, it is probable that the nitrate-based index will always have considerable variability when compared to TN trophic status. Especially for agriculturally impacted sites such as Buck Run and Bigelow creeks, nitrate concentrations will be relatively low when compared to TN due to the presence of organic N and ammonia. Such an inherently incomprehensive index will likely yield consistently inaccurate results as observed in this study. There was a generally good agreement between NBI-P and chemically-derived TP trophic state, there were large disparities between nitrate and TN concentrations, and differences between NBI-N and TN chemistry-derived trophic status, in this study. Therefore, it was concluded that using TN instead of nitrate would improve NBI trophic state predictions, which would also make comparing to other studies easier. Improving NBI tolerance values to include wider nutrient ranges and for more taxa was suggested for the NBI-P, which would also benefit the NBI-N.

Additionally, the time period used for obtaining an average nutrient concentration is critically important to trophic state designations. A short-term (90-day) average compared to an annual average can give different trophic status results based on the chemistry (e.g., Buck Run Creek 62.3 µg P/L = mesotrophic versus 150.5 µg P/L= eutrophic; Table 5b). The inclusion of event periods in calculating averages is especially important for agriculturally-impacted sites. For this reason, it is concluded that annual nutrient averages will have a larger sample size and will therefore describe the water chemistry of a stream more accurately than a short-term average. Ultimately, it is the combination of all the previously mentioned factors that will improve NBI trophic state designations so then they will more reliably agree with chemistry-derived trophic states, and thus would make the NBI a more powerful measure of stream chemical and biological quality.

Aforementioned studies suggested nutrient criteria, but the feasibility of reaching those proposed water quality targets was not often discussed. Models such as SWAT can be extremely useful in identifying minimum attainable nutrient concentrations, as was done with TP in this study. The CCSWAT model was used to simulate a completely forested ('undeveloped') Canaseraga Creek watershed, which resulted in a TP concentration of 33.5 µg P/L near the outlet (Table 14). Similarly, Winslow (2012) and Pettenski (2012) used the SWAT model to identify 'undeveloped' TP concentrations of 45.6 µg P/L for Bigelow Creek and 22.9 µg P/L for the Oatka Creek site at Garbutt, NY. These models indicate that some proposed nutrient criteria are impossibly low (e.g., 30 µg P/L proposed by Dodds *et al.* 1997, Stevenson *et al.*

2006, Smith and Tran 2010; 33.00 µg P/L and 24.13 µg P/L proposed by USEPA 2000b). Knowing the absolute minimum possible TP concentrations does not mean that that concentration should be the limit for a particular waterbody. Some human land use impacts must be accounted for if practical water quality targets are going to be set. With intensive BMP implementation, TP concentrations in Bigelow Creek will remain high (71.7 µg P/L, Winslow 2012), while Oatka Creek and Buck Run Creek could reach proposed TP concentrations (Oatka Creek at Garbutt, NY: 29.6 µg P/L, Pettenski 2012; Buck Run Creek: 23.4 µg P/L, Table 14). The model allows for whole watershed or tributary specific conditions to be simulated and analyzed for appropriateness of water quality goals. One TP concentration target such as 30 µg P/L will not be possible to obtain in Bigelow Creek, but might be feasible for Buck Run Creek and Oatka Creek at Garbutt, NY, if enough funds are available to implement extensive BMPs. More realistically, a higher TP concentration value of 45 µg P/L or 65 µg P/L should be considered for practicality. Even though a higher concentration target could cause some changes in biological communities (Smith and Tran 2010), it would help to focus management efforts on the most polluted streams, which would then benefit the aquatic life in those streams by removing the sources of impairment. A higher TP target would also be protective of streams that already meet the target by effectively capping the allowable amount of TP in those streams. For streams already under a higher proposed nutrient limit, lower waterbody-specific criteria could be developed to ensure the continuance of good water quality.

This study made it clear that a compromise must be made in setting nutrient criteria that will minimize the effects of human development on stream biologic communities, be proactive enough to prevent deleterious changes in biologic community structure, and be realistic. Since NBI scores were inconsistent, it can be concluded that chemistry samples provide a more reliable and discreet measure of chemical stream water quality. However, more work can be done in refining NBI tolerance values, creating more tolerance values for more taxa, and collecting more chemistry data. It is conceivable that repeated chemistry and macroinvertebrate sampling would result in more reliable and consistent designations of stream water quality, and would thus validate the NBIs.

Tables

Table 1. Land use in the Genesee River Basin. [USDA Cropland Data Layer (CDL) 2009 (includes National Land Cover Database (NLCD) data)]. Percentages calculated by [(number of cells in given land use class/total number of cells in watershed)*100]. The remaining 1.8% is comprised of various other uses such as open water, idle cropland, and barren land. Total number of land uses =56.

Land Use	**%**
Forested (NLCD deciduous, evergreen, mixed)	46.0%
Agriculture	38.9%
Urban Land (NLCD open space, low, medium, high)	8.4%
Wetlands (NCLD herbaceous, woody)	2.4%
Shrubland (NCLD)	2.6%
Total	**98.2%**

Table 2. Summary of 2001 NYS DEC Priority Waterbodies List/Waterbody Inventory data by river/tributary of the Genesee basin (all data); n=155.

Watershed	**Impaired**	**Minor**	**Threatened**	**Need Verification**	**No Known Impacts**	**Unassessed**	**Total**
Black Creek	3	1	0	2	0	5	11
Oatka Creek	0	5	0	0	0	5	10
Canaseraga Creek	1	2	0	3	5	12	23
Honeoye Creek	3	1	1	0	8	8	21
Genesee Basin	14	27	2	14	26	72	155

Table 3. Land uses in Canaseraga Creek watershed as determined by the SWAT model.

Land Use	**Percent**
Forest	44.4
Agriculture	46.8
Urban	5.7
Range Grass/Brush	3.0
Wetlands	0.2
Total	**100.0**

Table 4. Confined animal feeding operation (CAFO) names, number of animals, and areas (area used is only land used for manure application) in the Canaseraga Creek watershed, 2010 (data provided by NYSDEC Region 8). Also included are SWAT model input values for manure application area, rate (kg manure per hectare per 30 days), subbasin (sub) and land use used for manure application.

Facility Name	**Area Owned (ha)**	**Area Used 2010 (ha)**	**SWAT area Used (ha)**	**Total Animals**	**Manure Application Rate (kg manure/ha/30 d)**	**Subbasin**	**Land Use**
Wilson Dairy & Sheep Farms	259.0	121.4	127.7	603	3,696.1 (dairy) 84.6 (sheep)	58	Alfalfa, Soybean
R. Schramm Ent.	299.1	182.1	175.3	413	2,759.3	50	Corn, Generic Agriculture
Sparta Farms LP	1529.7	1,011.7	1,040.4	2,555	2,876.2	31, 21, 19	Corn (subs 19, 21, 31), Alfalfa (sub31)
T. Joseph Swyers	736.9	519.2	515.7	1,210	2,748.0	38	Corn, Alfalfa, Winter Wheat
Roll-N-View	1018.6	688.0	711.2	2,490	4,100.5	26, 24	Hay, Corn (sub 26), Alfalfa (subs 24, 26)
Mt. Morris Dairy Farms, Inc.	829.6	485.6	475.4	1,430	3,523.0	13, 8	Corn, Winter Wheat (sub 13), Alfalfa (subs 13, 8)
Edgewood Farms	993.1	477.9	469.7	1,140	2,842.6	22	Corn, Alfalfa, Winter Wheat
Hainsworth Calf Management, Inc.	514.3	264.3	263.5	2,300	1,777.9 (dairy) 757.1 (veal)	9	Alfalfa, Soybean
Merrimac Farms, Inc.	634.5	141.6	143.0	660	5,405.5	1	Alfalfa, Generic Agriculture

Table 5. **(A)** Nutrient biotic index (NBI) scores and nutrient criteria for total phosphorus (TP) and nitrate with corresponding trophic state designations (Smith *et al*. 2007, 2009). **(B)** Scores for the TP NBI (NBI-P) and the nitrate NBI (NBI-N), trophic state, and average nutrient concentrations at Buck Run Creek, Stony Brook, Bigelow Creek and Garbutt, NY. Trophic state was determined using the annual (long-term) average, while short-term (all water chemistry samples within 90-days preceding macroinvertebrate sample) averages are provided for comparison. All macroinvertebrate samples were taken on 23 August 2011. Bigelow Creek is a tributary of Black Creek (BC), Garbutt, NY, is a downstream main stem site on Oatka Creek (OC), and Stony Brook and Buck Run Creek are tributaries of Canaseraga Creek (CC). **(C)** Summary of proposed and selected State nutrient criteria values for streams: single values represent 'thresholds' above which streams will experience nutrient impairment, while multiple values from a single source indicate nutrient ranges for trophic states. O= oligotrophic, M= mesotrophic, E= eutrophic, N/A= not applicable.

A. **NBI Score**	**TP Boundary Criteria (µg P/L)**	**NO_3^- Boundary Criteria (mg N/L)**	**Trophic State**
0-5	0 - 17.5	0 - 0.24	Oligotrophic (O)
5-6	17.6 - 64.9	0.25 - 0.97	Mesotrophic (M)
6-10	> 65	> 0.98	Eutrophic (E)

Table 5. Continued.

B. **Site Name**	**NBI-P Score**	**NBI-P Trophic State**	**Average TP (µg P/L)**			**TP Trophic State, annual (Dodds *et al.* 1998)**	**NBI-N Score**	**NBI-N Trophic State**	**Average NO_3^- (mg N/L)**			**Average TN (mg N/L)**		**TN Trophic State, annual (Dodds *et al.* 1998)**
			short-term 2010	**short-term 2011**	**annual**				**short-term 2010**	**short-term 2011**	**annual**	**short-term**	**annual**	
Bigelow Creek (BC)	5.5	M	69.8 n= 15	79.9 n= 2	114.5 n= 55	E	5.7	M	0.25 n= 15	0.42 n= 2	0.75 n= 55	N/A	1.42	M
Garbutt, NY (OC)	5.9	M	24.5 n= 15	36.6 n= 3	41.3	M	5.2	M	1.70 n= 15	2.15 n= 3	2.07	N/A	2.52	E
Stony Brook (CC)	5.0	O	N/A	13.9 n= 14	21.0 n= 51	O	4.5	O	N/A	1.07 n= 14	0.92 n= 51	1.31	1.18	M
Buck Run Creek (CC)	6.1	E	N/A	62.3 n= 14	150.5 n= 51	E	5.4	M	N/A	1.44 n= 14	0.97 n= 51	1.97	2.03	E

Table 5. Continued.

C. Source	TN (mg N/L)	Nitrate (mg N/L)	TP (µg P/L)
Proposed stream nutrient criteria			
USEPA 1986	10	-	100
USEPA 2000b, Aggregate Ecoregeion VII	0.54	-	33.00
USEPA 2000b, level III ecoregion 83	0.48	-	24.13
Dodds *et al.* 1997	0.35	-	30
Stevenson *et al.* 2006	1.0	-	30
Smith and Tran 2010	0.7	0.3	30
Dodds *et al.* 1998			
oligotrophic	<0.7	-	<25
mesotrophic	0.7-1.5		25-75
eutrophic	>1.5	-	>75
CCME 2004			
ultra-oligotrophic	-	-	<4
oligotrophic	-	-	4-10
mesotrophic	-	-	10-20
meso-eutrophic	-	-	20-35
eutrophic	-	-	35-100
hyper-eutrophic	-	-	>100
State Criteria (from USEPA 2003)			
New Jersey, New Mexico, Arkansas	-	-	100
North Dakota	-	1.0	100
Oaklahoma	-	-	37
Illinois	-	10	50
Vermont	-	0.20-5.0	10

Table 6. Latitude/longitude (decimal degrees) for routine sampling sites in Canaseraga Creek watershed and macroinvertebrate sampling sites in Black Creek and Oatka Creek watersheds.

Location	**Latitude (North)**	**Longitude (West)**
Canaseraga Creek at Shakers Crossing	42.736260	-77.842090
Twomile Creek	42.684102	-77.798152
Mill Creek	42.554160	-77.700850
Canaseraga Creek at Dansville	42.542500	-77.701730
Canaseraga Creek at Faulkner Rd.	42.472886	-77.755948
Buck Run Creek	42.713476	-77.866876
Canaseraga Creek at Pioneer Rd.	42.680637	-77.784165
Stony Brook	42.527043	-77.695329
Bigelow Creek in Black Creek watershed	43.32278	-78.11583
Oatka Creek at Garbutt, NY	43.01	-77.791667

Table 7. Wastewater treatment plant (WWTP) sampling results within the Canaseraga Creek watershed. Above and below values are average concentration ± standard error. **A.** The nonparametric Wilcoxon test was used for all sites. P <0.05 (bold) indicates that the median residual concentration (below – above) is significant. TP= total phosphorus, SRP= soluble reactive phosphorus, TN= total nitrogen, TSS= total suspended solids, N.D. = non-detectable. **B.** Daily (kg/d and CFU/d) and yearly (kg/yr and CFU/yr) WWTP loadings using daily average discharge for each WWTP in Canaseraga Creek watershed.

A. **Location**			**TP**	**SRP**	**TN**	**Nitrate**	**TSS**	**Total Coliform**
			(µg P/L)	(µg P/L)	(mg N/L)	(mg N/L)	(mg/L)	(CFU/100ml)
Canaseraga	Lat: 42.468 N	Above (~1 m)	20.2 ± 1.0	3.6 ± 0.5	0.64 ± 0.01	0.34 ± 0.01	1.7 ± 0.4	3,000 ± 365
6/21/2011	Long : -77.766 W	Below (~1 m)	25.7 ± 2.2	4.8 ± 1.0	0.68 ± 0.02	0.34 ± 0	4.1 ± 1.6	3,440 ± 194
	Avg. Discharge: 146 m^3/d	P-value	**0.03**	0.14	**0.03**	0.39	**0.05**	0.14
	Max Discharge: 379 m^3/d	Effluent	3,573.3	3,211.7	5.72	4.80	0.6	ND
Dansville	Lat: 42.565 N	Above (~14 m)	57.9 ± 1.0	9.6 ± 0.4	1.07 ± 0.01	0.79 ± 0	20.2 ± 0.3	18,800 ± 1,855
7/26/2011	Long: -77.717 W	Below (~30 m)	260.0 ± 12.4	133.1 ± 3.9	3.36 ± 0.05	3.05 ± 0.03	16.8 ± 0.1	28,400 ± 2,482
	Avg. Discharge: 5,209 m^3/d	P-value	**0.03**	**0.03**	**0.03**	**0.03**	0.99	**0.03**
	Max Discharge: 5,678 m^3/d	Effluent	725.6	224.8	10.16	9.64	6.7	50,000
Nunda	Lat: 42.582 N	Above (~1 m)	12.8 ± 0.8	3.8 ± 0.2	1.12 ± 0.01	0.90 ± 0	6.8 ± 0.6	10,600 ± 808
7/12/2011	Long: -77.927 W	Below (~20 m)	271.5 ± 63.5	257.3 ± 63.2	2.54 ± 0.34	2.28 ± 0.32	9.7 ± 1.4	13,680 ± 1,105
	Avg. Discharge: 386 m^3/d	P-value	**0.03**	**0.03**	**0.03**	**0.03**	0.07	**0.03**
	Max Discharge: 757 m^3/d	Effluent	3,653.8	2,878.8	20.84	18.81	2.1	18,000

Table 7. Continued.

Location			**TP**	**SRP**	**TN**	**Nitrate**	**TSS**	**Total Coliform**
			(µg P/L)	(µg P/L)	(mg N/L)	(mg N/L)	(mg/L)	(CFU/100ml)
Groveland	Lat: 42.66333 N	Above (~1 m)	24.4 ± 1.0	5.2 ± 0.7	1.60 ± 0.02	1.4 ± 0.01	12.0 ± 0	6,260 ± 633
Station	Long:-77.7705 W	Below (~7 m)	34.4 ± 1.4	15.2 ± 2.7	1.90 ± 0.08	1.4 ± 0.02	15.2 ± 0.5	4,480 ± 1,197
7/19/2011	Avg. Discharge: 32 m^3/d	P-value	**0.03**	**0.03**	**0.03**	0.91	**0.03**	0.71
	Max Discharge: 246 m^3/d	Effluent	6,426.5	5,618.8	5.63	3.58	4.2	20,100
Wayland	Lat: 42.560917 N	Above (~30 m)	35.2 ± 7.1	7.5 ± 0.4	1.84 ± 0.06	1.62 ± 0.03	16.3 ± 2.7	14,440 ± 2,024
8/9/2011	Long:-77.593389 W	Below (~118 m)	1,624.3 ± 90.5	1,399.4 ± 33.5	5.47 ± 0.11	5.29 ± 0.10	8.6 ± 1.3	48,000 ± 7,899
	Avg. Discharge: 668 m^3/d	P-value	**0.03**	**0.03**	**0.03**	**0.03**	0.99	**0.03**
	Max Discharge: 1,325 m^3/d	Effluent	3,292.5	1,542.3	23.09	21.47	5.30	50,000
Mt. Morris	Lat: 42.726722 N	Above (~1 m)	18.4 ± 0.2	4.2 ± 0.2	1.57 ± 0.03	1.45 ± 0.02	7.1 ± 0.3	2,340 ± 169
12/14/2011	Long:-77.86591 W	Below (~10 m)	492.6 ± 26.8	358.9 ± 20.2	4.38 ± 0.20	3.23 ± 0.11	11.8 ± 0.4	55,200 ± 5,678
	Avg. Discharge: 1,545 m^3/d	P-value	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**
	Max Discharge: 3,271 m^3/d	Effluent	3,565.8	2,748.2	32.66	25.18	21.5	154,000
Groveland	Lat: 42.686833 N	Above (~1 m)	4.9 ± 0.3	0.8 ± 0.2	1.25 ± 0.02	0.99 ± 0.02	3.4 ± 0.2	320 ± 111
Correctional	Long:-77.828556 W	Below (~10 m)	2,973.7 ± 17.9	2,812.3 ± 76.0	18.37 ± 0.13	16.43 ± 0.39	47.2 ± 7.5	1,380 ± 66
Facility	Avg. Discharge: 1,264 m^3/d	P-value	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**
2/21/2012	Max Discharge: 3,028 m^3/d	Effluent	3,487.4	3,487.4	18.76	16.88	14.3	2,100

Table 7. Continued.

B. **Location**	**WWTP Loadings Using Average Discharge**						
		TP (kg)	**SRP (kg)**	**TN (kg)**	**Nitrate (kg)**	**TSS (kg)**	**Total Coliform (CFU)**
Canaseraga	Daily	0.5	0.5	0.82	0.69	0.1	0
	Yearly	188.0	169.0	300.8	252.4	30.1	0.0E+00
Dansville	Daily	3.3	1.0	46.6	44.2	30.8	2.29.E+12
	Yearly	1,214.2	376.2	16,993.9	16,126.6	11,235.4	8.4E+14
Nunda	Daily	1.4	1.1	8.0	7.3	0.8	6.95.E+10
	Yearly	514.9	405.7	2,936.5	2,650.3	302.0	2.5E+13
Groveland Station	Daily	0.2	0.2	0.2	0.1	0.2	7.60.E+09
	Yearly	88.7	77.6	77.8	49.4	57.8	2.8E+12
Wayland	Daily	2.1	1.0	15.0	13.9	3.5	3.24.E+11
	Yearly	778.1	364.5	5,457.3	5,074.7	1,260.5	1.2E+14
Mt. Morris	Daily	5.4	4.2	49.5	38.1	32.6	2.33.E+12
	Yearly	1,970.7	1,518.8	18,050.2	13,916.2	11,882.4	8.5E+14
Groveland Correctional Facility	Daily	4.4	4.4	23.7	21.3	18.1	2.66.E+10
	Yearly	1,609.4	1,609.4	8,657.4	7,789.8	6,599.2	9.7E+12

Table 8. Summary of final SWAT values used for key parameters in the Canaseraga Creek SWAT model at Shaker's Crossing.

Parameter	*Description*	*Value*
	Water	
CN2	SCS Curve Number	-20%
SFTMP/SMTMP	Snow Fall Temperature	1/0.5
PET	Potential Evapotranspiration Method	Hargreaves
ESCO	Soil Evaporation Compensation Factor	1
EPCO	Plant Evaporation Compensation Factor	0.5
CN_Froz	Curve Number Adjusted for Frozen Soil	Active
SURLAG	Surface Runoff Lag Factor	4
GW_Delay	Groundwater Delay Time (days)	0
ALPHA_BF	Baseflow Alpha Factor (days)	0.2
GW_REVAP	Groundwater 'revap' Coefficient	0.02
	Total Suspended Solids	
CH_N2	Mannings 'n' Value for the Main Channel	0.043
CH_K2	Effective Hydraulic Conductivity in Main Channel	350
CH_COV1	Channel Erodibility Factor	0.6
CH_COV2	Channel Cover Factor	0.6
ALPHA_BNK	Baseflow Alpha Factor for Bank Storage	1
CH_EQN	Sediment Routing Method	2
USLE_P	USLE Eqn. Cropping Practices Factor	0.8
ADJ_PKR	Peak Rate Adjustment for Sediment in Tributary Channels	0
PRF	Peak Rate Adjustment Factor for Sediment in the Main Channel	0.8
SPCON	Factor for Maximum Amount of Sediment to be Reentrained	0.0001
SPEXP	Exponent Parameter for Calculating Sediment Reentrained	1
	Total Phosphorus	
P_UPDIS	Phosphorus Uptake Distribution Parameter	20
PPERCO	Phosphorus Percolation Coefficient	10
PHOS_KD	Phosphorus Soil Partitioning Coefficient	175
PSP	Phosphorus Availability Index	0.1
RSDCO	Residue Decomposition Coefficient	0.05
BC4	Rate Constant for Mineralization of Organic P to Dissolved P	0.35
RS2	Benthic Sediment Source Rate for Dissolved P	0.05
RS5	Organic P Settling Rate in the Reach	0.05
RSDIN	Initial Residue Cover	0
ERORGP	Phosphorus Enrichment Ratio for Loading with Sediment	2.4
BIOMIX	Biological Mixing	0.2

Table 9. **A.** Summary of SWAT output and observed data at the two USGS monitoring sites, including Nash Sutcliffe (NS), percent bias (PBIAS) and r^2 for the time period June 2010 – January 2012 for water and August 2010 – January 2012 for TSS and TP loading and TP concentration. **B.** Summary of the PBIAS between SWAT output and observed data at all non-USGS monitoring sites for the time period February 2011 through January 2012.

A.	Jun10-Apl 12					Aug 10 - Jan 12				
	Flow (m^3/s)					TSS (MT)				
	Observed	SWAT	NS	PBIAS	r^2	Observed	SWAT	NS	PBIAS	r^2
Dansville	81.9	74.6	0.70	-8.8	0.74	20,816	21,212	0.76	1.9	0.76
Shaker's Crossing	274.4	276.4	0.76	0.7	0.76	89,290	88,689	0.70	-0.7	0.70
	Aug 10 - Jan 12									
	P (kg)					Flow Weighted TP Concentration (µg P/L)				
	Observed	SWAT	NS	PBIAS	r^2	Observed	SWAT	PBIAS		
Dansville	14,096	12,073	0.77	-14.4	0.80	50.3	57.3	13.9		
Shaker's Crossing	78,704	76,576	0.82	-2.7	0.83	100.3	101.0	0.7		

B.	Feb11-Apl 12			Feb11-Jan12								
	Flow (m^3/s)			TSS (MT)			P (kg)			Flow Weighted TP Concentration (µg P/L)		
	Observed	SWAT	PBIAS	Observed	SWAT	PBIAS	Observed	SWAT	PBIAS	Observed	SWAT	PBIAS
Stony Brook	11.9	10.9	-8.4	1,041	1,104	6.1	970	732	-24.6	24.0	26.3	9.6
Mill Creek	21.8	21.1	-3.2	1,661	1,818	9.4	2,101	1,980	-5.7	43.2	52.1	20.7
Twomile Creek	22.7	21.0	-7.6	4,387	4,056	-7.5	6,963	8,516	22.3	148.7	112.6	-24.2
Buck Run	5.63	5.61	-0.3	2,195	2,118	-3.5	4,263	4,193	-1.6	207.5	218.1	5.1

Table 10. Total annual loadings at each routine monitoring site in metric tons per year (MT/yr) and colony forming units per year (CFU/yr). Percentages indicate contribution of each segment to the total load at the outlet (Shaker's Crossing). M= main stem site, T= tributary site. TP = total phosphorus, TSS = total suspended solids, SRP = soluble reactive phosphorus, TN = total nitrogen.

	TP (MT/yr)	**SRP (MT/yr)**	**TN (MT/yr)**	**Nitrate (MT/yr)**	**TSS (MT/yr)**	**Total Coliforms (CFU/yr)**
Faulkner Road (M)	4.2 (6.5%)	0.7 (6.6%)	79.1 (9.6%)	43.3 (7.4%)	3,236 (5.2%)	2.2E+12 (8.0%)
Stony Brook (T)	1.0 (1.5%)	0.1 (1.0%)	31.0 (3.8%)	24.6 (4.2%)	1,042 (1.7%)	4.6E+11 (1.7%)
Dansville (M)	9.1 (14.2%)	0.3 (3.0%)	162.2 (19.7%)	118.9 (20.4%)	10,999 (17.7%)	3.6E+12 (12.9%)
Mill Creek (T)	2.1 (3.3%)	0.2 (2.2%)	65.6 (8.0%)	51.9 (8.9%)	1,662 (2.7%)	1.3E+12 (4.6%)
Pioneer Road (M)	24.4 (37.8%)	1.9 (18.8%)	446.9 (54.3%)	337.7 (58.1%)	22,632 (36.4%)	1.3E+13 (46.0%)
Twomile Creek (T)	7.0 (10.8%)	1.0 (10.2%)	142.8 (17.4%)	102.8 (17.7%)	4,394 (7.1%)	5.5E+12 (19.7%)
Buck Run (T)	4.3 (6.6%)	1.1 (11.0%)	30.9 (3.8%)	10.4 (1.8%)	2,195 (3.5%)	1.1E+12 (4.0%)
Shaker's Crossing (M)	64.5	9.9	822.7	581.4	62,180	2.8E+13

Table 11. Total annual loadings normalized by segment area (kg/ha/yr and CFU/ha/yr). M= main stem site, T= tributary site. TP = total phosphorus, TSS = total suspended solids, SRP = soluble reactive phosphorus, TN = total nitrogen.

Segment Name	**Segment Area (ha)**	**TP (kg/ha/yr)**	**SRP (kg/ha/yr)**	**TN (kg/ha/yr)**	**Nitrate (kg/ha/yr)**	**TSS (kg/ha/yr)**	**Total Coliforms (CFU/ha/yr)**
Headwaters to Faulkner Road (M)	15,100	0.3	0.04	5.2	2.9	214	1.5E+11
Stony Brook (T)	5,491	0.2	0.02	5.6	4.5	190	8.5E+10
Faulkner Road to Dansville (M)	13,908	0.4	-0.03	6.0	5.4	558	9.9E+10
Mill Creek (T)	10,800	0.2	0.02	6.1	4.8	154	1.2E+11
Dansville to Pioneer Road (M)	19,943	0.8	0.1	14.3	11.0	583	4.6E+11
Twomile Creek (T)	11,241	0.6	0.1	12.7	9.1	391	4.9E+11
Buck Run (T)	1,751	2.4	0.6	17.6	5.9	1,254	6.4E+11
Pioneer Road to Shaker's Crossing (M)	39,627	1.0	0.2	9.5	6.1	998	3.8E+11
Total Area	88,578	0.7	0.1	9.3	6.6	702	3.2E+11

Table 12. Summary of results from an erosion inventory taken at two segments of Canaseraga Creek. The reference site is a forested upstream segment, while the Groveland Flats site is a downstream, straightened, agricultural segment.

	Reference Site	**Groveland Flats Site**
Number of Sites	14	14
Number of Scores >20	11	14
Average Score	24	39
Score Range	19 - 30	22-60
Average Measured Bank Length (m)	24.5	222.6
Measured Bank Length Range (m)	7 - 43.5	42 - 748
Total Measured Bank Length (m)	343.5	3,116.5
Distance Traveled (km)	4.49	5.71
Percent Highly Erodible Banks (%)	7.7	54.6
Percent of Erodible Banks with Agriculture within 20 m (%)	0.0	69.0

Table 13. Phosphorus load allocation by land use/activity as determined by the calibrated Canaseraga Creek SWAT model for the time period February 2011 – January 2012.

Land Use/Activity	**Current P load (kg/yr)**	**Percent of Total Allocated Load (%)**	**Method of Determination**
Agricultural Crops	20,677	35.6	Subtraction
Tile Drains	5,521	9.5	Subtraction
Farm Animals (CAFO only)	8,383	14.5	Subtraction
Stream Bank Erosion	2,606	4.5	Subtraction
Wetlands	0.5	0.0	HRU Table
Groundwater	10,326	17.8	HRU Table
Forest	557	1.0	HRU Table
Urban Runoff	855	1.5	Subtraction
Wastewater Treatment Plants	5,584	9.6	Subtraction
Septic Systems	3,506	6.0	Subtraction
Sum of Allocated Loads	58,014	100.0	
Total Predicted Load (From SWAT)	59,364		
Allocation Error	-1,350		

Table 14. **A.** Results of the percent reduction of total phosphorus (TP) load, total suspended solids (TSS) load and TP concentration (µg P/L) for various BMP scenarios from the Canaseraga Creek SWAT model compared to the base calibrated model. Negative values indicate an increase in loading or concentration. Red = reduction. **B.** TP and TSS load reductions, TP concentration, and TP concentration reduction for targeted tributaries (Twomile and Buck Run Creeks) and Shaker’s Crossing.

A.

			Shaker's Crossing		**Dansville**		**Shaker's Crossing**		**Dansville**	
			P Load (kg/yr)	**TSS Load (MT/yr)**	**P Load (kg/yr)**	**TSS Load (MT/yr)**	**TP (µg P/L)**		**TP (µg P/L)**	
		Base Model	59,364	70,923	8,650	12,943	104.3		56.2	
			Percent Effectiveness of BMP (% load reduction)							
			Shaker's Crossing		**Dansville**		**Shaker's Crossing**		**Dansville**	
Category	**Subcategory**	**BMP**	**P**	**TSS**	**P**	**TSS**	**TP (µg P/L)**	**TP Red %**	**TP (µg P/L)**	**TP Red %**
Forest	Forest	Forested	68.7	28.1	75.3	86.5	33.5	67.9	13.5	75.9
Agriculture	Farm Animals	No CAFO Manure Application	14.1	-0.1	5.3	-0.3	94.9	9.0	54.7	2.6
	Cropland	No Agricultural Crops	34.8	13.8	58.5	77.7	81.6	21.7	32.0	43.1
Wastewater	WWTP	No WWTPs	9.4	0.0	2.2	0.0	83.9	19.6	53.0	5.7
		Upgrade WWTPs to Tertiary	9.4	0.0	2.2	0.0	84.0	19.5	53.0	5.7
	Septic	No Septic	5.9	14.2	0.7	5.2	143.1	-37.3	108.9	-94.0
BMP	Stream Banks	Streambank Stabilization	4.4	49.4	4.9	20.5	101.5	2.7	53.9	4.0
	Crop Fields	Filter Strips	19.4	6.5	25.7	38.7	89.9	13.8	47.1	16.2
		Contouring	30.1	2.4	43.9	55.9	80.8	22.6	37.5	33.2
		Grassed Waterways	44.8	4.5	59.8	79.4	69.9	33.0	34.0	39.5
		No Till	-18.4	1.0	-3.1	23.0	119.3	-14.4	57.9	-3.0
		Cover Crops	31.2	5.4	34.0	44.7	82.8	20.6	44.2	21.3
		Strip Cropping	28.0	1.9	41.5	52.9	82.4	21.0	38.4	31.6

Table 14. Continued.

			Percent Effectiveness of BMP (% load reduction)										
			Shaker's Crossing			Dansville			Shaker's Crossing			Dansville	
Category	**Subcategory**	**BMP**	**P**	**TSS**		**P**	**TSS**		**TP (µg P/L)**	**TP Red %**		**TP (µg P/L)**	**TP Red %**
		Terracing	37.8	4.8		52.7	65.4		75.0	28.1		34.5	38.5
	Fertilizer	No Fertilizer (100% Reduction)	3.1	-0.4		4.9	-0.8		102.1	2.1		55.0	2.1
		75% Nutrient Management	2.8	-0.4		4.4	1.5		102.1	2.1		54.8	2.5
		50% Nutrient Management	2.0	-0.4		3.8	2.5		102.7	1.5		55.1	1.9
		25% Nutrient Management	1.3	-0.3		3.0	2.0		103.2	1.0		55.2	1.6
Combination	Whole Basin	Tertiary WWTPs + Grassed Waterways	54.1	4.5		61.8	79.4		49.7	52.3		31.0	44.9
		45 Target Scenario 1	55.2	5.6		63.5	79.9		48.4	53.6		28.4	49.5
		Tertiary WWTPs + Terracing	47.1	4.8		54.8	65.4		54.8	47.4		31.5	43.9
		Tertiary WWTPs + Contouring	39.4	2.4		46.0	55.9		60.6	41.9		34.5	38.6
	Tributary	Tributary Remediation 1	12.8	0.2		0.0	0.0		95.2	8.7		56.2	0.0
		Tributary Remediation 2	12.6	0.2		0.0	0.0		95.3	8.6		56.2	0.0
		Tributary Remediation 3	27.2	18.7		2.2	0.0		71.6	31.4		53.0	5.7

Table 14. Continued.

B.

	% Load Reduction			**TP Concentration**	
Scenario/Site	**P**	**TSS**		**TP (µg P/L)**	**TP Red %**
Tributary Remediation 1					
Shaker's Crossing	12.8	0.2		95.2	8.7
Twomile Creek	68.3	97.0		29.2	74.1
Buck Run Creek	93.1	98.0		23.4	89.3
Tributary Remediation 2					
Shaker's Crossing	12.6	0.2		95.3	8.6
Twomile Creek	64.3	96.5		31.1	72.3
Buck Run Creek	92.5	97.6		25.1	88.5

Table 15. Canaseraga Creek macroinvertebrate list from sample taken 23 August 2011 from Buck Run Creek near Mt. Morris, NY. NBI-P = phosphorus nutrient biotic index tolerance value, NBI-N = nitrate nutrient biotic index tolerance value. NBI tolerance values range from 0 (nutrient intolerant, or 'oligotrophic' indicators) to 10 (nutrient tolerant, or 'eutrophic' indicators).

Order	Family	Genus	Count	NBI-P	NBI-N	Reference	Comment
Ephemeroptera	Baetidae	*Baetis*	15	6	3	Merritt *et al.*(2008)	
Gastropoda	Physidae	*Physella*	24	8	7	Peckarsky *et al.* (1990)	
Trichoptera	Hydropsychidae	*Cheumatopsyche*	3	6	6	Peckarsky *et al.* (1990)	
Amphipoda	Crangonyctidae	*Crangonyx*	1	NS	NS	Peckarsky *et al.* (1990)	
Megaloptera	Sialidae	*Sialis*	4	5	6	Peckarsky *et al.* (1990)	
Coleoptera	Elmidae	*Stenelmis*	3	7	7	Peckarsky *et al.* (1990)	Adults
Coleoptera	Elmidae	*Stenelmis*	1	7	7	Peckarsky *et al.* (1990)	Adult
Coleoptera	Elmidae	*Optioservus*	1	7	7	Peckarsky *et al.* (1990)	Adult
Coleoptera	Elmidae	*Stenelmis*	18	7	7	Peckarsky *et al.* (1990)	Larvae
Coleoptera	Elmidae	*Microcylloepus*	2	NS	NS	Peckarsky *et al.* (1990)	Larvae
Diptera	Empididae		1	NS	NS	Merritt *et al.*(2008)	Pupae
Diptera	Ceratopogonidae		2	8	9	Peckarsky *et al.* (1990)	
Diptera	Tiplulidae	*Tipula*	3	10	10	Peckarsky *et al.* (1990)	
Diptera	Chironomidae		1	NS	NS		Damaged
Diptera	Chironomidae	*Dicrotendipes*	2	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Diamesa*	6	10	10	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Natarsia*	1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Telopelopia*	2	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Paratanytarsus*	2	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Rheopelopia*	1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Parameteriocnemus*	2	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Phaenopsectra*	1	NS	NS	Peckarsky *et al.* (1990)	

Table 15. Continued.

Order	Family	Genus	Count	NBI-P	NBI-N	Reference	Comment
Diptera	Chironomidae	Undetermined *Tanypodinae*	1	NS	NS	Peckarsky *et al.* (1990)	

Table 16. Black Creek watershed macroinvertebrate list from sample taken 23 August 2011 from Bigelow Creek near Byron, NY. NBI-P = phosphorus nutrient biotic index tolerance value, NBI-N = nitrate nutrient biotic index tolerance value. NBI tolerance values range from 0 (nutrient intolerant, or 'oligotrophic' indicators) to 10 (nutrient tolerant, or 'eutrophic' indicators).

Order	Family	Genus	Species	Count	NBI -P	NBI- N	Reference	Comment
Coleoptera	Elmidae	*Stenelmis*		22	7	7	Peckarsky *et al.* (1990)	Larvae
Coleoptera	Elmidae	*Microcylloepus*		5	NS	NS	Peckarsky *et al.* (1990)	Larvae
Coleoptera	Elmidae	*Stenelmis*	*crenata*	5	7	7	Peckarsky et al. (1990), Brown (1972)	Adult
Coleoptera	Elmidae	*Stenelmis*	*mera*	1	7	7	Peckarsky et al. (1990), Brown (1972)	Adult
Coleoptera	Psephenidae	*Psephenus*		26	3	4	Peckarsky *et al.* (1990)	Larvae
Diptera	Chirinomidae	*Microtendipes*		1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chirinomidae	*Polypedilum*	*illinoense*	1	10	7	Simpson and Bode (1980)	
Diptera	Chirinomidae	*Microtendipes*		1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chirinomidae	*Natarsia*		1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Athericidae	*Atherix*		4	8	5	Peckarsky *et al.* (1990)	
Diptera	Ceratopogonidae	*Dasyhelea*		5	8	9	Peckarsky *et al.* (1990)	Undetermined Ceratopogonidae score
Trichoptera	Apataniidae	*Apatania*		2	3	4	Peckarsky *et al.* (1990)	
Trichoptera	Hydropsychidae	*Hydropsyche*		1	5	4	Peckarsky *et al.* (1990)	

Table 16. Continued.

Order	**Family**	**Genus**	**Species**	**Count**	**NBI -P**	**NBI-N**	**Reference**	**Comment**
Trichoptera	Limnephilidae	*Pseudostenophylax*		2	3	4	Peckarsky *et al.* (1990)	Undetermined Limnephilidae score
Trichoptera	Hydropschidae	*Hydropsyche*		2	5	4	Schefter and Wiggins (1986)	
Trichoptera	Hydropschidae	*Hydropsyche*	*valanis*	7	5	4	Schefter and Wiggins (1986)	
Trichoptera	Hydropschidae	*Cheumatopsyche*		10	6	6	Peckarsky *et al.* (1990)	
Mollusca	Sphaerriidae	*Psidium*		4	8	10	Peckarsky *et al.* (1990)	

Table 17. Oatka Creek macroinvertebrate list from sample taken 23 August 2011 from Oatka Creek at Garbutt, NY. NBI-P = phosphorus nutrient biotic index tolerance value, NBI-N = nitrate nutrient biotic index tolerance value. NBI tolerance values range from 0 (nutrient intolerant, or 'oligotrophic' indicators) to 10 (nutrient tolerant, or 'eutrophic' indicators).

Order	**Family**	**Genus**	**Species**	**Count**	**NBI-P**	**NBI-N**	**Reference**	**Comment**
Coleoptera	Elmidae	*Stenelmis*		3	7	7	Peckarsky *et al.* (1990)	Larvae
Coleoptera	Elmidae	*Promoresia*	*elegans*	3	10	10	Peckarsky et al. (1990), Brown (1972)	Adult
Coleoptera	Elmidae	*Optioservus*		7	9	4	Peckarsky *et al.* (1990)	Larvae
Coleoptera	Elmidae	*Optioservus*	*ovalis*	6	9	4	Peckarsky et al. (1990), Brown (1972)	Adult
Crustacea	Gammaridae	*Gammarus*		1	8	9	Peckarsky *et al.* (1990)	
Diptera	Empididae			1	NS	NS	Merritt *et al.* (2008)	Pupae
Diptera	Simuliidae	*Simulium*	*tuberosum*	1	1	0	Peckarsky *et al.* (1990), Stone and Jamnback (1955)	
Diptera	Athericidae	*Atherix*		6	8	5	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Cricotopus*	*trifascia group*	1	9	9	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Eukiefferiella*	*devonica group*	1	9	9	Peckarsky *et al.* (1990)	

Table 17. Continued.

Order	**Family**	**Genus**	**Species**	**Count**	**NBI-P**	**NBI-N**	**Reference**	**Comment**
Diptera	Chironomidae	*Parametriocnemus*		1	NS	NS	Peckarsky *et al.* (1990)	
Ephemeroptera	Heptageniidae			1	5	2	Peckarsky *et al.* (1990)	Damaged
Ephemeroptera	Ephemerellidae	*Ephemerella*		4	3	6	Peckarsky *et al.* (1990)	
Ephemeroptera	Baetidae	*Acerpenna*	*pygmaea*	4	3	3	Peckarsky et al. (1990), Morihara and McCafferty (1979)	
Ephemeroptera	Baetidae	*Acentrella/ Pseudocloeon*		1	5	5	Peckarsky *et al.* (1990)	
Ephemeroptera	Caenidae	*Caenis*		5	0	4	Peckarsky *et al.* (1990)	
Ephemeroptera	Baetidae	*Baetis*		4	6	3	Peckarsky *et al.* (1990)	
Ephemeroptera	Ephemerellidae			2	3	6	Peckarsky *et al.* (1990)	
Ephemeroptera				2	NS	NS	Peckarsky *et al.* (1990)	Damaged
Megaloptera	Sialidae	*Sialis*		1	5	6	Peckarsky *et al.* (1990)	
Megaloptera	Corydalidae	*Nigronia*		1	10	8	Peckarsky *et al.* (1990)	
Gastropoda	Physidae			1	NS	NS	Peckarsky *et al.* (1990)	
Gastropoda	Lymnaeidae	*Radix*	*auricluria*	1	NS	NS	Peckarsky *et al.* (1990)	
Gastropoda	Planorbidae	*Gyraulus*		1	NS	NS	Peckarsky *et al.* (1990)	
Plecoptera	Perlidae	*Paragnetina*		1	1	6	Peckarsky *et al.* (1990)	
Plecoptera	Perlidae	*Agnetina*		3	NS	NS	Peckarsky *et al.* (1990)	
Trichoptera	Brachycentridae	*Brachycentrus*	*appalachia*	2	3	4	Peckarsky *et al.* (1990), Flint (1984)	
Trichoptera	Hydropsychidae	*Hydropsyche*	*sparna*	5	6	7	Peckarsky et al. (1990), Schuster and Etnier (1978)	
Trichoptera	Hydropsychidae	*Cheumatosyche*		21	6	6	Peckarsky *et al.* (1990)	
Trichoptera	Hydropsychidae	*Hydropsyche*		9	5	4	Peckarsky *et al.* (1990)	

Table 18. Canaseraga Creek macroinvertebrate list from sample taken 23 August 2011 from Stony Brook near Dansville, NY. NBI-P = phosphorus nutrient biotic index tolerance value, NBI-N = nitrate nutrient biotic index tolerance value. NBI tolerance values range from 0 (nutrient intolerant, or 'oligotrophic' indicators) to 10 (nutrient tolerant, or 'eutrophic' indicators).

Order	**Family**	**Genus**	**Species**	**Count**	**NBI-P**	**NBI-N**	**Reference**	**Comments**
Megaloptera	Corydalidae	*Nigronia*	*serricornis*	2	10	8	Peckarsky et al. (1990), Neunzig (1966)	
Plecoptera	Perlidae	*Agnetina*	*capitata*	3	3	6	Peckarsky et al. (1990), Stark (1986)	
Coleoptera	Psephenidae	*Psephenus*		14	3	4	Peckarsky *et al.* (1990)	Larvae
Coleoptera	Elmidae	*Optioservus*		3	7	8	Peckarsky *et al.* (1990)	Larvae
Coleoptera	Elmidae	*Optioservus*	*fastiditus*	1	6	7	Peckarsky *et al.* (1990), Brown (1972)	Adult
Coleoptera	Elmidae	*Stenelmis*		2	7	7	Peckarsky *et al.* (1990)	Adults
Coleoptera	Hydrophilidae			1	NS	NS	Peckarsky *et al.* (1990)	
Ephemeroptera	Heptageniidae	*Epeorus*		1	NS	NS	Merritt *et al.*(2008)	
Ephemeroptera	Baetidae			1	NS	NS	Peckarsky et al. (1990), Merritt et al.(2008)	Damaged
Trichoptera	Odontoceridae	*Psilotreta*		1	NS	NS	Peckarsky *et al.* (1990)	
Trichoptera	Hydropsychidae	*Cheumatopsyche*		2	6	6	Peckarsky *et al.* (1990)	
Trichoptera	Hydropsychidae	*Hydropsyche*	*slossonae*	3	6	10	Peckarsky et al. (1990), Schuster and Etnier (1978)	
Trichoptera	Hydropsychidae	*Hydropsyche*	*sparna*	13	6	7	Peckarsky et al. (1990), Schuster and Etnier (1978)	
Trichoptera	Hydropsychidae	*Hydropsyche*	*morosa*	15	5	1	Peckarsky et al. (1990), Schuster and Etnier (1978)	
Trichoptera	Hydropsychidae	*Hydropsyche*		2	5	4	Peckarsky et al. (1990), Schuster and Etnier (1978)	
Trichoptera	Hydropsychidae			5	NS	NS	Merritt *et al.*(2008)	Pupae
Diptera	Chironomidae	*Orthocladius*		1	NS	NS	Merritt *et al.*(2008)	Pupa
Diptera	Empididae			2	NS	NS	Merritt *et al.*(2008)	Pupae

Table 18. Continued.

Order	**Family**	**Genus**	**Species**	**Count**	**NBI-P**	**NBI-N**	**Reference**	**Comments**
Diptera	Athericidae	*Atherix*		9	8	5	Peckarsky *et al.* (1990)	
Diptera	Tipulidae	*Antocha*		5	8	6	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Potthastia*	*gaedii group*	1	9	10	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Eukiefferiella*		1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Meropelopia*		1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Cricotopus*	*trifascia group*	9	9	9	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Parorthocladius*		1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Tvetenia*	*discoloripes group*	1	NS	NS	Peckarsky et al. (1990), Bode (1983)	
Diptera	Chironomidae	*Dicrotendipes*		1	NS	NS	Peckarsky *et al.* (1990)	
Diptera	Chironomidae	*Polypedilum*	*fallax group*	1	NS	NS	Peckarsky et al. (1990), Simpson and Bode (1980)	

Table 19. Percent reductions of TP (total phosphorus) and TSS (total suspended solids) for additional CCSWAT model scenario results.

Segment/Scenario	TP Load Reduction (%)	TSS Load Reduction (%)
Faulkner Road		
Grassed Waterways	64.4	91.7
Terracing	52.3	80.7
Contouring	41.6	68.0
Upgrade Canaseraga WWTP	3.6	0.0
Sugar Creek		
Grassed waterways	77.5	98.2
Terracing	66.8	88.6
Contouring	57.0	76.2
Mill Creek		
Grassed waterways	2.8	26.8
Contouring	8.6	19.7
Upgrade Wayland WWTP	30.0	0.0
Mud Creek		
Filter Strips	29.8	49.5
Grassed Waterways	71.6	94.8
Terracing	55.8	76.7
Contouring	39.5	53.3
Pioneer Road		
Grassed Waterways	32.0	4.8
Terracing	25.5	4.2
Contouring	19.2	3.5
Streambank Stabilization, Groveland Flats main stem area	NA	2.0
Streambank Stabilization, main stem from Dansville to Pioneer Road	NA	19.8
Grassed Waterways in Groveland Flats	18.2	0.3
Upgraded WWTPs	6.5	0.0
Shaker's Crossing		
Streambank Stabilization, main stem from Dansville to Pioneer Road	NA	14.3
Grassed Waterways in Groveland Flats	16.1	0.4
Upgraded Nunda, Mt. Morris and Groveland Correctional Facility WWTPs	6.3	0.0

Figures

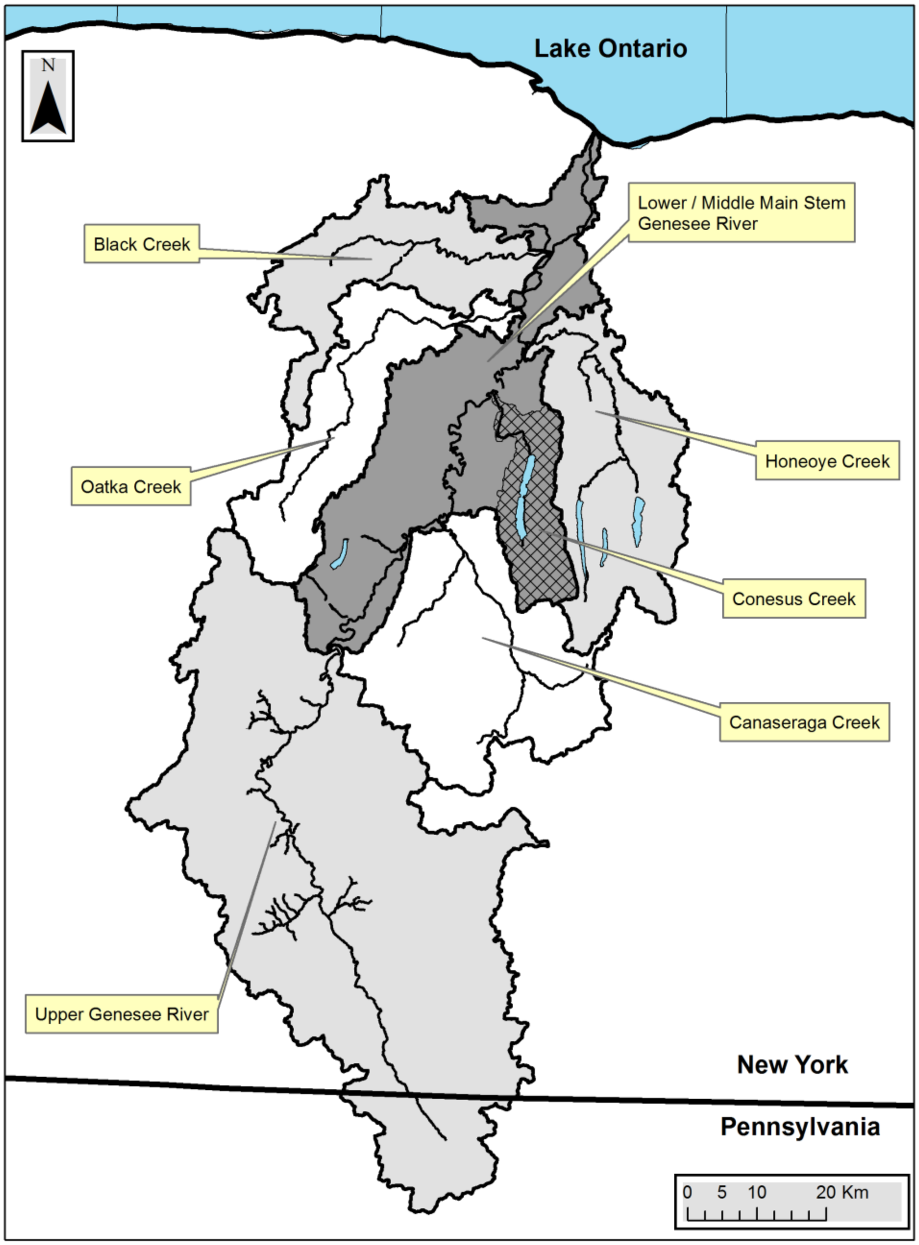


Figure 1. Location of the Genesee River and subwatersheds, including Canaseraga Creek, in western New York State and parts of Pennsylvania. Flow is northward from the headwaters in PA to the outlet in Lake Ontario in Rochester, NY.

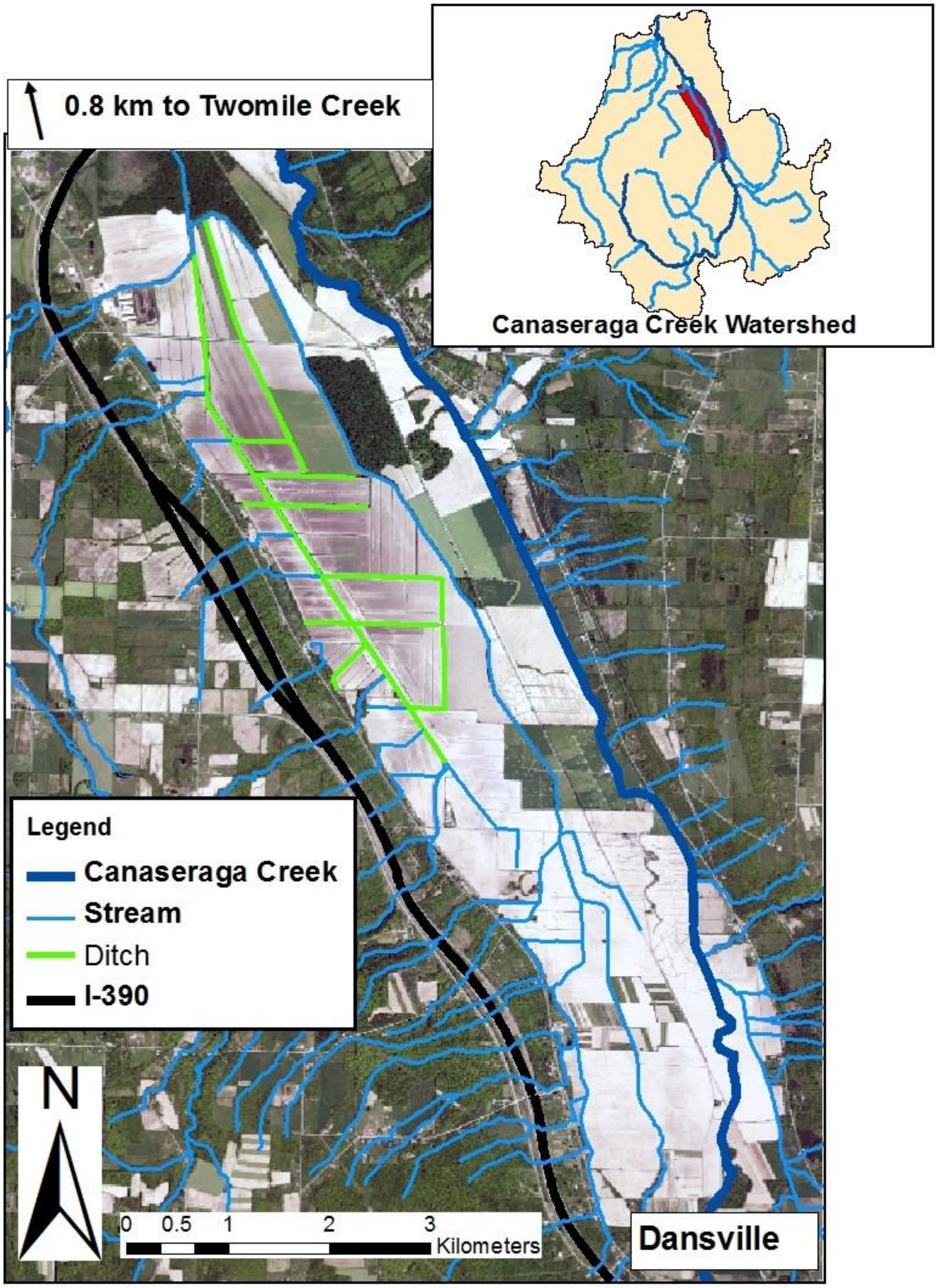


Figure 2. Map inset showing the Groveland Flats area (circled above) between I-390 and Canaseraga Creek, stretching from the Village of Dansville towards the Twomile Creek site.

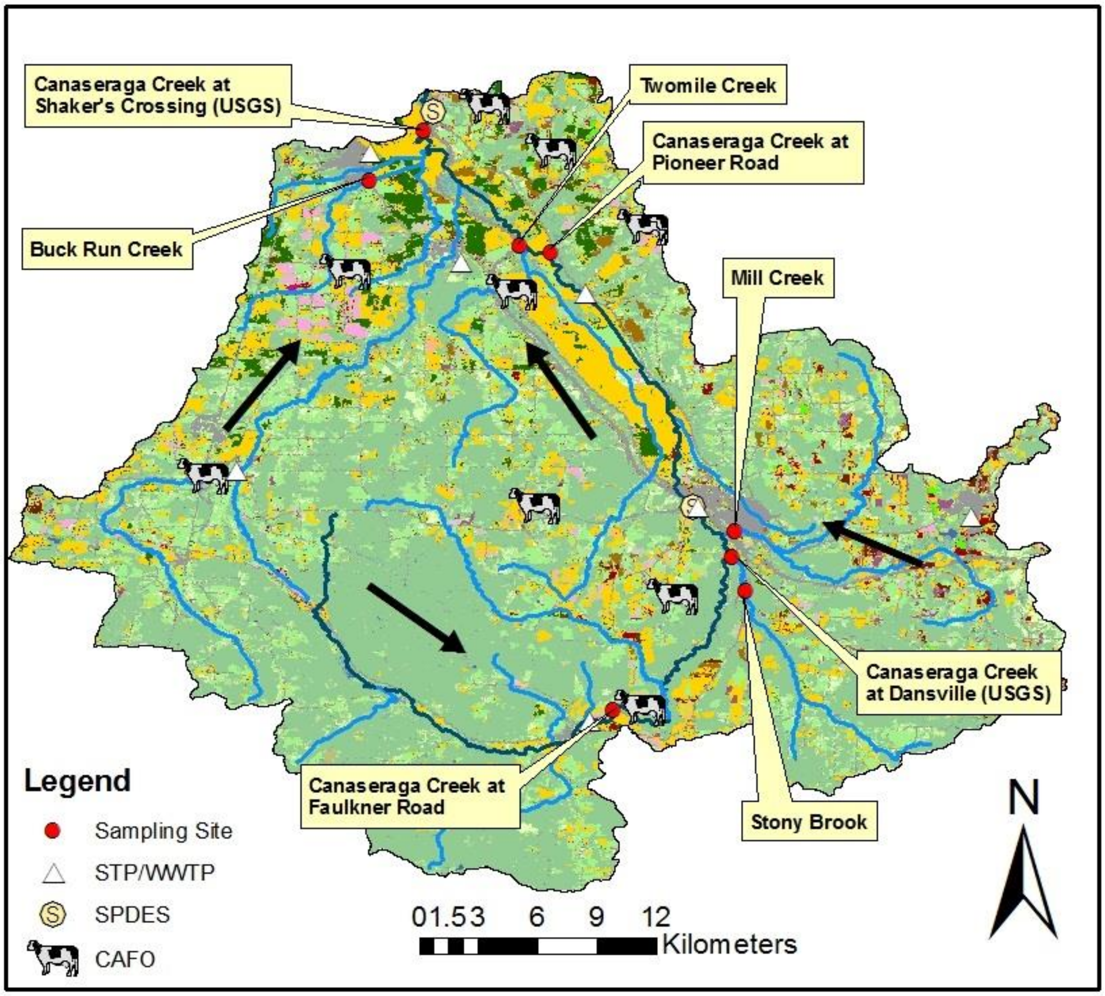


Figure 3. Land uses (light green indicates hay, medium green areas indicate forest, dark green indicates soybeans, yellow is corn, and grey is developed land) and potential pollution source areas in Canaseraga Creek watershed. State Pollution Discharge Elimination System (SPDES), Concentrated Animal Feeding Operation (CAFO), and Sewage Treatment Plant (WWTP)/ Waste Water Treatment Plant (WWTP). Arrows indicate flow direction.

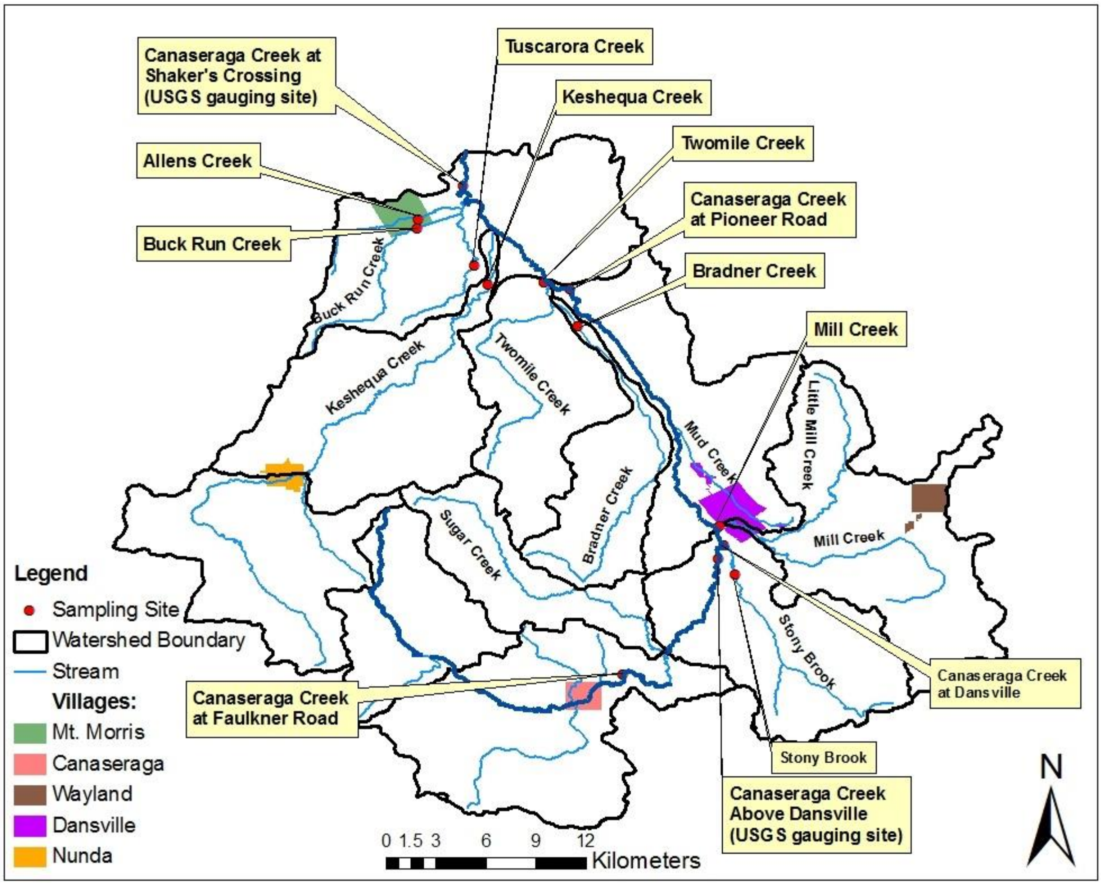


Figure 4. Initial sampling locations, subwatershed boundaries and creek names in the Canaseraga Creek watershed.

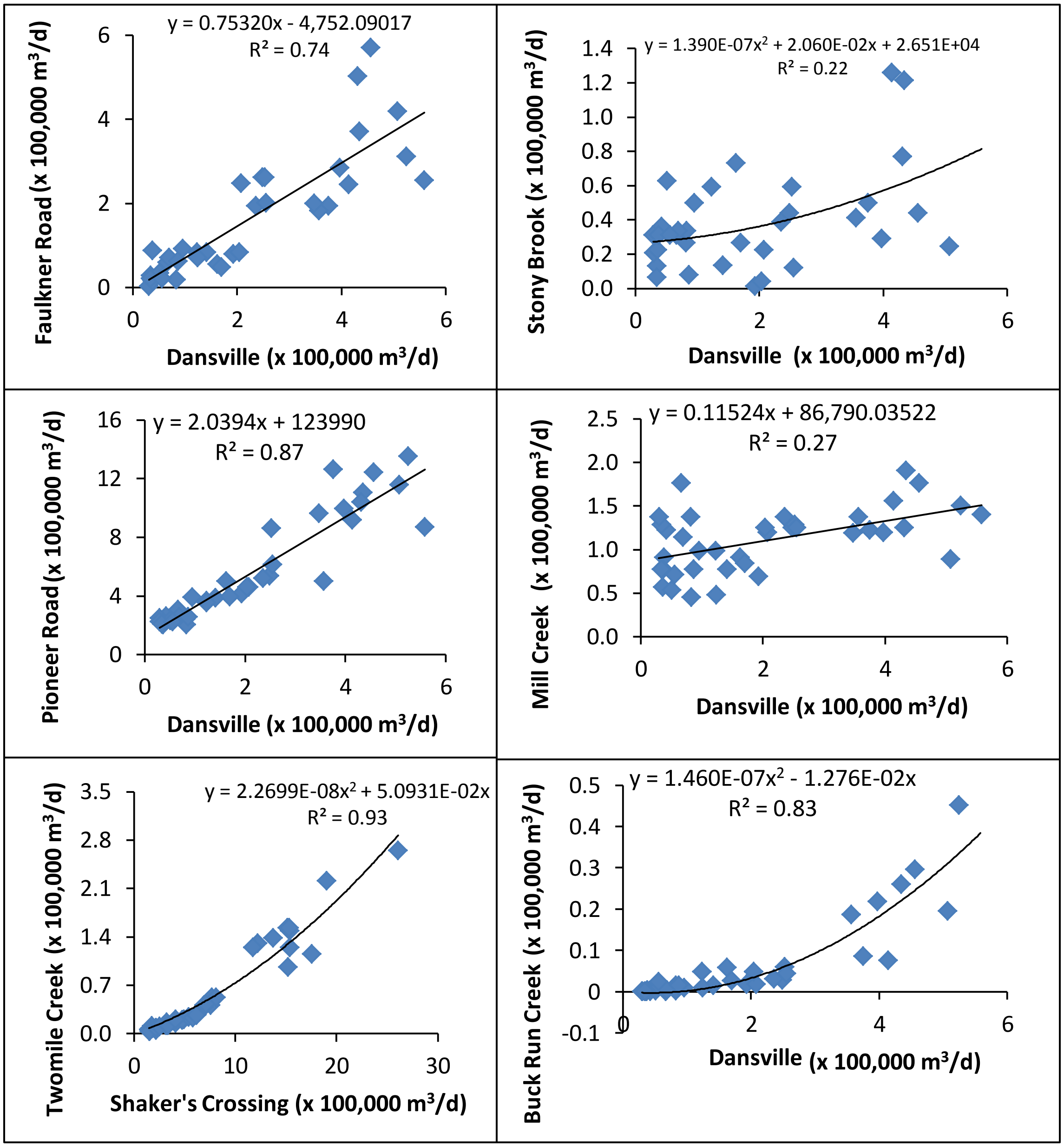


Figure 5. Regressions using daily USGS data at Shaker's Crossing or Dansville to predict daily discharge at sites without discharge measurements. Negative predicted discharges at Buck Run Creek were replaced with one-half the value of the lowest positive predicted discharge.

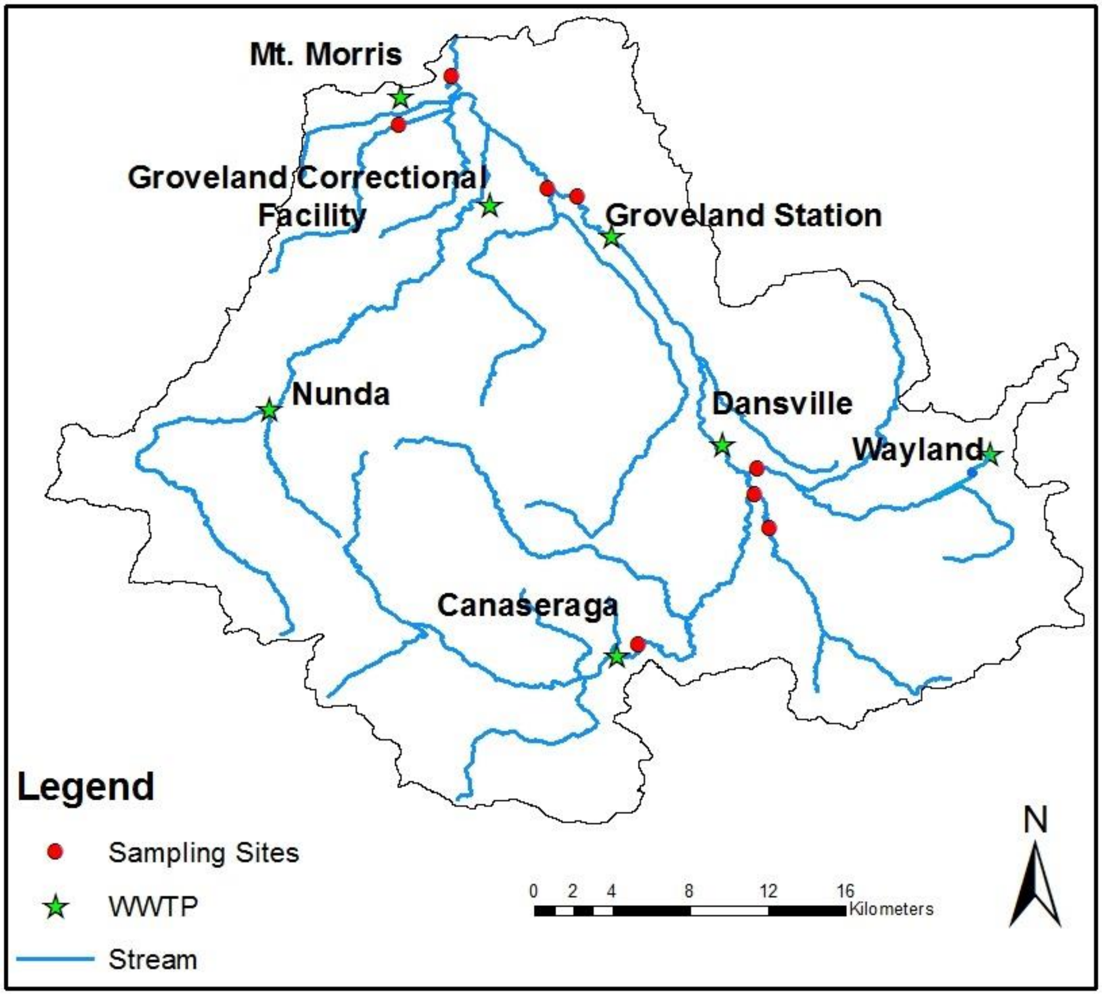


Figure 6. Locations of wastewater treatment plants (WWTPs) in Canaseraga Creek watershed.

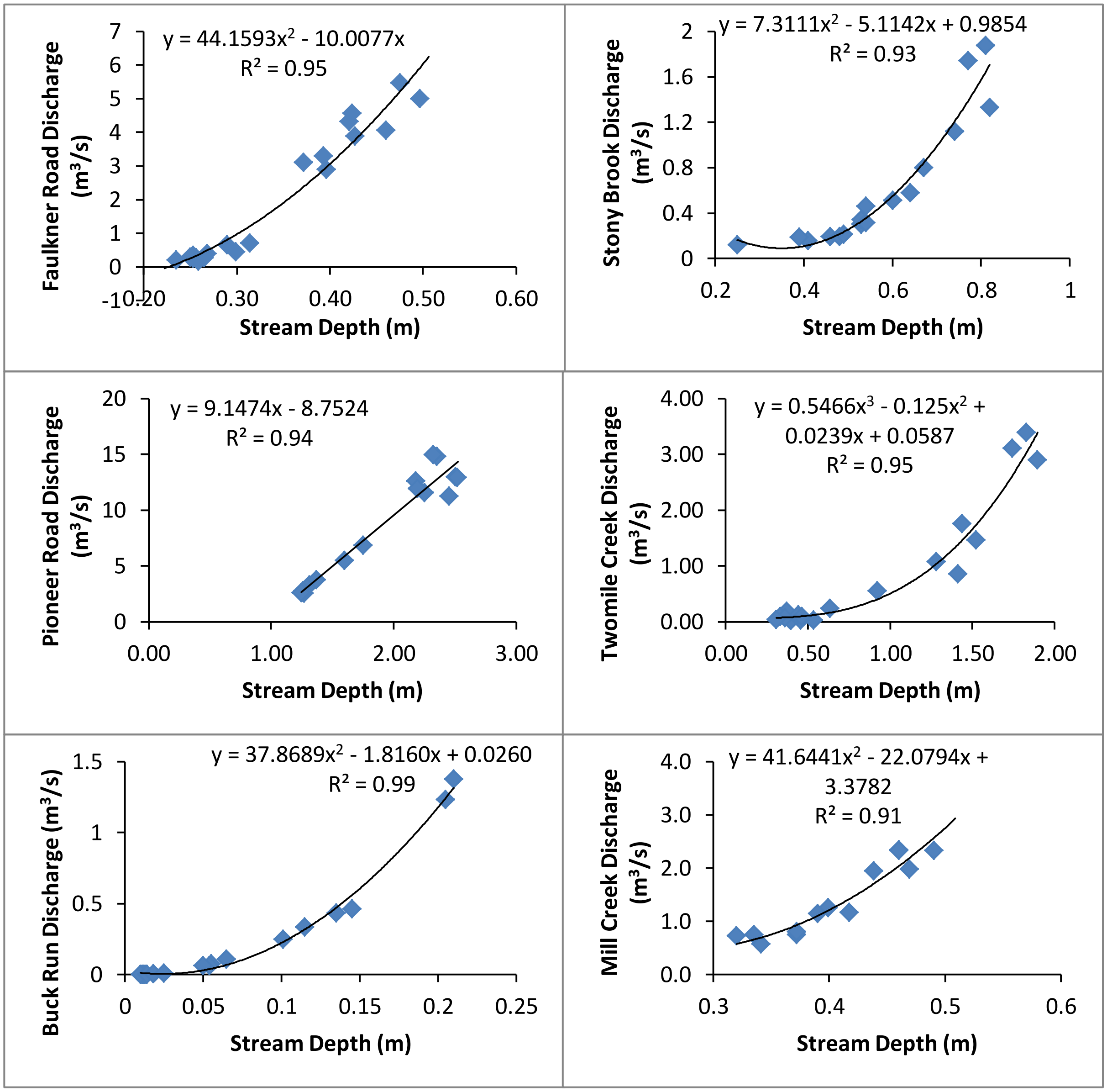


Figure 7. Discharge (m^3/s) versus depth (m) rating curves for all non-USGS sites in Canaseraga Creek watershed 12 July 2011 – 8 May 2012.

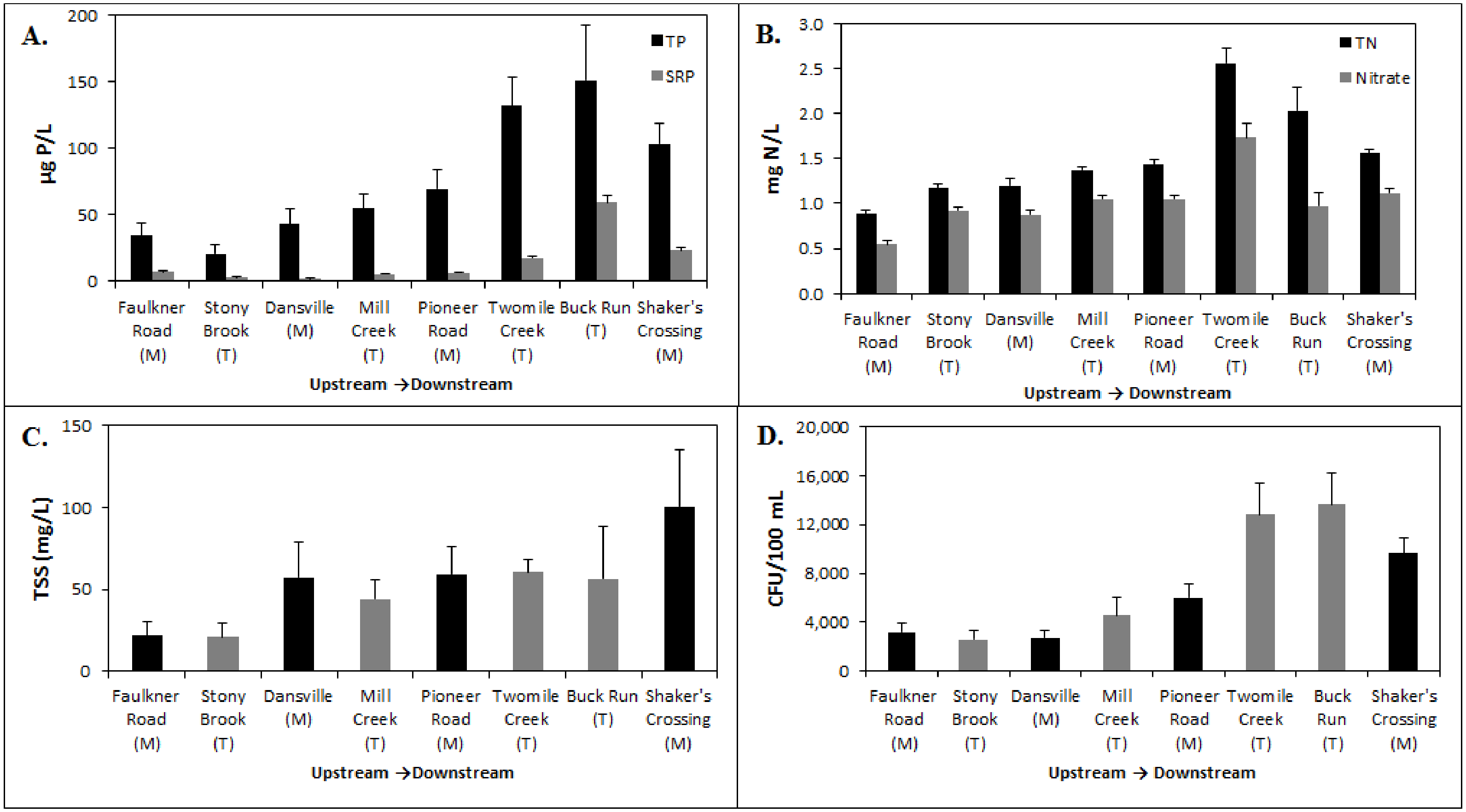


Figure 8. **A.** Average total phosphorus (TP) and soluble reactive phosphorus (SRP) concentration (µg P/L). **B.** Average total nitrogen (TN) and nitrate concentration (mg N/L). **C.** Average total suspended solids (TSS) concentration (mg/L). **D.** Average total coliform bacteria abundance (CFU/100 mL). Error bars show standard error of the mean. (Shaker's Crossing and Dansville: August 2010-February 2012; all other sites: February 2011 to February 2012). M= main stem site, T = tributary site.

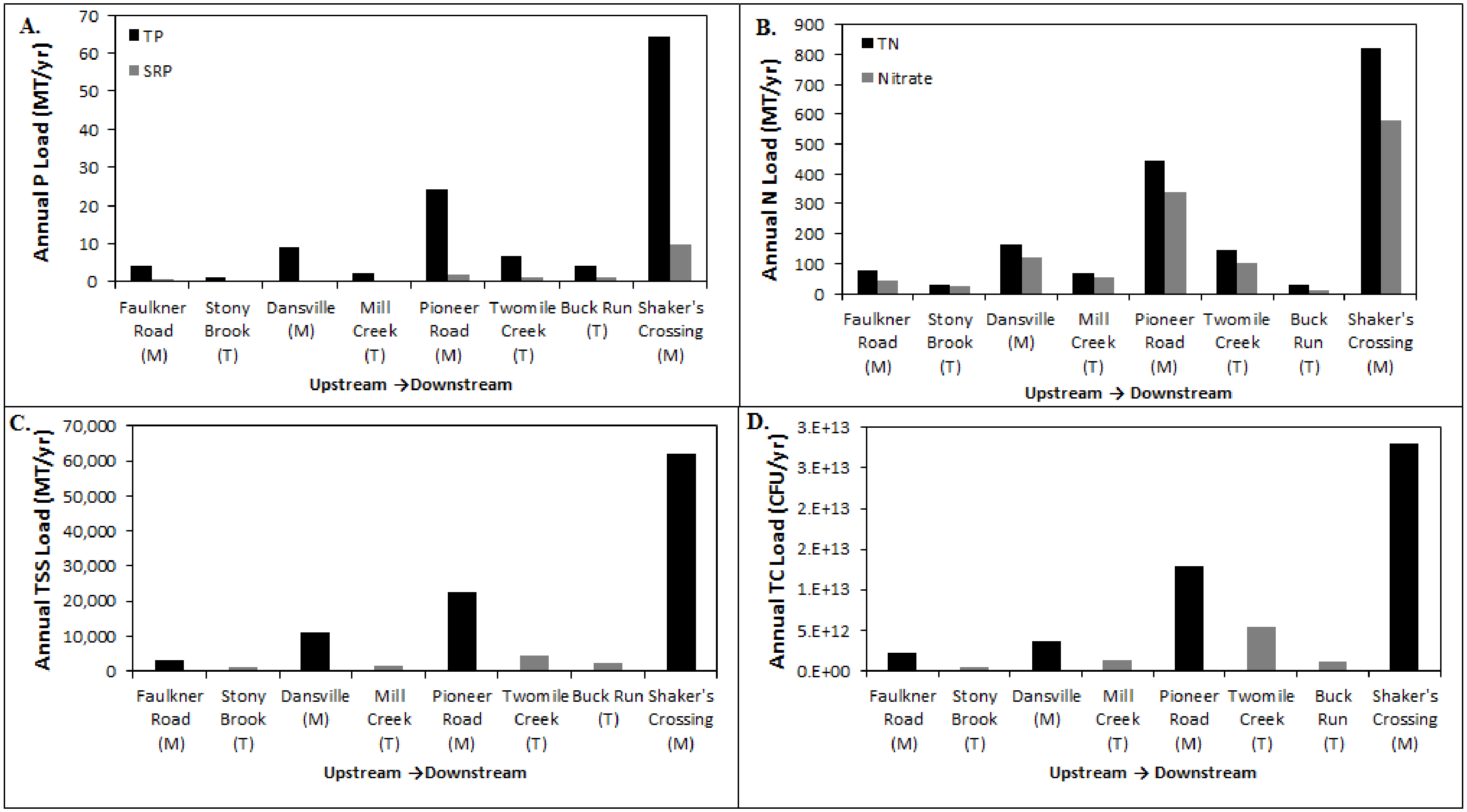


Figure 9. Annual loadings of total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), nitrate, total suspended solids (TSS) and total coliform (TC) in metric tons/year (MT/yr) and colony forming units per year (CFU/yr) at each routine monitoring site, 8 February 2011 to 7 February 2012. M= main stem site, T= tributary site.

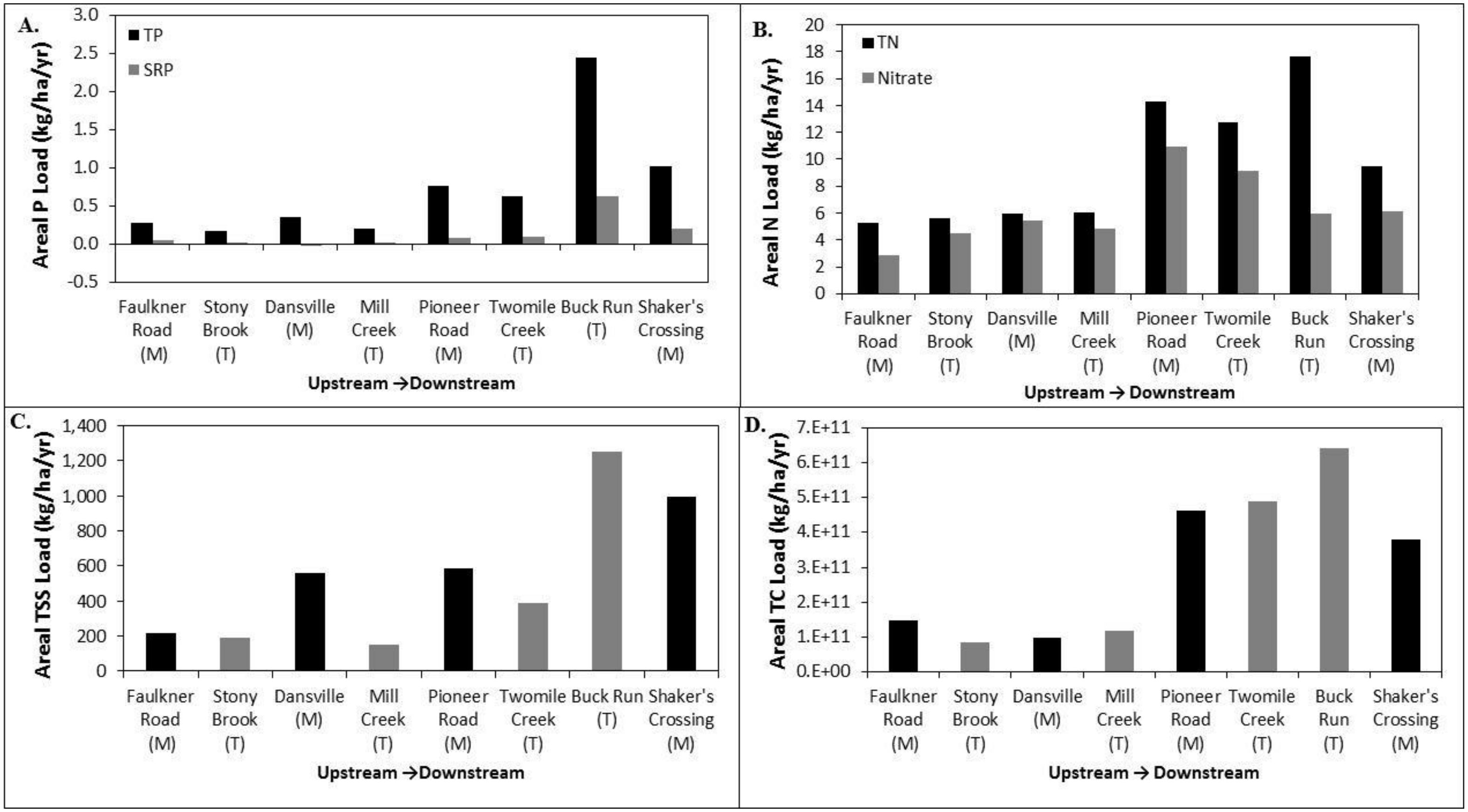


Figure 10. Areal loadings of: **A.** total phosphorus (TP) and soluble reactive phosphorus (SRP); **B.** total nitrogen (TN) and nitrate; **C.** total suspended solids (TSS); and **D.** total coliform bacteria (TC), in kg/ha/year or CFU/ha/yr at each routine monitoring site, 8 February 2011 to 7 February 2012. M= main stem site, T= tributary site.

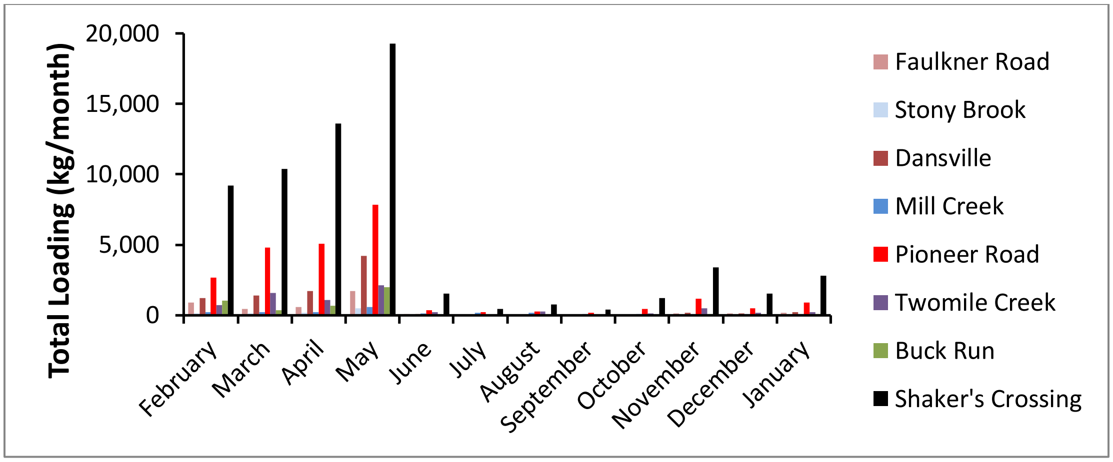


Figure 11. Total monthly total phosphorus (TP) loadings for all routine sites in kg/month, February 2011 to February 2012.

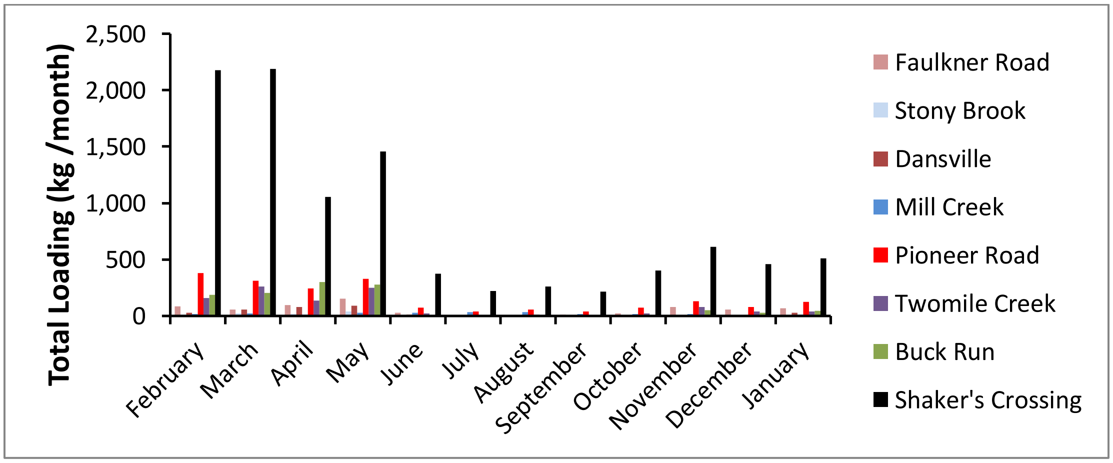


Figure 12. Total monthly soluble reactive phosphorus (SRP) loadings for all routine sites in kg/month, February 2011 to February 2012.

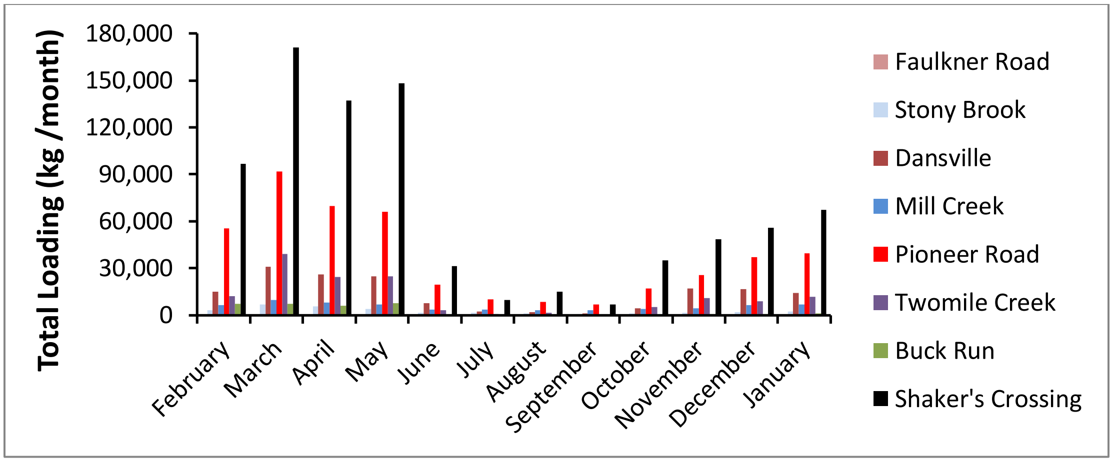


Figure 13. Total monthly total nitrogen (TN) loadings for all routine sites in kg/month, February 2011 to February 2012.

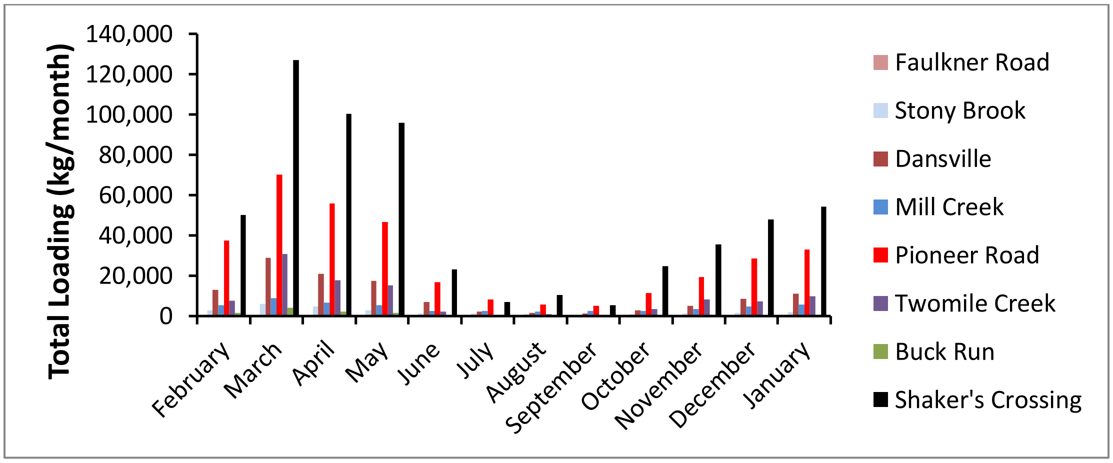


Figure 14. Total monthly nitrate loadings for all routine sites in kg/month, February 2011 to February 2012.

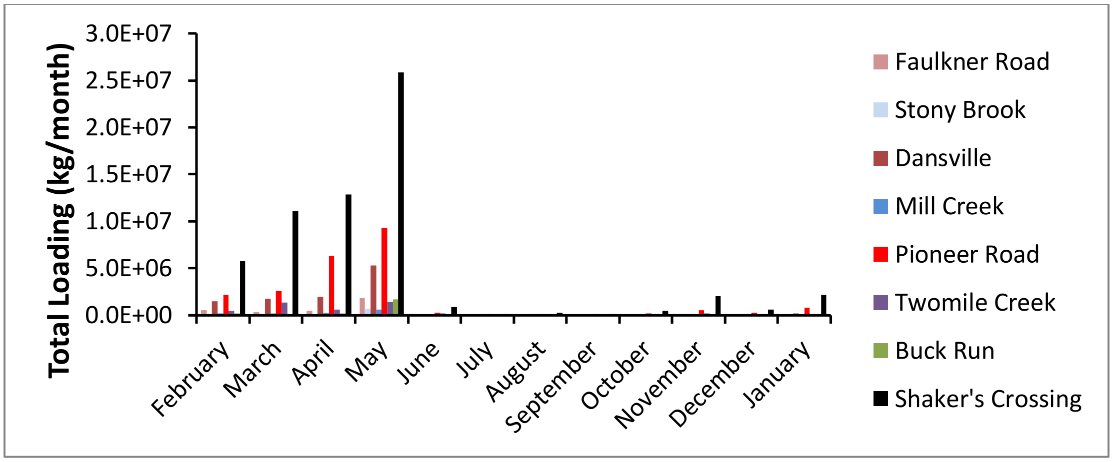


Figure 15. Total monthly total suspended solids (TSS) loadings for all routine sites in kg/month, February 2011 to February 2012.

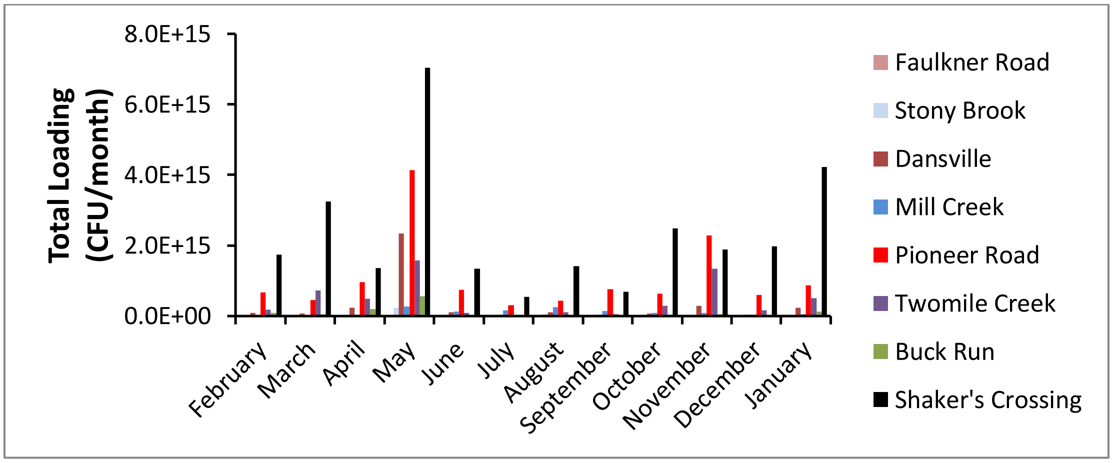


Figure 16. Total monthly total coliform bacteria (TC) loadings for all routine sites in CFU/month, February 2011 to February 2012.

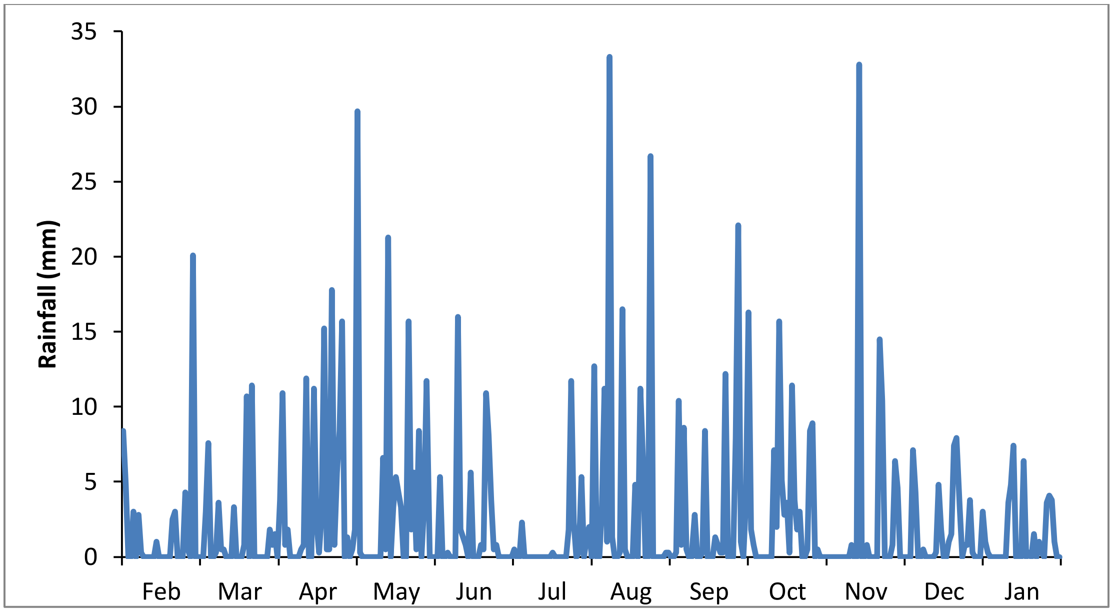


Figure 17. Plot of rainfall at the Dansville municipal airport during the study period February 2011 – January 2012.

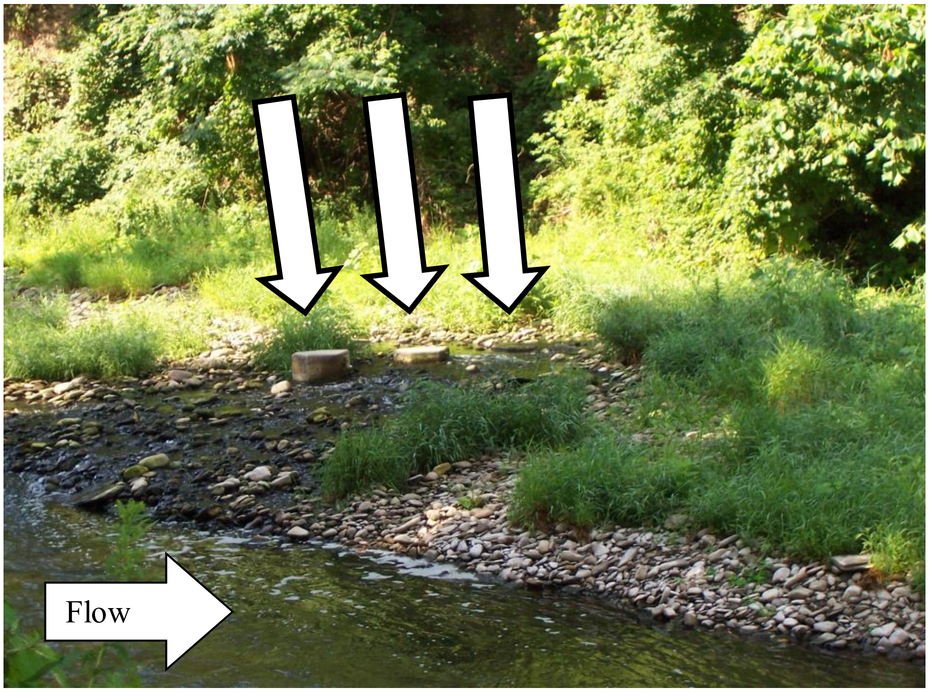


Figure 18. Dansville sewage treatment plant outfall pipes (indicated by arrows) discharging into Canaseraga Creek.

Figure 19. Nunda sewage treatment plant (WWTP) aerial view. White line shows ditch carrying effluent (approx. 56 m) into Keshequa Creek with arrow showing flow direction.

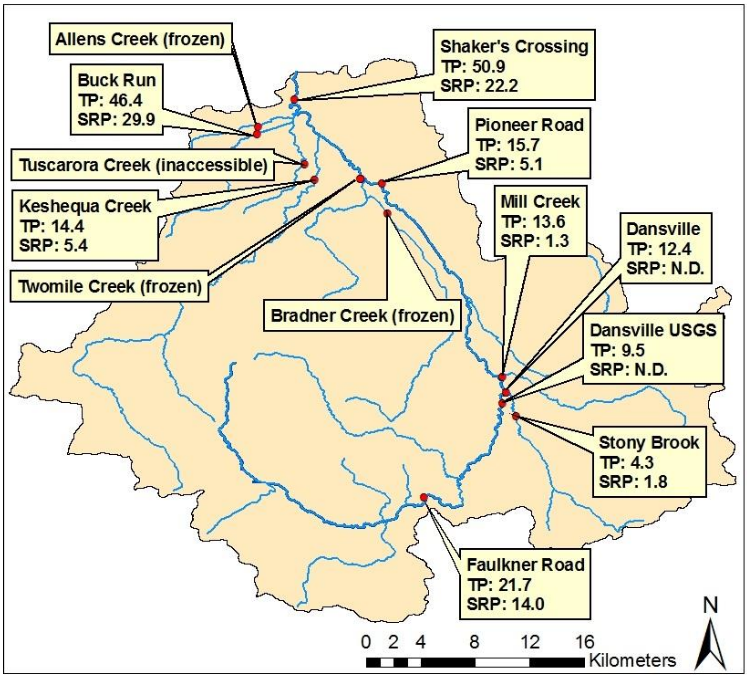


Figure 20. Total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations (μg P/L) in Canaseraga Creek watershed, 8 February 2011.

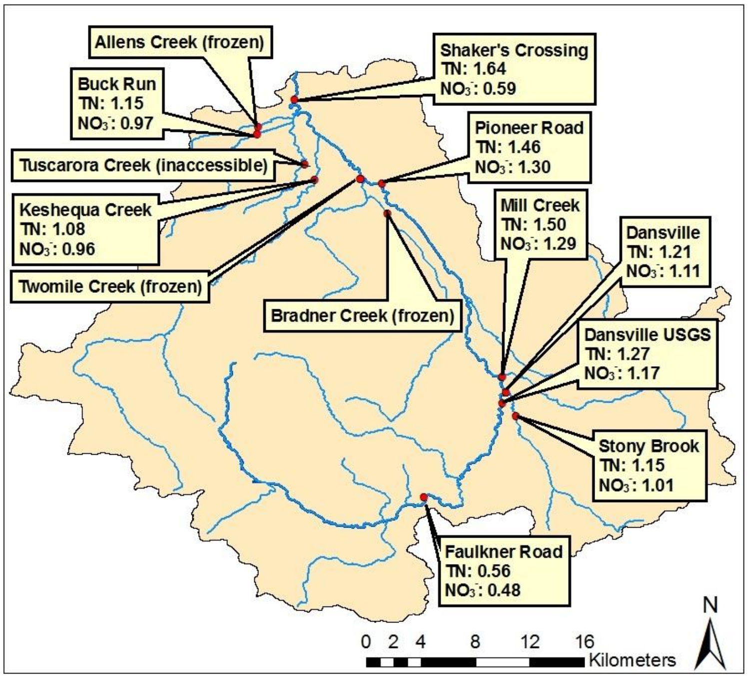


Figure 21. Total nitrogen (TN) and nitrate (NO_3^-) concentrations (mg N/L) in Canaseraga Creek watershed, 8 February 2011.

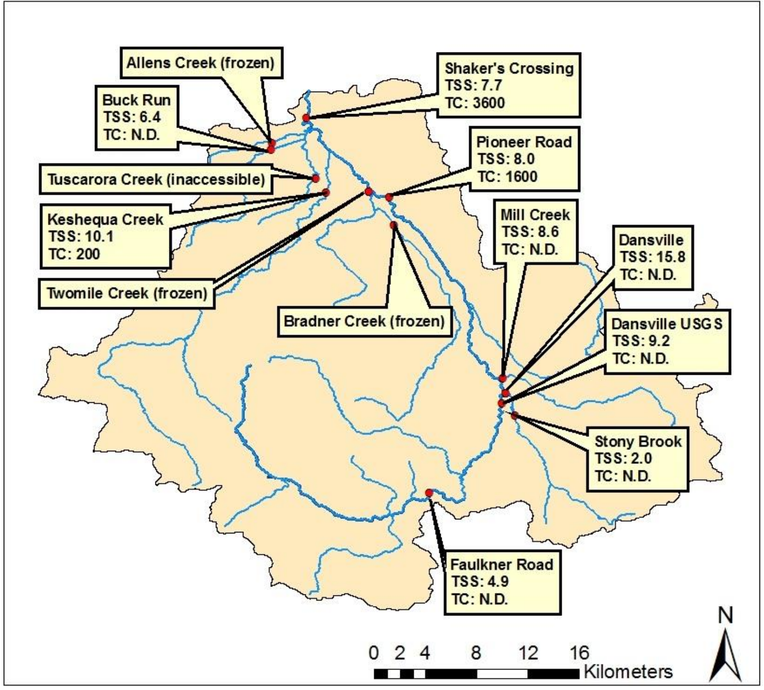


Figure 22. Total suspended solids (TSS) (mg/L) and total coliform bacteria (TC) (CFU/100 mL) in Canaseraga Creek watershed, 8 February 2011.

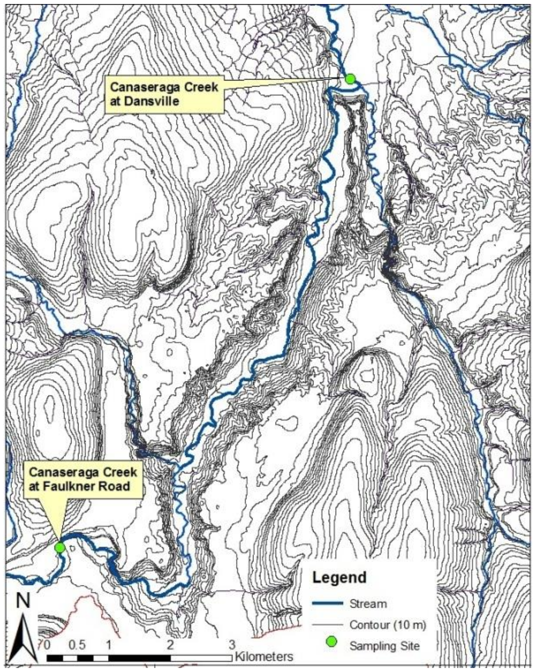


Figure 23. Contour map showing 10 m contour intervals in the area between main stem sampling sites at Faulkner Road and Dansville.

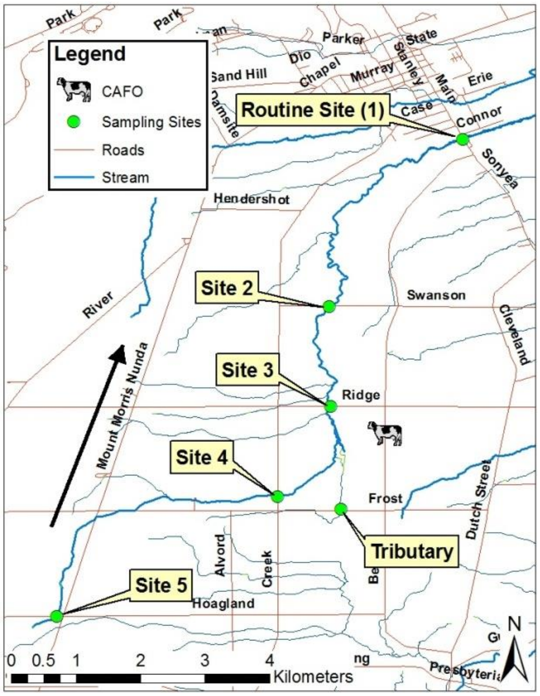


Figure 24. Segment analysis sites on Buck Run Creek, 15 March 2011 along with tributary site added on 10 May 2011. Arrow indicates flow direction.

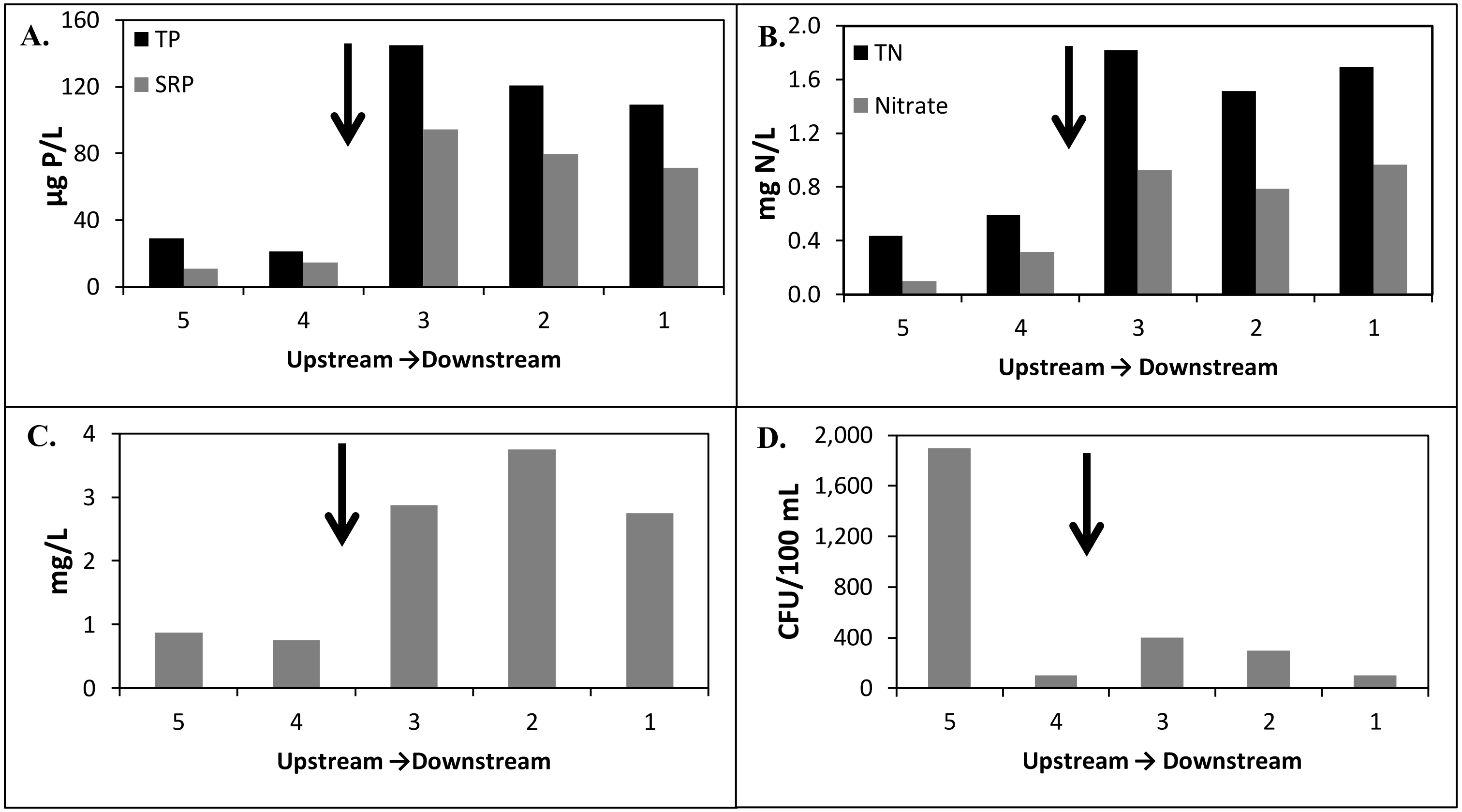


Figure 25. Concentrations of analytes measured during segment analysis of Buck Run Creek on 15 March 2011. Arrows indicate location of CAFO. See Figure 24 for site locations. **A.** Total phosphorus (TP) and soluble reactive phosphorus (SRP) (µg P/L); **B.** total nitrogen (TN) and nitrate (mg N/L); **C.** total suspended solids (TSS) (mg/L) and **D.** total coliform bacteria (CFU/100 mL).

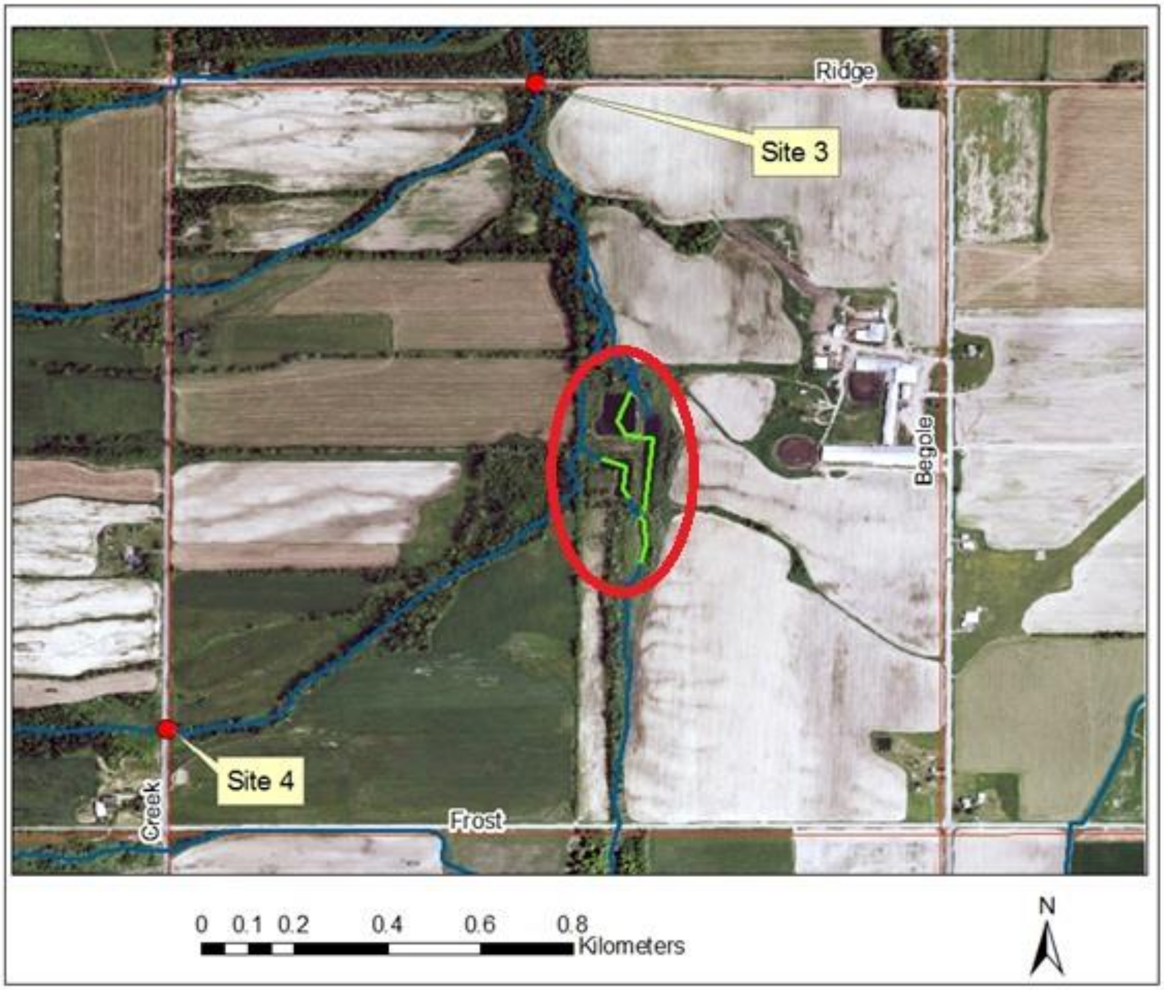


Figure 26. Aerial photograph showing sample sites, the CAFO (Mt. Morris Dairy Farms, Inc.), retention ponds (inside red circle), and ditches (symbolized in green) draining into Buck Run Creek. Flow is from site 4 to site 3.

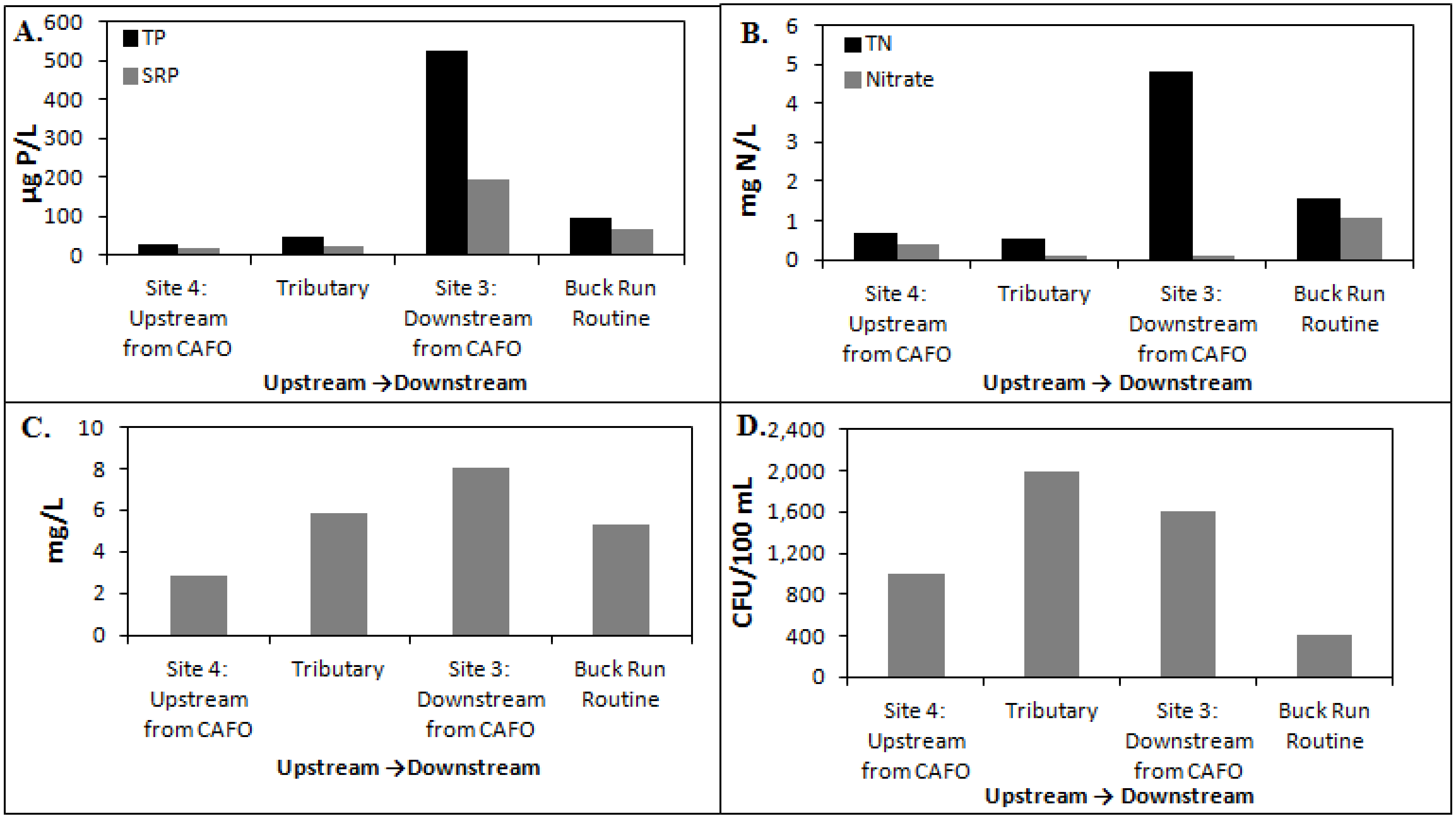


Figure 27. Concentrations of analytes measured during segment analysis on Buck Run Creek on 10 May 2011. See Figure 24 for site locations. **A.** Total phosphorus (TP) and soluble reactive phosphorus (SRP) (µg P/L); **B.** total nitrogen (TN) and nitrate (mg N/L); **C.** total suspended solids (TSS) (mg/L) and **D.** total coliform bacteria (CFU/100 mL).

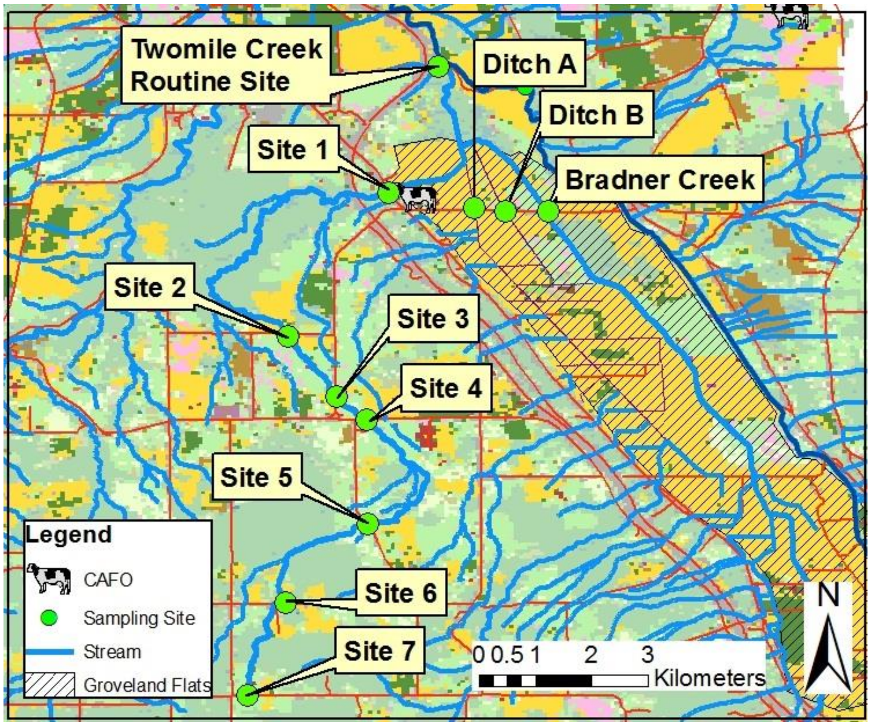


Figure 28. Twomile Creek stressed stream analysis sites, 5 April 2011. Hatchmarked region highlights the Groveland Flats area. Canaseraga Creek darkened. Flow direction is northward. The following colors represent dominant land uses: yellow = corn, dark green = soybean, light green = hay, moderate green = forest, grey = impervious.

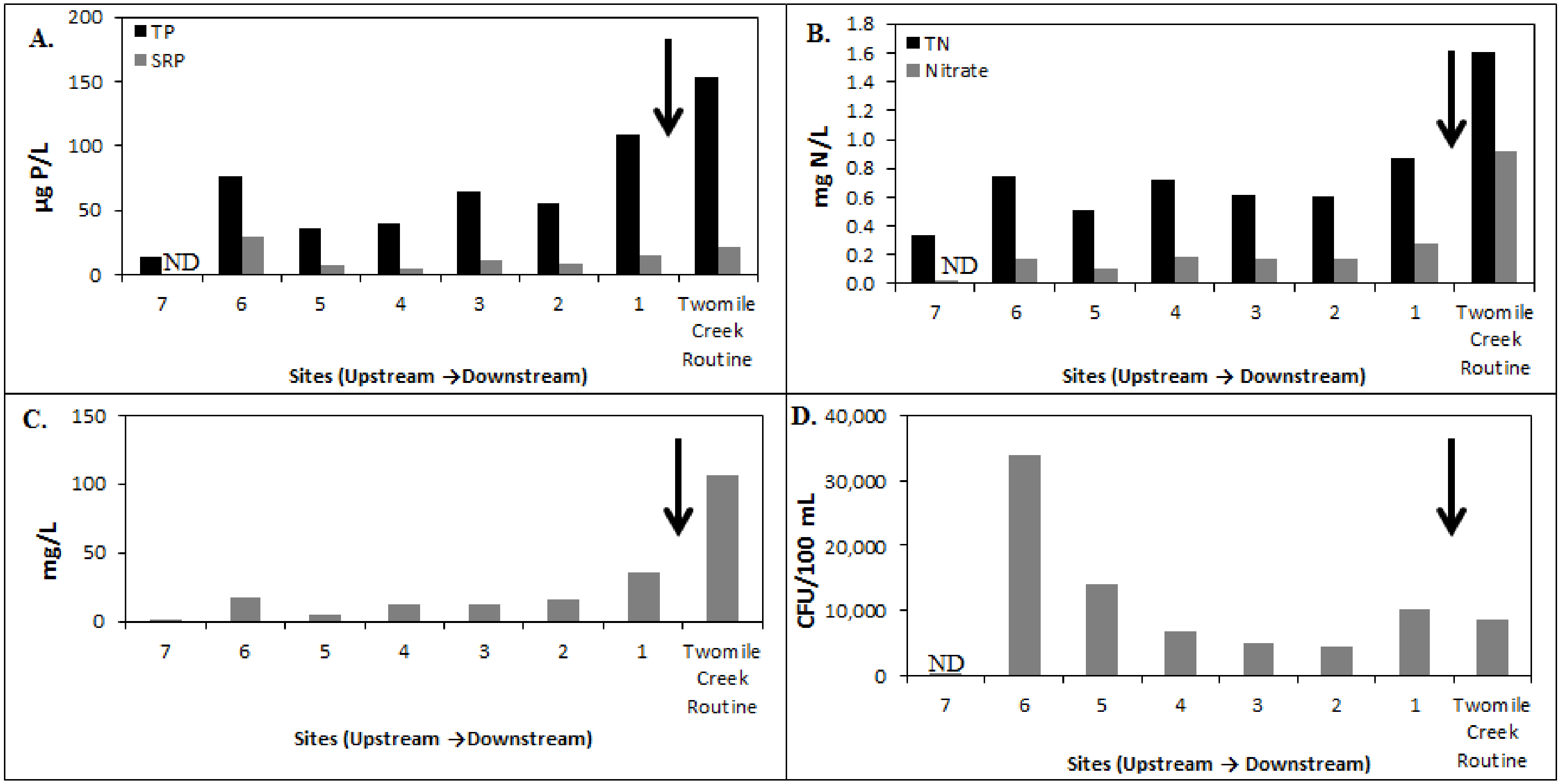


Figure 29. Concentrations of analytes in Twomile Creek during segment analysis on 5 April 2011. **A.** Total phosphorus (TP) and soluble reactive phosphorus (SRP) (µg P/L); **B.** total nitrogen (TN) and nitrate (mg N/L); **C.** total suspended solids (TSS) (mg/L); and **D.** total coliform bacteria (CFU/100 mL). ND = non detectable. Arrow indicates location of CAFO between site 1 and the routine site.

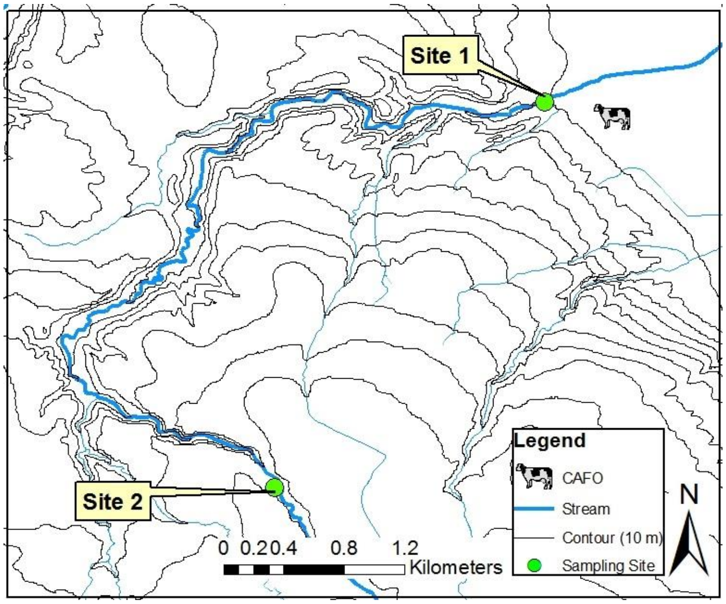


Figure 30. Contour (10 m intervals) of the reach from site 2 to site 1 in which Twomile Creek enters Sonyea State Forest and becomes very steep. Flow direction is from site 2 to site 1.

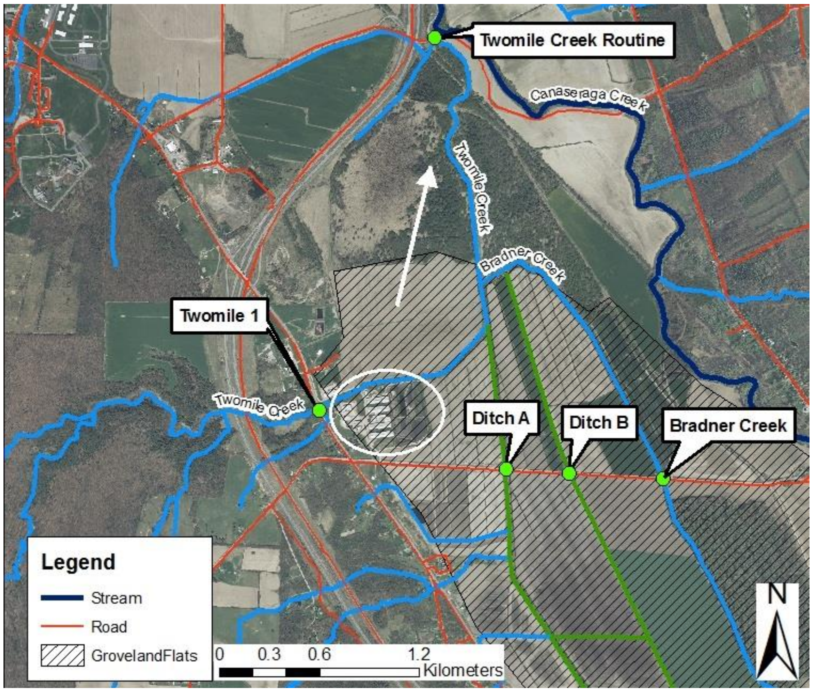


Figure 31. Segment analysis of Twomile Creek, agricultural ditches, and Bradner Creek, 24 May 2011. The white circle highlights Sparta Farms (a CAFO). Canaseraga Creek is darkened. Arrow indicates flow direction, except for Ditch B, which flows south to Ditch A.

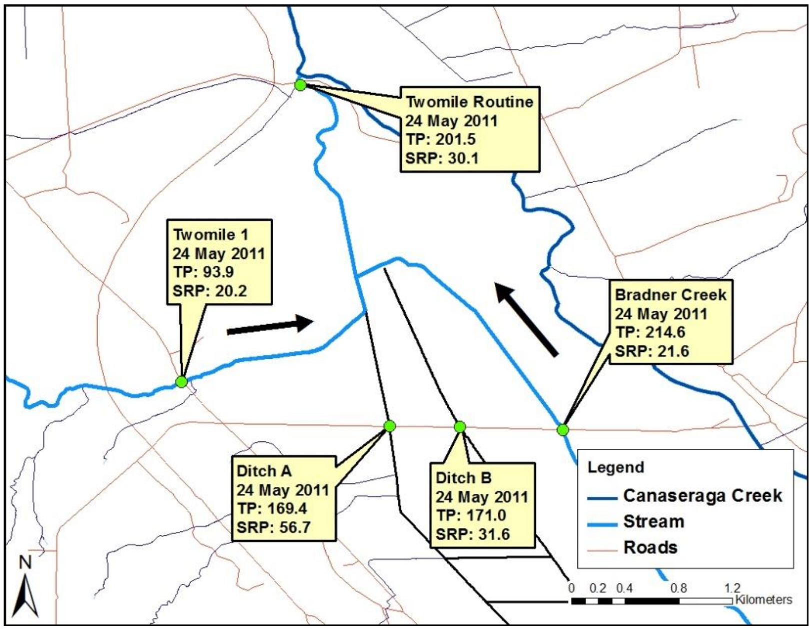


Figure 32. Total phosphorus (TP) and soluble reactive phosphorus (SRP) (µg P/L) in Twomile Creek, 24 May 2011. Arrows indicate flow direction, ditches darkened.

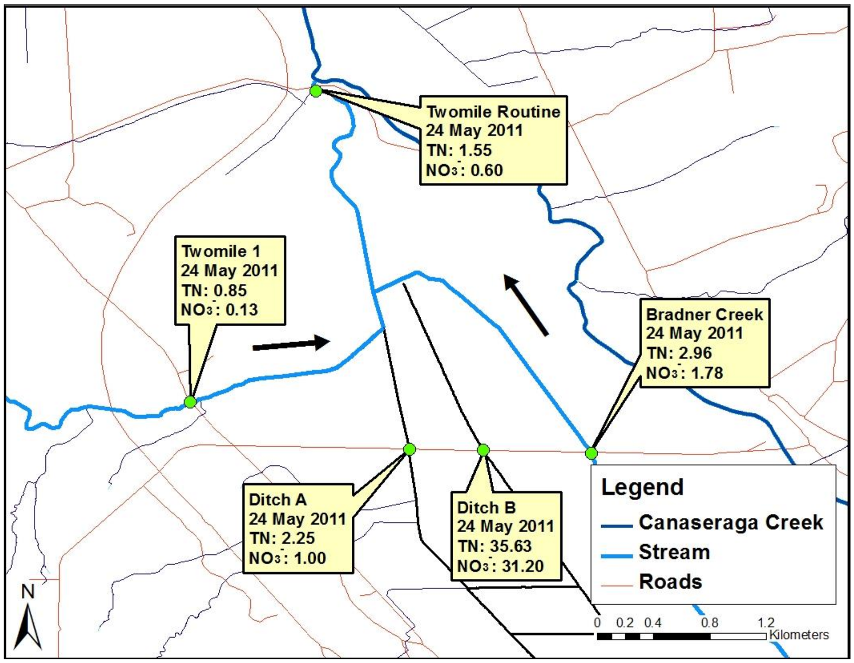


Figure 33. Total nitrogen (TN) and nitrate (NO_3^-) (mg N/L) in Twomile Creek, 24 May 2011. Arrows indicate flow direction, ditches darkened.

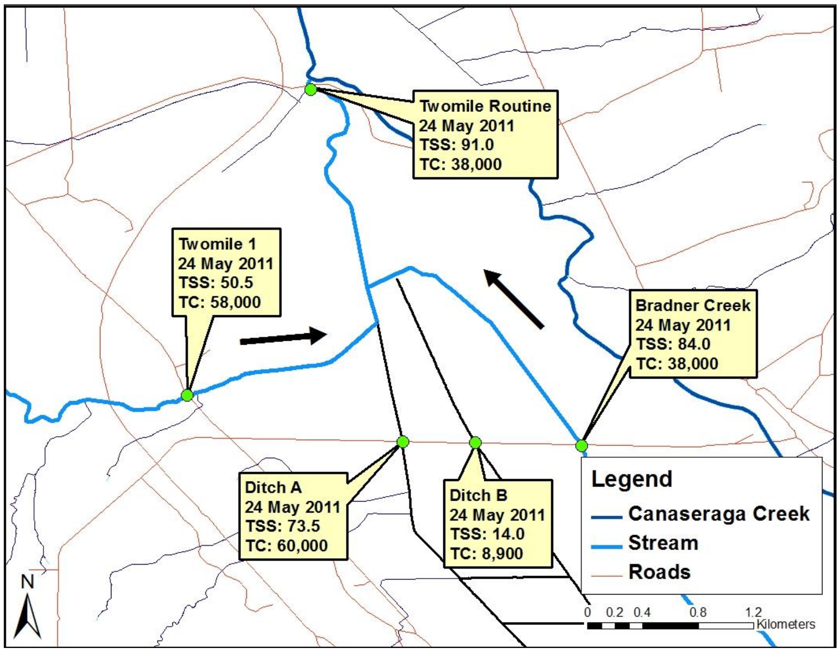
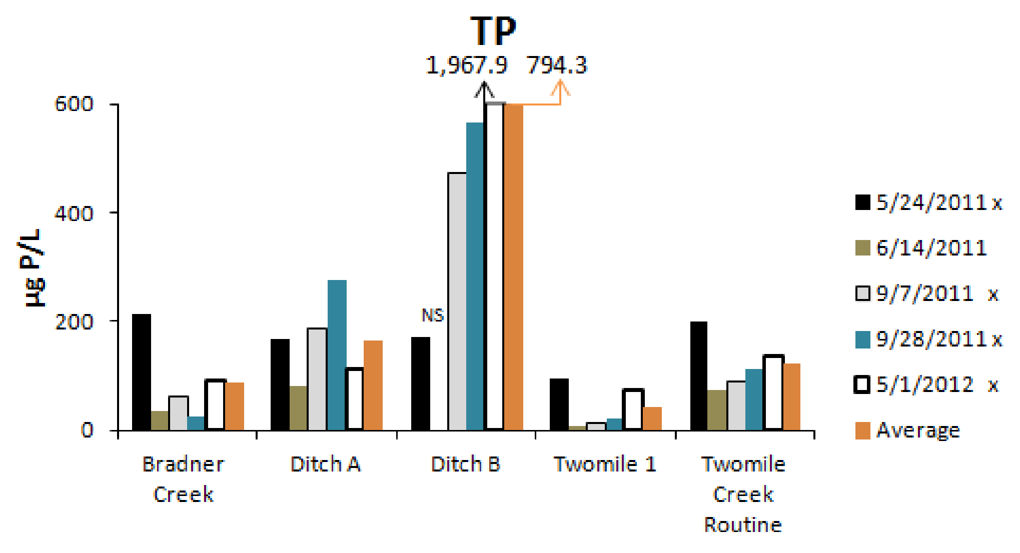
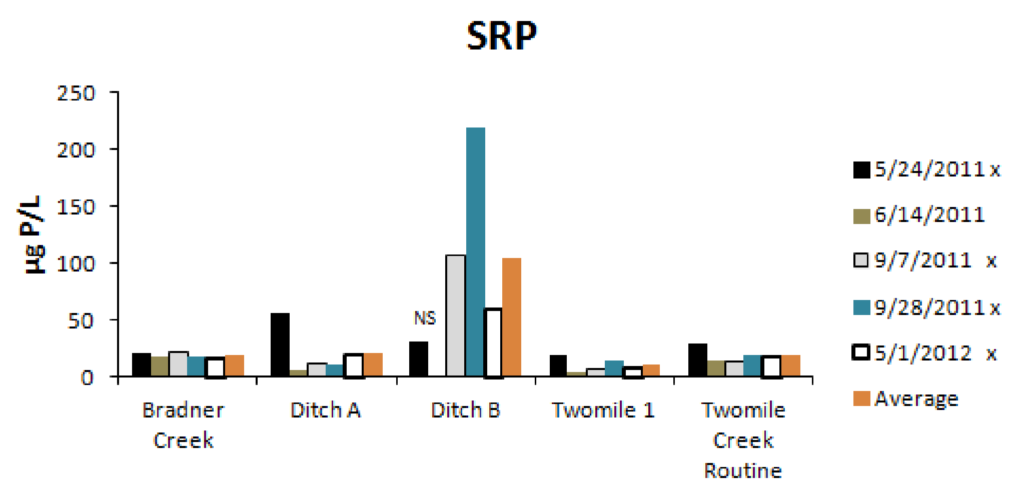
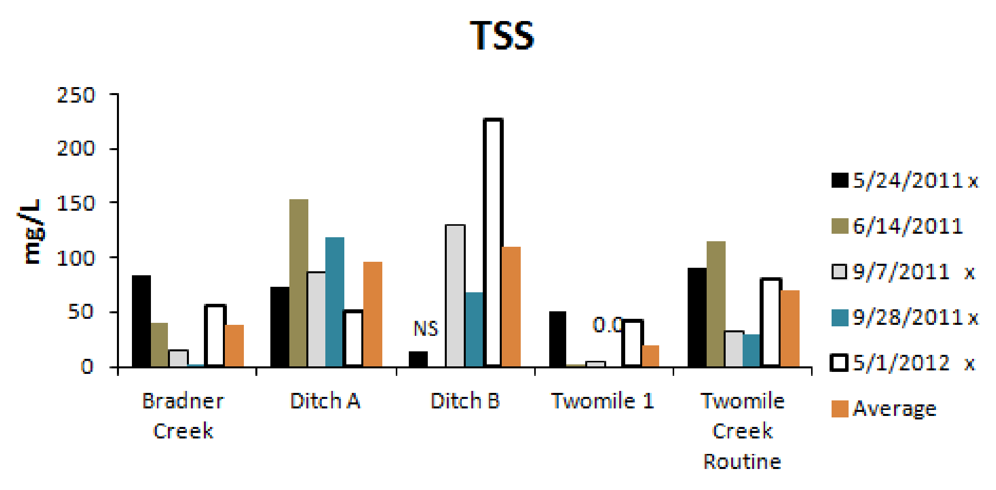


Figure 34. Total suspended solids (TSS) (mg/L) and Total Coliforms (TC) (CFU/100 mL) in Twomile Creek, 24 May 2011. Arrows indicate flow direction, ditches darkened.


TP
1,967.9
794.3
µg P/L
600
400
200
0
NS
Bradner Creek
Ditch A
Ditch B
Twomile 1
Twomile Creek Routine
■ 5/24/2011 x
■ 6/14/2011
☐ 9/7/2011 x
■ 9/28/2011 x
☐ 5/1/2012 x
■ Average


SRP
µg P/L
250
200
150
100
50
0
NS
Bradner Creek
Ditch A
Ditch B
Twomile 1
Twomile Creek Routine
■ 5/24/2011 x
■ 6/14/2011
☐ 9/7/2011 x
■ 9/28/2011 x
☐ 5/1/2012 x
■ Average


TSS
mg/L
250
200
150
100
50
0
NS
0.0
Bradner Creek
Ditch A
Ditch B
Twomile 1
Twomile Creek Routine
■ 5/24/2011 x
■ 6/14/2011
☐ 9/7/2011 x
■ 9/28/2011 x
☐ 5/1/2012 x
■ Average

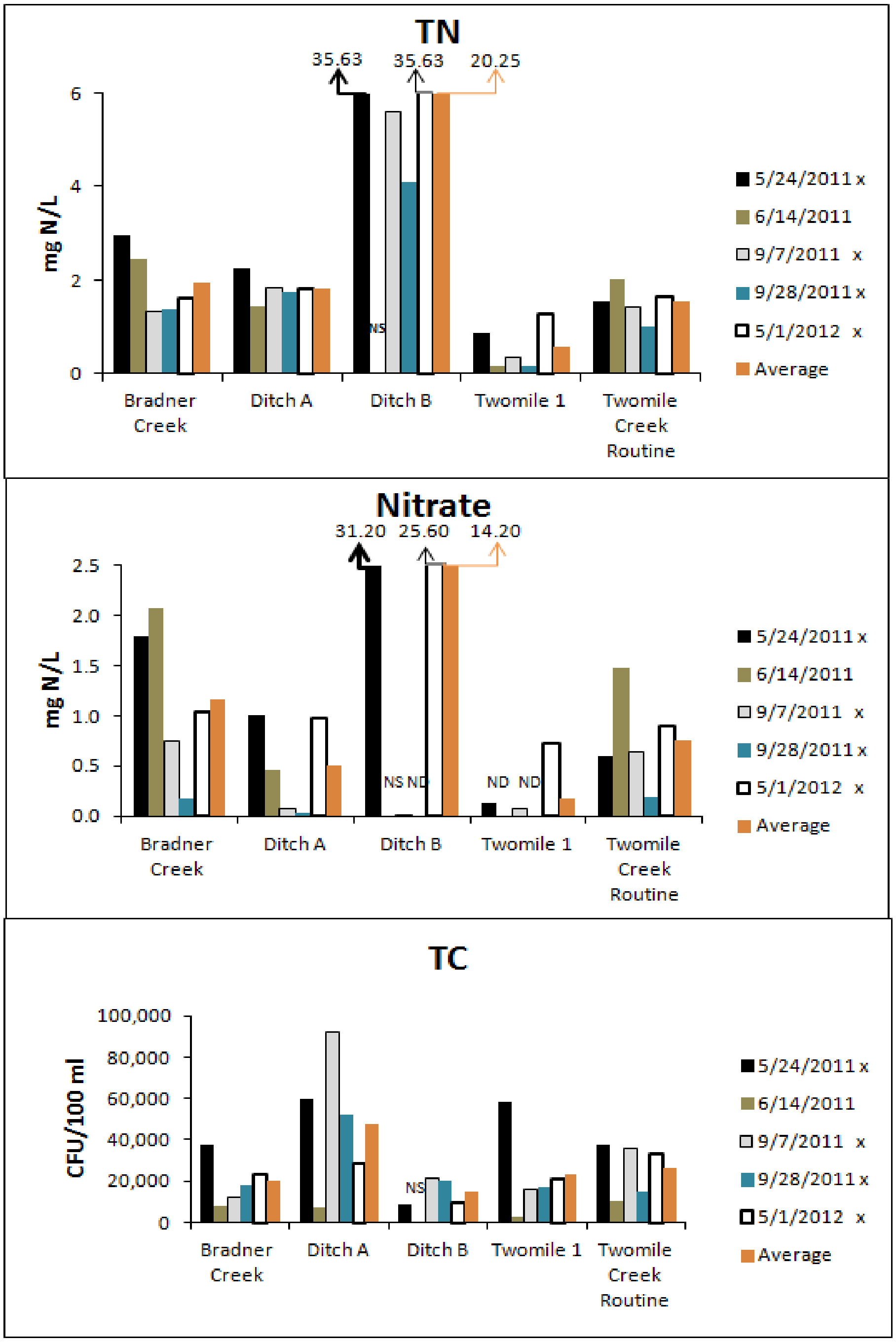


Figure 35. Groveland Flats area samples by date. TP = total phosphorus, SRP = soluble reactive phosphorus, TN = total nitrogen, TSS = total suspended solids, TC = total coliform bacteria, ND = no detection, NS = no sample, X next to date indicates event sample (site locations shown on Figure 31).

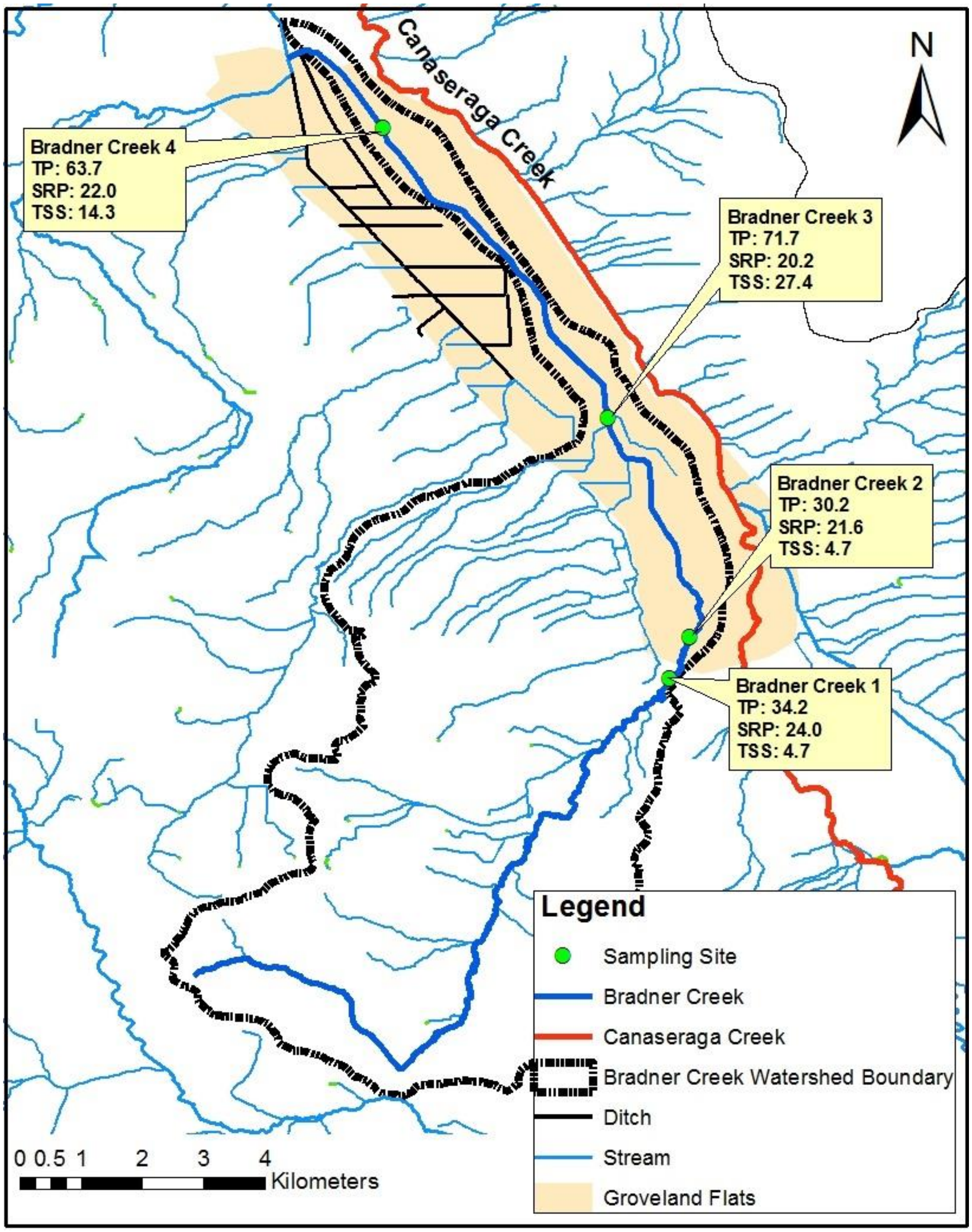


Figure 36. Sampling locations on Bradner Creek, 7 September 2011. Total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations are µg P/L, total suspended solids (TSS) concentrations are mg/L.

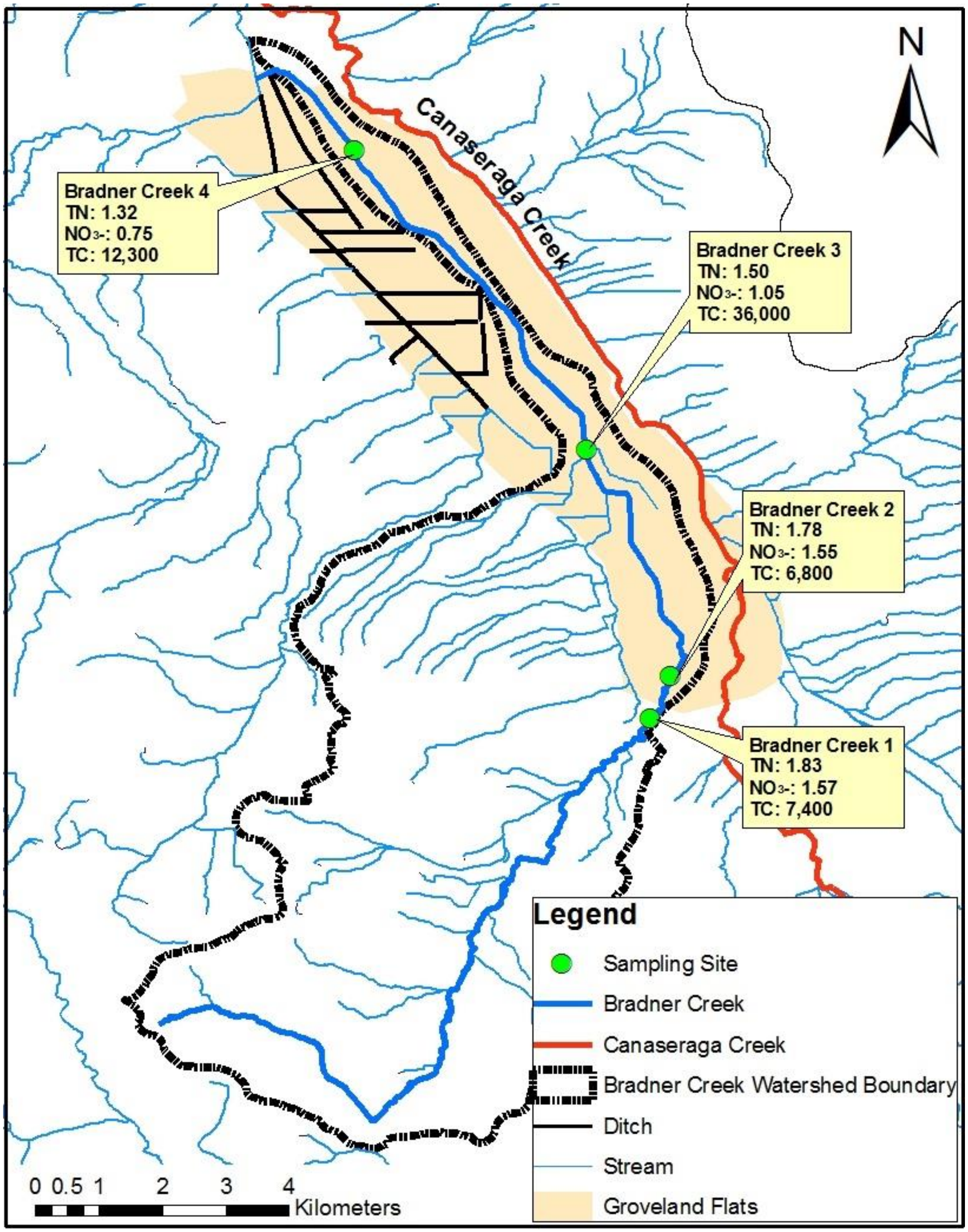


Figure 37. Sampling locations on Bradner Creek, 7 September 2011. Total nitrogen (TN) and nitrate (NO_3-) concentrations are mg N/L, total coliform bacteria (TC) units are CFU/100 mL.

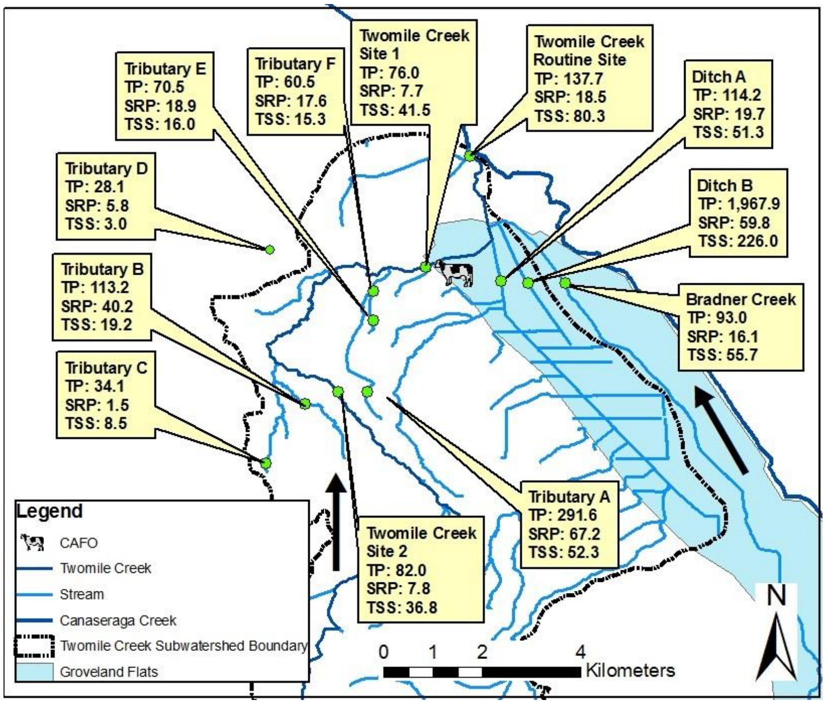


Figure 38. Total phosphorus (TP) (μg P/L), soluble reactive phosphorus (SRP) (μg P/L), and total suspended solids (TSS) (mg/L) in Twomile Creek subwatershed during segment analysis, 1 May 2012. Arrows indicate flow direction.

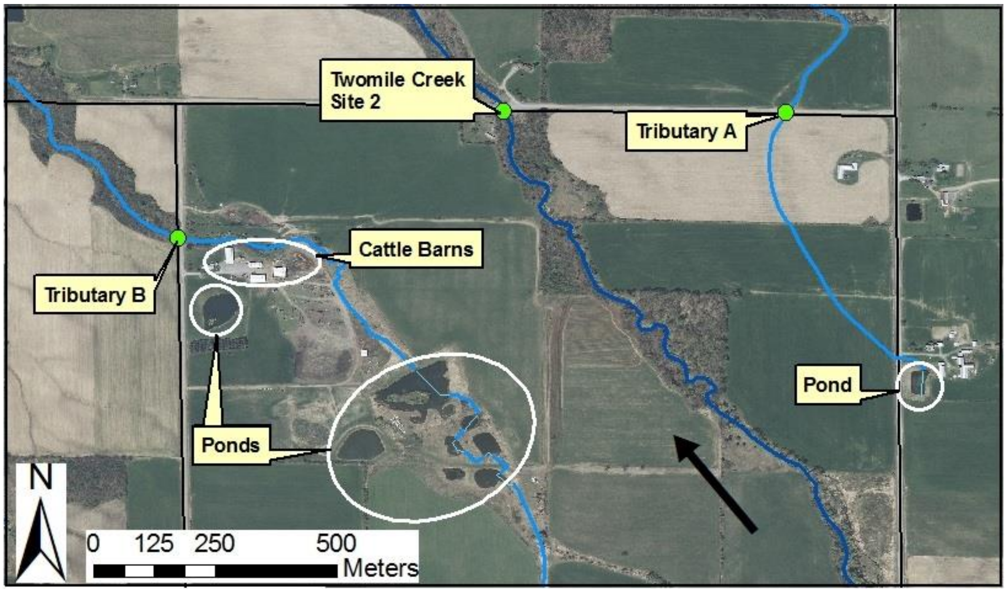


Figure 39. Orthoimage showing Tributary B flowing through several ponds and past a cattle farm upstream from the sampling site and tributary A originating in a pond, then flowing through a corn field upstream from the sampling site during event sampling on 1 May 2012. Twomile Creek site 2 location provided for reference. Arrow indicates flow direction.

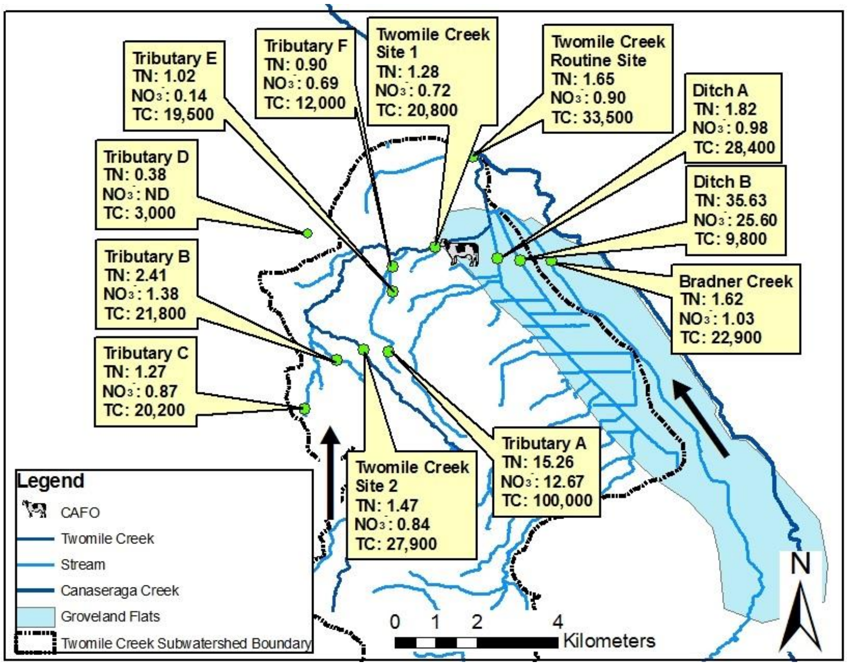


Figure 40. Total nitrogen (TN) (mg N/L), nitrate (NO_3^-) (mg N/L), and total coliform bacteria (CFU/100 mL) in Twomile Creek subwatershed during segment analysis, 1 May 2012. Arrows indicate flow direction.

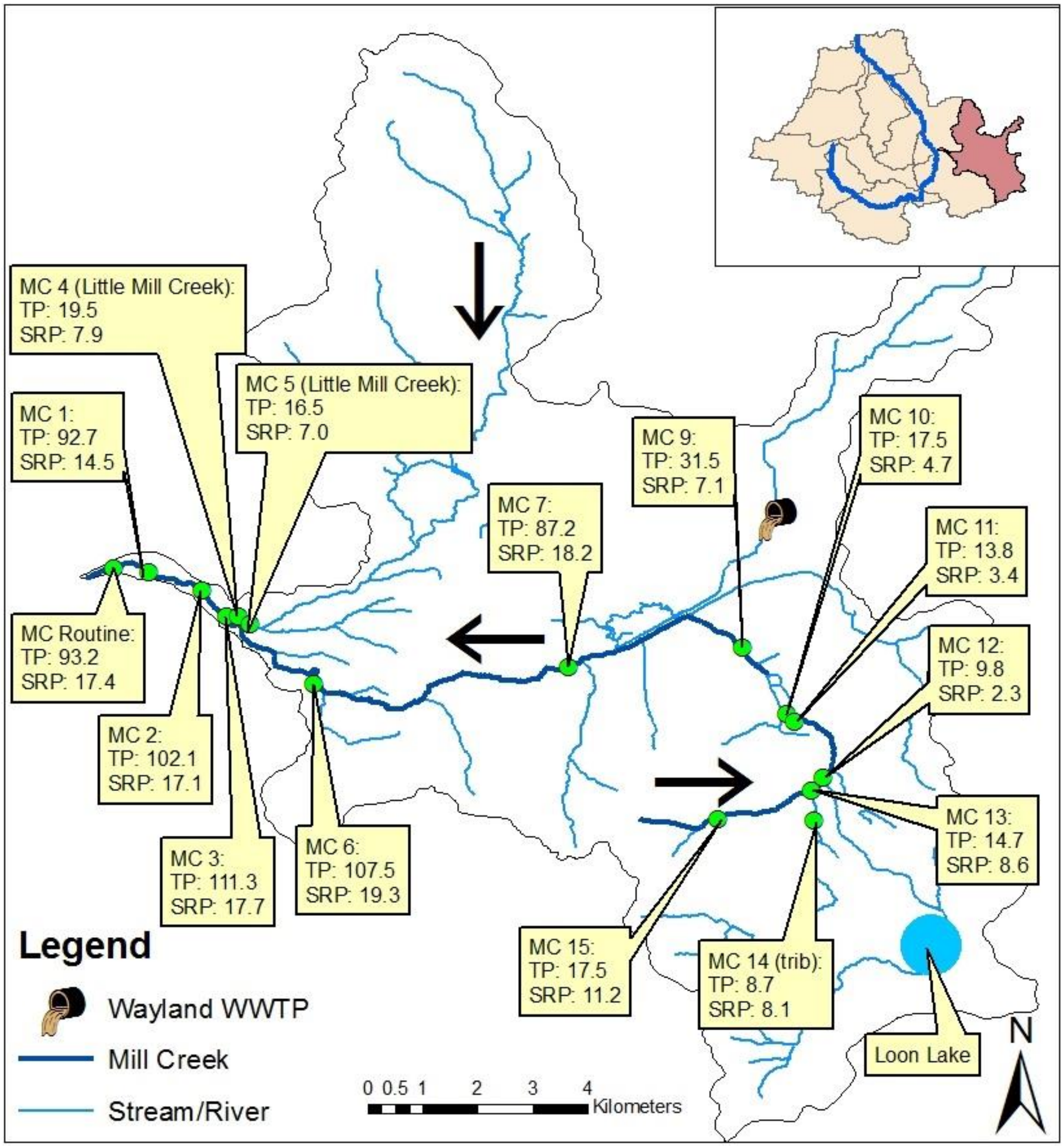


Figure 41. Inset map showing the subbasins of Canaseraga Creek watershed with Mill Creek subwatershed highlighted. Larger map displays stressed stream analysis sites in Mill Creek subwatershed, 16 August, 2011. Total phosphorus (TP) and soluble reactive phosphorus (SRP) units are µg P/L. Arrows indicate flow direction.

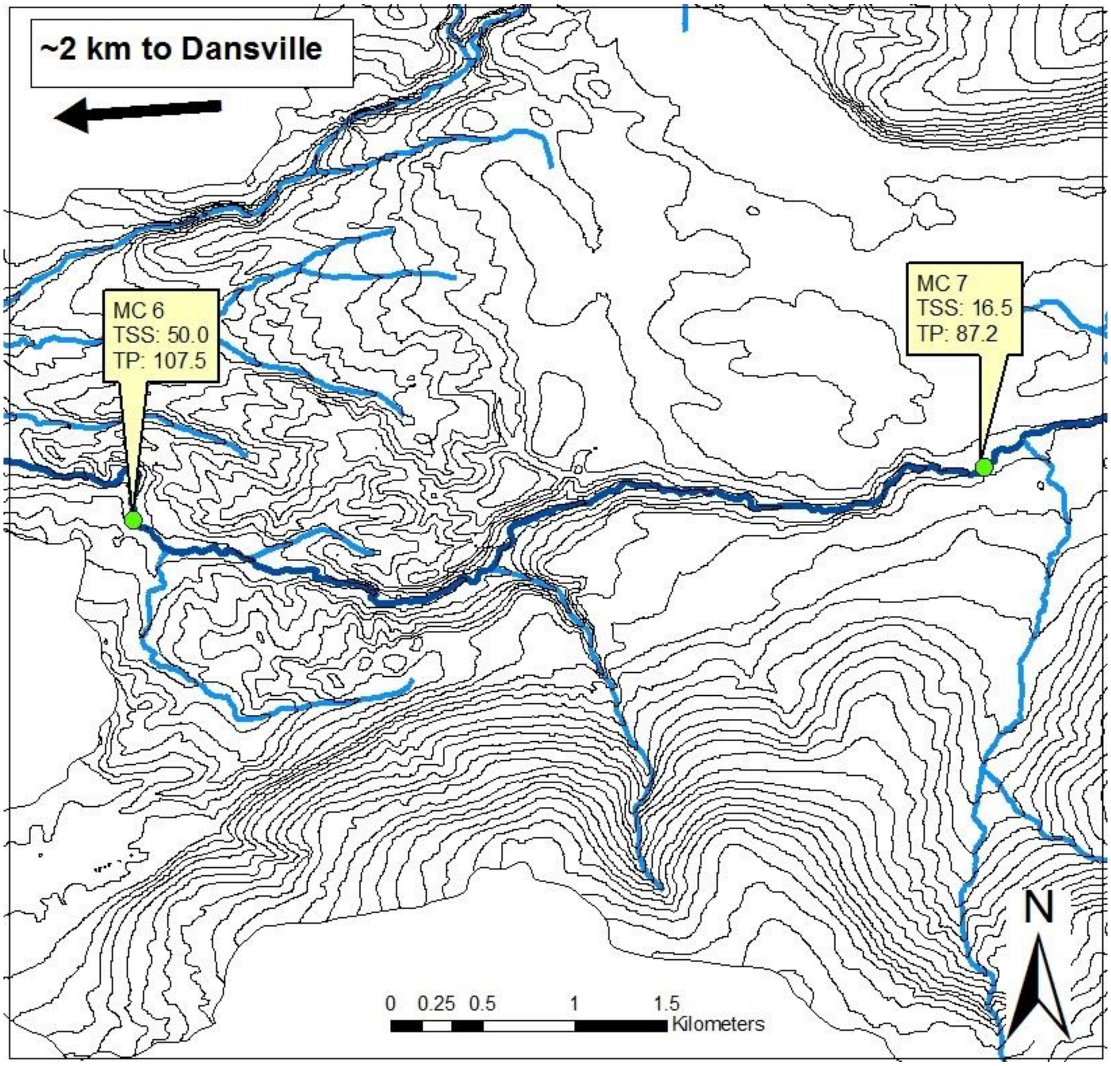


Figure 42. Map showing steepness of terrain (10 m intervals) of Mill Creek between segment analysis sites 6 and 7, 16 August 2011.

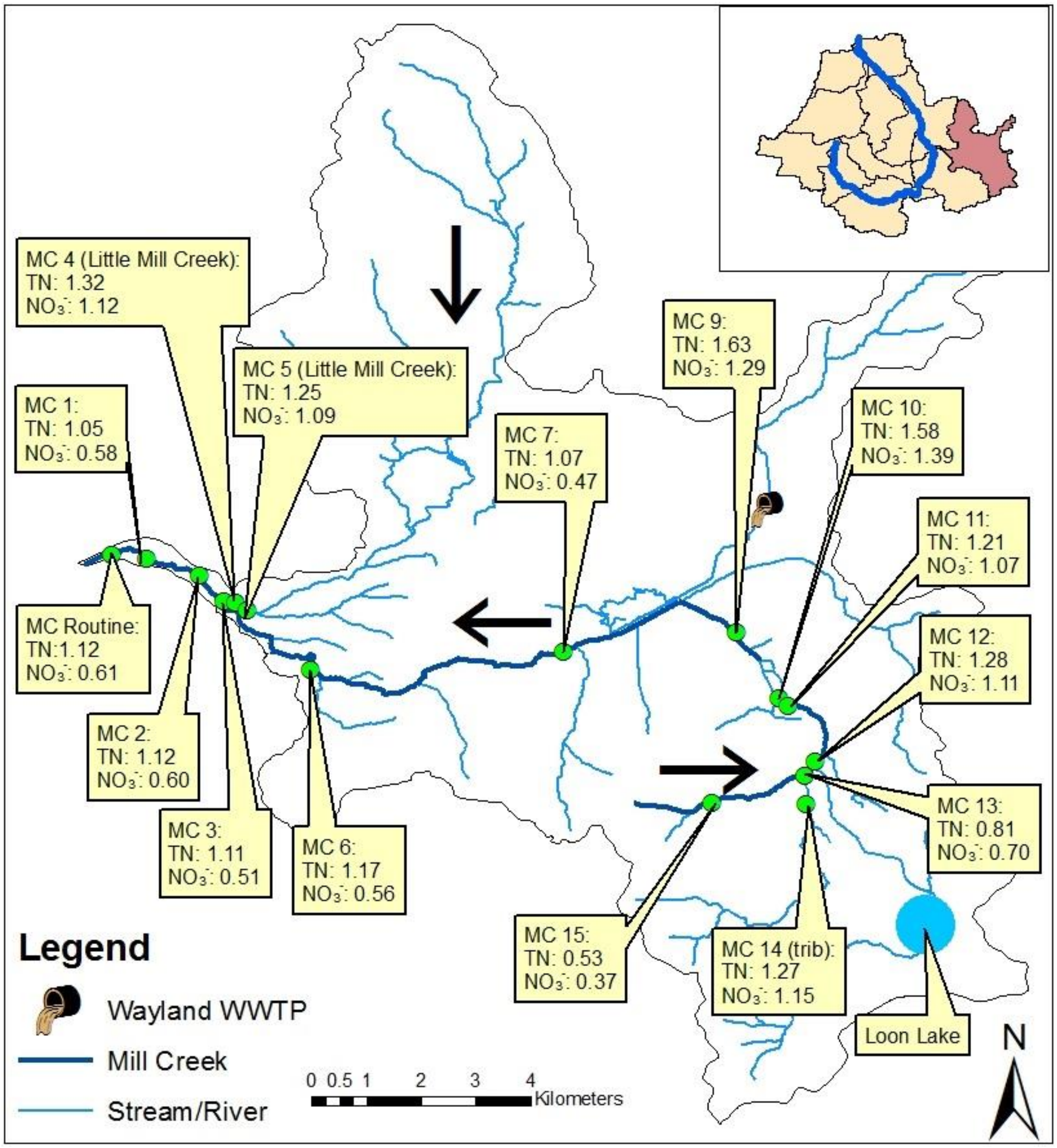


Figure 43. Inset map showing the subbasins of Canaseraga Creek watershed with Mill Creek subwatershed highlighted. Larger map displays stressed stream analysis sites in Mill Creek subwatershed, 16 August, 2011. Total nitrogen (TN) and nitrate (NO_3^-) units are mg N/L. Arrows indicate flow direction.

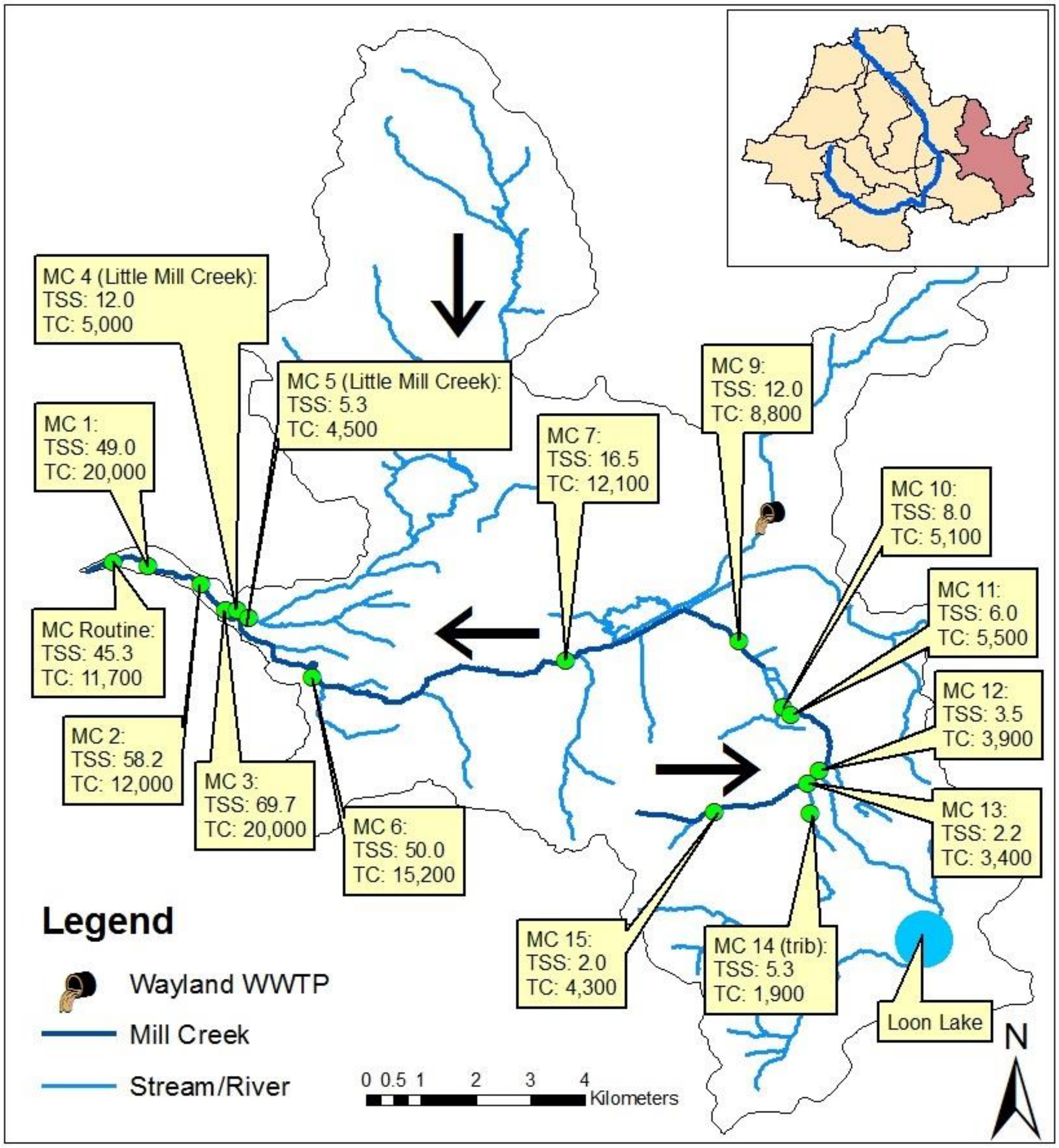


Figure 44. Inset map showing the subbasins of Canaseraga Creek watershed with Mill Creek subwatershed highlighted. Larger map displays concentrations of total suspended solids (TSS) (mg/L) and total coliform bacteria (TC) (CFU/100 mL) at stressed stream analysis sites in Mill Creek subwatershed, 16 August, 2011. Arrows indicate flow direction.

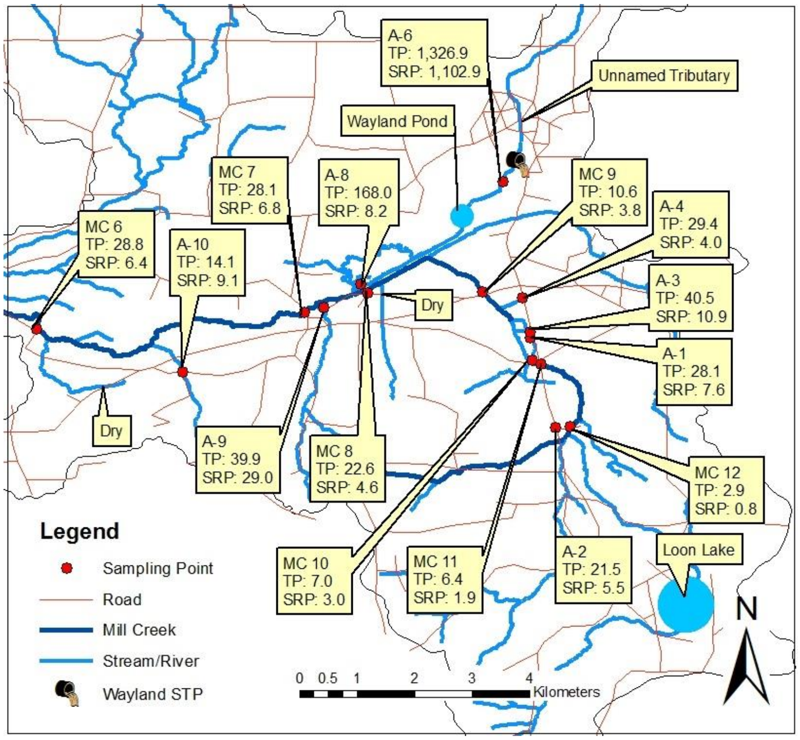


Figure 45. Total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) in Mill Creek during segment analysis, 31 August 2011.

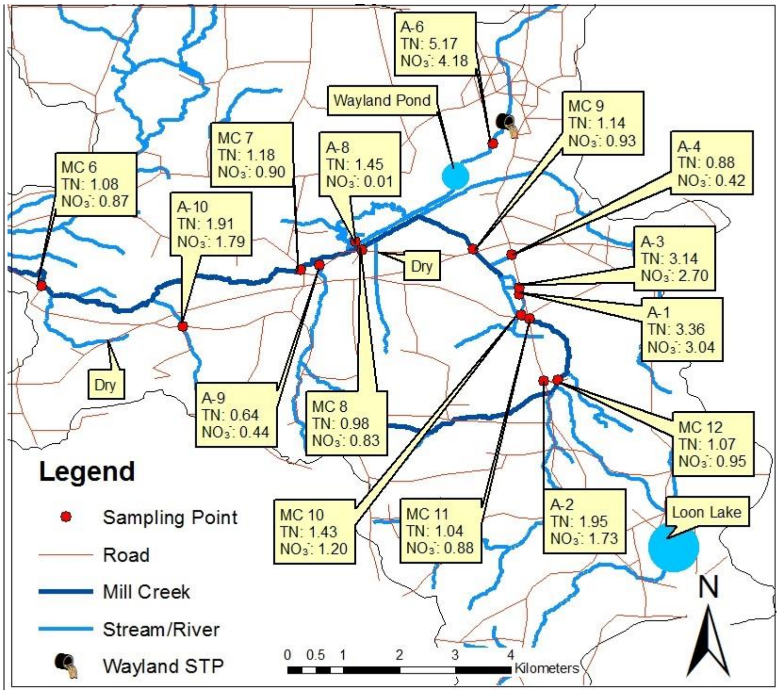


Figure 46. Total nitrogen (TN) (mg N/L) and nitrate (NO_3^-) (mg N/L) in Mill Creek during segment analysis, 31 August 2011.

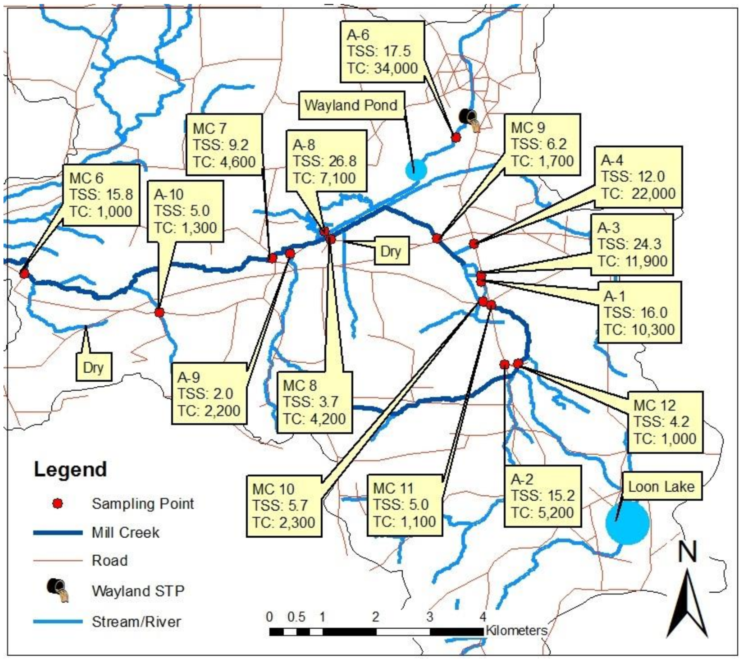


Figure 47. Total suspended solids (TSS) (mg/L) and total coliform abundance (TC) (CFU/100 mL) in Mill Creek during segment analysis, 31 August 2011.

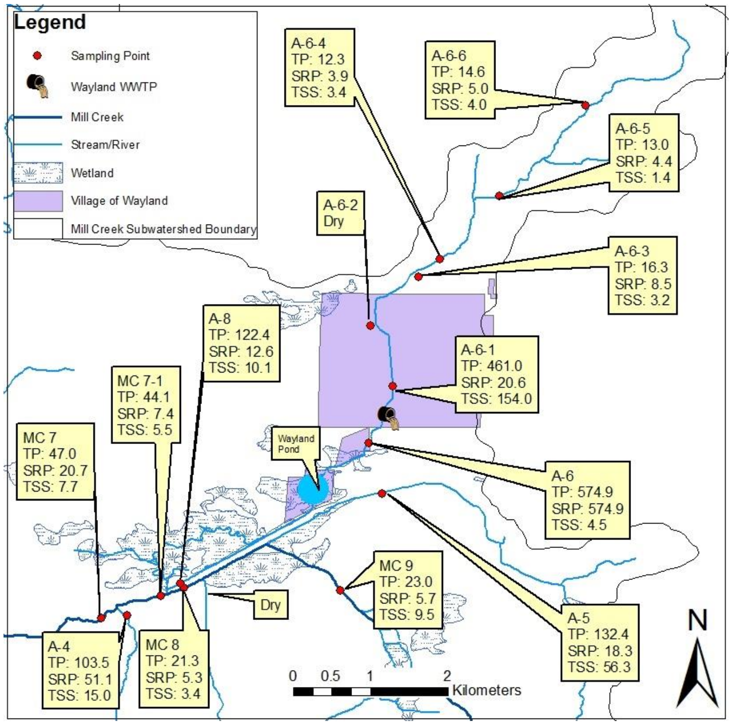


Figure 48. Upstream portions of Mill Creek subwatershed with concentrations of total phosphorus (TP) (µg P/L), soluble reactive phosphorus (SRP) (µg P/L) and total suspended solids (TSS) (mg/L) during segment analysis, 23 April 2012.

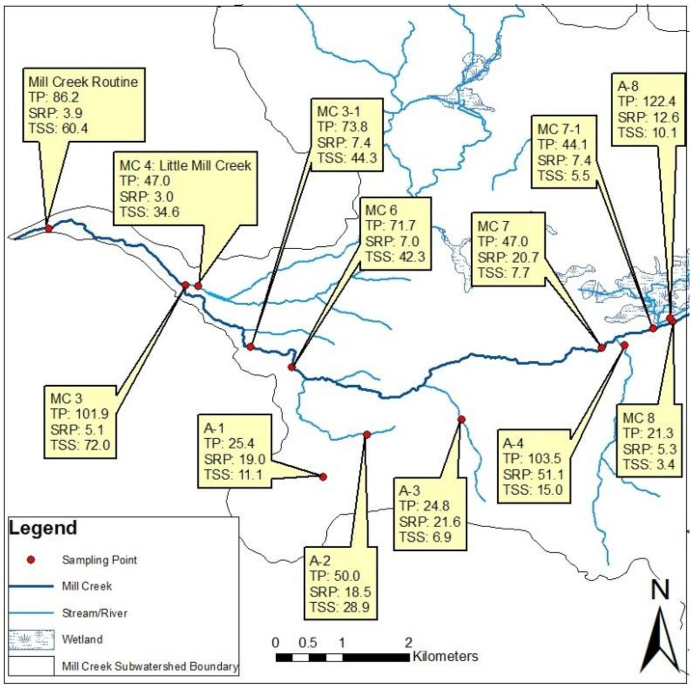


Figure 49. Downstream portions of Mill Creek subwatershed with concentrations of total phosphorus (TP) (µg P/L), soluble reactive phosphorus (SRP) (µg P/L), and total suspended solids (TSS) (mg/L) during segment analysis, 23 April 2012.

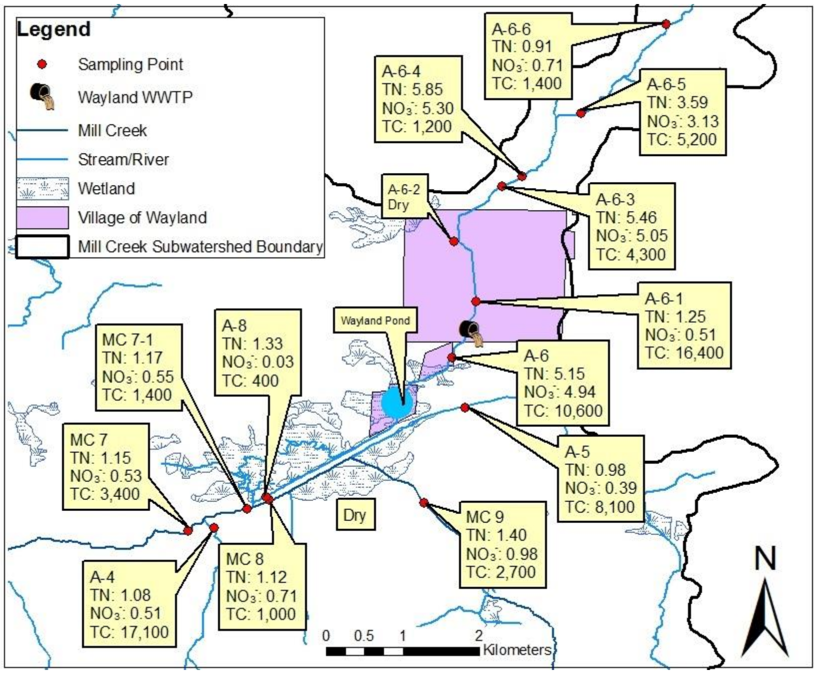


Figure 50. Upstream portions of Mill Creek subwatershed with concentrations of total nitrogen (TN) (mg N/L), nitrate (NO_3^-) (mg N/L) and total coliform bacteria (TC) (CFU/100 mL) during segment analysis, 23 April 2012.

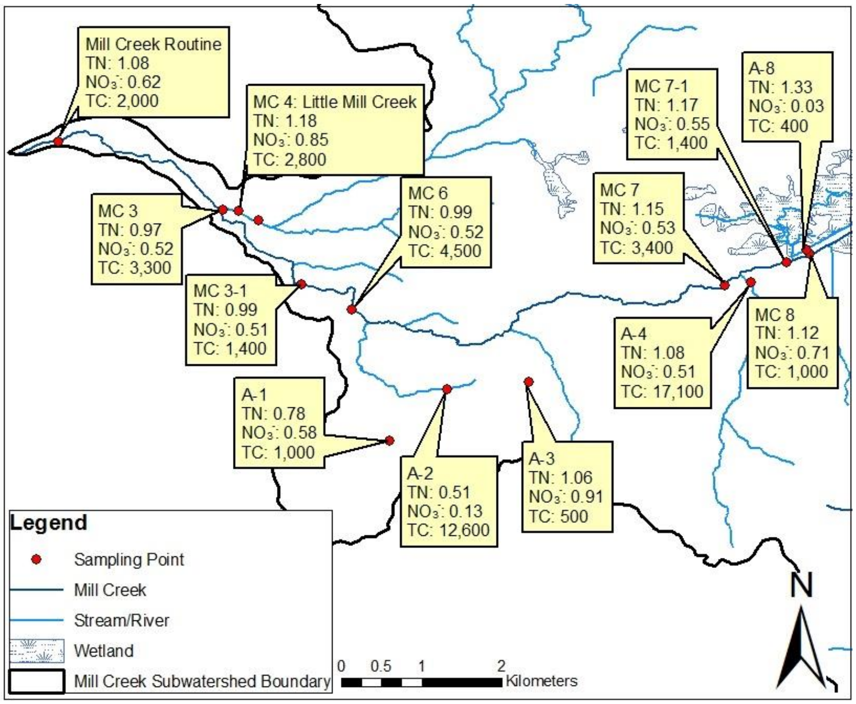


Figure 51. Downstream portions of Mill Creek subwatershed with concentrations of total nitrogen (TN) (mg N/L), nitrate (NO_3^-) (mg N/L) and total coliform bacteria (TC) (CFU/100 mL) during segment analysis, 23 April 2012.

Figure 52. Orthoimagery of tributary A-4 from Mill Creek segment analysis, 23 April 2012. A cattle farm is highlighted by the white circle, through which the stream flows northward into Mill Creek (dark blue).

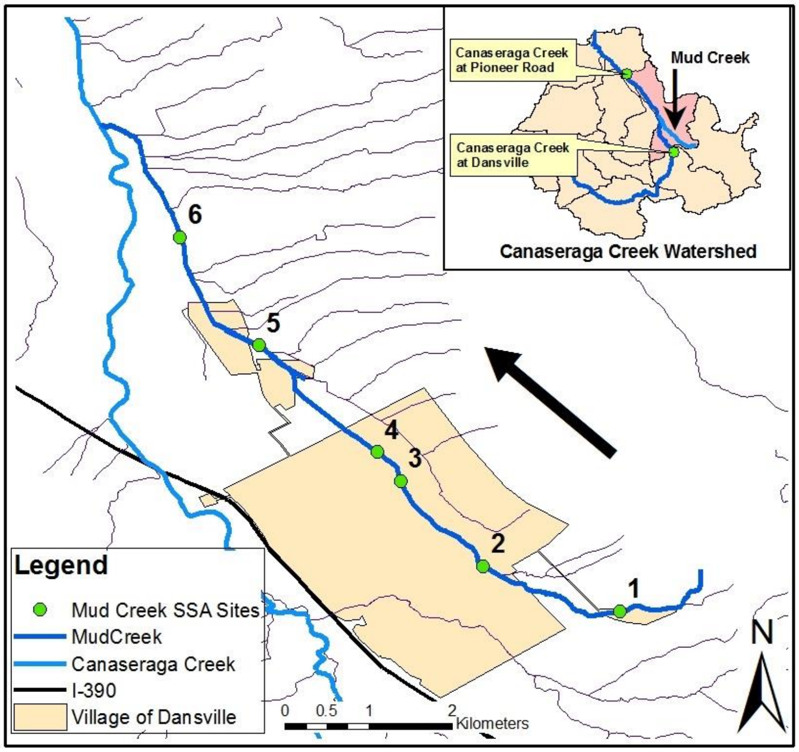


Figure 53. Inset map with arrow showing Mud Creek within Canaseraga Creek watershed. Larger map shows Mud Creek segment analysis sites in and near Dansville, NY.

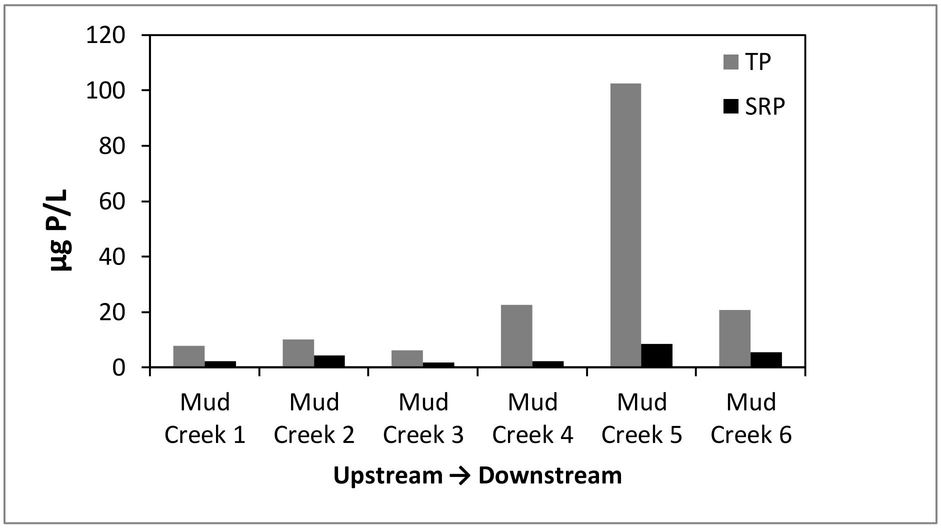


Figure 54. Total phosphorus (TP) and soluble reactive phosphorus (SRP) (µg P/L) in Mud Creek, 21 September 2011.

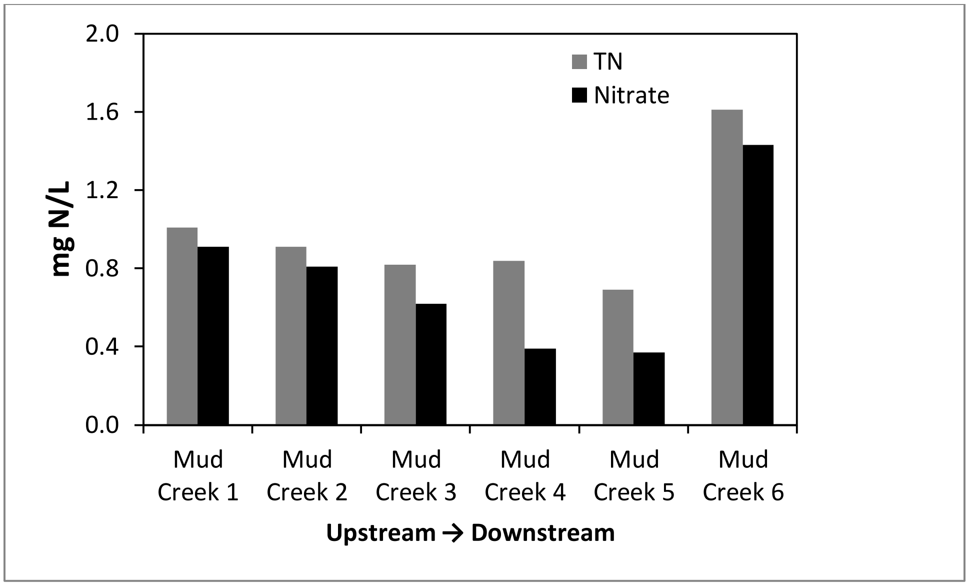


Figure 55. Total nitrogen (TN) and nitrate (mg N/L) in Mud Creek, 21 September 2011.

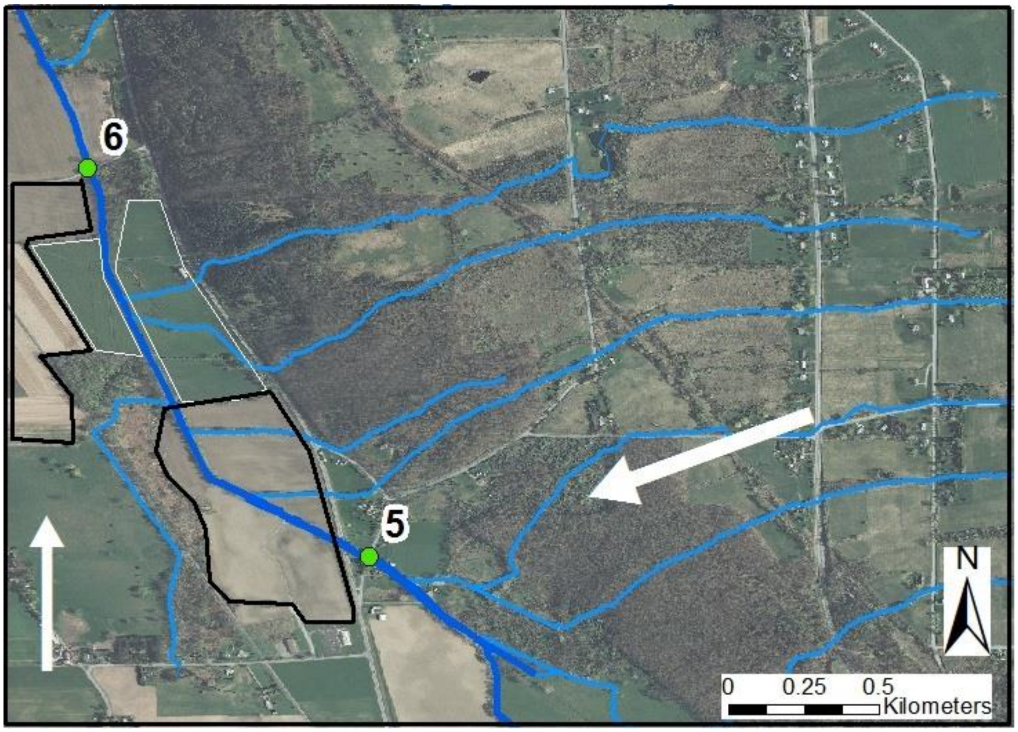


Figure 56. Orthoimage of Mud Creek segment analysis sites, 21 September 2011 depicting corn fields (black outlines) and hay fields (white outlines) bordering the creek downstream from site 5. Arrows indicate flow direction.

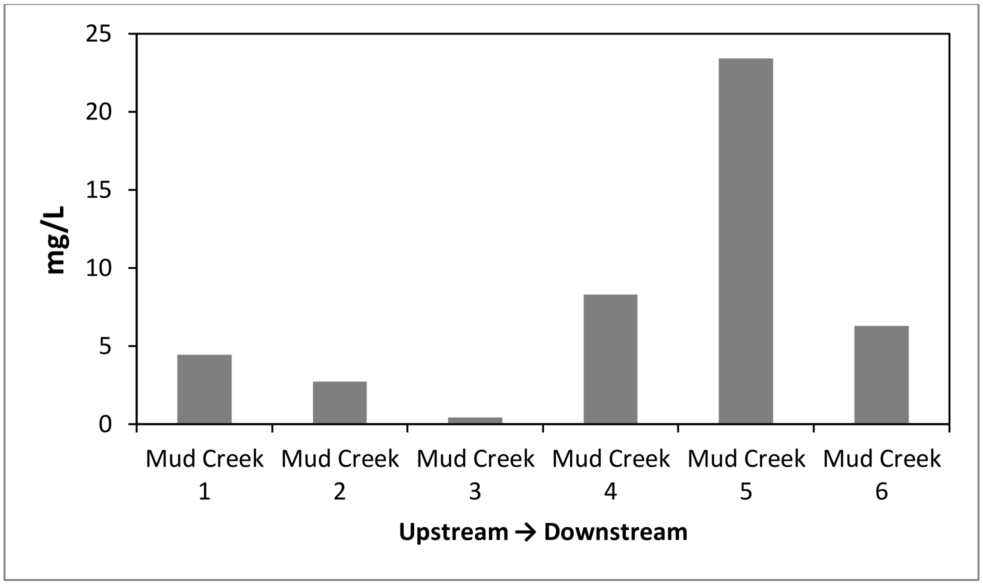


Figure 57. Total suspended solids (TSS) (mg/L) in Mud Creek, 21 September 2011.

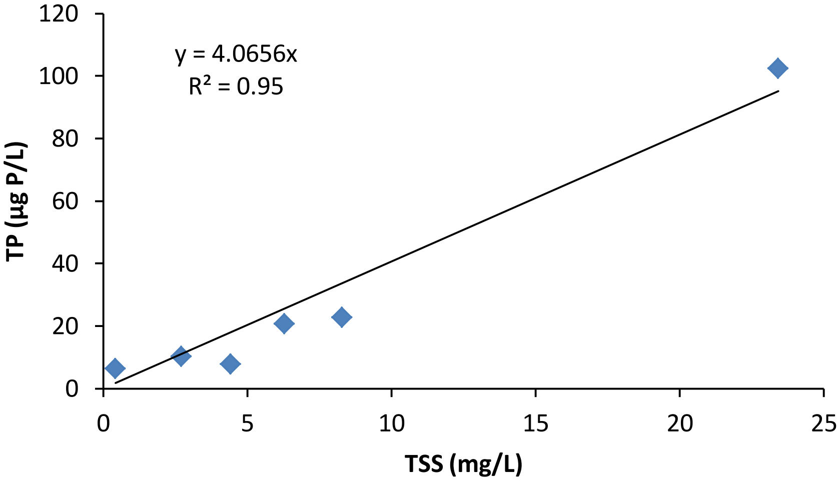


Figure 58. Regression of total phosphorus (TP) (µg P/L) and total suspended solids (TSS) (mg/L) from six samples taken along Mud Creek during segment analysis, 21 September 2011.

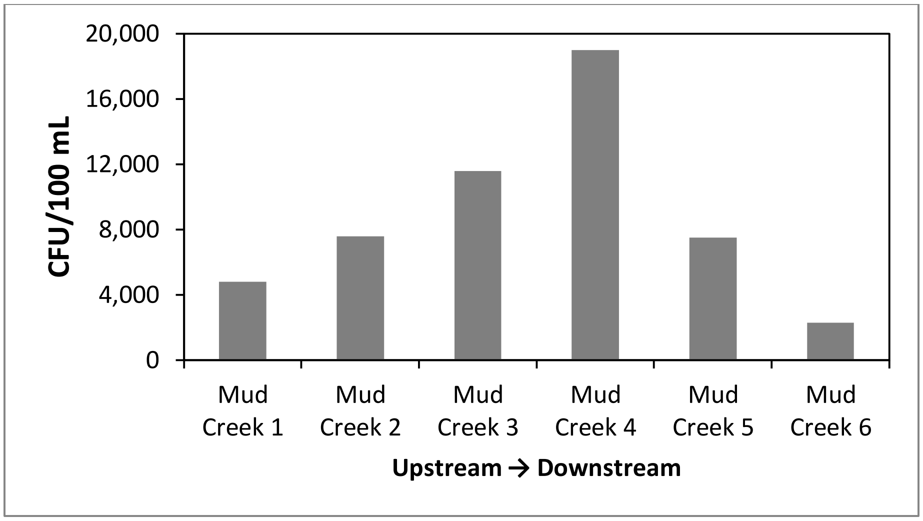


Figure 59. Total coliform bacteria (CFU/100 mL) in Mud Creek, 21 September 2011.

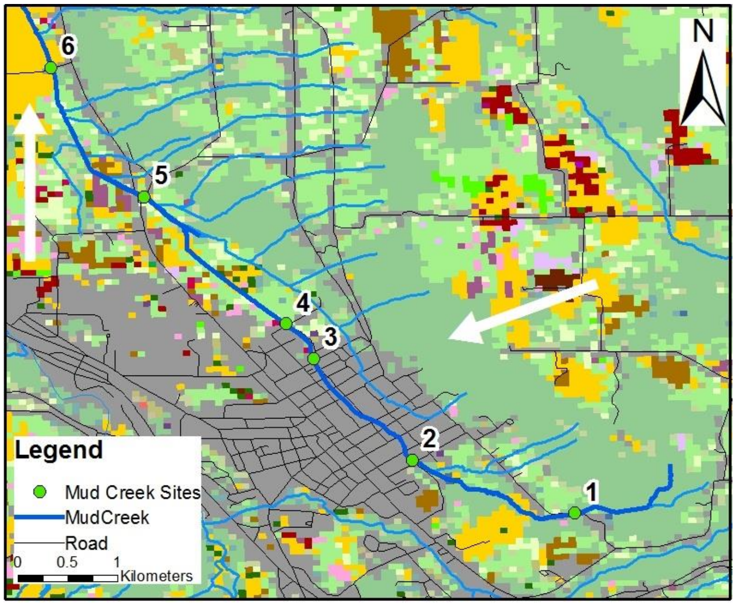


Figure 60. Land use map of Mud Creek segment analysis sites. Grey areas indicate impervious surfaces (developed areas), light green is hay, yellow is corn, and dark green is forest. Other colors indicate various other crops such as potato and beans. Arrows indicate flow direction.

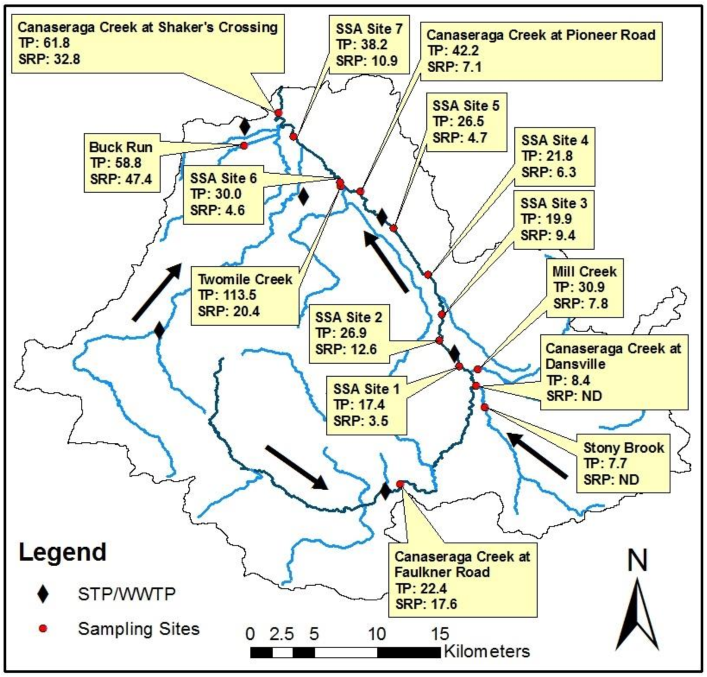


Figure 61. Total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) in Canaseraga Creek during segment analysis sampling, 28 September 2011. Arrows indicate flow direction.

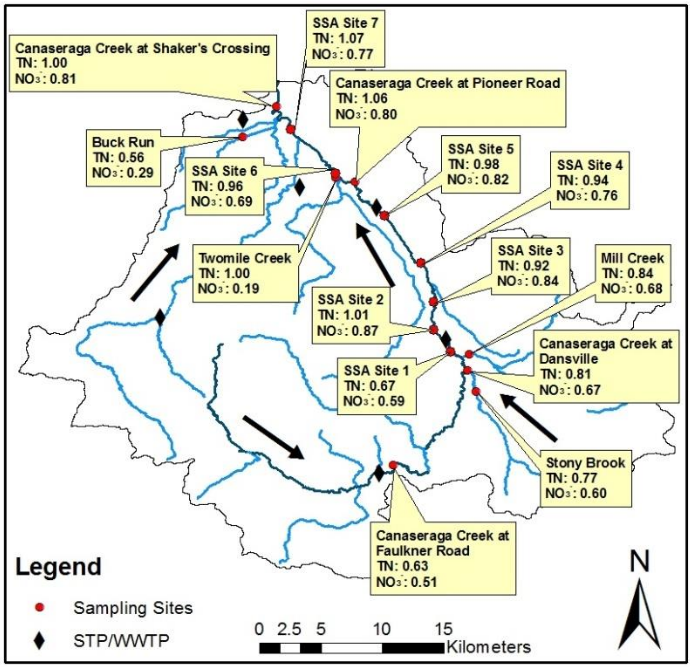


Figure 62. Total nitrogen (TN) (mg N/L) and nitrate (NO_3^-) (mg N/L) in Canaseraga Creek during segment analysis sampling, 28 September 2011. Arrows indicate flow direction.

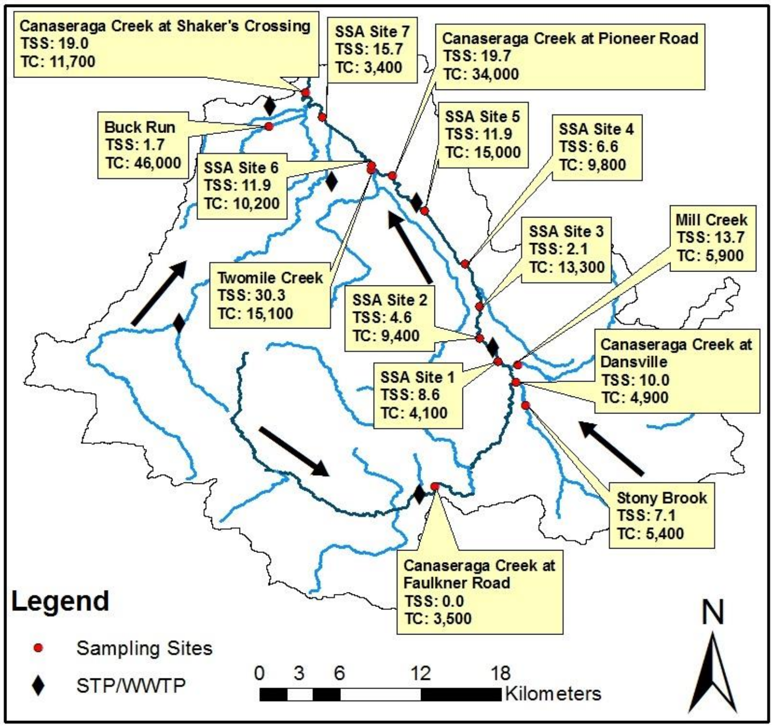


Figure 63. Total suspended solids (TSS) (mg/L) and total coliform bacterial (TC) (CFU/100 mL) in Canaseraga Creek during segment analysis sampling, 28 September 2011. Arrows indicate flow direction.

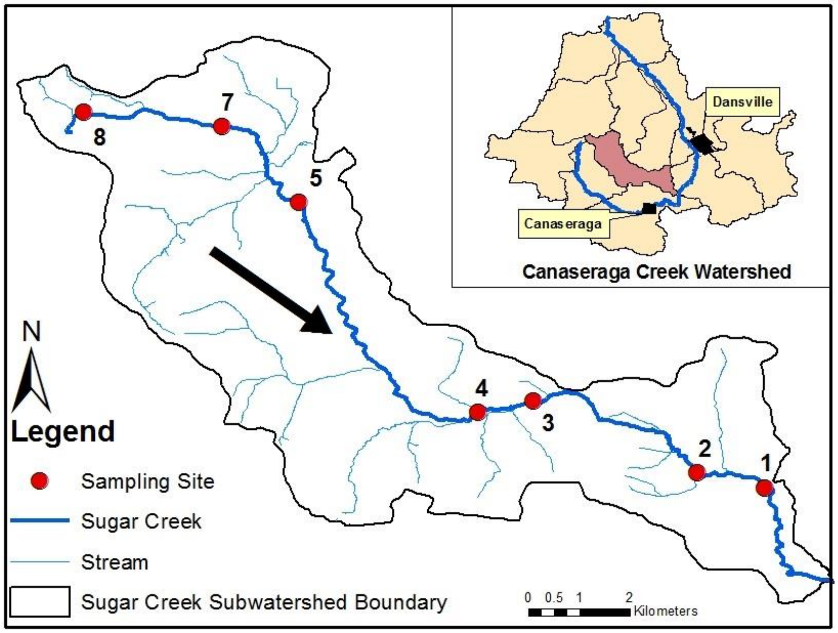


Figure 64. Inset map of the Sugar Creek subwatershed between the Villages of Canaseraga and Dansville. Larger map shows locations of segment analysis sites in Sugar Creek subwatershed, 5 October 2011. Arrow indicates flow direction.

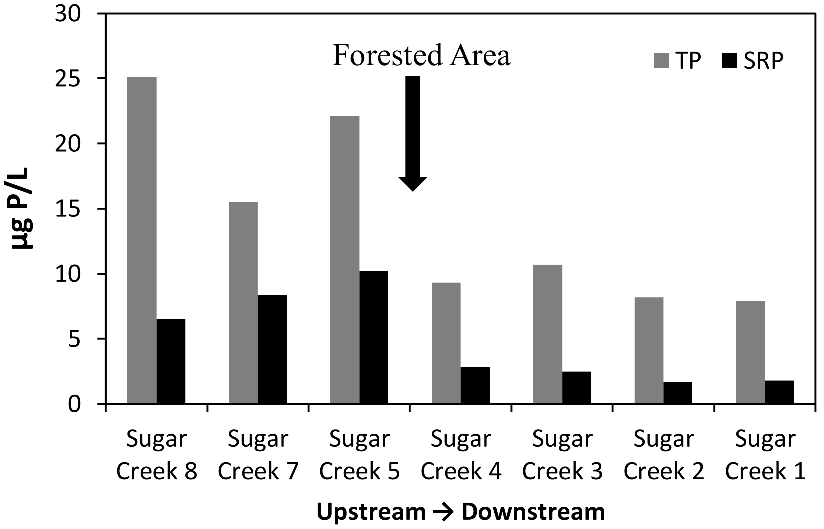


Figure 65. Total phosphorus (TP) (µg P/L) and soluble reactive phosphorus (SRP) (µg P/L) in Sugar Creek, 5 October 2011.

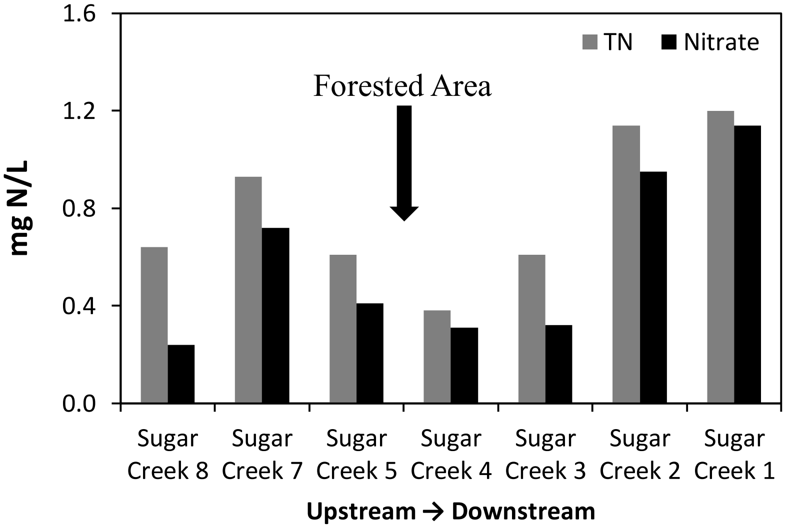


Figure 66. Total nitrogen (TN) (mg N/L) and nitrate (mg N/L) in Sugar Creek, 5 October 2011.

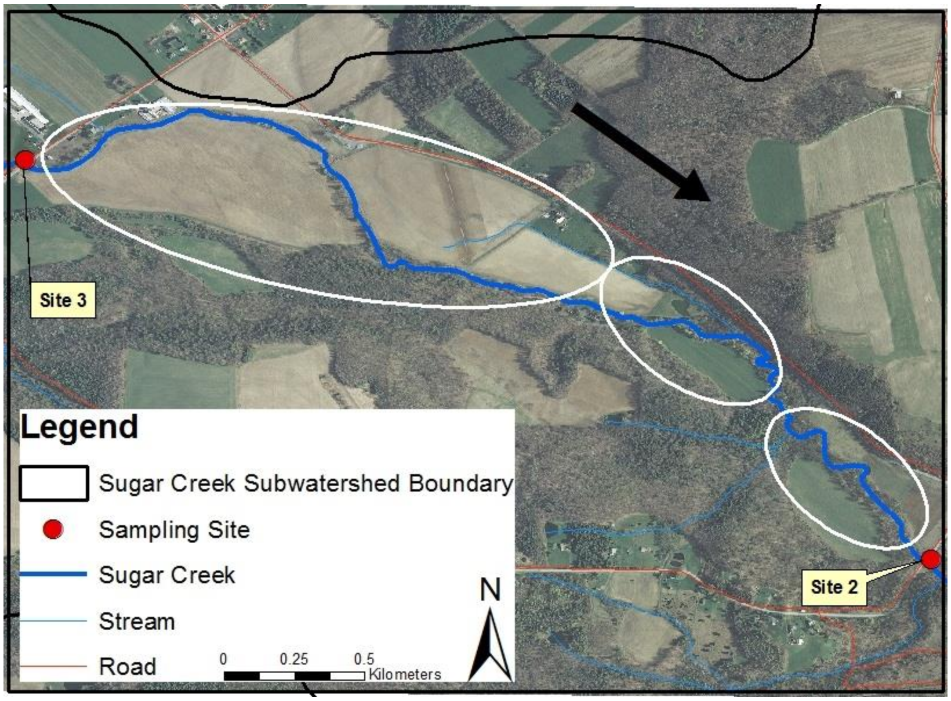


Figure 67. Orthoimagery between sites 3 and 2 from Sugar Creek segment analysis, 5 October 2011. White circles highlight agricultural fields (corn, soybean, and hay).

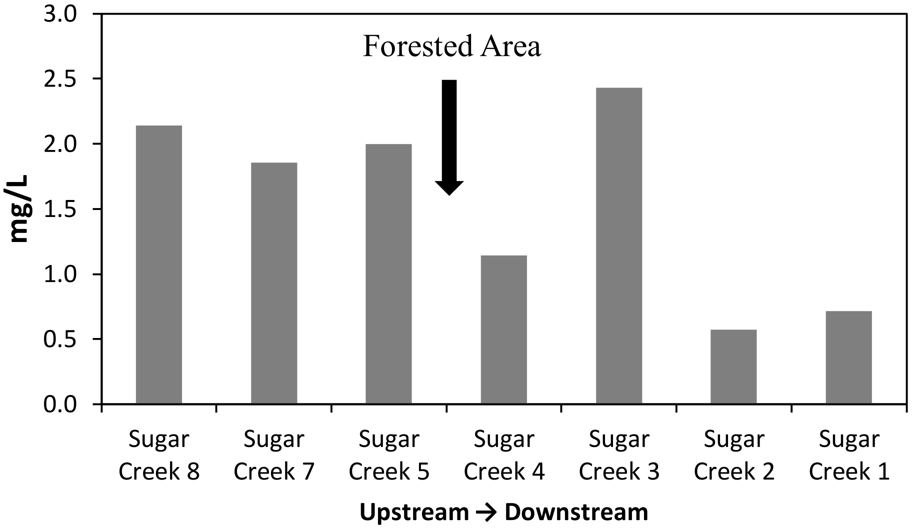


Figure 68. Total suspended solids (TSS) (mg/L) in Sugar Creek, 5 October 2011.

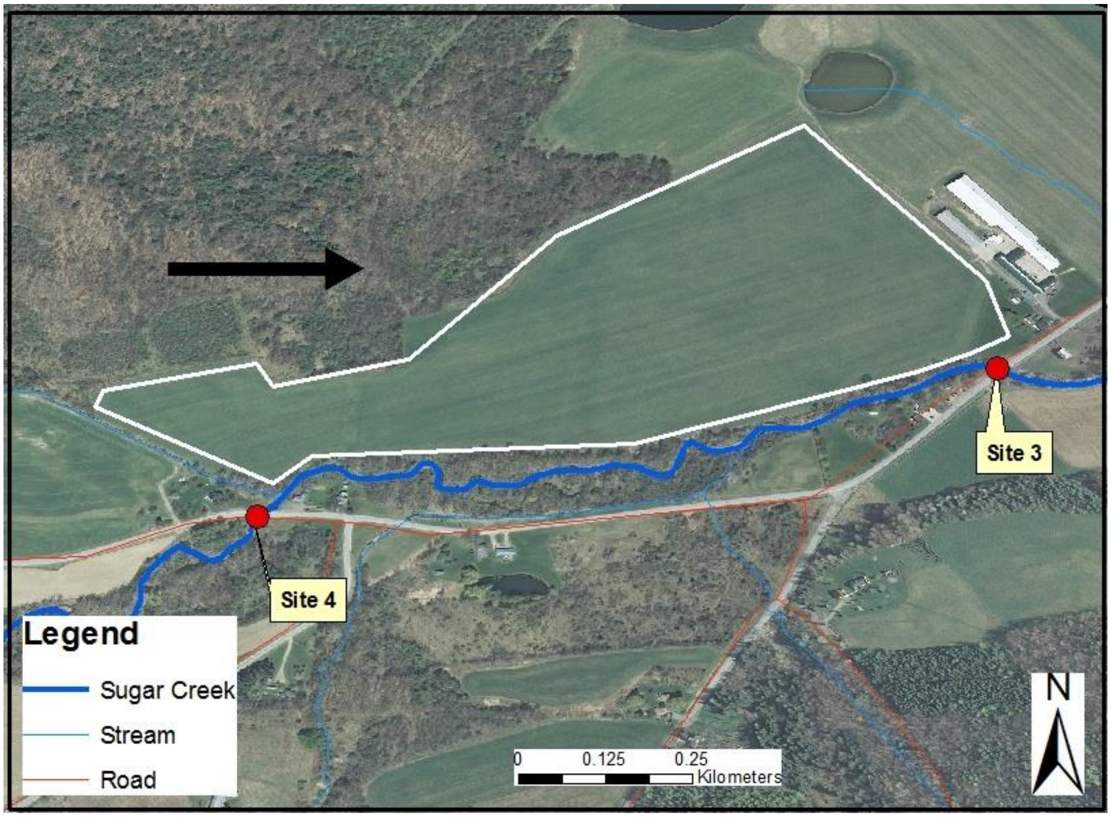


Figure 69. Orthoimagery between sites 4 and 3 from Sugar Creek segment analysis, 5 October 2011. The broad green hay field (white outline) situated close to the northern border is a suspected TSS source. Arrow indicates flow direction.

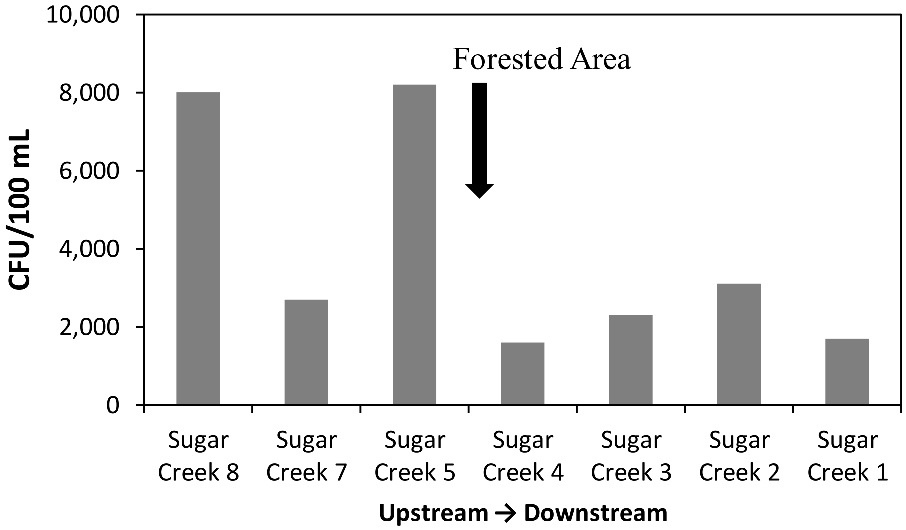


Figure 70. Total coliform bacteria (CFU/100 mL) in Sugar Creek, 5 October 2011.

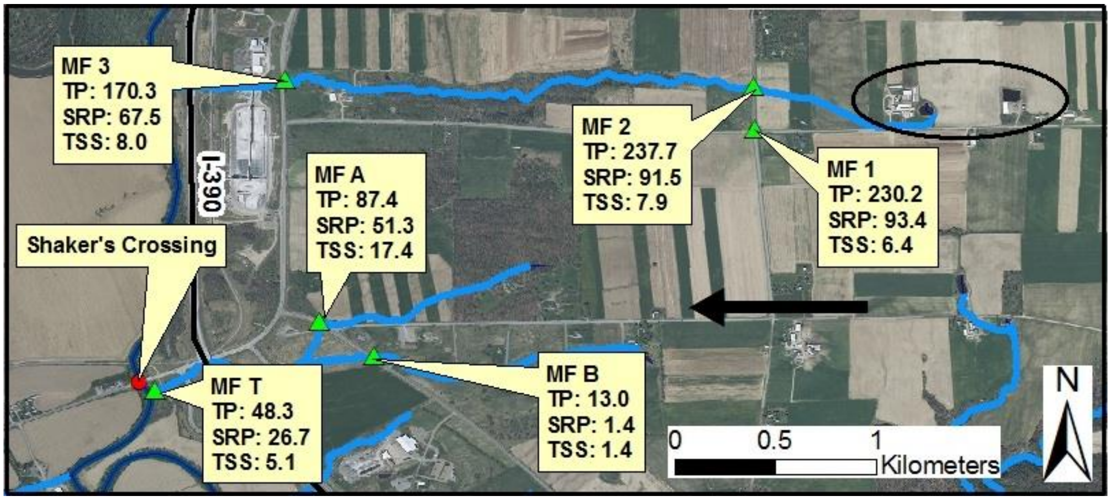


Figure 71. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) in µg P/L and total suspended solids (TSS) in mg/L on 7 December 2011 near Merrimac Farms (black circle). Arrow indicates flow direction.

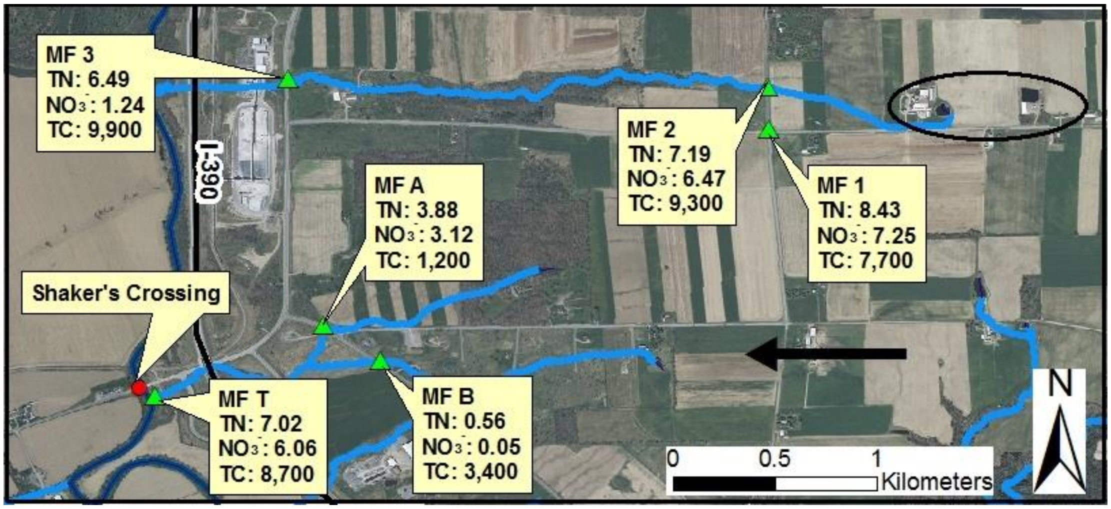


Figure 72. Concentrations of total nitrogen (TN) (mg N/L), nitrate (NO_3^-) (mg N/L) and total coliform bacteria (TC) (CFU/100 mL) on 7 December 2011 near Merrimac Farms (black circle). Arrow indicates flow direction.

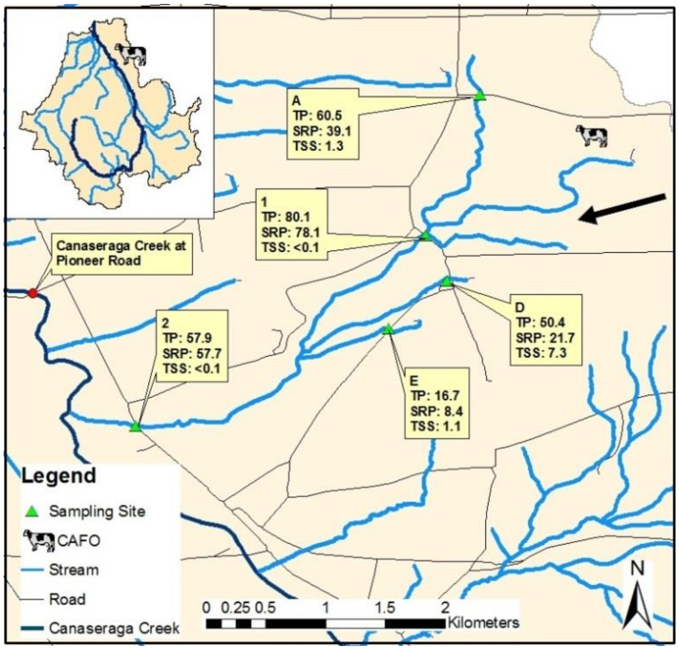


Figure 73. Inset map of Canaseraga Creek watershed with symbol depicting location of Edgewood Farms. Detail map showing stream network, concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) in µg P/L and total suspended solids (TSS) in mg/L on 26 October, 2011 near Edgewood Farms. Arrow indicates flow direction.

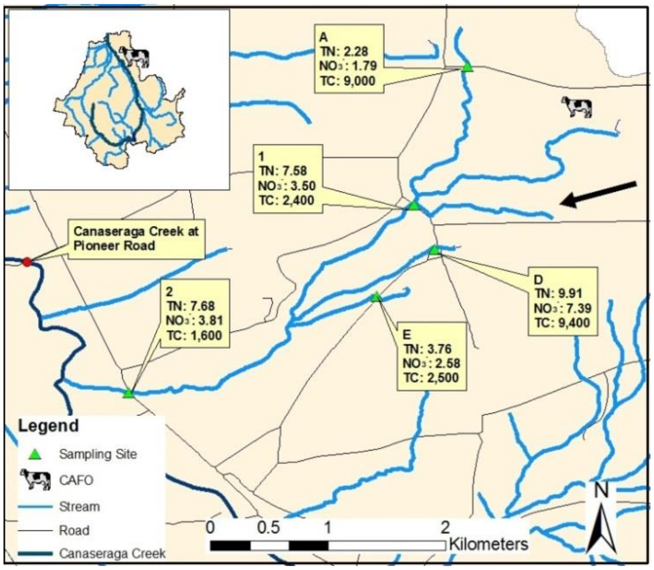


Figure 74. Inset map of Canaseraga Creek watershed with symbol depicting location of Edgewood Farms. Detail map showing stream network and concentrations of total nitrogen (TN) (mg N/L), nitrate (NO_3^-) (mg N/L) and total coliform bacteria (TC) (CFU/100 mL) on 26 October 2011 near Edgewood Farms. Arrow indicates flow direction.

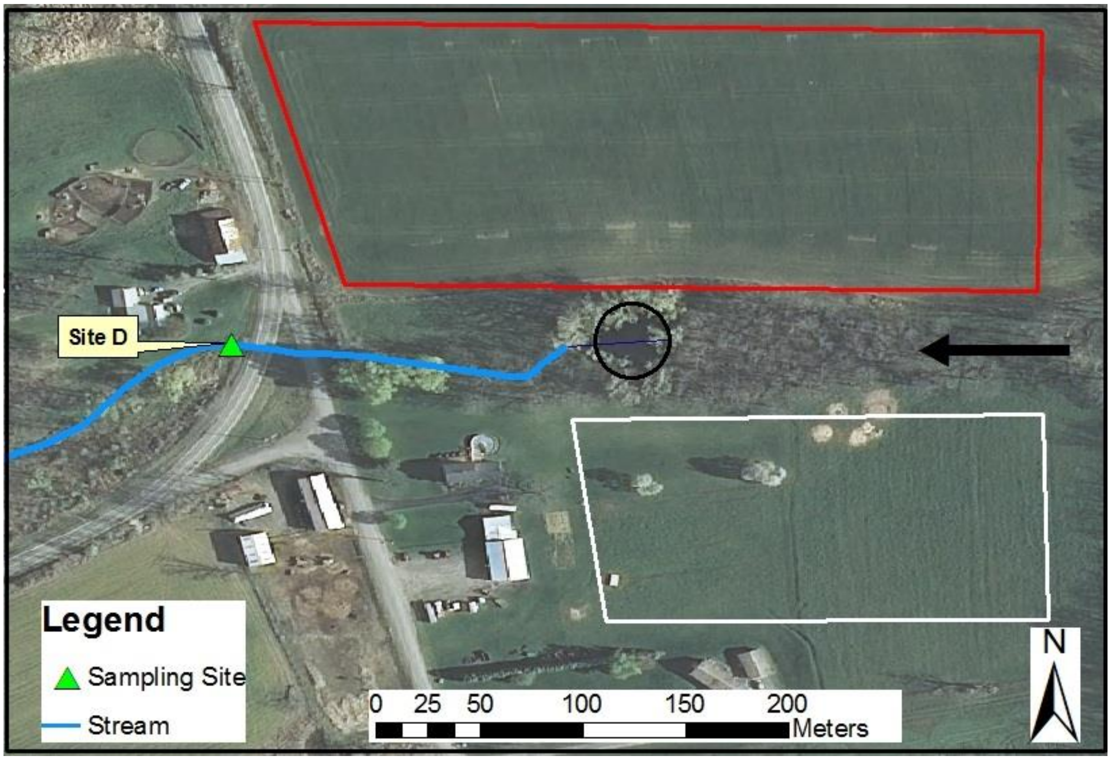


Figure 75. Orthoimage of the area upstream from Site D during segment analysis of Edgewood Farms on 26 October 2011. The orthoimage shows the streams origin in a small pond (black circle), which is bordered by a soybean field to the north (red box) and a residence with a large grass/hay field (white box) to the south. Arrow indicates flow direction.

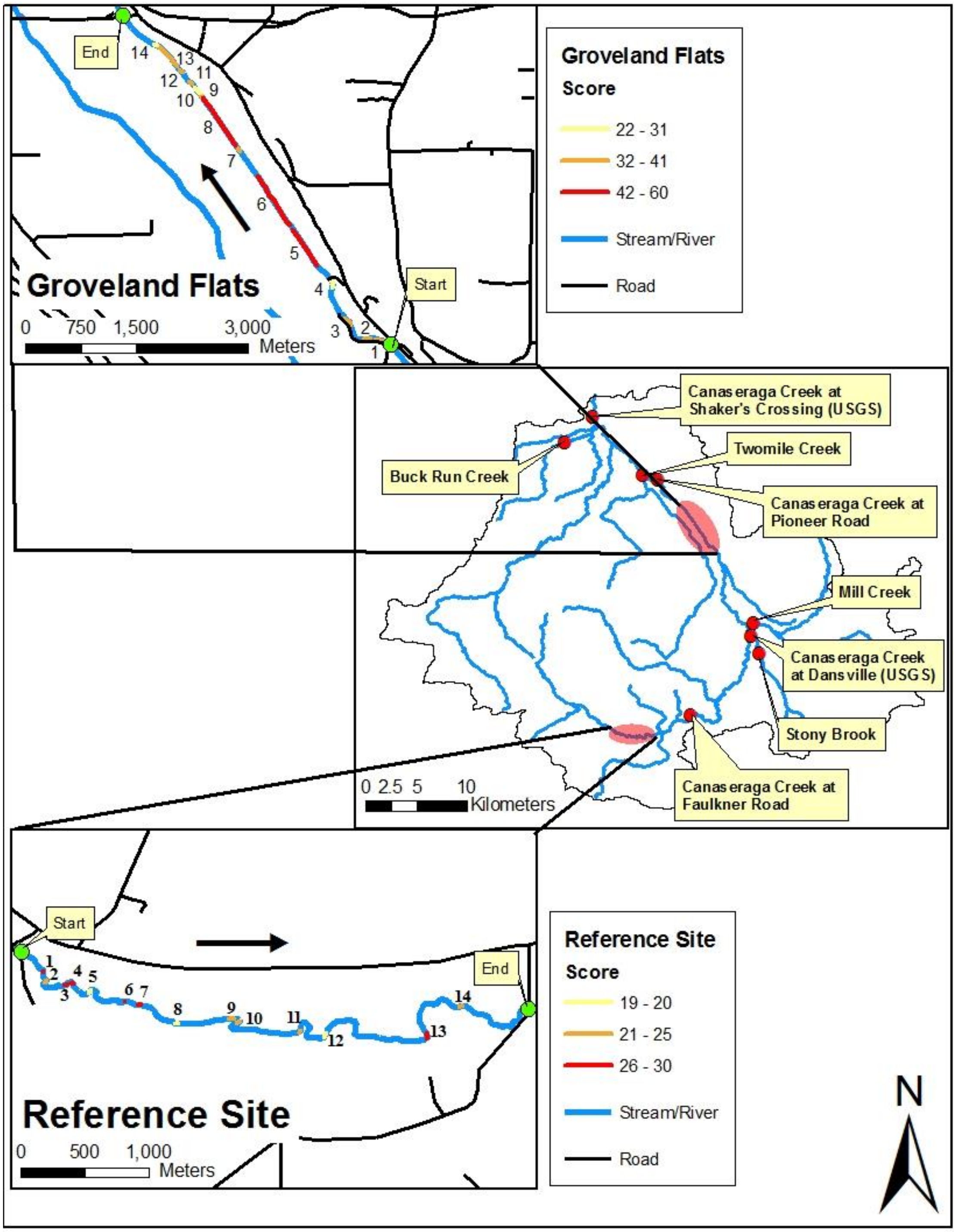


Figure 76. Canaseraga Creek watershed with highlighted regions showing locations of erosion inventory segments. Inset maps depict locations of stream bank erosion inventory sites at the Groveland Flats (top) and the reference site (bottom) upstream from Faulkner Road routine monitoring site. Maps are labeled with site number, and arrows indicate flow direction. Higher scores (red) indicate more severe erosion.

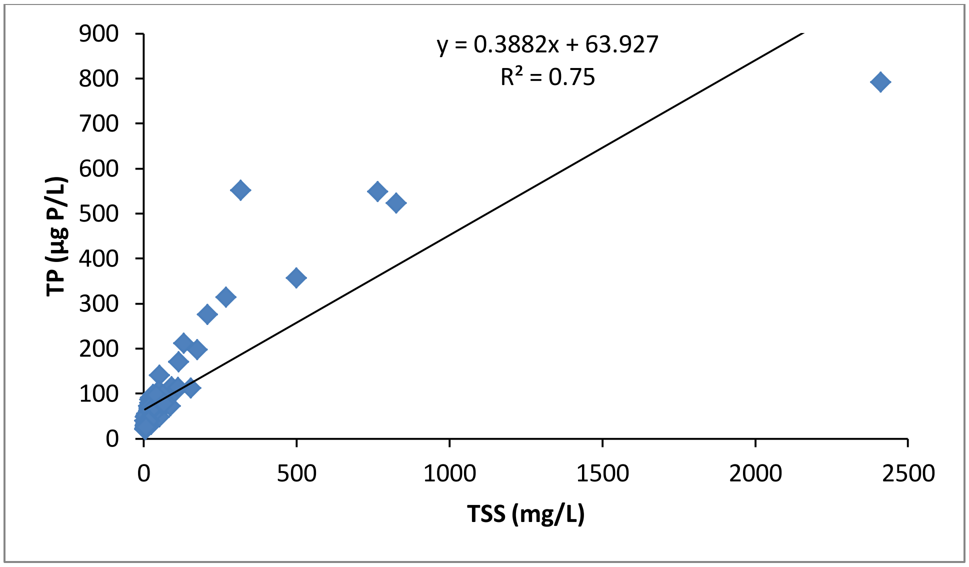


Figure 77. Regression of weekly observed water chemistry samples with concentration of total phosphorus (TP) (µg P/L) versus total suspended solids (TSS) (mg/L) at the Shaker's Crossing USGS site in the Canaseraga Creek watershed, 3 August 2010 to 14 February 2012 (n=77).

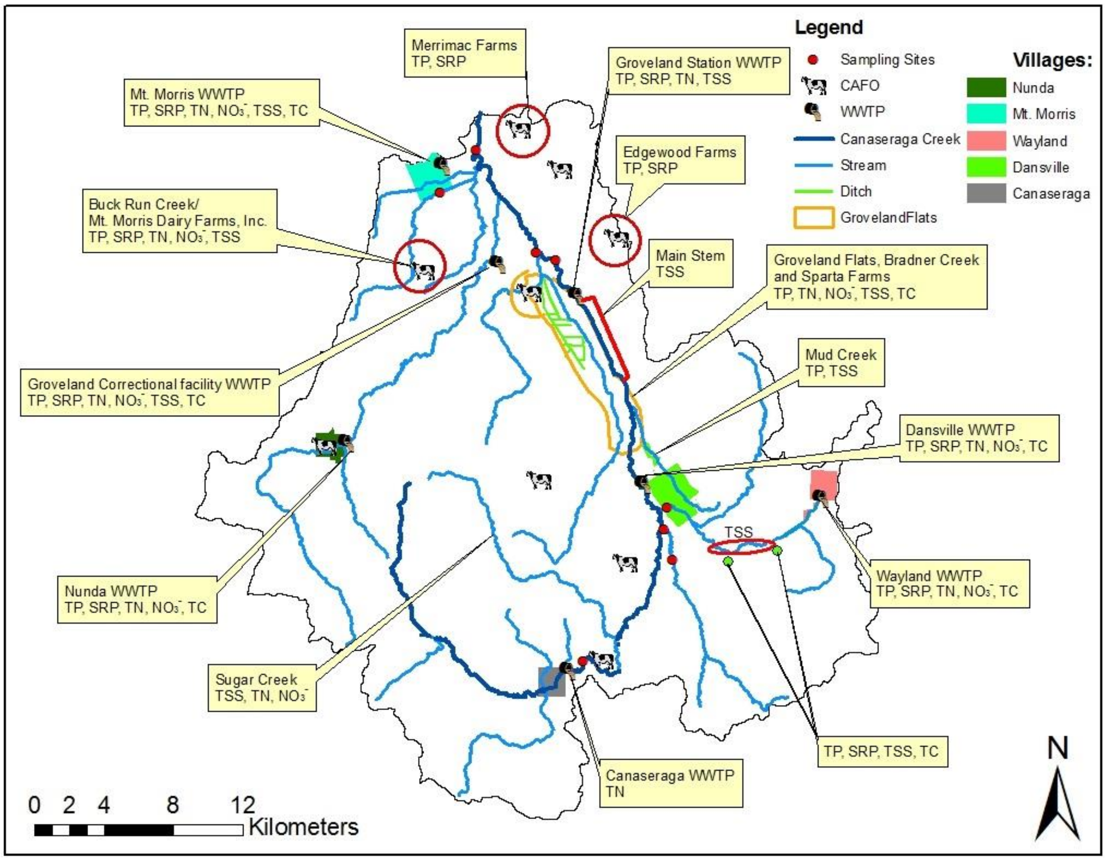


Figure 78. Summary map of critical source areas within the Canaseraga Creek watershed. TP = total phosphorus, SRP = soluble reactive phosphorus, TN = total nitrogen, NO_3^- = nitrate, TSS = total suspended solids, TC = total coliform bacteria. CAFO = concentrated animal feeding operation. WWTP = wastewater treatment plant.

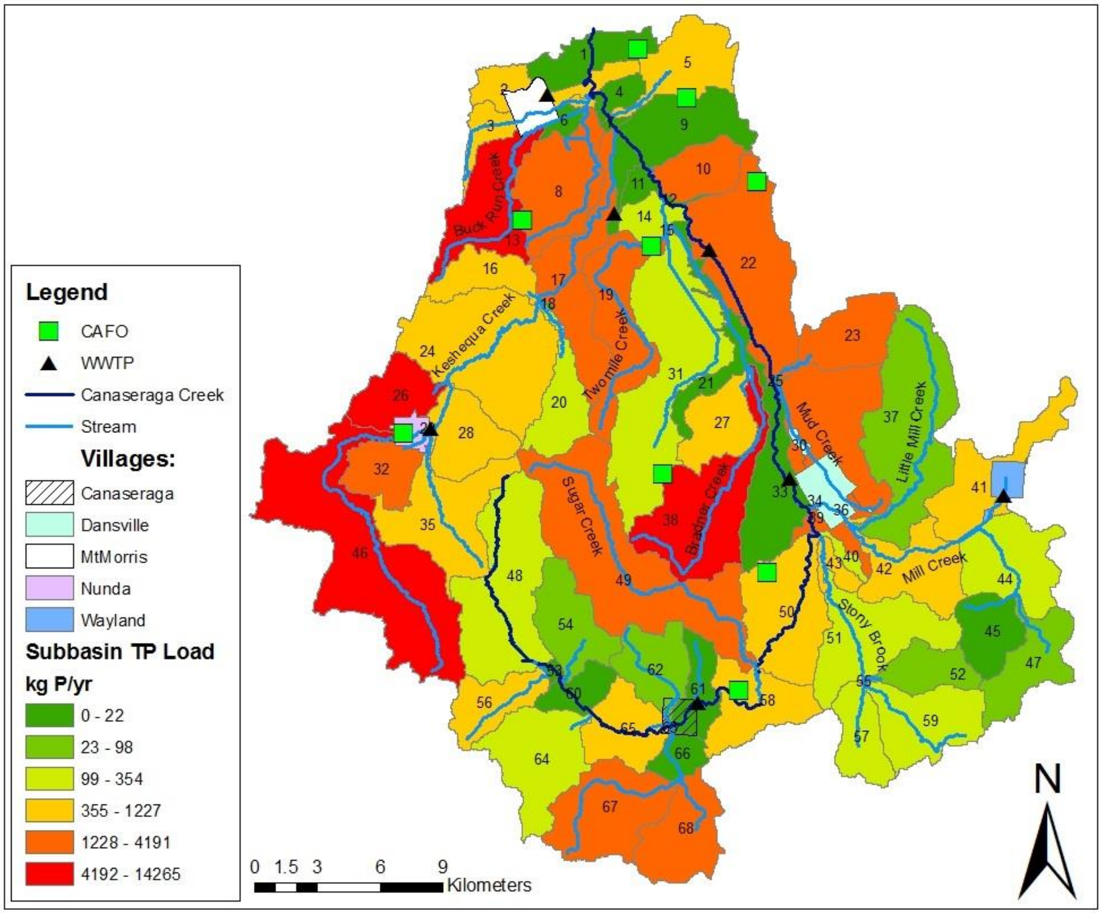


Figure 79. Annual subbasin total phosphorus (TP) loads (kg P/yr) derived from the CCSWAT model. Green areas indicate low TP loss, while red areas indicate high TP loss. CAFO = concentrated animal feeding operation, WWTP = wastewater treatment plant.

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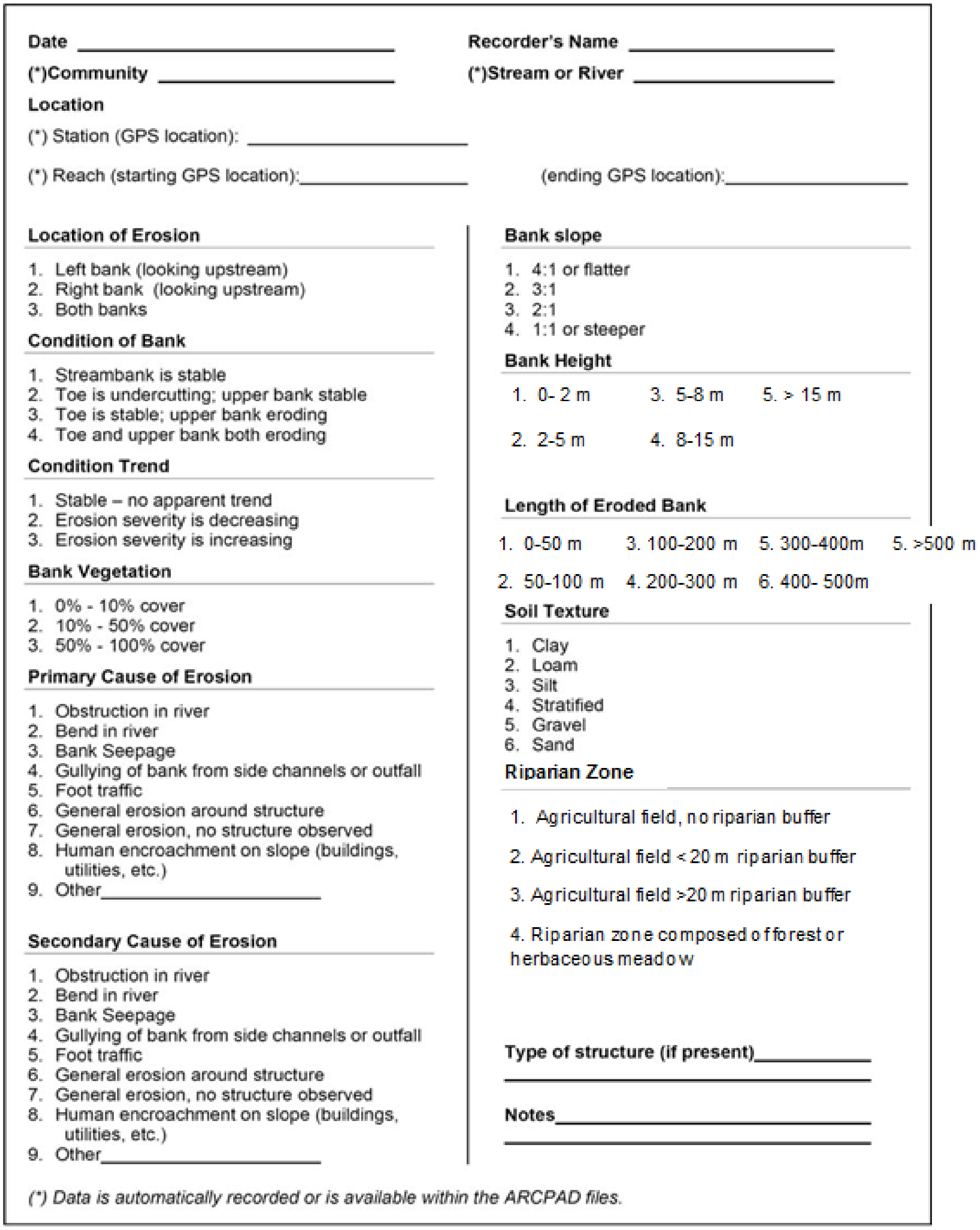
Appendices

Appendix A. Stream bank erosion checklist used to quantify erodible areas in Canaseraga 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)____________________

____

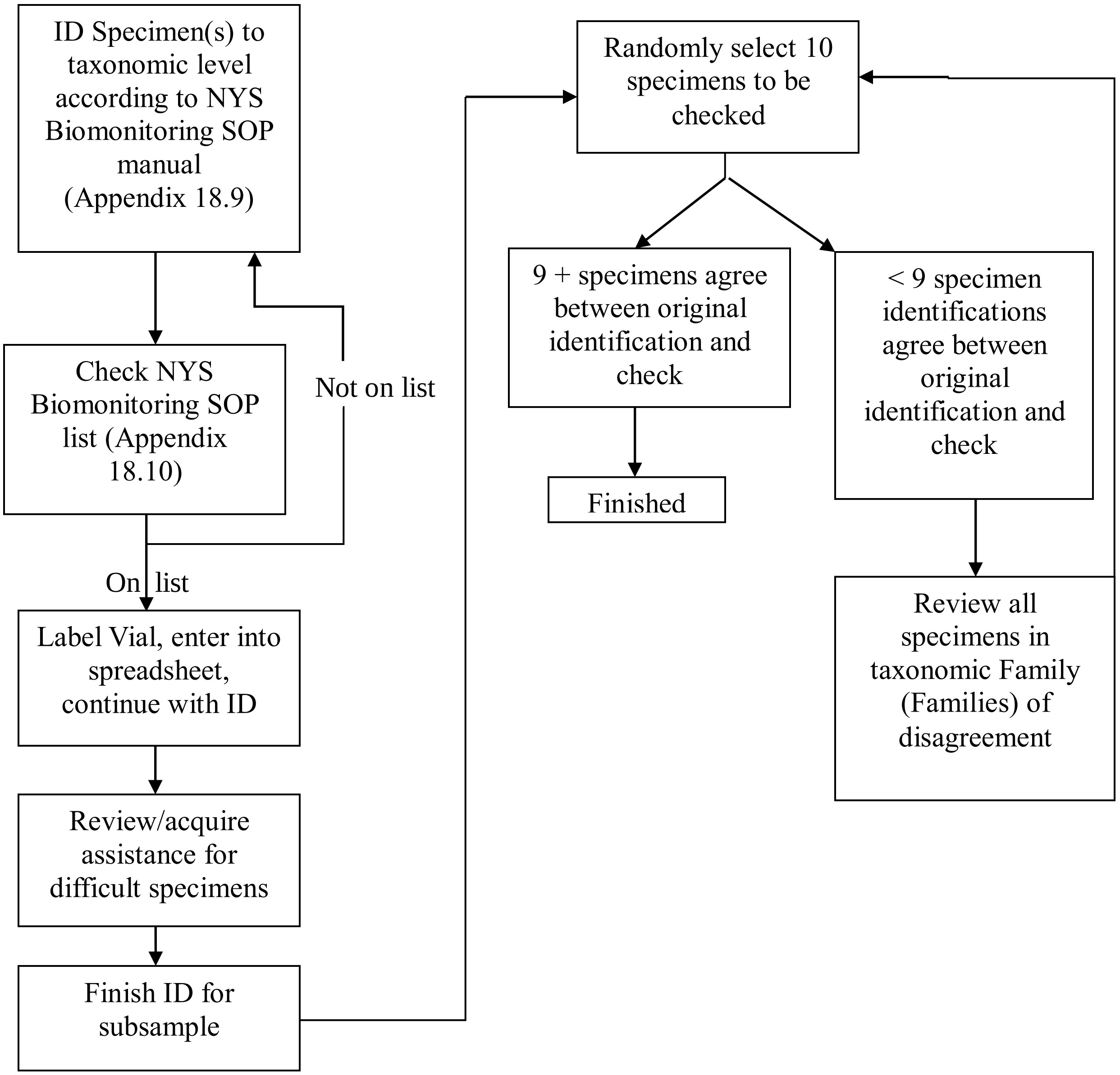
Notes____________________

____

(*) 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. Quality control procedures for macroinvertebrate samples.



Appendix C. Comprehensive list of parameters used in the Canaseraga Creek SWAT model organized by input table. The parameter name and description are provided as well as value entered. If one value is shown, then that value was applied to the whole model. If multiple values are shown, that parameter was changed for specific locations. A= Dansville main stem segment, subbasins 40,43,48-50,54,56,58,60-68, B= Stony Brook tributary site, subbasins 51, 52, 55, 57, 59, C= Mill Creek tributary site, subbasins 36, 37, 41, 42, 44, 45, 47, D= Twomile Creek tributary site, subbasins 14, 15, 19, 21, 27, 31, 38, E= Buck Run Creek tributary site, subbasin 13, F= Shaker’s Crossing main stem outlet site, subbains 1-12, 16-18, 20, 22-26, 28-30, 32-35, 39, 46.

<table>
<tr><th colspan="8">Canaseraga Creek SWAT Calibration Parameters by Input Table</th></tr>
<tr><th colspan="8">Soils (.sol)</th></tr>
<tr><td>Parameter</td><td>Description</td><td colspan="6">Value</td></tr>
<tr><td></td><td></td><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td></tr>
<tr><td>CN2</td><td>SCS Curve Number</td><td colspan="6">-20%</td></tr>
<tr><td>All Parameters</td><td>Soil Type Specific Parameters</td><td colspan="6">Default</td></tr>
<tr><td>SOL_AWC</td><td>Soil Antecedent Water Content</td><td colspan="6">-30%</td></tr>
<tr><th colspan="8">Subbasin (.sub)</th></tr>
<tr><td>Parameter</td><td>Description</td><td colspan="6">Value</td></tr>
<tr><td></td><td></td><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td></tr>
<tr><td>CH_N1</td><td>Mannings 'n' Value for the tributary channels</td><td>0.014</td><td>0.014</td><td>0.014</td><td>0.014</td><td>0.012</td><td>0.014</td></tr>
<tr><td>CH_K1</td><td>Effective Hydraulic Conductivity in tributary channels</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.5</td><td>2.5</td><td>0.5</td></tr>
<tr><td>All Parameters</td><td>Subbasin Specific Parameters</td><td colspan="6">Default</td></tr>
<tr><th colspan="8">HRU (.hru)</th></tr>
<tr><td>Parameter</td><td>Description</td><td colspan="6">Value</td></tr>
<tr><td></td><td></td><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td></tr>
<tr><td>RSDIN</td><td>Initial Residue Cover</td><td colspan="6">0</td></tr>
<tr><td>ERORGN</td><td>Nitrogen Enrichment Ratio for Loading with Sediment</td><td colspan="6">0</td></tr>
<tr><td>ERORGP</td><td>Phosphorus Enrichment Ratio for Loading with Sediment</td><td>1.15</td><td>0.04</td><td>0.002</td><td>2.1</td><td>1</td><td>2.4</td></tr>
<tr><td>POT_FR</td><td>Fraction of HRU Area that Drains Into Pothole</td><td colspan="6">0</td></tr>
</table>

FLD_FR	Fraction of HRU Area that Drains into Floodplain	0					
EVPOT	Pothole Evaporation Coefficient	0.5					
DIS_Stream (m)	Average Distance to the Stream	Default					
ESCO	Soil Evaporation Compensation Factor			0			
EPCO	Plant Evaporation Compensation Factor			0			
OVN	Manning's n value for overland flow	0.14	0.14	0.14	0.14	0.01	0.14
CANMX	Maximum Canopy Storage			0			
All Other	HRU Specific Parameters	Default					
Groundwater (.gw)							
Parameter	*Description*	*Value*					
		A	B	C	D	E	F
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)	0					
ALPHA_BF	Baseflow Alpha Factor (days)	0.2					
GWQMIN	Threshold Depth of Water in Shallow Aquifer Required for Return Flow	0					
GW_REVAP	Groundwater 'revap' Coefficient	0.02					
REVAPMN	Threshold Depth of Water in Shallow Aquifer Required for Percolation	30					
RCHRG_DP	Deep Aquifer Percolation Fraction	0					
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	0.02	0.02	0.003	0.02	0.02	0.035
HLIFE_NGW	Halflife of Nitrogen in Water	0					
LAT_ORGN	Organic Nitrogen in Lateral Flow	0					
GWLATP	Organic P in Baseflow	0					
Routing (.rte)							

		Value					
Parameter	*Description*	A	B	C	D	E	F
CH_N2	Mannings 'n' Value for the Main Channel	0.077	0.03	0.054	0.025	0.052	0.043
CH_K2	Effective Hydraulic Conductivity in Main Channel	38	150	0	15	0	350
CH_COV1	Channel Erodibility Factor	0	0	0	0.55	0.6	0.6
CH_COV2	Channel Cover Factor	0	0	0	0.55	0.6	0.6
ALPHA_BNK	Baseflow Alpha Factor for Bank Storage	0	0	0	0.12	1	1
CN_OPCO	Organic Phosphorus Concentration in the Channel	0	0	0	0.01	0.03	0.01
CH_BNK_BD	Bulk Density of Channel Bank Sediment	0	0	0	1.4	1.1	1.7
CH_BED_BD	Bulk Density of Channel Bed Sediment	0	0	0	1.4	1.1	1.7
CH_BNK_KD	Erodability of Channel Bank Sediment by Jet Test	0	0	0	1.4	0.001	0.001
CH_BED_KD	Erodability of Channel Bed Sediment by Jet Test	0	0	0	1.4	0.001	0.001
CH_BNK_D50	D50 Median Particle Size of Channel Bank Sediment	0	0	0	200	2000	500
CH_BED_D50	D50 Median Particle Size of Channel Bed Sediment	0	0	0	200	2000	500
CH_BNK_TC	Critical Stress Range for Bank Erosion	0	0	0	100	0	10
CH_BED_TC	Critical Stress Range for Bed Erosion	0	0	0	100	0	10
CH_EQN	Sediment Routing Method	0	1	1	3	2	2
All Other	Other Sediment Parameters	Default					
Management (.mgt)							
Parameter	*Description*	*Value*					
BIOMIX	Biological Mixing	0.2					
CN2	Curve Number Factor	Default					
USLE_P	USLE Eqn. Cropping Practices Factor	1	1	1	1	1	0.8
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	10

Pond/Wetland (pnd.)

		Value					
Parameter	*Description*	A	B	C	D	E	F
PND_FR/ WET_FR	Fraction Of Subbasin Area that Drains Into Ponds			0.8	0.9		
PND_PSA/ WET_NSA	Surafec Area of Ponds when Filled to Principal Spillway			19	348		
PND_PVOL/ WET_NVOL	Volume of Water Needed to Fill Ponds to the Principal Spillway			28.5	100		
PND_ESA/ WET_MXSA	Surface Area of Ponds when Filled to Emergency Spillway			19	200		
PND_EVOL/ WET_MXVOL	Volume of Water Stored in Ponds when Filled to the Emergency Spillway			28.5	200		
PND_VOL/ WET_VOL	Initial Volume of Water in Ponds			28.5	100		
PND_SED/ WET_SED	Initial Sediment Concentration in Pond Water			10	44		
PND_NSED/ WET_NSED	Normal Sediment Concentration in Pond Water			10	44		
PND_K/WET_K	Hydraulic Conductivity Through Bottom of Ponds			0.5	0		
PSETL1/ PSETLW1	Phosphorus Settling Rate in Ponds for Months IPND1 through IPND2			15	15		
PSETL2/ PSETLW2	Phosphorus Settling Rate in Ponds for Months Other than IPND1 through IPND2			15	15		
NSETL1/ NSETLW1	Nitrogen Settling Rate in Ponds for Months IPND1 through IPND2			5.5	0		

NSETL2/ NSETLW2	Nitrogen Settling Rate in Ponds for Months Other than IPND1 through IPND2			5.5	0		
CNLA/CNLAW	Chlorophyll a Production Coefficient for Ponds			1	0		
SECCI/SECCIW	Water Clarity Coefficient for Ponds			1	0		
PND_NO3/ WET_NO3	Initial Concentration of NO3-N in Pond			0	0		
PND_SOLP/ WET_SOLP	Initial Concentration of Soluble P in Pond			0.03	0.02		
PND_ORGN/ WET_ORGN	Initial Concentration of Organic N in Pond			0	0		
PND_ORGP/ WET_ORGP	Initial Concentration of Organic P in Pond			0.018	0.15		
PNDEVCOEFF/ WETEVCOEFF	Pond Evaporation Coefficient			0	0		
PND_D50	Median Particle Diameter of Sediment (Ponds only)			20	-		
IPND1	Beginning Month of Mid-Year Nutrient Settling Season			1	1		
IPND2	Ending Month of Mid-Year Nutrient Settling Season			1	1		
IFLOD1	Beginning Month of Non-Flood Season			0	0		
IFLOD2	Ending Month of Non-Flood Season			0	0		
NDTARG	Number of Days Needed to Reach Target Storage from Current Pond Storage			0	0		
Stream Water Quality (swq.)							
Parameter	*Description*	*Value*					
		A	B	C	D	E	F
RS1	Local Algal Settling Rate in the Reach at 20C	1					
RS2	Benthic Sediment Source Rate for Dissolved P	0.05	0.05	0.001	0.05	0.05	0.05
RS3	Benthic Source Rate for NH4-N in the Reach at 20C	0.5					
RS4	Rate Coefficient for Organic N Settling in the Reach at 20C	0.05					
RS5	Organic P Settling Rate in the Reach	0.05	0.05	0.1	0.05	0.05	0.05
RS6	Rate Coefficient for Settling of Arbitrary Non-conservative Constituent in the Reach at 20C	2.5					

RS7	Benthic Source Rate for Arbitrary Non-conservative Constituent in the Reach at 20C	2.5					
RK1	Carbonaceous Biological Oxygen Demand Deoxygenation Rate Coefficient in the Reach at 20C	1.71					
RK2	Oxygen Rearation Rate in Accordance with Fician Diffusion in the Reach at 20C	50					
RK3	Rate of Loss of Carbonaceous Biological Oxygen Demand Due to Settling in the Reach at 20C	0.36					
RK4	Benthic Oxygen Demand Rate in the Reach at 20C	2					
RK5	Coliform Die-off Rate in the Reach at 20C	2					
RK6	Decay Rate for Arbitrary Non-conservative Constituent in the Reach at 20C	1.71					
BC1	Rate Constant for Biological Oxidation of NH4 to NO2 in the Reach at 20C in Well-aerated Conditions	0.55					
BC2	Rate Constant for Biological Oxidation of NO2 to NO3 in the Reach at 20C in Well-aerated Conditions	1.1					
BC3	Rate Constant for Hydrolysis of Organic N to NH4 in the Reach at 20C	0.21					
BC4	Rate Constant for Mineralization of Organic P to Dissolved P	0.55	0.35	0.7	0.35	0.35	0.35
Basin (.bsn)							
Parameter	*Description*	*Value*					
SFTMP/SMTMP	Snow Fall Temperature	1 / 0.5					
SMFMX	Snow Melt Factor Rate Maximum	3.5					
SMFMN	Snow Melt Factor Rate Minimum	5					
TIMP	Snow Pack Temperature Lag Factor	1.0					
SNOCOVMX	Minimum Snow Water Content of 100% Snow Cover	21					
SNO50COV	Fraction of Snow Volume That Corresponds To 50% Snow Cover	0.56					
PET	Potential Evapotranspiration Method	Hargreaves					
ESCO	Soil Evaporation Compensation Factor	1					
EPCO	Plant Evaporation Compensation Factor	0.5					
EVLAI	Leaf Area Index at Which No Evaporation Occurs from Water Surface	3					
FFCB	Initial Soil Water Storage Expressed as a Fraction of 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	Crack Flow Code	Inactive
SURLAG	Surface Runoff Lag Factor	4
ADJ_PKR	Peak Rate Adjustment Factor for Sediment in Tributary Channels	0
TB_ADJ	Adjustment Variable for Hydrograph Basetime	0
PRF	Peak Rate Adjustment Factor for Sediment in the Main Channel	0.8
SPCON	Factor for Maximum Amount of Sediment to be Reentrained	0.0001
SPEXP	Exponent Parameter for Calculating Sediment Reentrained	1
MSK_COV1	Calibration Coefficient to Control Impact of Storage Time Constant for Base Flow	0
MSK_CO2	Calibration Coefficient to Control Impact of Storage Time Constant for Low Flow	3.5
MSK_X	Weighing Factor Controls Importance of Inflow and Outflow for Reach Storage	0.2
Channel Degradation	Degradation of the Main Channel Sediment	Inactive
TRNSRCH	Fraction of Transmission Losses from Main Channel that Enter Deep Aquifer	0
EVRCH	Reach Evaporation Adjustment Factor	1
EROS_SPL	The splash erosion coefficient.	1
RILL_MULT	Multiplier to USLE_K for soil susceptible to rill erosion	0.7
EROS_EXPO	Exponent coefficient for the overland flow erosion equation	1.2
SUBDCHSED	Sub-Daily Channel Sediment Erosion Factor	0
C_FACTOR	Universal Soil Loss Equation (USLE) Cover (C) factor	0.03
CH_D50	Median particle diameter of channel bed (mm)	50
RCN	Concentration of Nitrogen in Rainfall	1
CMN	Rate Factor for Humus Mineralization of Active Organic Nutrients (N and P)	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	20
NPERCO	Nitrogen Percolation Coefficient	0.2

PPERCO	Phosphorus Percolation Coefficient	10
PHOS_KD	Phosphorus Soil Partitioning Coefficient	175
PSP	Phosphorus Availability Index	0.1
RSDCO	Residue Decomposition Coefficient	0.05
PERCOP	Pesticide Percolation Coefficient	0.5
CH_OPCO_BSN	Channel Organic Phosphorus Concentration in Basin	0
BC4_BSN	Rate Constant for Hydrolysis of Organic Nitrogen to Ammonia	0
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 Per Unit of Algal Photosynthesis	1.6
AI4	Rate of Oxygen Uptake Per Unit of Algal Respiration	2
AI5	Rate of Oxygen Uptake Per Unit 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 Computed in the Temperature Heat Balance that is Photosynthetically Free	0.3
K_L	Half-saturation Coefficient for Light	0.75
K_N	Michaelis-Menton Half-saturation Constant for Nitrogen	0.02
K_P	Michaelis-Menton Half-saturation Constant for Phosphorus	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
CHLA_SUBCO	Regional Adjustment on Sub Chl-a Loading	1

Appendix D. Additional P load allocation data for the CCSWAT model.

Extensive field chemistry data at Shaker's Crossing and Dansville USGS sites allowed for an 18 month calibration period (August 2010 – January 2012) for TSS and TP. However, the sampling period for all other routine monitoring sites was February 2011 – January 2012, and the phosphorus allocations must be in terms of kg/yr. In order to establish a robust calibration for the entire 18 month period, another allocation table was produced for the first 12 months (August 2010 – July 2011) to compare to the sampling time period, which corresponds to the last 12 months of the calibration period (February 2011 – January 2012). The differences between the two time periods were minimal in terms of percent of total allocated load. The largest departures were in streambank erosion and groundwater, where the percentages of the total allocated load differed by 2.2% and 2.5%, respectively. The August 2010 – July 2011 time period allocated 6.7% (4,050 kg P/yr) to streambank erosion while the February 2011 – January 2012 time period allocated 4.5% (2,606 kg P/yr). For groundwater, the August 2010 – July 2011 time period allocated 15.3% (9,319 kg P/yr) of the total allocated load whereas the February 2011 – January 2012 time period allocated 17.8% (10,326 kg P/yr). The difference in allocated percentages between the two time periods for all other sources was less than 2.0%.

By comparing the output from two different time periods within the same calibration period, it was determined that the Canaseraga Creek SWAT model accurately predicts TP loading allocations for both time periods. Furthermore, it can be concluded that changes to the model for the whole 18 month calibration period will equally effect both time periods.

Land Use/Activity	**Current P load (kg/yr)**	**Percent of Total Allocated Load (%)**	**Method of Determination**
Ag Crops	22114	36.4	Subtraction
Tile Drains	5,031	8.3	Subtraction
Farm Animals	9,518	15.7	Subtraction
Stream Bank Erosion	4,050	6.7	Subtraction
Wetlands	0.6	0.0	HRU Table
Groundwater	9,319	15.3	HRU Table
Forest	820	1.3	HRU Table
Urban Runoff	278	0.5	Subtraction
Wastewater Treatment Plants	5,750	9.5	Subtraction
Septic Systems	3,889	6.4	Subtraction
Sum of Allocated Loads	60,768	100.0	
Total Predicted Load (From SWAT)	62,053		
Allocation Error	-1,284		

Appendix E. Table and pictures of selected most severe erosion sites along Canaseraga Creek at an eroded segment (Groveland Flats) and a non-eroded segment (Reference)

Table E1. Description of selected severely eroded sites in the Groveland Flats and Reference segments. Severely eroded sites have high erosion inventory scores, nearby agriculture, and little to no riparian buffer.

Reach Name/ Site Number	**Latitude**	**Longitude**	**Score**	**Length (m)**	**Primary Erosion Causes**	**Figure**
Groveland Flats						
5	42.63097	-77.7448	50	542	Steep banks, corn fields <20 m from stream	E1
6	42.63584	-77.74805	60	748	Steep banks, corn fields <20 m from stream	E2
7	42.64521	-77.75444	35	53	Steep banks, corn fields <20 m from stream	E3
8	42.64546	-77.75471	49	713	Steep banks, corn fields <20 m from stream	E4
9	42.65169	-77.7589	39	51	Steep banks, corn fields <20 m from stream	E5
12	42.65443	-77.76107	41	42	Steep banks, corn fields <20 m from stream	E6
Reference						
6	42.45602	-77.81673	30	7.5	Downstream obstruction, bend in stream, steep banks	E7

Figure E1. Groveland Flats site 5. Steep banks with thinly buffered (<20 m) corn fields on the left side.

Figure E2. Groveland Flats site 6. The steep banks along this reach permit a dense but thin (<20 m) riparian buffer between the stream and the adjacent corn fields.

Figure E3. Groveland Flats site 7. Weed growth covering steep eroded banks. A break in the thin (<20 m) riparian buffer is visible, which is preceded by a hay field.

Figure E4. Groveland Flats site 8. The corn fields on either side of the stream in this reach limit the riparian zone to a thin (<20 m) strip. Trees were observed to be in the process of falling into the stream due to bank erosion.

Figure E5. Groveland Flats site 9. Corn fields on either side of this site caused a restricted riparian buffer zone of <20 m. Trees were observed to be severely undercut by the stream, and streambank sediment was observed to be descending towards the stream.

Figure E6. Groveland Flats site 12. A bend in the otherwise straight channel was a source of erosion at this site, as well as the thinly buffered (<20 m) corn fields on either side of the stream.

Figure E7. Reference site 6. An obstruction downstream (to the right of the photograph, not visible) formed a pool which was the suspected source of erosion along this short segment. Tree roots were visible in this otherwise non-eroded reach, indicating that a possible eddy current is formed due to the upstream bend and the downstream obstruction. This site scored the highest (30) of all reference sites.