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Oatka Creek Water Quality Assessment: Identifying Point and Nonpoint Sources of Pollution with Application of the SWAT Model

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Oatka Creek Water Quality Assessment:
Identifying Point and Nonpoint Sources of Pollution
with Application of the SWAT Model

by

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

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Thesis Defense by:

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Oatka Creek Water Quality Assessment: Identifying Point and Nonpoint Sources of Pollution with Application of the SWAT Model

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Introduction

The Clean Water Act of 1972 was a turning point in waterway management in the United States. Since implementation, the ecological health of many lakes, streams, and watersheds has improved significantly (Keller and Cavallaro 2008). However, according to the 2002 Section 303(d) list of impaired waters of the Clean Water Act (CWA) in 2002 (Keller and Cavallaro 2008), 59,783 impairments in 34,225 water bodies still exist. A majority of the impairments fall under the following categories: excessive nutrients, sediment, metals, pathogens, and/or bacteria (Keller and Cavallaro 2008). The two most common pollutants in the United States caused by agriculture are excessive nutrients and sediment.

Overseen by the USEPA, New York State implements the CWA and Best Management Practices (BMPs) to watersheds with excessive impairments. If a water body has been listed as impaired, states are required under Section 303(d) of the CWA to develop a Total Maximum Daily Load (TMDL). A TMDL is the sum of all sources of pollution: nonpoint source (NPS), point source, and natural sources; a TMDL quantifies the pollutant loading capacity of a water body for a particular pollutant such as phosphorus, nitrate, and/or suspended solids (DeBarry 2004). The TMDL is developed through a mathematic model, such as the Soil and Water Assessment Tool (SWAT), BATHTUB, and the CE-QUAL-W2, which assesses the percentage of contribution of a pollutant from agriculture, industry, confined animal feeding operations (CAFOs), sewage treatment plants (WWTPs), state pollutant discharge elimination system (SPDES) sites, failing septic systems, and urban runoff.

Nonpoint and point sources cause the majority of water quality issues in the United States. A nonpoint source is not from a direct discharge point, but rather a diffuse source where the pollution originates from a hard to define area (DeBarry 2004). Nonpoint sources include farm field runoff, highway deicing, malfunctioning septic systems, storm water runoff, feedlot drainage, and construction site drainage (DeBarry 2004). Nonpoint sources of pollution constitute 76 percent of the pollution to lakes and 65 percent to rivers (Ribaudo and Young 1989). The key to managing for nonpoint sources is to recognize sources and create a list of priority areas to focus management practices.

Agriculture is the largest contributor of nonpoint sources of pollution and poses a threat to water quality in the United States (Ribaudo and Young 1989). Sediment loss and nutrients loss contribute about $6.8 billion dollars in damages each year, and $2.2 billion of it is from crop land erosion (Ribaudo and Young 1989). Sediment is defined as solid materials, both organic and mineral, which are deposited into the water systems via runoff caused by either storm events or the spring thaw period during the first month of snowmelt (APHA 2005). Sediment is operationally defined for my study as total suspended solids (TSS), is considered a water pollutant. First, soil decreases the volumetric capacity of lakes and streams which contributes to eutrophication (lake aging). Secondly, soil particles can disturb lake and stream ecosystems by settling out of the water column, smothering benthic habitats, and impacting fish survival while enhancing particle forms of nutrients in the water column (Ritter 1988).

A nutrient commonly associated with sediment is phosphorus. Phosphorus is a nutrient that is found in natural waterways and impaired waters (APHA 2005) and is often the limiting nutrient to algae and macrophytes in freshwater streams (Mitsch and Gosselink 2000). Phosphorus is found in fertilizers, detergents, and organic wastes (DeBarry 2004) and is readily taken up by plants as dissolved inorganic phosphorus (soluble reactive phosphorus) (Andraski *et al*. 1985). On agricultural lands, phosphorus is applied as a fertilizer and may be transported to streams via storm runoff and snowmelt (APHA 2005). Soluble reactive phosphorus (SRP) is formed by either biological processes such as human and animal wastes from sewage or occurring naturally in the environment (APHA 2005). Both total phosphorus (TP) and SRP losses from watershed are thus important nutrient inputs to downstream systems.

Best Management Practices (BMPs) are management techniques that reduce loss of nutrient and soil to downstream systems. Two different types of BMPs exist: structural and non-structural. Structural BMPs, such as check dams, sand fences, rock embankments, sediment basins, and turbidity curtains, are those that are physically implemented into the land. Non-structural BMPs include education and land use changes. For example, conservation tillage systems, contour farming, cover crops, diversions, grassed waterways, crop rotation, sediment basins, and filter strips are some examples of structural or nonstructural BMPs (Ritter 1988). An issue in developing BMPs for certain areas of impairment is the time it takes for structural BMPs to start having an impact by reducing nutrient loading (Ritter 1988).

Segment Analysis

Also commonly called “stressed stream analysis,” segment analysis is one method to identify source and nonpoint sources of pollution within watersheds (Makarewicz and Lewis 2004a and b). Segment analysis encompasses many different fields including aquatic ecology and toxicology, ecology, limnology, hydrology, watershed science, and biology (Makarewicz and Lewis 1994). Segment analysis is a fairly simple and effective way to pinpoint sources of nutrients and soil loss by systematically dividing watersheds and following the concentrations of nutrients and sediments to their source. By using GIS, topography maps, or other stream maps, the watershed is separated into “segments” and grab samples are taken at each spot of interest along the stream. Segment analysis not only identifies sources of pollution, but it also gives managers an idea of its severity by quantifying the amount of soil or nutrients found in the water by laboratory analysis (Makarewicz and Lewis 2004a and b). If a segmented area is found to have high (soil or nutrient) concentrations, then the segment can be further broken into smaller reaches to further identify the source of pollution. Such an approach allows managers to reduce the area under consideration and create smaller more focused management plans rather than manage for the whole watershed. These management applications or BMPs can be adapted to the SWAT Model and placed in those small reaches of impairment to see the future impact. This technique had demonstrated great success through studies performed at Johnson Creek, Canandaigua Lake, and Oneida Creek. (Makarewicz and Lewis 2001a and b, 2004b). For example, at Johnson Creek, a watershed located in the southwest coast of Lake Ontario, major sources of sodium, nutrients, and soil were identified (Makarewicz and Lewis 2001b). Similarly at Deep Run and Gage Gully subwatersheds, located in the Canandaigua Lake watershed, sources of chloride from deicing salt were identified along with elevated nitrate concentrations throughout both subwatersheds (Makarewicz and Lewis 2001a). At Oneida Creek, a tributary of Oneida Lake, both point and nonpoint sources of nutrient and sediment loss were identified (Makarewicz and Lewis 2004a) including three sewage treatment plants (Oneida, Sherill, and Vernon).

Ecological Indicators

Biological indicators, such as macro-invertebrate populations, also can serve as another approach for monitoring the health of a watershed and its reaches (DeBarry 2004). One biological method for assessing potential water quality issues by analyzing macro-invertebrate populations is a Rapid Bioassessment Protocol (RBP). This method assesses species biodiversity and relates it to potential water quality stressors by using the Shannon Index of Species Diversity formula (DeBarry 2004):

$$\overset{s}{\underset{i=1}{H}} = -\sum(\rho_i)(\log\rho_i)$$

Where:

H = diversity index
S= Number of species
i= Species number
P_i = Proportion of individuals of the total sample belonging to the *i*th species

A higher species diversity index number indicates potentially better water quality conditions. Adversely a lower index number could indicate stressors/pollutants upstream.

A newer approach is the nutrient biotic index (NBI) which can be developed for a watershed to correlate the health of macro-invertebrate populations with nutrient levels. The nutrient levels are then incorporated with specific trophic states. For example, if a stream is characterized as being eutrophic, a high potential for impairment exists (Smith *et al*. 2007). Similarly, a mesotropic state indicates slight impairment; an oligotrophic state indicates potentially no impairment. Nutrient concentrations are related to trophic states to signify potential maximum nutrient boundaries for oligotrophic-mesotropic (TP: 17.5 µg P/L; nitrate: 0.024 mg N/L) and mesotrophic-eutrophic (TP: 65 µg P/L; nitrate: 0.95 mg N/L) conditions (Smith *et al*. 2007). Pollution sensitive macro-invertebrates, such as caddisflies and mayflies, can be correlated with nutrient concentration. Abundance or lack of either species would suggest a trophic state and thus a likely nutrient concentration. An indicator study approach could provide a cost-effective way of identifying potential watershed nutrient issues without conducting complex chemical sampling regimes. With standardized NBI programs in place, it could provide a unique measure of potential water quality impairments based on the health of macro-invertebrate populations in geographically different locations.

THE SWAT Model

Management scenarios can be evaluated without actually physically performing them by using models such as the SWAT (Soil Water Assessment Tool) Model. This model predicts the impacts of BMPs on water quality, soil loss, and the hydrology of a watershed (Shen *et al.* 2010, Rosenthal *et al.* 1995). The SWAT Model will calculate daily, monthly, and yearly nutrients, and TMDLs. This continuous time model is versatile and can be implemented to any major or minor watershed if proper variables (land management and land use, hydrology, weather, erosion/sedimentation, soil temperature, plant growth, nutrients, and pesticides) are known (Santhi *et al.* 2001).

As with any model, this model has to be calibrated and validated for each watershed by comparing the actual discharge rates, nutrient levels, and soil loss to model predictions. Typically, predicted and actual values are compared by using the *Coefficient of Determination*, *Nash-Sutcliffe Coefficient*, and the *Percent Difference (PBIAS)*. Two validation tests are determined by r^2 values, the coefficient of determination ($r^2 \geq 0.6$) and the Nash-Sutcliffe ($r^2 \geq 0.5$) (Santhi *et al.* 2001). The Nash-Sutcliffe statistic compares the predictability of the model to the prediction of the result based on a simple average of all of the data. The coefficient of determinations (r^2) determines how much of the variance of the observed data are explained by the variance of the model (Santhi *et al.* 2001). In our study we consider a loading estimation from the SWAT model that lies within 20% of the observed data to be an acceptable result given that the watershed has a unique characteristic (karst) that is not properly incorporated in the model.

Background: Genesee River Basin

The Genesee River, a major tributary (257.5 km) to Lake Ontario, serves as an area with historical, ecological, and cultural values to its residents (Genesee/Finger Lakes Regional Planning Council 2004). The basin drains 6,423 km^2 of watershed, most of which is in New York (DEC, Division of Water, Bureau of Watershed Assessment and Research 2003), and stretches from Northern Pennsylvania to the outlet at Lake Ontario in Rochester, NY (Fig. 1). The elliptical-shaped basin is located between 41^O 45' and 43^O 15' north latitude and a longitude of 77^O 25' and 78^O West (U.S. Army Corp of Engineers 2000).

Topography of the basin changes dramatically from the headwaters to the outlet. The headwaters are hilly with high local relief. Local relief decreases northward, with two prominent escarpments being formed by the Onondaga and Lockport Carbonate formations. (U.S. Army Corp of Engineers 2000). The largest subwatershed of the Genesee River Basin is the Canaseraga subbasin which drains 865 km^2 followed by the Oatka Creek subbasin (557 km^2). The Genesee River Basin is physically manipulated by numerous man-made control structures to regulate the flow of the river (U.S. Army Corp of Engineers 2000). These structures include a mainstem concrete gravity dam located at Mount Morris and a number of reservoirs, hydroelectric power structures, and operated gated dams located in the City of Rochester, Hemlock Lake, and Caneadea Creek. Other services provided by the Genesee River Basin include recreation, wildlife habitat, drinking water, energy production, and industrial uses (Genesee/Finger Lakes Regional Planning Council 2004). In 2000 the land use was primarily agriculture (52%) followed by forested land (40%) (U.S. Army Corp of Engineers 2000). Only a small portion is urban (4.6%), mostly Rochester, and water/wetlands (2%).

There are many environmental issues and problems associated with the Genesee River basin. Problems, such as storm water runoff, habitat modification, invasive species, and limited wastewater treatment, have also caused the Genesee River basin to become degraded (Genesee/Finger Lakes Regional Planning Council 2004). Accordingly, portions of the Genesee River Basin are listed as impaired (DEC, Division of Water, Bureau of Watershed Assessment and Research 2003). The 2001 Genesee River Basin Water Body Inventory lists (DEC, Division of Water, Bureau of Watershed Assessment and Research 2003) over three quarters of the subwatersheds as being either stressed or threatened by nutrients.

Sediment loss from the watershed is a major Beneficial Use Impairment (BUI). For example, degradation of benthos is due to excess sediment being transported by the Genesee River. Also, the amount of soil dredged out of the mouth of the river each year is about 228,000 m^3 (US Army Corp of Engineers 2000) which costs time and money. In general, the increase of human activity to this area through activities, such as agricultural and industrial uses, has greatly degraded the river itself and the shoreline of Lake Ontario (Makarewicz 2000). Nutrients, such as phosphorus, are linked with sediment in particle form and are discharged from the mouth of the Genesee into Lake Ontario. A limiting nutrient for growth, phosphorus stimulates algae colonies, such as *Cladophora*, to grow rapidly along beaches and shorelines of Lake Ontario. For example, elevated concentrations of SRP stimulate bacteria and plankton growth which often leads to beach closures at Charlotte Beach in Rochester, NY (DEC, Division of Water, Bureau of Watershed Assessment and Research 2003). Also, shoreline property owners on Lake Ontario are subject to foul odors from rotting algae and bacteria washed up on shore. Reducing the amount of sediment and phosphorus may significantly reduce the amount of *Cladophora* washed up on shore.

Several attempts to remediate the watersheds have taken place. A major initiative was funded through the U.S. Army Corps of Engineers. A SWAT Model was developed in 2000 (U.S. Army Corp of Engineers 2000) for the Genesee River Basin to simulate the amount of TSS that was being lost each year. The model was validated for sediment loss but not for TP, SRP, nitrate, and total nitrogen (TN). If pollution sources are identified, the SWAT Model may be used to predict how different BMPs would affect subwatersheds and the overall impact on the Genesee River Basin over time. A TMDL for the Genesee River is being developed by Dr. Joseph Makarewicz (personal communication, Dr. Joseph Makarewicz, Distinguished Professor, The State University of New York at the College of Brockport) to determine a target nutrient goal.

A program developed with the intention of enhancing protection for streams and lakes is the Agricultural Environmental Management (AEM) (New York State Soil & Water Conservation Committee 2009). This program was developed by farmers, members of the USDA, and state, local, and government officials to maintain the economy in agriculture with conservation in mind (Makarewicz and Lewis 2001a). Farmers provide solutions to agricultural problems within the watershed and are partly funded in the remediation process by the State Environmental Protection Fund (EPF). This provides a win-win situation for watershed managers and farmers because the water quality can be improved while farmers save money in reducing the amount of fertilizer they spray on the fields.

Background: Oatka Creek Watershed

With a drainage area of 557 km^2, the Oatka Creek watershed is the second largest tributary of the Genesee River (The Oatka Creek Watershed Committee 2001) (Fig. 1). The creek flows north until the water reaches the Village of Leroy where it flows east and discharges into the Genesee River at the Village of Garbutt, New York (Takakis 2002). Major differences in the bedrock geology are apparent from the upper (southern) and lower (northern) reaches of Oatka Creek. Soil types in the upper reach consist mainly of shale and limestone while the lower reach downstream of Leroy consists of limestone, dolomite, gypsum, and shale (Takakis 2002). A karst region, located just downstream of Leroy, often flows underground and reemerges at Buttermilk Falls (Takakis 2002). The karst region (Fig. 2) is located across the Oatka Creek subwatershed from west to east horizontally just downstream of Leroy. This karst region consists of multiple layers of soluble carbonate rock such as limestone and dolomite (Genesee/Finger Lakes Regional Planning Council 2010). Due to the drainage, parts of the creek may be absent and then reappear downstream. In Oatka Creek the karst region decreases flow significantly (Genesee/Finger Lakes Regional Planning Council 2010).

Two USGS discharge stations exist on Oatka Creek: Warsaw (Upper reach) and Garbutt, New York (Lower reach) (USGS 2010) (Fig. 2). Flows range from 0.57 m^3/sec to 3.54 m^3/sec at Warsaw and 1.70 m^3/sec to 16.28 m^3/sec at Garbutt, with flow rates increasing from March to April due to snowmelt and decreasing each month from August to October. Flow rates at Warsaw were about 21% to 36% of the flow rates at Garbutt (Takakis 2002).

Land use in Oatka Creek is primarily agriculture (73.8%), forest (21.6%), and small urban areas (2.7%) based on the 2001 National Land Cover Database (NLCD) (Takakis 2002). No change in land use was identified with the new 2006 NLDC version (USGS 2011). Two main agricultural practices make up a majority of Oatka Creek: cultivated cropland (25,378 hectares) and pastured land (15,580 hectares). In 2002, many farms (112) and barnyards (90) were located in Oatka Creek with over 23,000 animal units recorded (Takakis 2002). Four sewage treatment plants (WWTPs) are stationed on the main stem (Warsaw, Pavilion, LeRoy, and Scottsville)

(Table 1). Human uses include recreational boating, fishing, and drinking water. Oatka Creek is noted for its trout fishery (Takakis 2002), mainly for brown trout downstream of Buttermilk Falls. Oatka Creek has very few wetlands (0.8%) which may be important in serving as sinks for nutrients and sediments.

In the 2002 State of the Basin report (Takakis 2002), greater concentrations of TSS were often found (highest concentration: 66 mg/L) during periods of higher flow (snowmelt, storm events). Increased amounts of TSS affected the turbidity in the water flowing downstream, showing a positive relationship between turbidity and flow rates. Nitrogen, which is associated with waste products found in most living organisms and is a major component in many fertilizers used for agriculture (Takakis 2002), had concentration spikes in the winter months and short spikes during June and July. The Takakis study (2002) also suggested that there was a statistically positive relationship between TP and higher flow periods. Soluble reactive phosphorus concentrations did not change which indicated that increases in TP levels were due to an increase amount of particulate phosphorus. Most of the phosphorus entering Oatka Creek is from nonpoint sources of pollution during high discharge periods (Takakis 2002).

In 2004, a segment analysis of the Oatka Creek subwatershed was performed by Makarewicz and Lewis (2004a). Two point sources identified were the Warsaw and Leroy WWTPs, which elevated nutrients downstream of treatment plants. Nonpoint sources were identified in several areas in the subwatershed: Evans, Buck, Wyoming, Oatka Trail and Woodrow Roads. A small tributary that flows underneath Evans Road had elevated levels of SRP, TP, total Kjeldahl nitrogen (TKN), and TSS attributed to upstream nonpoint sources identified as agricultural and CAFOs (Makarewicz and Lewis 2004a). The Buck Road tributary also had elevated levels of nutrients and sediment and the land use in this area is mainly agriculture (dairy and row crop farming) (Makarewicz and Lewis 2004a). The Pearl Creek tributary at Wyoming Road was a source of nitrate under nonevent conditions and as a source of TKN, SRP, TP, and TSS during event conditions. An area between Wyoming Road and Crossman Road in the Pearl Creek subwatershed had elevated SRP, TP, nitrate, TKN, and TSS due to agricultural sources (Makarewicz and Lewis 2004a). The Oatka Trail Road, a small ditch, is a source for surface runoff, having elevated concentrations of nutrients and sediment during large event periods (Makarewicz and Lewis 2004a). Lastly, a small tributary located upstream of Woodrow Road was a source for nitrate, SRP, TP, TKN, and sodium on one sampling day (Makarewicz and Lewis 2004a). This tributary flows through a residential area and the Pavilion School District. Many point and nonpoint sources of nutrients occur in the Oatka Creek watershed. Many of the studies are fragmented, are not integrated into a watershed approach, and offer no mechanism to review management plans.

Objectives and Goals

In this Oatka Creek study, I determined the sinks and sources of nutrients, sediment and bacteria pollution, evaluated the effectiveness of best management practices on reducing phosphorus and sediment losses from the watershed, and developed a total maximum daily load (TMDL). The objectives were as follows:

Objective 1: Conduct segment analyses throughout the Oatka Creek watershed to identify sources of nutrients and sediment.

Objective 2: Evaluate nutrient and sediment load contributions of segments of Oatka Creek and its tributaries within the basin and to the Genesee River using discharge measurements and weekly water chemistry monitoring.

Objective 3: Create, calibrate and validate a Soil Water Assessment Tool (SWAT) model to evaluate allocated source contributions, and sources identified via segment analysis and flux (load) measurements and suggest remediation strategies to reduce phosphorus loads and concentrations in Oatka Creek.

Methodology

Study Sites

Four Mainstem Sites

Four mainstem sampling sites were established: Garbutt, Warsaw, Ellicott Road, and Evans Road. Oatka Creek (Fig. 2) has two USGS real-time discharge stations, one located at the headwaters on Court Street in Warsaw, New York, and the other station located at the base of the watershed at Union Street in Garbutt, New York. The discharge station located in Warsaw, New York [(N 42.733493^{O}, W 78.133399^{O}), Hydrologic Unit (HNU) 04130003] has discharge records dating back to December 1963 to present. The second USGS real-time site located in Garbutt, New York [(N 43.01025^{O}, W 77.79169^{O}), Hydrologic Unit (HNU) 04130003] has discharge records dating back to October 1945 to present. A third mainstem weekly sampling and discharge site (Ellicott Road) (Fig. 2) was added between the two USGS stations (Fig. 2) at Ellicott Road in Pavilion, New York (N 42.881^{O}, W 78.02925^{O}). Lastly, the fourth mainstem weekly sampling and discharge site (Evans Road) is located in the headwaters near Warsaw, New York (N 42.68447^{O}, W -78.10132^{O}) (Fig. 2, Table 2).

Four Tributary Sites

The Oatka Creek subwatershed was segmented into four smaller tributaries and associated subwatersheds within the main subwatershed (Fig. 2): one headwater tributary (Buck

Road), two middle tributaries (Wyoming Road and Roanoke Road), and one downstream tributary (Parmelee Road) (Fig. 2). The one tributary located at the headwaters, Buck Road (N 42.72795^O, W -78.16161^O) is just upstream of the USGS discharge station at Warsaw, New York. The middle tributary site on Wyoming Road (N 42.84858^O, W -78.04319^O) is upstream; the second middle tributary site on Roanoke Road (N 42.94206^O, W -78.05186^O) is downstream of the main stem site at Ellicott Road. The last tributary site at Parmelee Road (N 43.01498^O, W -77.97026^O) is downstream of the main stem site at Ellicott Road and upstream of the USGS discharge station in Garbutt, New York (Fig. 2).

Weekly Water Chemistry Sampling

Weekly water samples were taken at the eight mainstem (Garbutt, Warsaw, Ellicott Road and Evans Road) and tributary sites (Buck Road, Wyoming Road, Roanoke Road and Parmelee Road) for a period of 12 months under event and nonevent conditions. Samples were filtered on site with 0.45-µm MCI Magna Nylon 66 membrane filters. Both the raw sample and filtered sample were transported on ice to maintain a temperature of 4^{O}C. When the samples reached SUNY Brockport's Water Quality Laboratory (NELAC # 11439), they were logged into the laboratory database. All nutrient analyses were completed within 24 hours of sampling. The samples were then analyzed for soluble reactive phosphorus (SRP) and nitrate+nitrite (NO_3 $+NO_2$) with the filtered sample and total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) with the raw sample using standard methods (APHA 2005) (Table 3). Total coliform analysis was also conducted on site by using a 10-mL serological pipet and extracting 1 mL from the raw sample bottle and placing it on a Petri-film plate (3M 2010).

Discharge

Discharge for Oatka Creek subwatershed was obtained from the two USGS monitoring stations in Warsaw and Garbutt, New York (Fig. 2). In addition to the two USGS sites, six other discharge sites (two mainstem, four tributary) were added to aid in the predictability of the SWAT Model. At these six locations (Ellicott Road, Buck Road, Evans Road, Wyoming Road, Roanoke Road, and Parmelee Road) (Fig. 2) precise dimensional measurements were taken at each culvert to determine the cross-sectional area. These measurements were drawn to scale on pieces of grid paper, and then area increments were measured by using a planimeter. The measurements recorded by the planimeter were transferred to Microsoft Excel, and a 2nd and 3rd degree polynomial regression lines were utilized to determine water area from which discharge was calculated to establish a rating curve.

Velocity measurements were taken by using a Gurley 625 and 622 velocity meters during ‘event’ and ‘nonevent’ periods to obtain low and high ranges for velocity measurements. Depending on the site, velocity was measured at increments horizontally across the streams. Ellicott Road (1.524-m increments); Buck Road (0.3048-m increments); Evans Road (0.6096-m increments); Wyoming Road (0.6096-m increments); Roanoke Road (0.6096-m increments); and Parmelee Road (0.3048-m increments). Maximum water depth measurements were taken using a meter stick or tape measure from a predetermined fixed point at a culvert or bridge every time the site was visited at least once per week. Discharge was calculated by taking multiple velocity measurements across the culvert or bridge to obtain the total average velocity. That average velocity (m/s) was then multiplied by the cross-section of water that covered the culvert or bridge (m^2/s) resulting the discharge (m^3/s). Rating curves were then developed based on multiple measurements throughout the sampling year (Figs. 3 and 4).

Loading was calculated at each of the eight weekly sampling locations from the concentrations of soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate, total nitrogen (TN) and total suspended solids (TSS) and from daily discharge using Equation 1. The loading from Ellicott Road and Roanoke Road was calculated by adding the loadings from both culverts.

Equation 1: $Loading\left(\frac{mass}{unit}\right) = Discharge\left(\frac{m3}{s}\right) * Concentration\,(\frac{mg}{L}\, or\ \mu g/L)$

The discharge on days where sampling and water depth was not taken, event and nonevent periods, were estimated from a regression of measured discharge for the sampling site versus the discharge at the USGS gauge. Evans Road, Buck Road, Ellicott Road, and Wyoming Road were regressed against the USGS gauge at Warsaw while Roanoke Road and Parmelee Road were regressed against the USGS gauge at Garbutt (Fig. 5). Predictive regressions for daily discharge were good with r^2 ranging from 0.86 to 0.91. Annual loadings were estimated based on correlated discharge regressions (Garbutt: Roanoke Road and Parmelee Road; Warsaw: Evans Road, Buck Road, Ellicott Road and Wyoming Road) between measured discharge and USGS discharge where event loadings were estimated based on hydrograph attenuation. Normalized loading based on per hectare for each segment (Evans Road, Buck Road, Warsaw, Wyoming Road, Ellicott Road, Roanoke Road and Parmelee Road) was calculated from the annual loading estimations. Subbasin areas for all eight segments were calculated using a USGS StreamStats web program. Monthly and seasonal loadings were calculated to determine trends in the data.

Wastewater Treatment Plants

An effluent grab sample was taken along with four replicate samples above and below the Warsaw, Leroy, Pavilion, and Scottsville WWTPs (Fig. 2) and were analyzed for SRP, TP, NO_3 + NO_2, TN, TSS, and coliform analysis. Statistical difference was determined using a paired T-test using Microsoft Excel ($p = 0.05$) if data was normally distributed, if not, a Wilcoxon test was utilized ($p = 0.05$).

Segment Analysis

Segment analyses were conducted to identify point and nonpoint sources of nutrients and sediment in the Oatka Creek watershed (Makarewicz and Lewis 1994. 2004a and b). This process indicates the size, extent and location of sources in a watershed by systematically dividing the watershed into smaller areas (stream segments). By analyzing the water chemistry at each stream segment, sources were pinpointed by noting large nutrient or sediment increases between sites. Segment analysis was conducted at the mainstem and at each of the five major discharge segments (Parmelee Road, Roanoke Road, Wyoming Road, Evans Road, and Buck Road) (Fig. 2) during 'nonevent' and 'event' periods to better localize sources of contamination. Once sources had been identified within each tributary, more segments were added to pinpoint sources of pollution. Segment water samples were analyzed as the weekly discharge samples. Dissolved nutrients (SRP and nitrate) were filtered on site and stored in a ice filled cooler and transported at $4^{o}C$ to SUNY Brockport's Water Quality Laboratory (NELAC # 11439). All samples were analyzed for SRP, TP, nitrate, TN, TSS and total coliform as discussed under the weekly water chemisty sampling section.

Sediment Erosion Inventory

Erosion occurring upstream from Warsaw was determined via a sediment erosion inventory on 28 July 2011. The inventory was performed by hiking upstream from Warsaw along the mainstem to identify areas with excessive stream bank erosion. Areas with excessive stream bank erosion were marked with a handheld Garmin 550T GPS and photographed for later analysis of the severity of erosion on the mainstem. The areas of concern were measured using a rangefinder for length (m) and height (m) of eroded area and then implemented into the sediment erosion index which estimated the severity of erosion on the stream bank. Erosion variables such as location of erosion, condition of stream bank, condition trend, bank vegetation, primary and secondary causes of erosion, bank slope, bank height, length of eroded bank, and soil texture are all taken into account when scoring the severity of erosion (Limno-Tech, Inc 2006). A Reference site was scored on 22 August 2011 along with the eroded site (28 July 2011) to compare highly eroded sites with natural, unimpacted locations.

Macro-invertebrate Identification

A macro-invertebrate survey was conducted on 10 August 2011 at Garbutt, NY to determine the biological health of Oatka Creek. One hundred macro-invertebrates were extracted at random from the full sample for further taxonomic identification (NYSDEC 2009). All standard operating procedures followed the manual of Biological Monitoring of Surface Waters (NYSDEC 2009).

Soil Water Assessment Tool (SWAT) Model

Model Setup

A Soil Water Assessment Tool (SWAT) model was created for the Oatka Creek sub-watershed (SWAT 12). Five main datasets were used when building the model: Multi-resolution Land Cover dataset (land cover) (USGS-MRLC 2006), Soils Data Mart (soils) (USDA-NRCS 2006), USGS (DEM, 1/3 arc second, 10 meter resolution) (USGS 2010), and National Weather Service (precipitation and temperature) (NOAA-NWS 2011)]. Weather data was obtained for the 29-month study duration (1 January 2008 to 31 May 2011) from four stations associated with

SWAT12 (Warsaw, Batavia, Mount Morris, and Avon) (Table 4). The in-program generator for SWAT12 provided all other weather data.

Pour point outlets were manually created for both USGS monitoring stations (Garbutt and Warsaw), and at the six routine monitoring locations (Evans Road, Buck Road, Wyoming Road, Ellicott Road, Roanoke Road and Parmelee Road) (Fig. 2). In addition, outlets were placed at point source discharge locations and where CAFO (Confined Animal Feeding Operation) sites existed. In the HRU analysis drop down menu, five slope classes were created (0-2%, 2-5%, 5-8%, 8-15% and 15-9999%) to better define the elevation change in the southern reaches of Oatka Creek. The default multiple hydrological response units threshold percentage (%) was used for the SWAT model (land use: 5%; soil: 20%; DEM: 20%). The model setup resulted in 81 subbasins and outlets (Fig. 6) and 3,546 hydrologic response units (HRU's).

Source Inputs

Crop Data

The percent crop distribution for the Oatka Creek watershed was determined using the New York State 2010 Crop Data Layer (USDA-NASS 2010). Within the watershed the crop distribution for the year 2010 was 37% corn, 20% alfalfa, 16% pasture/grass, 12% generic agriculture (a cumulative total of all other crops less than 1%), 9% soybeans, 3% winter wheat, 2% apples and 1% oats. This information was used to split the agricultural row crops land-use class into subclasses in order to account for the specific agricultural practices for the calibration period.

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

Point Sources

To calibrate and determine source impacts in the Oatka Creek SWAT model (SWAT 12), five point source locations known to have nutrient inputs to Oatka Creek (four WWTP and one SPDES) were added to the SWAT model (Tables 1 and 5). To determine the location of each point source, a GIS layer of the WWTPs and SPDES sites was overlaid in the model. Separate subbasins were created for each of the five point sources to accurately input nutrients individually.

All discharge values for WWTPs and SPDES sites were acquired from the Environmental Protection Agency NPDES permit database and the New York State Department of Environmental Conservation web for Water Discharge Permits (WDP) (USEPA 2011). Average monthly discharge data available from the permit data, were used as follows: Warsaw WWTP (1,113 m^3/day), Leroy WWTP (2,410 m^3/day), Pavilion WWTP (128 m^3/day), Scottsville WWTP (2,068 m^3/day), Caledonia Fish Hatchery (est: 13,136 m^3/day). The nutrient concentrations observed in one effluent grab sample were used to calculate a constant annual load.

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

Once a point source output was quantified, it was inserted directly into the SWAT model via the edit SWAT input file function in the SWAT interface into the appropriate subbasin as a constant daily load. Flow was inserted in cubic meters, and loads of organic P and mineral P were added as kg/d as specified by the SWAT manual.

Confined Animal Feeding Operations

Confined animal feeding operations (CAFOs) are a nonpoint source of nutrients and sediments that were incorporated into SWAT12. There are a total of twenty CAFOs (Table 6), eighteen of which were placed into eighteen subbasins of Oatka12. The two CAFO sites that were not included transferred 100% of the manure away from Oatka Creek (Victory Acre Farms and Synergy, ICC) (personal communication, William Smythe, NYSDEC). The eighteen CAFO sites were added to the model as fertilizer in manure spread (Table 6). The amount of manure that was applied was dependent on the CAFO size (head of cattle) and hectares spread for each farm and obtained from the 2010 CAFO annual permit (personal communication, Nancy Rice, Region 8, NYSDEC) or from the Monroe County Soil and Water Conservation District (SWCD) (personal communication, Tucker Kautz, Monroe County SWCD). Total allocated area in Oatka

Creek that CAFOs were permitted to spread manure on was 9,546 hectares, but only 7,480 hectares were used in SWAT12.This is due to applying manure to the appropriate HRUs within each subbasin by overlaying the HRU map created by the model with the actual GIS CAFO layer (Santhi *et al.* 2001). All of the CAFOs in the Oatka Creek watershed coincided with HRUs with only corn, hay or generic agricultural crops. When the manure data were not available for a CAFO site (Hildene Farms, Inc and Mowacres Farm II, LLC), the total amount of produced by each farm (kg manure/d) as viable dairy manure for fertilizer was calculated using the number of cows and the amount of manure produced per cow per day (30.94 kg/ha) (American Society of Agricultural Engineers, 1988).

The manure application rate (kg/ha/d) for each CAFO was calculated by dividing the total amount of manure produced by the CAFO by the total hectares of land area where manure is actually spread in the watershed. Manure application rates were applied as continuous fertilization applied to the surface soil layer with a frequency of 30 days in a 365 day year span.

Septic Input

When septic systems are activated in an HRU within SWAT, the entire HRU is considered as having septic systems (personal communication, Raghavan Srinivasan, Texas Agricultural Experiment Station, Blackland Research Center). Thus, septic systems must be applied only to residential areas where septic systems are likely to occur. Active septic systems were applied to HRUs with the land-use designation Low Intensity Residential Developed Land which are areas with a mixture of constructed materials and vegetation, 20 to 49% imperviousness, and most commonly include single-family housing units (NLCD) (USGS-MRLC 2006).

Active septic systems were then applied to all HRUs with residential land-use with the exception of subbasins 9, 19, 20, 26, 27, 28, 42, 44, 66, 68, 71 and 72 to account for sewered regions in the Oatka Creek watershed. The septic system type used was ‘septic tank with conventional drainfield’ which is the most accurate for homes in western, NY.

Model Calibration and Validation

The model was calibrated for water balance, sediment and phosphorus for the study year 1 June 2010 through 31 May 2011. A ramp up of the model was initiated in January 2008. The validation year for discharge was from 1 June 2003 through 31 May 2004.

Calibration criterion used included the Nash-Sutcliffe prediction efficiency, coefficient of determination (r^2), the percent bias (PBIAS) between observed values to SWAT output, and visual distribution of peaks (Moriasi *et al.* 2007). The Nash-Sutcliffe ranges from $-\infty$ to 1 and is a measure of the goodness of fit between values predicted by the model and the actual observed parameter in the watershed. A Nash Sutcliffe of $E > 0.7$ is considered a very good fit between modeled and actual values (Moriasi *et al.* 2007). The correlation coefficient ranges from -1 to 1 and was used to measure the strength of the linear dependence between observed and simulated variables in the watershed; an $r^2 > 0.7$ is considered very good (Moriasi *et al.* 2007). The PBIAS is a measure between the difference in magnitude of actual observed versus simulated peaks of discharge or nutrient load. A PBIAS of less than 10.0% was accepted with the ultimate goal to achieve a difference of 0.0% (Moriasi *et al.* 2007).

Water Balance

Carbonic Rock Aquifer

The initial SWAT12 simulation run, when compared to the measured USGS discharge at Garbutt, suggested that a deficit of water was present in SWAT12 between December through

May. All input parameters (precipitation, temperature, soil, land use, DEM) were checked to determine that an incorrect dataset was not the cause of the water deficit resulting in the initial SWAT model simulation. More water is being lost from the watershed than predicted. A carbonate rock aquifer is located just north of Leroy (Fig. 2) which is a likely outside groundwater input to the Oatka Creek watershed (Richards *et al.* 2010). To estimate outside groundwater inputs from the carbonate rock aquifer, discharge data from the two USGS monitor stations within Oatka Creek (Garbutt and Warsaw) were analyzed (Fig. 2). If groundwater is entering from the aquifer, the percentage of water contributed from Warsaw to Garbutt would decrease due to an increased water contribution from the carbonate rock aquifer to Oatka Creek with fluctuation in groundwater. Forty years of discharge data (1970-2009) were averaged by month to analyze the percent of water contributed from Warsaw and to determine the average discharge difference between Warsaw and Garbutt. After October, the percent contribution of water from Warsaw decreased until June even though flows at Garbutt were still high (Fig. 7). An outside water source (carbonate rock aquifer) is suggested that exists between Garbutt and Warsaw; that is the karst region indicated by Richards *et al* (2010). To estimate the quantity of water being added by the karst region, the following equation was developed:

$$Flow\ Deficit\ (m^3/day) = ((G-W)-A)*60*60*24$$

G = Average monthly flow at Garbutt
W = Average monthly flow at Warsaw
A = Average flow difference between Garbutt and Warsaw over 12 month period

The analysis indicated a flow deficit upstream from Garbutt that existed between the months of December through May. A rise in water table between the months of January through

April was also noted at Oak Orchard Creek in which the same carbonate rock aquifer exists (Richards *et al.* 2010a). A regression of the average monthly discharge at Garbutt and the flow deficit calculated at Garbutt was developed with data from a 40 year period. Strong correlations ($r^2 > 0.96$) between the average monthly discharge and calculated flow deficit at Garbutt (Figs. 8 and 9) were evident suggesting that water from the carbonate rock aquifer could be calculated from average monthly discharge measurements at Garbutt. For example, to calculate the karst water input for March 2011, the average monthly discharge at Garbutt was obtained for March 2011 then applied to the mathematical equation (Table 7). An example calculation of the water added in March is below:

$$\begin{aligned}\text{Water added in March} &= 1974.4(x) - 555879 \\ &= 1974.4\,(674.97) - 555879 \\ &= 77.68\ \text{m}^3{*}1000/\text{day}\end{aligned}$$

where,

x= Average March 2011 discharge at Garbutt

Monthly estimates were totaled and added into SWAT12 via the "water use" tab (December: -5.96 m^3*1000/day; February: -5.16 m^3*1000/day; March: -77.68 m^3*1000/day; April: -69.67 m^3*1000/day; May: -63.04 m^3*1000/day). The numerical values added to the water use tab were divided into the nine major subbasins that the karst region occupies (subbasins: 6, 12, 14, 15, 21 to 24 and 27) (Richards *et al.* 2010a).

Curve Number

To predict surface runoff under peak flow conditions, the SCS curve number was changed in the SWAT12 model. Because curve number is based on soils and land use, some studies suggest that the curve number should stay within ±10% of the initial curve number

SWAT creates based on soils and land use (Richards *et al.* 2010, Neitsch *et al.* 2002). However, other studies calibrating peak surface runoff have made CN adjustments of -6% to -29 % to obtain good model flow calibration (Richards *et al.* 2010). In the SWAT12 model, the curve number reduction closely resembled those of previous studies (Richards *et al.* 2010) by reducing the value by – 23%.

Alpha Base-flow

ALPHA base flow, a groundwater base flow parameter, greatly impacted the SWAT12 model. Richards *et al.* (2010b) mathematically solved ALPHA base flow by obtaining stream flow data from the USGS monitoring station at Garbutt, NY during recession periods. Richard's calculations resulted in values ranging from 0.03 to 0.11 in which a value of 0.11 was used for the SWAT12 model.

SWAT Model Calibration Criterion

For the 2010-2011 water year, the SWAT12 model accurately predicted discharge: Nash-Sutcliffe: 0.94, coefficient of determination: $r^2 = 0.95$, and PBIAS (+ 5.1 %) (Fig. 10 and Table 8). Once flow was calibrated for Oatka Creek, the SWAT model was then calibrated for sediment (TSS) and phosphorus (TP) from measured water chemistry samples taken from 1 June 2010 through 31 May 2011 at Garbutt NY. SWAT model parameters for groundwater, evaporation methods and surface water were changed and applied to all 81 subbasins, but some parameters were changed within specific subbasins after determining PBIAS at other monitoring locations (See Appendix A) to obtain a better fit of the model.

In addition to tillage and fertilizer applications, the erodibility of sediments, initial soil P concentration (mg P/kg soil), sediment routing method, phosphorus enrichment ratio and initial soluble phosphorous concentration of the groundwater were parameters that were most sensitive for TSS and TP calibration. Because the spring of the calibration year (2011) was considered a 'wet year' with frequent and intense rain, the tillage and initial fertilization of crop lands occurred in May rather than in April as in the Oak Orchard study of Richards *et al.* (2010). Parameters that were utilized to calibrate for sediment and phosphorus are summarized in Appendix A. The resulting calibration criterion for model performance for sediment was "very good" (Nash-Sutcliffe: 0.90; coefficient of determination: 0.90; and PBIAS: +2.5%) (Moriasi *et al*. 2007) (Fig. 10, Table 8). Similar to sediment, the resulting calibration criterion for phosphorus was "very good" (Nash-Sutcliffe: 0.71; coefficient of determination: 0.80; and PBIAS: +10.3%) (Moriasi *et al*. 2007) (Fig. 10, Table 8).

To further verify that the output from the other monitoring stations (Evans Road, Buck Road, Warsaw, Wyoming Road, Ellicott Road, Roanoke Road and Parmelee Road) was being accurately predicted, the predicted TP and TSS loads (kg/year) were compared to the actual observed loads and the percent bias was calculated. Initially, some monitoring locations in the model did not accurately predict the actual measured loads. To correct this, parameters were changed within each subbasin upstream from the monitoring location outlet in an attempt to improve measured loads in the SWAT model. The final parameters utilized to calibrate PBIAS for the other monitoring locations are summarized in Appendix A. The TP PBIAS were within ± 26% for all sites and the TSS PBIAS were within ± 31% (Tables 9 and 10). Total phosphorus PBIAS ranged from -24.8 to 25.7 with an average of -0.8 all eight sites while TSS PBIAS ranged from -30.2 to high 30.1 with an average of 3.6 for all eight sites. These values for PBIAS reflect that all sites predict the actual loads with confidence (Moriasi *et al*. 2007). Concentration calibration of TP along the mainstem of Oatka Creek was also used to further increase the models predictive precision.

Once SWAT12 model was calibrated for flow, sediment and phosphorus, the model was validated for flow for the water year of June 2003 through May 2004. The 2003 to 2004 validation run resulted in a “good” fit (Nash-Sutcliffe: 0.73; coefficient of determination: 0.84; PBIAS: + 4.8%) (Table 11). After SWAT12 was calibrated and validated, the next step was to run scenarios to determine the impact of specific allocations and to create remediation scenarios to estimate the percent reduction of sediment and phosphorus under management simulation run.

Model Simulations

With calibration and verification of SWAT12 (Oatka Creek SWAT model) completed, the model was used to simulate management practices throughout the watershed. Scenarios were broken down into several categories based on source type and management option. These categories were as follows: natural forested simulation, agricultural BMPs, wastewater source options, and CAFO management operations.

Natural Forested Simulation

The model was first used to determine the natural, background levels of phosphorus coming out of Oatka Creek; that is if all anthropogenic impacts were removed from the watershed. This was achieved by creating and implementing a 100% forested land-use layer using the land-use update option in the model with all point and nonpoint sources removed.

Wastewater Source Options

To determine the impact of upgrading treatment or rerouting all WWTPs and SPDES sites outside the watershed, the Scottsville, Leroy, Pavilion and Warsaw WWTP were removed from the watershed. A similar simulation was run to determine the percent reduction of P by upgrading all WWTPs to tertiary treatment with a chemical addition, two-stage filtration system.

The tertiary wastewater treatment plant TP concentration used for this scenario was based on other wastewater treatment plants in New York State of similar size that utilize this treatment system (0.01 mg P/L) (USEPA 2007). Lastly, a scenario to determine the impact of removing all point sources from the watershed was simulated by including all SPDES listed point sources in the watershed.

Agricultural BMPs

The Oatka12 was used to predict the impact of changes in agricultural land-use through BMPs, several BMPs were simulated: no till/conservation tillage, grassed waterways, terrace farming, contour farming, filter strips, strip cropping, retirement of agricultural land, and cover cropping. Nutrient management scenarios were simulated using a 25, 50, 75, and 100 % reduction in the quantity of fertilizer spread over cropland.

Confined Animal Feeding Operations (CAFO) Management

To determine the impact of CAFOs on the Oatka Creek watershed and on the TP and TSS load, a remediation simulation was run. The manure application from all eighteen CAFOs throughout the watershed was removed to simulate the effect of using alternative manure practices and thereby completely eliminating the runoff from manure waste application fields from Oatka Creek.

Stream bank Erosion Mitigation

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

Oatka Creek Watershed Management

When attempting to achieve the 45 μg P/L water quality target, five remediation scenarios were simulated (tributary remediation, point source remediation, grassed waterways, cover crops and buffer strips combinations on all agricultural land) to reach the target goal in Oatka Creek at Garbutt, NY. Simulations that achieved the 45 μg P/L concentration target consisted of: land use management techniques, tributary management and point source remediation (upgrading WWTPs).

Source P Load Allocation

Based on Oatka12, a TP load allocation table was created considering: agricultural land, tile drainage, farm animals, stream bank erosion, wetlands, quarries, groundwater, forests, urban runoff, sewage treatment, and septic systems (Table 12). Agricultural land includes the runoff of all phosphorus from crops excluding the contribution of P from CAFOs and was derived by computing the difference between the calibrated model run versus a scenario where all crops (crops, hay, and pasture) are converted to forest minus the contribution from CAFOs. The manure produced from CAFOs was applied to crops (corn, hay and general agriculture) and therefore was accounted for separately. This source of P from farm animals (CAFOs) was obtained by the difference between the calibrated Oatka Creek model run and a scenario where the manure from all CAFOs was removed. Tile drainage or subsurface drainage from croplands was obtained from the difference in the calibrated model and a scenario with 15.4% tile drainage (personal communication, Wayne Howard, Center for Environmental Information) added to all soybean, pasture and range-brush land uses.

Erosion associated with stream banks was the difference in the calibrated model and the stream bank stabilization scenario, where Manning's n is increased by 50% (0.8 to 1.2). The P contribution from wetlands, groundwater, and forests was determined using direct output from the calibrated model (HRU output). Urban runoff was determined from the difference in the calibrated SWAT 12 model and a scenario where all residential areas are converted to forested while septic remains in the model. By keeping septic systems in the model for this run, the amount of P from urban runoff rather than the entire contribution from residential/urban areas is identified. Septic systems were considered a separate entity and were derived from the difference in the calibrated model and a scenario where septic is inactive. Lastly, the phosphorus from sewage treatment was the difference between the calibrated P output and a scenario where all WWTPs are removed from the model. This analysis allows for identification and quantification of P from different sources in the watershed.

Results

Nutrient Biotic Index (NBI) Results

Ninety percent (90/100 specimens) of the sample was used to determine the NBI trophic states in the Oatka Creek watershed. Nutrient Biotic Index (NBI) values rated Oatka Creek as being mesotrophic (NBI-Phosphorus: 5.9; NBI-Nitrogen: 5.2), while the concentration rating indicated mesotrophic conditions for phosphorus (24.5 µg P/L) and eutrophic for nitrogen (1.70

mg N/L) (Appendix B). Nutrient Biotic Index results will be present in Evan Rea's research study on NBI.

Segment and Tributary Loading

Discharge Measurements

Rating curves were developed at Evans Road, Buck Road, Wyoming Road, Parmelee Road, Ellicott Road (East and West culverts) and Roanoke Road (North and South culverts) (Fig. 5). Strong correlations existed ($r^2 \geq 0.94$) between discharge and stream depth (Fig. 5).

Average Concentration (June 2010 through May 2011)

Of the eight sites monitored, the average annual SRP and TP concentrations and total coliform abundances were highest at Wyoming Road (SRP: 27.5 µg P/L; TP: 74.4 µg P/L; total coliform: 8,237 CFU/100 mL), Ellicott Road (SRP: 47.5 µg P/L; TP: 100.3 µg P/L; total coliform: 8,770 CFU/100 mL) and Roanoke Road (SRP: 32.5 µg P/L; TP: 86.8; total coliform: 11,129 CFU/100 mL) compared to the average annual phosphorus concentration among all sampling locations (SRP: 20.2 µg P/L; TP: 61.0 µg P/L; total coliform: 6,977 CFU/100 mL) (Fig. 11). The Wyoming, Ellicott and Roanoke Roads segments (Fig. 2) within Oatka Creek appears to be when the most water quality issues are located. Further evidence suggesting that the Wyoming Road area is of concern are the elevated average nitrogen concentration (average - nitrate: 3.28 mg N/L; TN: 3.98 mg N/L) compared to the average of the other 'eight' sites (average - nitrate: 1.76 mg N/L; TN: 2.29 mg N/L) (Fig. 11). Average annual TSS concentrations were elevated at Warsaw (60.3 mg/L) when compared to the average annual TSS concentrations of all 'eight' sites (23.4 mg/L) (Fig. 11).

Average monthly mainstem (Evans Road, Warsaw, Ellicott Road and Garbutt) (Fig. 12) TP concentrations were highest during December 2010, February 2011 and May 2011 due to event runoff during the winter and spring months. All other months tended to be relatively low due to nonevent periods. Tributary locations (Parmelee, Roanoke, Buck and Wyoming Roads) (Fig. 12) indicated a similar trend were elevated TP concentrations resulted in September 2010, December 2010, March 2011 and May 2011 again due to event conditions.

Event versus Nonevent Concentrations (Table 13, Appendix C)

Headwater reaches tended to be more responsive to rain events [(nonevent to event)Buck Road (e.g., TP: 16.7 to 114.8 µg P/L , + 587%), Evans Road (e.g., TP: 15.9 to 189.9 µg P/L , + 1,094%), Wyoming Road (e.g., TP: 29.9 to 191.6 µg P/L , + 541%) and Warsaw (e.g., TP: 12.5 to 182.7 µg P/L , + 1,362%)] than downstream reaches [Roanoke Road (e.g., TP: 38.0 to 198.4 µg P/L , +422%), Ellicott Road (e.g., TP: 59.3 to 175.5 µg P/L , +196%), Parmelee Road (e.g., TP: 18.3 to 26.2 µg P/L , +43%) and Garbutt (e.g., TP: 29.6 to 74.3 µg P/L , +151%)] (Table 13). Soluble reactive phosphorus, TP, TSS and total coliform abundances indicated large concentration increases from nonevent to event periods [(Average of all eight monitoring locations – SRP: 11.6 to 39.2 µg P/L, +238%; TP: 27.6 to 144.2 µg P/L, +422; TSS: 5.3 to 71.5, +1,250%; total coliform: 2,888 to 17,075 CFU/100 mL, +491%)] while this was not indicated by nitrate and TN (Average of all eight monitoring locations – nitrate: 1.78 to 1.71 mg N/L, -4%; TN: 2.21 to 2.47 mg N/L, +12%). Parmelee Road tended to be the least responsive to rain event periods, mainly due to the continuous low discharge (Fig. 3) throughout the reach.

Measured Total Annual Nutrient and Sediment Load

Total annual nutrient and sediment loading was calculated (kg/yr) for 1 June 2010 to 31 May 2011 period at four mainstems (Evans, Warsaw, Ellicott, and Garbutt) and four tributary sites (Buck, Wyoming, Roanoke, and Parmelee) (Table 14). Soluble reactive phosphorus, total phosphorus, nitrate, and total nitrogen load increased incrementally from the most upstream mainstem site at Evans (e.g., TP: 787 kg P/yr) to Warsaw (e.g., TP: 5,231 kg P/yr) to Ellicott (e.g., TP: 9,211 kg P/yr) to the furthest downstream mainstem site with the highest load at Garbutt (e.g., TP: 15,018 kg P/yr) (Table 14a). TSS load displayed a different spatial pattern. Total suspended solid annual loads increased from the furthest upstream mainstem site at Evans (TSS: 292,147 kg/yr) to Warsaw (TSS: 5,791,046 kg P/yr (+ 1,882 %) (Table 14) but decreased from Warsaw to Ellicott (TSS: 2,811,827 kg/yr (- 51 %)], then increased to the furthest downstream site at Garbutt [TSS: 5,006,876 kg/yr (+ 78 %)] (Table 14).

The monitored tributaries accounted for 35.3 % (Buck: 2.9 %; Wyoming: 19.1 %; Roanoke: 12.5 %; Parmelee: 0.8 %) of the total SRP load at Garbutt, NY. The Buck Road tributary, which empties just downstream of Evans Road but upstream from Warsaw (Fig. 2), contributes 5.6 % of the TP and 7.4 % of the total annual TSS load at Garbutt, respectively. This relatively low contribution contrasted with the huge loss of sediment (TSS) in the Warsaw reach (5,791,046 kg/yr) suggested other source(s) of erosion, perhaps bank erosion in the mainstem in of the Warsaw reach.

The Wyoming Road tributary (Fig. 2) had the highest nitrogen load of all four tributary sampling locations [nitrate: 95,864 kg N/yr (17.2% of total), TN: 119,139 kg N/yr (17.6 % of total)], indicating a source(s) of nitrogen upstream, while the Parmelee tributary contributed only a very small fraction of the nutrients and sediment to Garbutt (SRP: 0.8 %; TP: 1.4 %; nitrate: 2.1 %; TN: 2.4 %; TSS: 1.5 %). Similarly, the total annual nitrate and TN load at the two tributary sites downstream from Ellicott but upstream from Garbutt (Roanoke and Parmelee) (Fig. 2) account for a small fraction of the total load at Garbutt (nitrate: 5.6 %; TN: 7.0 %). This suggests other tributary or mainstem sources of nitrogen downstream from Ellicott but upstream from Garbutt.

Areal nutrient and sediment loading (kg per hectare/yr) (Table 14b)

Areal loads presented in Table 14b represent the load for a segment divided by the watershed area of that segment. In general, areal SRP, TP, nitrate, and TN loads were lower in the tributaries (tributary:mainstem range – SRP = 12 to 307 g/ha/yr: 47 to 512 g/ha/yr, TP = 54 to 1,085 g/ha/yr: 40 to 1,165 g/ha/yr, nitrate = 3.0 to 27.4 kg/ha/yr: 10.2 to 83.5 kg/ha/yr, TN = 4.1 to 34.1 kg/ha/yr:12.3 to 102.0 kg/ha/yr). Of the four tributary sites, Parmelee tributary had the lowest areal contribution (SRP: 12 g/ha/yr; TP: 54 g/ha/yr; nitrate: 3.0 kg/ha/yr; TN: 4.1 kg/ha/yr) to the total losses of the watershed.

The Wyoming tributary, which is located just upstream from the mainstem site at Ellicott (Fig. 2), had the highest areal tributary load for SRP, TP, nitrate, TN, and TSS (SRP: 307 g P per ha/yr; TP: 1,085 g P per ha/yr; nitrate: 27.4 kg N per ha/yr; TN: 34.1 kg N per ha/yr; TSS: 684.5 kg per ha/yr) (Table 14). This segment is clearly a source and an area of concern for nutrients and soil erosion. Similar to the Wyoming tributary, Roanoke tributary had high SRP (297 g P per ha/yr) and TP (850 g P per ha/yr) areal load when compared to all other reaches (mean – SRP: 215 g P per ha/yr; TP: 603 g P per ha/yr) (Table 14b). At both the Wyoming and Roanoke tributaries, these relatively high losses of phosphorus and other analytes indicate areas of concern to focus management practices.

With the exception of SRP (117 to 47 g/ha/yr), areal mainstem losses of TP, nitrate, TN, and TSS tend to increase from the mainstem Evans reach (e.g., TP: 460 g/ha/yr) to the mainstem Warsaw segment suggesting sources of nutrients and sediment are downstream (e.g., TP: 770 g/ha/yr) (Figs. 2, Table 14) from Evans Road but upstream from Warsaw (Fig. 2). In fact, areal TSS loading was high at the mainstem Warsaw site (1,095.7 kg/ha/yr) compared to all tributary (range – 18.4 to 684.5 kg/ha/yr) and mainstem (range – 0.0 to 495.2 kg/ha/yr) sites. Buck tributary (TP: 396 g/ha/yr; nitrate: 11.2 kg/ha/yr; TN: 13.7 kg/ha/yr) (Table 14), which empties just downstream of Evans but upstream from Warsaw (Fig. 2), is a likely source of TP, nitrate, and TN in the Warsaw reach. Also TSS areal losses increased from 171 to 1,096 kg P/ha/yr (+ 541 %) from the Evans Road to Warsaw segment, while Buck Road TSS tributary losses were low (174 kg P/ha/yr), suggesting an erosion issue along the mainstem.

To confirm this, an erosion inventory was conducted between site C to OC Warsaw (4.00 km), and site H to OC Evans Road (3.57 km) (Table 15), to identify the cause of elevated TSS levels in the Warsaw segment (Fig. 2). Initial results indicated large TSS increases between site C to OC Warsaw (+203%), an area mainly in agriculture and residential use, while the forested reference reach between site H and OC Evans Road had minimal increases (+ 37%) (Table 15). After concluding the erosion inventory, it was determined that 27.3 % (1.09 km of 4.00 km) of the stream bank between site C and OC Warsaw were highly erodible while the stream bank between site H and OC Evans Road had only 10.0 % (0.40 of 3.59 km) highly erodible portion indicating the ultimate cause for soil loss in the Warsaw segment is due to stream bank erosion.

On the mainstem of Oatka Creek, with the exception of SRP (351 to 512 g/ha/yr), total phosphorus, nitrate, TN, and TSS areal load decreased from Warsaw to the mainstem site at Ellicott (TP: 40 g/ha/yr; nitrate: 12.5 kg/ha/yr; TN: 12.3 kg/ha/yr; TSS: 0.0 kg/ha/yr) (Fig. 2, Table 14), suggesting no major sources of nutrients are between both sites on the mainstem. Areal loads increased from the mainstem site at Ellicott to furthest downstream site at Garbutt (SRP: 592 g/ha/yr; TP: 1,165 g/ha/yr; nitrate: 83.5 kg/ha/yr; TN: 102.0 kg/ha/yr; TSS: 495.2 kg/ha/yr) (Figs. 2, Table 14) indicating sources of nutrient and sediment load between both mainstem sites.

The four upstream weekly monitoring sites (Evans Road, Buck Road, Warsaw, and Wyoming Road) (Fig. 2) had a greater areal nutrient and sediment load (mean –TP: 678 g P per/yr; TSS: 531.4 kg per ha/yr) (Table 14) than the four downstream (Ellicott Road, Roanoke Road, Parmelee Road, and Garbutt) monitoring locations (mean –TP: 527.3 g P per ha/yr; TSS: 191.8 kg per ha/yr) (Fig. 2, Table 14). Major nutrient and erosion issues in Oatka Creek appear to begin upstream from Ellicott (Fig. 2).

Monthly and Seasonal Loading (Fig. 13, Table 16)

Monthly and seasonal loading was measured for nutrients (SRP, TP, nitrate, and TN) and sediment (TSS) at the furthest downstream site at the USGS monitoring station in Garbutt, NY. In general, nutrients and sediment loads were low in the summer (June 2010 to August 2010) (Fig. 13, Table 16) and high in the spring (March 2011 to May 2011). Seasonally, the greatest loss of nutrients and soil from the Oatka watershed was in the spring (SRP: 2,211 kg P; TP: 5,846 kg P; TSS: 2,701,094 kg) (Table 16) and the lowest was in the summer (SRP: 666 kg P; TP: 1,527 kg P; TSS: 318,658 kg). Management practices need to focus on the spring when a substantial amount of discharge of water from the watershed occurs.

Chronological Account of Stressed Stream Analysis

12 July 2010: Entire Watershed (Fig. 14)

Segment analysis was performed on the Oatka Creek subwatershed to identify point and nonpoint sources of pollution under nonevent stream conditions. Samples were taken over a 4-hour period (10:53 am to 2:53 pm) under fairly cloudy skies with air temperatures in the low 80s (27-28 ^{o}C) at all sites. Of these sites, two which were non-mainstem sites, had no flow (site 3, site 6) (Fig. 14). Site 4 had low flow conditions. Analysis is provided below by reaches of the stream.

Upstream of Warsaw Sewage Treatment Plant (WWTP): Upstream of the Warsaw WWTP site are the "Headwaters" of the Oatka Creek subwatershed (Fig. 14). This upstream segment consists of three weekly monitoring locations: one mainstem (OC Warsaw), and two tributary sites (OC Evans Road and OC Buck Road) along with two mainstem initial segment sites (14 and 15).

Phosphorus: Soluble Reactive Phosphorus and TP levels were low at all sites with OC Buck Road (SRP: 18.2 µg P/L; TP: 29.3 µg P/L) and OC Evans Road (SRP: 19.4 µg P/L; TP: 40.6 µg P/L) (Fig. 15) having the highest concentrations.

Nitrogen: Nitrate concentrations were slightly elevated at sites upstream of the Warsaw WWTP site (mean = 1.32 mg N/L) compared to sites between the Warsaw WWTP and Leroy WWTP (mean = 1.06 mg N/L). Total nitrogen concentrations decreased slightly from headwater streams (e.g., site 15: 1.96 mg N/L) to the Warsaw WWTP (OC Warsaw: 1.53 mg N/L) indicating that no significant sources of nitrogen were between these sites. Site 15 had the highest concentration of nitrate (1.40 mg N/L) and TN (1.96 mg N/L) (Fig. 16) suggesting a source of nitrogen is upstream. Site 15 is directly downstream of OC Evans Road which also had elevated concentrations of nitrate (1.24 mg N/L) and TN (1.77 mg N/L). Both site 15 (Broughton Farm Operation LLC) and OC Evans Road (Double B Farms) have registered CAFOs upstream of the sampling site and are the likely sources of contaminants in the headwaters portion of the Oatka Creek subwatershed.

Total Suspended Solids and Total Coliforms: Site 15 had the highest TSS (5.33 mg/L) concentrations (Fig. 17) and total coliform abundances (12,300 CFU/100 mL) (Fig. 17), suggesting that a source of TSS and coliform bacteria is located upstream. Concentrations of TSS and total coliforms decreased as the water flowed downstream towards the Warsaw WWTP.

Between the Warsaw and Leroy Wastewater Treatment Plant (WWTP): Downstream of the Warsaw WWTP site and upstream of the Leroy WWTP site is the "Middle Portion" of the Oatka Creek subwatershed (Fig. 14). This middle segment has one mainstem weekly monitoring location (OC Ellicott St), two monitoring tributary sites (OC Wyoming Road and OC Roanoke Road), and seven mainstem segment sites (7-13).

<u>Phosphorus:</u> Soluble Reactive Phosphorus and TP concentrations increased substantially from site OC Warsaw (SRP: 5.2 µg P/L; TP: 18.2 µg P/L) (Fig. 15) to downstream from the Warsaw WWTP at site 13 (SRP: 47.5 µg P/L; TP: 93.5 µg P/L). The SRP and TP concentrations stayed consistently elevated from site 13 (47.5 µg P/L) to site 7 (69.0 µg P/L) along the mainstem, suggesting that the Warsaw WWTP site is a likely source of phosphorus to the headwaters of the Oatka Creek subwatershed. Soluble reactive phosphorus and TP concentrations increased slightly from middle mainstem site OC Ellicott St (SRP: 55.0 µg P/L; TP: 109.5 µg P/L) to downstream mainstem site 9 (SRP: 69.7 µg P/L; TP: 130.1 µg P/L) suggesting a small source of phosphorus is between these two sites. This source is not located in the OC Roanoke Road subwatershed as P concnetrations in the tributary are low (SRP: 16.0 µg P/L; TP: 40.4 µg P/L) indicating that the source is located on the mainstem. Soluble reactive phosphorus and TP concentrations upstream from the Pavilion WWTP at Site 10 (SRP: 48.8 µg P/L; TP: 98.0 µg P/L) slightly increased downstream from the Pavilion WWTP at OC Ellicott St (SRP: 55.0 µg P/L; TP: 109.5 µg P/L) indicating that the Pavilion WWTP is a likely source for phosphorus.

Wastewater Treatment Plant sites on the Oatka Creek subwatershed were significant sources of SRP and TP as concentrations upstream (OC Warsaw – SRP: 5.2 µg P/L;TP: 18.2 µg P/L) were much lower than concentrations downstream (site 13 – SRP: 47.5 µg P/L;TP: 93.5 µg P/L) (Fig. 15) of the Warsaw WWTP site. Similarly for the Leroy WWTP, concentrations upstream (site 7 – SRP: 69.0 µg P/L; TP: 114.6 µg P/L) were slightly lower than downstream (site 5 – SRP: 92.6 µg P/L; TP: 132.6 µg P/L) from the Leroy WWTP site. These results suggest that during low flow conditions, WWTP sites on the Oatka Creek subwatershed are significant sources of SRP and TP. Further analysis on the WWTPs is provided later.

Nitrogen: Nitrate and TN concentrations stayed consistently high as the water flowed from site OC Warsaw (nitrate: 1.29 mg N/L; TN: 1.53 mg N/L) through the Warsaw WWTP site (Fig. 16) to site 13 (nitrate: 1.35 mg N/L; TN: 1.84 mg N/L). Only after site 13 did nitrate and TN concentrations decrease to downstream site 12 (nitrate: 1.01 mg N/L; TN: 1.77 mg N/L) (Fig. 16). Nitrate and TN concentrations increased from site 11 (nitrate: 0.83 mg N/L; TN: 1.61 mg N/L) to downstream site 10 (nitrate: 1.09 mg N/L; TN: 1.89 mg N/L) suggesting a source of nitrogen is present between these two sites. Tributary site OC Wyoming Road may be a likely source of nitrogen. This tributary discharges water into the mainstem of the Oatka Creek subwatershed between sites 11 and 10 and had the highest nitrate (2.40 mg N/L) and TN (3.17 mg N/L) suggesting a likely source of nitrogen was upstream in this subwatershed.

Total Suspended Solids and Total Coliforms: Total suspended solid concentrations and total coliform abundances followed the same pattern as phosphorus, as concentrations on the mainstem increased substantially from above (TSS: 4.43 mg/L; total coliform: 3,900 CFU/100 mL) to below the Warsaw WWTP (TSS: 15.80 mg/L; total coliform: 13,700/CFU 100 mL) (Fig. 17). The WWTP site appears to be a source of TSS and coliform bacteria to the Oatka Creek subwatershed. Total suspended solid concentrations remained consistently high between the Warsaw and Leroy WWTPs. However, from site 8 (15.50 mg/L) to downstream site 7 (7.08 mg/L) (Fig. 17), just upstream from the Leroy WWTP, there is a decrease in TSS. This suggests that the TSS settled between these two sites and that no other sources of TSS were present. Total coliform abundances ranged from low (site 8: 2,300 CFU/100 mL) to high at upstream site 11 (16,000 CFU/100 mL), just below the Warsaw WWTP (Fig. 17).

Downstream from the Leroy Sewage Treatment Plant (WWTP): Downstream from the Leroy WWTP site is the “Downstream Section” of the Oatka Creek subwatershed (Fig. 14). This downstream segment contains two weekly discharge sites (OC Garbutt and OC Parmelee Road), with two mainstem initial segment sites (2 and 5) and two small tributary subwatershed sites (1 and 4). A “Carbonate rock aquifer” (Fig. 2) is located downstream from the Leroy WWTP. Site 5 is between this “Aquifer” where flow is present part of the time during event and high flow conditions.

<u>Phosphorus:</u> Similar to the results found at the stream region above and below the Warsaw WWTP site, SRP and TP concentrations increased from above the Leroy WWTP at mainstem site 7 (SRP: 69.0 µg P/L; TP: 114.6 µg P/L) to below the WWTP at mainstem site 5 (SRP: 92.6 µg P/L; TP: 132.6 µg P/L) (Fig. 15) indicating that the Leroy WWTP site is a likely source of phosphorus. Soluble reactive phopshorus and TP concentrations decreased consistently from upstream mainstem site 5 to downstream mainstem site 2 (SRP: 28.0 µg P/L; TP: 43.9 µg P/L). Tributary site 4 had low SRP (7.2 µg P/L) concentrations and high TP (88.2 µg P/L), indicating a source of phosphorus upstream. Soluble reactive phosphorus and TP concentrations also increased from site 2 to downstream mainstem site OC Garbutt (SRP: 38.2 µg P/L; TP: 73.7 µg P/L) suggesting a source of phosphorus, probably the CAFO site (D & D Dairy).

<u>Nitrogen:</u> Nitrate did not have the same relationship as phosphorus at the Leroy WWTP. Nitrate concentrations were similar above (site 7: 0.86 mg N/L) and below (site 5: 0.93 mg N/L) (Fig. 16) from the Leroy WWTP site. Total nitrogen concentrations gradually increased from site 5 (TN: 1.83 mg N/L) to site 2 (TN: 2.05 mg N/L) (Fig. 16) to downstream site OC Garbutt (2.19

mg N/L). Nitrate increased from site 5 (0.93 mg N/L) to downstream site 2 (1.80 mg N/L), suggesting a source of nitrate is between these two sites.

Total Suspended Solids and Total Coliforms: Above and below the Leroy WWTP, TSS concentrations remained consistently low and similar, but the total coliform abundances increased from site 7 above the WWTP (4,100 CFU/100 mL) to downstream site 5 (15,600 CFU/100 mL) (Fig. 17). The Leroy WWTP is a likely source of total coliform bacteria but not TSS on this sampling day. Tributary site 4 which is downstream of site 5 (7.20 mg/L) and upstream from site 2 (4.07 mg/L) had high TSS (site 4: 23.67 mg/L) (Fig. 17) concentrations but did not significantly impact the TSS concentrations on the mainstem due to low tributary flow. Site 4 also had low concentrations of SRP and high concentrations of TP suggesting that a source of phosphorus is upstream. Total coliform abundances were high at tributary site OC Parmelee Road, a site between sites 5 and 2, (31,100 CFU/100 mL) but did not impact the mainstem stream as total coliform decreased from upstream site 5 (15,600 CFU/100 mL) to downstream site 2 (8,300 CFU/100 mL) (Fig. 17). A source of coliform bacteria was present upstream of OC Parmelee Road and was investigated more closely.

Segment Analysis Conclusions – Entire Watershed

The Warsaw and Leroy WWTPs were significant sources of nutrients, total suspended solids, and coliform abundances on 12 July 2010 within the Oatka Creek watershed. As a result, all four WWTPs (Leroy, Warsaw, Pavilion, and Scottsville) were sampled (Warsaw: 3 August 2010, Leroy: 19 October 2010, Pavilion: 2 November 2010, Scottsville: 4 January 2011) by taking four samples up and downstream during baseline conditions to confirm the impact of the WWTP sites on Oatka Creek.

Confined animal feeding operation sites may also be contributing nutrients, total suspended solids, and coliform bacteria to the Oatka Creek subwatershed. Sites of concern which are associated with CAFO sites were upstream of site 15, Evans Road tributary, Wyoming Road tributary, and upstream from the Genesee Country Village (Site 1) (Fig. 2) on 12 July 2010 (Fig. 14). To further investigate this and pinpoint sources of pollution a stream segment analysis was conducted during ‘event’ and ‘nonevent’ conditions on Evans Road and Wyoming Road on 3 August 2010, 5 October 2010, and 6 October 2010. Sources upstream from tributary site 1 and headwater site 15 were also investigated more closely, and weekly water quality samples were taken both (Warsaw and Garbutt) downstream mainstem USGS monitoring stations. The Parmelee Road subwatershed may also have a source of coliform bacteria.

Headwaters (Evans Road)

5 October 2010: A Segment Analysis of the headwaters (Evans Road) (Fig. 18) (Under Event Conditions)

A segment analysis was performed upstream from Evans Road (Fig. 18) to identify point and nonpoint sources of pollution. Samples were taken over a 2-hour period (1:53 pm to 3:59 pm) under event conditions with air temperatures in the mid to upper 50s (13-15 ^{o}C) under cloudy skies. The headwaters (Evans Road) are made up of three subwatersheds (Fig. 18). All sample sites (OC Evans Road, B, B-1, C, D to D-2, E, E-1) were sampled.

<u>Subwatershed #1:</u> Subwatershed #1 consists of site B and upstream site B-1 (Fig. 18). Sub-watershed #1 is closest to the main discharge site at Evans Road and flows from East to West. The sample at site B was taken directly downstream of the Double B Farms CAFO site. Soluble reactive phosphorus and TP concentrations were elevated at site B-1 (SRP: 96.8 µg P/L; TP: 122.7 µg P/L) and stayed consistently elevated to site B (SRP: 111.4 µg P/L; TP: 171.5 µg P/L)

(Fig. 19). This suggests that sources of phosphorus are located upstream from both sample sites. While SRP and TP levels were elevated at site B-1, nitrate concentrations (0.24 mg N/L) and TN concentrations (1.08 mg /L) were low compared to downstream site B, which had extremely high nitrate and TN concentrations (nitrate: 5.30 mg N/L; TN: 6.14 mg N/L) (Fig. 19) compared to upstream site B-1. Upstream from site B is a CAFO (Double B Farms) (Fig. 19) which is positioned alongside the stream and is a likely source for nutrients. Total suspended solid concentrations were elevated at upstream site B-1 (29.1 mg/L) but decreased in concentration to downstream site B (7.9 mg/L) (Fig. 19). Due to elevated TSS concentrations, particle phosphorus may be the cause for high TP levels. Subwatershed #1 had extremely high coliform abundances when compared all other sites in the Evans Road tributary. Site B-1 had elevated coliform abundances (50,000 CFU/100 mL) and substantially increased to downstream site B (98,000 CFU/100 mL) indicating that the Double B Farms CAFO is a likely source of coliform bacteria between these two sites (Fig. 19).

Subwatershed #2: Subwatershed #2 is located just upstream from subwatershed #1. Sub-watershed #2 consists of three sample sites (D, D-1, D-2) and also flows from the east (Fig. 18). Soluble reactive phosphorus concentrations were elevated at upstream site D-2 (41.2 µg P/L) compared to the other two sites located on subwatershed #2 (D-1: 8.6 µg P/L; D: 7.5 µg P/L) (Fig. 19). This suggests a source of SRP upstream from site D-2. In relation with SRP, TP was also elevated at Site D-2 (103.0 µg P/L), decreased in concentration to downstream site D-1 (40.4 µg P/L), and increased slightly to furthest downstream site D (71.6 µg P/L) (Fig. 19).

Unlike the elevated phosphorus levels, site D-2 had no detectable nitrate along with downstream site D-1 (Fig. 18). Nitrate concentrations increased slightly at site D (0.13 mg N/L). While there were no detectable levels of nitrate at sites D-2 or D-1, TN concentrations were slightly elevated (D-2: 0.95 mg N/L; D-1: 1.00 mg N/L) (Fig. 19). Total nitrogen concentrations increased slightly at downstream site D (1.37 mg N/L), indicating a small source of nitrate and TN is upstream of site D (Fig. 19). Total suspended solid concentrations were low at site D-2 (4.5 mg/L) and downstream site D-1 (3.6 mg/L) (Fig. 19). Total suspended solid concentrations increased to furthest downstream site D (16.8 mg/L), indicating a source of TSS between sites D and D-1. Elevated TP concentrations could be attributed to an increase in TSS in the form of particulate phosphorus. Similar to phosphorus, total coliform abundances were elevated at upstream site D-2 (26,900 CFU/100 mL) and then decreased to downstream site D-1 (6,200 CFU/100 mL) (Fig. 19). This suggests a source of coliform bacteria is present upstream of site D-2. Total coliform abundance increased slightly from site D-1 to downstream site D (13,300 CFU/100 mL) (Fig. 19), indicating a source of coliform bacteria upstream from site D.

Subwatershed #3: Subwatershed #3 is located just upstream from subwatershed #1 and west of subwatershed #2. Subwatershed #2 consists of two sample sites (E, E-1) and flows from north to south (Fig. 18). Soluble reactive phosphorus and TP concentrations were slightly elevated at upstream site E-1 (SRP: 20.5 µg P/L; TP: 46.1 µg P/L) when compared to downstream site E (9.8 µg P/L; TP: 22.8 µg P/L) (Fig. 19) indicating a source of phosphorus upstream of site E-1. Similar to phosphorus, nitrate concentrations were slightly higher at site E-1 (0.45 mg N/L) when compared to downstream site E (0.28 mg N/L) (Fig. 19). Total nitrogen concentrations were slightly elevated at site E-1 (0.97 mg N/L) and remained slightly elevated to downstream site E (0.92 mg N/L) (Fig. 19) when compared to upstream site E-1. Similar to phosphorus, TSS concentration and total coliform abundances were slightly elevated at upstream site E-1 (TSS: 12.3 mg/L; coliform: 14,200 CFU/100 mL) and decreased downstream at site E (TSS: 4.0 mg/L;

coliform: 11,800 CFU/100 mL) (Fig. 19). This suggests a source of TSS and coliform bacteria upstream of site E-1 during event conditions.

19 October 2010: A Segment Analysis of the Headwaters (Evans Road) (Fig. 21) (Under Nonevent Conditions)

Another stream segment analysis was performed on 19 October 2010 to determine if the wetland acts as a sink for nutrients flowing from site D-2. Elevated nutrient concentrations upstream of site E-1 and downstream of site C are likely caused by agriculture (Fig.21).Samples were taken over a 1-hour period (9:48 am to 10:46 am) under event conditions with air temperatures in the mid to upper 50s (13-15 ^{o}C) under sunny skies. The Evans Road tributary is made up of three subwatersheds (Fig. 18). All sample sites (OC Evans Rd, C, D to D-2, E, E-1) were sampled, with the exception of subwatershed #1 which occupies Sites B and B-1and the Double B Farms CAFO due to no flow.

Subwatershed #2: Subwatershed #2 is located just upstream from subwatershed #1 and consists of three sample sites (D, D-1, D-2) (Fig. 18). Soluble reactive phosphorus and TP concentrations were highest at upstream site D-2 (SRP: 228.2 µg P/L; TP: 295.0 µg P/L) (Fig. 21) and decreased substantially to downstream site D (SRP: 6.0 µg P/L; TP: 48.3 µg P/L). These results suggest that the wetland between these two sites is likely acting as a nutrient sink or diluting nutrients flowing from upstream (Fig. 22). Nitrate concentrations were almost non-detectable in all three sites (D-2: No detection; D-1: <0.02 mg N/L; D: 0.03 mg N/L) suggesting no major source of nitrate in subwatershed #2. However, TN concentrations were slightly elevated at upstream site D-2 (1.37 mg N/L) when compared to nitrate and decreased slightly downstream (D-1: 1.06 mg N/L; D: 0.95 mg N/L) (Fig. 21) and may suggest that the agricultural field is the likely source of nutrients upstream from site D-2 (Fig. 22). Total suspended solid and total coliform concentrations remained consistently low among all sites in subwatershed #2 with the highest concentrations of TSS being at site D-1 (4.5 mg/L) and total coliform abundances at site D (3,000 CFU/100 mL) (Fig. 21).

Subwatershed #3: Subwatershed #3 is located just upstream from subwatershed #1 and flows to the west of subwatershed #2. Subwatershed #3 consists of two sample sites (E, E-1) and also flows from the north (Fig. 18). Soluble reactive phosphorus and TP concentrations decreased slightly from upstream site E-1 (SRP: 9.6 µg P/L; TP: 20.9 µg P/L) to downstream site E (SRP: 3.7 µg P/L; TP: 16.1 µg P/L) (Fig. 21). Nitrate and TN concentrations showed a different trend with nitrogen upstream at site E-1 (nitrate: non-detectable; TN: 0.34 mg N/L) (Fig. 21), increasing in concentration to downstream site E (nitrate: 0.66 mg N/L; TN: 1.20 mg N/L) (Fig. 21). These results suggest a likely source of nitrogen is upstream from site E but downstream of site E-1. Total suspended solid concentrations decreased slightly from upstream site E-1 (3.6 mg/L) to downstream site E (0.9 mg/L), indicating no TSS source between both sites (Fig. 21). Total coliform abundances showed a different relationship. Upstream at site E-1 (2,700 CFU/100 mL) (Fig. 21) had lower abundances than downstream site E (5,400 CFU/100 mL) suggesting a minor source, if any, coliform bacteria upstream from site E that is between sites E and E-1.

Mainstem sites: The mainstem of the Evans Road subwatershed consists of two sampling sites (C and OC Evans Rd). Site C is downstream from subwatersheds #2 and #3 but upstream of subwatershed #1 (Fig. 18). OC Evans Road is the furthest downstream site of the Evans Road tributary and is a weekly sample site. Soluble reactive phosphorus and TP concentrations decreased from upstream site C (SRP: 4.1 µg P/L; TP: 11.8 µg P/L) (Fig. 21) to downstream site OC Evans Road (SRP: 2.3 µg P/L; TP: 6.7 µg P/L) suggesting no source of phosphorus downstream of site C during nonevent conditions. Unlike phosphorus, nitrogen concentrations increased from site C (nitrate: 0.52 mg N/L; TN: 0.98 mg N/L) (Fig. 21) to the furthest downstream site OC Evans Road (nitrate: 1.17 mg N/L; TN: 1.56 mg N/L) indicating a likely source of nitrogen between these two sites. Since subwatershed #1 had no flow on 19 October 2011, the source is located on the mainstem of the tributary. However, TSS and total coliform abundances decreased from upstream site C (TSS: 1.8 mg/L; total coliform: 4,800 CFU/100 mL) (Fig. 21) to furthest downstream site OC Evans Road (TSS: 0.5 mg/L; total coliform: 1,600 CFU/100 mL) (Fig. 21).

Stream Segment Conclusions – Evans Road

During event conditions, the Double B Farms CAFO, which is just upstream of site B (Fig. 19) appeared to be a likely source of nitrogen in the Evans Road tributary (Figs. 19 and 20). Samples were taken on under nonevent conditions indicated that Double B Farms was a significant source of nutrients during event periods, but was not a source under nonevent conditions. Since subwatershed #1, which is occupied by the Double B Farms CAFO (Fig. 18), had no flow, the agricultural field upstream from site D-2 in subwatershed #2 is a likely source of phosphorus (Fig. 21). Phosphorus concentrations decreased substantially from the agricultural field to the wetland located at site D-1. These results suggest that the wetland at site D-1 acts as a nutrient sink for water flowing from site D-2 (Fig. 22). From the Digital Elevation Map (Fig. 23), the two retention ponds next to agricultural fields (Fig. 24) that slope towards the stream are likely sources of nitrogen. Just upstream is an agricultural field (corn) (Fig. 25) that slopes toward the mainstem which is likely a source for nitrogen.

Buck Road Tributary

15 March 2011: A Segment Analysis of Buck Road Tributary (Fig. 26)
(Under Nonevent Conditions)

A segment analysis was conducted on the Oatka Creek (OC) Buck Road subwatershed to identify sources of nutrients and erosion. Sixteen sites (OC Buck Road, A, B to B-2, C, D-1, E to

E-3, F to F-2 and G to G-1) (Fig. 26) were sampled over a 3-hour period (10:20 am to1:16 pm) under nonevent conditions with air temperatures in the mid to upper 50s (13-14 ^{o}C) under sunny skies. A sample was not obtained at site B and site F-2 due to private property.

Subwatershed #1

Subwatershed #1 consists of two stream arms (sites B-1, F and F-1) (sites B-2, G, and G-1). Soluble reactive phosphorus and TP concentrations were high at site F-1 (SRP: 42.4 µg P/L;TP: 54.6 µg P/L) when compared to all other sites in subwatershed #1 (range – SRP: 5.8 to 42.4 µg P/L; TP: 15.7 to 54.6 µg P/L) (Fig. 27) and decreased in concentration to downstream site F. Similar to phosphorus, nitrogen concentrations were high at site F-1 (nitrate: 4.92 mg N/L; TN: 5.10 mg N/L) when compared to all other sites in subwatershed #1 (range – nitrate: 1.24 to 4.94 mg N/L; TN:1.46 to 5.32 mg N/L) (Fig. 28) suggesting a likely source of nutrients upstream from site F-1. However, TSS concentrations indicated a different trend. Site G-1 had high TSS (23.8 mg /L) concentrations (subwatershed #1 range – 3.0 to 23.8 mg/L) (Fig. 27) suggesting a likely source of erosion upstream from site G-1. No major increases in nutrients or TSS were noticed downstream from sites F-1 and G-1. Total coliform abundances increased from upstream site F-1 (100 CFU/100 mL) to downstream site F (1,800 CFU/100mL) (Fig. 28).

Subwatershed #2

Subwatershed #2 consists of six sampling locations (sites C, D-1 and E to E-3) (Fig. 26). Soluble reactive phophorus and TP concentrations were generally low (range – SRP: 1.8 to 4.8 µg P/L; TP: 9.1 to 20.1 µg P/L) when compared to subwatershed #1 (range – SRP: 5.8 to 42.4 µg P/L; TP: 15.7 to 54.6 µg P/L) (Fig. 27). Total suspended solid concentrations were high at sites E-3 (13.3 mg/L) and D-1 (11.7 mg/L) when compared to all other sites in subwatershed #2 (range – 2.0 to 13.3 mg/L) (Fig. 27) suggesting a likely source of erosion upstream from sites D-

2 and E-3. Further observations were made on 10 August 2011 for sources of sediment erosion. Site C had elevated nitrogen concentrations (nitrate: 2.91 mg N/L; TN: 3.03 mg N/L) (subwatershed #2; mean – nitrate: 1.35 mg N/L; TN: 1.45 mg N/L) (Fig. 28) suggesting a likely source of nitrogen upstream from site C but downstream from sites E and D-1. Total coliform abundances ranged from low (site E-2: non-detectable) to high (1,200 CFU/100 mL) at site D-1 (Fig. 28).

Stream Segment conclusions – Buck Road

In subwatershed #1 and #2, likely sources of nutrients and sediment erosion are upstream from sites F-1 and G-1 and upstream from site C. Probable source areas upstream from those three sampling locations (sites G-1, F-1, and C) were due to manure applications on cropland.

Warsaw Segment

8 March 2011: A Segment Analysis upstream of Warsaw (Figs. 29 and 30)
(Under event Conditions)

A segment analysis was conducted on the Oatka Creek (OC) mainstem and tributaries upstream from Warsaw (Fig. 29) to identify sources of nutrients and erosion. Fifteen sites (OC Buck Road, OC Evans Road, OC Warsaw, A-J) (Fig. 29) were sampled over a 3.5-hour period (9:36 am to 1:13 pm) under event conditions with air temperatures in the low to mid 50s (10-12 ^{o}C) under cloudy skies. Out of the fifteen samples taken, five mainstem (OC Evans Road, OC Warsaw, sites C, E, and H) and ten tributary sites (OC Buck Road, sites A, B, D, F, G and I-L) were selected.

Confined animal feeding operation sites upstream from sites B and L are likely causes of elevated soluble reactive phoshporus and TP concentrations at sites B (SRP: 30.3 µg P/L; TP: 223.6 µg P/L) and L (SRP: 32.5 µg P/L; TP: 109.1 µg P/L) (Fig. 29) when compared to all other sites on the same day (mean – SRP: 9.8 µg P/L; TP: 42.0 µg P/L). Also, the CAFO upstream from site B may be a proximate cause for high TP concentrations observed at OC Buck Road (211.1 µg P/L) (Fig. 29). This was further investigated on 15 March 2011 to identify any sources of pollution upstream from OC Buck Road. Increases of TP on the mainstem were identified between sites H (36.5 µg P/L) to E (66.5 µg P/L), and site C (66.8 µg P/L) to furthest upstream site OC Warsaw (103.3 µg P/L) (Fig. 29). OC Buck Road (211.1 µg P/L), which is between mainstem site C and upstream mainstem site OC Warsaw, is a likely source of TP. However, sources of TP between sites E and H are unknown. An investigation was performed on 10 August 2011 to further identify sources of nutrients upstream from mainstem site E but downstream from mainstem site H.

Similar to TP, high TSS concentrations were identified at the tributary site OC Buck Road (97.3 mg/L) and mainstem site OC Warsaw (123.8 mg/L) when compared to all other sample sites (mean - 19.9 mg/L) (Fig. 29). Showing a similar trend as TP, major increases of TSS on the mainstem were identified between upstream site H (13.3 mg/L) and downstream site E (48.3 mg/L) (+ 363.2%), and between upstream site C (40.8 mg/L) and downstream site OC Warsaw (123.8 mg/L) (+ 303.4%) (Fig. 29). A stream bank erosion inventory was performed on 28 July 2011 to identify likely causes of erosion.

Nitrate and TN concentrations were high at tributary site A (nitrate: 5.89 mg N/L; TN: 6.05 mg N/L) and site I (nitrate: 10.23 mg N/L; TN: 10.32 mg N/L) when compared to all other sample sites (range – nitrate: 1.94 to 10.23 mg N/L; TN: 2.01 to 10.32 mg N/L) (Fig. 30). Sources of nitrogen were unknown, and a stream segment analysis was conducted on 15 March 2011 to further identify sources of nutrients. At the mainstem sites a major increase in nitrate were identified between upstream mainstem site OC Evans Road (nitrate: 2.62 mg N/L) to downstream mainstem site H (3.27 mg N/L) (+ 24.8%) (Fig. 30). The likely source of nitrate between these two mainstem sites is tributary site I (nitrate: 10.23 mg N/L) (Fig. 30). Total coliform abundances ranged from low (site L: non-detectable) to high (site C: 11,900/CFU 100 mL) (Fig. 30).

15 March 2011: A Segment Analysis of the CAFOs upstream from Warsaw and sampling of the Oatka Creek headwaters (Under Nonevent Conditions) (Fig. 31)

A segment analysis was conducted on the Oatka Creek (OC) CAFO sites upstream from OC Warsaw, with an addition to headwater sites for sources of nitrogen. Two CAFOs (Swiss Valley Farms and Broughton Farms) and four headwater samples (A-C and upstream from Swiss Valley Farms CAFO) (Fig. 31) were sampled over a 3-hour period (10:20 am to 1:16 pm) under nonevent conditions with air temperatures in the mid to upper 50s (13-14 ^{o}C) under sunny skies.

CAFO sampling

Swiss Valley Farms

Soluble reactive phophorus, TP, and total coliform abundances decreased from above Swiss Valley Farms (SRP: 9.0 µg P/L; TP: 24.5 µg P/L; total coliforms: 1,300 CFU/100 mL) to below (SRP: 1.4 µg P/L; TP: 8.3 µg P/L; total coliforms: 200 CFU/100 mL) (Fig. 31), suggesting that under nonevent conditions, Swiss Valley Farms is not a source of phosphorus and coliform bacteria. However, nitrate, TN and TSS concentrations increased substantially from above Swiss Valley Farms (nitrate: 0.14 mg N/L; TN: 0.37 mg N/L; TSS 12.8 mg/L) to below (nitrate: 6.83 mg N/L; TN: 6.85 mg N/L; TSS 15.4 mg/L) (nitrate: + 4,879%; TN: + 1,851 %; TSS: + 12 %) (Fig. 31), suggesting Swiss Valley Farms is a major source of nitrogen and sediment under nonevent conditions.

Broughton Farms

Soluble reactive phosphorus and TP concentrations were high downstream from Broughton Farms (SRP: 151.9 µg P/L; TP: 443.0 µg P/L) when compared to the headwater sites on the same day (mean – SRP: 11.0 μg P/L; TP: 53.6 μg P/L). Broughton Farms appears to be a likely source of phosphorus under nonevent conditions. A Digital Elevation Map (DEM, Fig. 32) illustrates that precipitate landing within the Broughton Farms runs downhill directly into Oatka Creek. Nitrate, TN, TSS, and total coliform abundances were not notably higher than at any other sites.

Headwater sites (A-C, upstream from Swiss Valley Farms)

Nitrate and TN concentrations were high at site B (nitrate: 8.54 mg N/L; TN: 10.44 mg N/L) (Fig. 31) when compared to the other three headwater sites (mean – nitrate: 0.65 mg N/L; TN: 1.01 mg N/L). Manure smell on cultivated cropland was noticeable upstream from site B and is the likely source of nitrogen. Low nitrogen concentrations upstream from cultivated cropland and CAFOs suggest that the major cause of nitrogen upstream from Warsaw is agricultural practices.

Wyoming Road Tributary

3 August 2010 Wyoming Road Tributary (Fig. 33)

A segment analysis was performed on the Oatka Creek Wyoming Road segment (Figs. 2 and 34) to identify sources of coliform bacteria and point and nonpoint sources of pollution. Samples were taken over a 5-hour period (10:35 am to 3:19 pm) under nonevent conditions with air temperatures in the mid to upper 70s (23-26 ^{o}C) under fairly cloudy skies.

Wyoming Road Tributary is made up of seven subwatersheds, five of which were sampled (Fig. 33). Subwatersheds 3 and 7 were not sampled because they were not easily accessible (subwatershed #3) from the road or had no flow (subwatershed #7). Segment sites E, G, and H had no flow on this sampling day.

Subwatershed #1: Subwatershed #1 occupies site E and upstream site E-1 (Fig. 33). Subwatershed #1 is the closest to the main discharge site at Wyoming Road. Site E had no flow, but upstream site E-1 had a low flow.

Soluble reactive phosphorus and TP levels were high at site E-1 (SRP: 102.2 µg P/L; TP: 159.9 µg P/L) when compared to all other sites on this sampling day (range – SRP: 13.2 to 328.9 µg P/L; TP: 40.0 to 1,268.8 µg P/L) (Fig. 34). Nitrate and TN concentrations were only slightly elevated (nitrate: 1.68 mg N/L; TN: 1.85 mg N/L) when compared to all other sites on the same day (range – nitrate: 0.05 to 14.40 mg N/L; TN: 0.93 to 15.50 mg N/L) (Fig. 35). The Bowhill Farms CAFO is located just upstream from site E-1 which may be a likely source for nutrients in the Wyoming Road tributary. Though nutrient concentrations were high, the TSS concentration was low at site E-1 (TSS: 4.9 mg/L) when compared to all other sampling sites on the same day (range – 2.5 to 183.0 mg/L) (Fig. 34). Evidence of total coliform bacteria was also present (coliform: 3,800 CFU/100 mL) (Fig. 35). Since site E, downstream of site E-1, had no flow during this sampling day, it is believed that subwatershed #1 had no impact on the Wyoming Road tributary on 3 August 2010.

Subwatershed #2: Subwatershed #2 is located just upstream from subwatershed #1 on a stream segment that branches off into two separate smaller subwatersheds (2a and 2b) (Fig. 33). One sampling site is located on subwatershed #2 (site F) which is downstream from both smaller subwatersheds. Subwatershed 2a is located on the western most segment of main sub-watershed #2 which has only one site (F-1). Site F-2 and upstream site F-3 are located on sub-watershed 2b.

Subwatershed 2a: Soluble reactive phosphorus concentrations increased from site F-1 (39.0 µg P/L) to downstream site F (85.6 µg P/L), but TP decreased slightly as the water flowed downstream (F-1: 113.1 µg P/L; F: 98.1 µg/L) (Fig. 34). This suggests that a source of SRP is between these two sites (F and F-1). Nitrate and TN concentrations were also high at site F-1 (nitrate: 3.51 mg N/L; TN: 3.87 mg N/L) (Fig. 35) but decreased in concentration from 3.51 mg N/L to 1.21 mg N/L and 3.87 mg N/L to 1.54 mg N/L at site F. The Bowhill Farms CAFO is a likely source of nitrogen upstream of site F-1. This is the same CAFO site that could be impacting subwatershed #1. Comparably, there was high TSS (87.5 mg/L) (Fig. 34) concentrations and high coliform abundances at site F-1 (13,700 CFU/100mL) when compared to downstream site F (TSS: 12.7 mg/L; coliform: 2,200 CFU/100 mL) (Figs. 34 and 35) suggesting sediment and bacteria sources upstream from site F-1.

Subwatershed 2b: Soluble reactive phosphorus and TP had little to no change in concentration from upstream site F-3 to site F-2 (Fig. 34). Similarly, nitrate and TN concentrations did not differ substantially from site F-3 to downstream site F-2 (Fig. 35). There was an increase in TSS (F-3: 13.0 mg/L; F-2: 35.3 mg/L) (Fig. 34) and coliform abundance (F-3: 2,900 CFU/100 mL; F-2: 11,800 CFU/100 mL) (Fig. 35) as water flowed from site F-3 to downstream site F-2. This suggests that a small source of TSS and coliform bacteria is present between sites F-3 and F-2.

Subwatershed #4: Subwatershed # 4 is located upstream from subwatershed #2 and is the fourth stream segment branching off the main stem of the Wyoming Road tributary (Fig. 33). Two sites, G and upstream site G-1 are located on subwatershed #4. On 3 August 2010 site G had no flow and site G-1 had low flowing conditions.

Soluble reactive phosphorus concentrations were low at site G-1 (19.4 µg P/L), but surprisingly TP concentrations were high (135.6 µg P/L) (Fig. 34). Nitrate (0.65 mg N/L) and TN (0.93 mg/L) were low at site G-1 (Fig. 35).The Victory Acres CAFO upstream from subwatershed #4 could be a likely source for TP and nitrogen. Total suspended solids and coliform abundances were also high at site G-1 (TSS: 135.3 mg/L; coliform: 10,600 CFU/100 mL) (Figs. 34 and 35), suggesting that the CAFO site could be contributing more than just nutrients to subwatershed #4. Since site G was dry, it is believed that subwatershed #4 had no impact on the Wyoming Road tributary on this sampling day.

Subwatershed #5: Subwatershed # 5 is located upstream from subwatershed #4 and further upstream from subwatershed #7 which was dry on 3 August 2010 (Fig. 33). One site (I) is located on Morrow Road in subwatershed #5.

Soluble reactive phosphorus concentrations were very low at site I (13.2 µg P/L) with slightly elevated levels of TP (88.6 µg P/L) when compared to all other sites (Fig. 34). Nitrate and TN concentrations were high (2.83 mg N/L) when compared to all other sample sites (Fig. 35) suggesting that a source of nitrogen is present upstream from site I. Comparably, high concentrations of TSS (80.1 mg/L) (Fig. 34) were also found when compared to all other sites on this day (range – 2.5 to 183.0 mg/L), but the total coliform bacteria abundances tended to be low (2,400 CFU/100 mL) (Fig. 35) compared to other subwatersheds in the Wyoming Road tributary. The source of TP, nitrogen, and TSS is still unknown.

Subwatershed #6: Subwatershed #6 is located at the headwaters of the Wyoming Road tributary and is the furthest most upstream subwatershed (Fig. 33). Site D-1 is the only site located on subwatershed #6 and is the most upstream site on this tributary.

Soluble reactive phosphorus concentrations were low at site D-1 (36.2 µg P/L) but had the second highest TP concentration (358.8 µg P/L) when compared to all other sites on this day (Fig. 34). Just downstream at site D, which is the most upstream mainstem site for the Wyoming Road tributary, SRP and TP concentrations increased from 36.2 µg P/L to 328.9 µg P/L and 358.8 µg P/L to 1,268.8 µg P/L. A major source of phosphorus is present between site D-1 and site D. Site D is located in the center of a marsh in which duckweed and phytoplankton were observed. The percentage of SRP was small (D = 25.9%, D-1 = 10.1%) suggesting that much of the SRP is taken up by duckweed and phytoplankton. Similar to TP, site D-1 had highest concentrations of nitrate (14.4 mg N/L) and TN (15.8 mg N/L) (Fig. 35). Concentrations of nitrate lowered substantially from site D-1 to near downstream site D (0.05 mg N/L) (Fig. 35). This suggests that the plants and phytoplankton were taking up the available nitrogen coming from site D-1 to downstream site D (Mitsch and Gosselink 2000). Site D-1 had the highest concentrations of TSS (183.0 mg/L) (Fig. 34) and coliform abundances (90,000 CFU/100 mL) (Fig. 35). This suggests a source of phosphorus, nitrogen, TSS, and total coliform bacteria is present upstream of site D-1. The Logwell Acres CAFO is located upstream from site D-1 which could be the cause of elevated nutrients present at site D-1.

Tributary Mainstem Sites: Four sampling sites are located on the mainstem of the Wyoming Road tributary (Fig. 33). These sites are the main discharge site at OC Wyoming Road and sites A, B, and D which are in order from downstream to upstream.

Soluble reactive phosphorus and TP concentrations decreased from upstream site D (328.9 μg P/L) to downstream site B (17.0 μg P/L) then had little change in concnetration to the main discharge site at OC Wyoming Road (17.5 μg P/L) (Fig. 34). These results suggest that during baseline conditions, much of the phosphorus comes from the marsh located at site D. Even though subwatershed #2 had high concentrations of SRP (85.6 μg P/L) and TP (98.1 μg P/L), it did not have enough phosphorus load to increase the SRP and TP concentrations from site A to the main discharge site.

Nitrate concentrations increased from upstream site B (0.29 mg N/L) to site A (1.58 mg N/L) to OC Wyoming Road (2.10 mg N/L) (Fig. 35). These results suggest that sources of nitrogen are between site B and site A, and also between site A and OC Wyoming Road. This indicates that the sources of nitrogen are coming from areas surrounding the mainstem between these sites (B, A, OC Wyoming Road).

Total suspended solids did not have the same pattern as nitrogen in that concentrations decreased from upstream site D (34.7 mg/L) to the OC Wyoming Road (2.5 mg/L) (Fig. 34). Total coliform abundance decreased from site D (12,900 CFU/100 mL) to site B (700 CFU/100 mL) and varied slightly downstream (Site A: 2,800 CFU/100 mL; Main discharge site: 1,500 CFU/100 mL) (Fig. 35). This suggests that a possible source of coliform bacteria is present between sites B and A.

6 October 2010: A Segment Analysis of Wyoming Road Tributary (Fig. 38) (Under Event Conditions)

A segment analysis was performed on the Oatka Creek (OC) Wyoming Road tributary (Fig. 38) to further identify point and nonpoint sources of pollution during a rain event. Samples were taken over a 2.5-hour period (12:24 pm to 3:00pm) under event conditions with air temperatures in the mid to upper 50s (13-15 ^{o}C) under cloudy skies. Wyoming Road Tributary is made up of seven subwatersheds, six of which were sampled (Fig. 38). Two additional sites (site G-2; D-2) were added to the 3 August 2010 nonevent segment analysis to further identify sources of pollution.

Subwatershed #1: Subwatershed #1 consists of site E and upstream site E-1 (Fig. 38). Subwatershed #1 is the closest to the main site at Wyoming Road. On 3 August 2010, site E had no flow. Both site E and E-1 had flow on 6 October 2011. Soluble reactive phosphorus and TP concentrations were elevated at upstream site E-1 (SRP: 145.8 µg P/L; TP: 201.3 µg P/L) when compared to downstream site E (SRP: 77.6 µg P/L; TP: 95.2 µg P/L) (Fig. 39). Similar to phosphorus, nitrogen concentrations were extremely elevated at both site E-1 (nitrate: 4.38 mg

N/L; TN: 5.44 mg N/L) and downstream site E (nitrate: 5.51 mg N/L; TN: 6.64 mg N/L) when compared to all other segment sites in the Wyoming Road tributary (range – nitrate: 0.99 to 7.05 mg N/L; TN: 1.78 to 8.00 mg N/L) (Fig. 40). Total suspend solid concentrations decreased from site E-1 (5.0 mg/L) to downstream Site E (3.5 mg/L) (Fig. 39) while total coliform abundances decreased from site E-1 (46,000 CFU/100 mL) to downstream site E (36,000 CFU 100 mL) (Fig. 39). These results suggest that the Bowhill Farms CAFO site (Fig. 40) is the ultimate cause of nutrients and coliform bacteria during event periods.

Subwatershed #2: Subwatershed #2 is located just upstream from subwatershed #1 on a stream segment that branches off into two separate smaller subwatersheds (2a and 2b) (Fig. 38). One sampling site is located on subwatershed #2 (site F) which is downstream from both smaller subwatersheds. Subwatershed 2a located on the western most segment of main subwatershed #2 which has only one site (F-1). Site F-2 and upstream site F-3 are located on sub-watershed 2b.

Subwatershed 2a: Soluble reactive phosphorus and TP concentrations increased slightly from site F-1 (SRP: 38.0 µg P/L; TP: 90.9 µg P/L) to downstream site F (SRP: 83.7 µg P/L; TP: 125.5 µg P/L) (Fig. 39), indicating a source of phosphorus is likely present upstream of site F but below site F-1. Unlike phosphorus, nitrogen concentrations were extremely high at upstream site F-1 (nitrate: 6.63 mg N/L; TN: 8.00 mg N/L) when compared to downstream site F (nitrate: 2.27 mg N/L; TN: 3.30 mg N/L) (Fig. 36). This indicates a major source of nitrogen upstream of site F-1 during event periods. Total suspended solids were high and total coliform abundances were low (site F-1, TSS: 7.4 mg/L; coliform: 16,100 CFU/100 mL) in comparison to the rest of the Wyoming Road tributary (range – TSS: 0.4 to 12.9 mg/L; coliform: 8,600 to 66,000 CFU/100 mL) (Figs. 39 and 40) suggesting subwatershed 2a, which is just downstream from the Bowhill

Farms CAFO site, is a source of nutrients and sediment rather than coliform bacteria during event periods.

Subwatershed 2b: Soluble reactive phosphorus and TP had little to no change in concentration from upstream site F-3 to site F-2 (Fig. 39), while nitrate and TN concentrations did not differ from site F-3 to downstream site F-2 (Fig. 40). Total suspended solid concentrations increased slightly from site F-3 (6.9 mg/L) to downstream site F-2 (8.5 mg/L) (Fig. 39) suggesting no major source of sediment between these two sites. Total coliform abundances were highest at upstream site F-3 (66,000 CFU/100 mL) when compared to all other sampling sites and decreased slightly as the water flowed downstream (site F-2: 44,000 CFU/100 mL) suggesting the Bowhill Farms CAFO site is a likely source of coliform bacteria. Sampling above and below Bowhill Farms was conducted on 29 March 2011 to determine the effects of the CAFO site.

Subwatershed #4: Subwatershed #4 is located upstream from subwatershed #2 and is the fourth stream segment branching off the main stem of the Wyoming Road tributary (Fig. 38). Three sites, G, G-1, and upstream site G-2, are located on subwatershed #4. Site G-2 is a new site added on 6 October 2010. No major sources of phosphorus were detected between sites during the event. Soluble reactive phosphorus and TP concentrations were low at all three sample sites when compared to the rest of the sampling sites (Fig. 39). Concentrations increased slightly as the water flowed from site G-2 (4.6 µg P/L) to G-1 (16.4 µg P/L) to furthest downstream site G (20.8 µg P/L) (Fig. 39).

Unlike phosphorus, nitrogen concentrations were slightly elevated at upstream site G-2 (nitrate: 2.38 mg N/L; TN: 3.01 mg N/L) when compared to all other sample sites (range – nitrate: 0.99 to 7.05 mg N/L; TN: 1.88 to 8.00 mg N/L) (Fig. 40). Nitrogen levels stayed consistently elevated as the water flowed downstream to site G (nitrate: 2.69 mg N/L; TN: 3.37

mg N/L). Total suspended solid and coliform abundances were low when compared to the other sample sites (range – TSS: 0.4 to 12.9 mg/L; coliform: 8,600 to 66,000 CFU/100 mL) and had very little variation from site G-2 (TSS: 2.8 mg/L; coliform: 8,600 CFU/100 mL) to downstream site G (TSS: 4.5 mg/L; coliform: 12,700 CFU/100 mL) (Figs. 39 and 40). Sub-watershed #4 is only a minor source of nitrogen during event periods resulting from the Victory Acres CAFO site.

Subwatershed #5: Subwatershed #5 is located upstream from subwatershed #4 and further upstream from subwatershed #7 (Fig. 38). One site (I) is located in subwatershed #5. Phosphorus was low and nitrogen concentrations were elevated at site I (SRP: 22.2 µg P/L; TP: 71.5 µg P/L; nitrate: 7.05 mg N/L; TN: 7.28 mg N/L) (Figs. 39 and 40) when compared to all other sample sites (range – nitrate: 0.99 to 7.05 mg N/L; TN: 1.88 to 8.00 mg N/L) suggesting a likely source of nutrients upstream from site I. Total suspended solid and total coliform abundances were low (TSS: 4.2 mg/L; coliform: 12,400 CFU/100 mL) (Figs. 39 and 40) suggesting no major source of TSS and coliform bacteria was present upstream from site I during event periods. Victory Acres CAFO site expands to the upstream reach of subwatershed #5 and is the likely cause of elevated nutrients.

Subwatershed #6: Subwatershed #6 is located at the headwaters of the Wyoming Road tributary and is the furthest most upstream subwatershed (Fig. 38). Field observations within subwatershed #6 revealed that site D-1 comes from a discharge pipe leading up to a household (Fig. 41). Site D-2 is the actual stream that discharges water from subwatershed #6, which was not sampled previously, and was added on 6 October 2010; site D-1 flows into the stream that site D-2 occupies. Phosphorus concentrations at site D-2 (SRP: 174.7 µg P/L; TP: 216.5 µg P/L) were elevated when compared to site D-1 (SRP: 45.9 µg P/L; TP: 77.3 µg P/L) (Fig. 39), suggesting the source of phosphorus in sub-watershed #6 is likely upstream from site D-2. Similar to phosphorus, nitrogen levels were extremely elevated at both site D-1 (nitrate: 5.86 mg N/L; TN: 6.40 mg N/L) and site D-2 (nitrate: 5.28 mg N/L; TN: 6.79 mg N/L) when compared to all other sample sites (range – nitrate: 0.99 to 7.05 mg N/L; TN: 1.88 to 8.00 mg N/L) (Fig. 40), suggesting likely sources (drainage pipe and Logwell Acres CAFO site) of nitrogen upstream of both sites (D-1 and D-2). The Logwell Acres Inc. CAFO is located at the headwaters of subwatershed #6 which is a likely source for nutrients (Figs. 39 and 40). Total suspended solid concentrations were low at both sites, but there was an abundance of total coliform bacteria at site D-2 (54,000 CFU/100 mL) suggesting Logwell Acres is also a likely source of coliform bacteria.

Subwatershed #7: Subwatershed #7 is located downstream from subwatershed #5 and #6 but further upstream from subwatershed #4 (Fig. 38). One site (H) is located in subwatershed #7. Nutrient concentrations were elevated at site H (SRP: 99.9 µg P/L; TP: 299.1 µg P/L; nitrate: 2.64 mg N/L; TN: 3.63 mg N/L) (Figs. 39 and 40) suggesting Logwell Acres Inc. is likely negatively impacting subwatershed #7. Sampling above and below Logwell Acres was conducted on 29 March 2011 to determine the effects of the CAFO on subwatershed #7. Total suspended solid concentrations and total coliform abundances were slightly elevated at site H (TSS: 8.0 mg/L; coliform: 28,100 CFU/100 mL) (Figs. 39 and 40) when compared to the other sampling sites suggesting subwatershed #7 is a source of TSS and coliform bacteria during event periods.

Tributary Mainstem Sites: Four sampling sites are located on the main stem of the Wyoming Road subwatershed (Fig. 38). These sites consist of OC Wyoming Road and sites A, B, and D which are in order from downstream (OC Wyoming Road) to upstream (site D). Phosphorus concentrations varied slightly from upstream site D (SRP: 45.9 µg P/L) to 22.3 µg P/L to 39.8 µg P/L and then increased at site OC Wyoming Road (64.0 µg P/L) (Fig. 39). These results suggest that subwatersheds #1 and #2 (Fig. 38) which are between site A and OC Wyoming Road, are likely sources of phosphorus load during event conditions in the Wyoming Road tributary.

Nitrogen concentrations increased slightly as the water flowed from upstream site D (nitrate: 1.25 mg N/L) to B (1.80 mg N/L) to A (1.92 mg N/L) and then increased substantially to furthest downstream site at OC Wyoming Rd (3.10 mg N/L) (Fig. 40) suggesting a major source of nitrogen between subwatersheds #1 and #2. Subwatershed #1 site E, which is just upstream of OC Wyoming Road, had elevated nitrate (5.51 mg N/L) concentrations when compared to site OC Wyoming Road. These results suggest that the Bowhill Hill Farms CAFO site identified on 3 August 2010 may impact the Wyoming Road subwatershed during event conditions. Total suspended solid and total coliform abundances varied slightly from upstream site D (TSS: 2.0 mg/L; coliform: 14,400 CFU/100 mL) to furthest downstream site OC Wyoming Road (TSS: 12.9 mg/L; coliform: 17,200 CFU/100 mL) (Figs. 39 and 40) indicating that during event conditions the Wyoming Road subwatershed is discharging by nutrients, TSS, and perhaps coliform bacteria to the Oatka Creek subwatershed.

29 March 2011: Analysis of the Wyoming Road CAFOs (Fig. 42)
(Under Nonevent Conditions)

A segment analysis was conducted on the Oatka Creek (OC) two CAFO sites in the Wyoming Road subwatershed. Two CAFOs (Logwell Acres and Bowhill Farms) (Fig. 42) were sampled over a 35- minute period (12:55 pm to 1:30 pm) under nonevent conditions with air temperatures in the upper 50s (14 ^{o}C) under partly cloudy skies.

Logwell Acres

Soluble reactive phosphorus, TP, TSS, and total coliform abundances decreased from above the Logwell Acres CAFO (SRP: 76.0 µg P/L; TP: 164.4 µg P/L; TSS 12.5 mg/L; total coliform: 1,300 CFU/100 mL) to below (SRP: 52.8 µg P/L; TP: 66.8 µg P/L; TSS 2.5 mg/L; total coliform: non-detectable) (Fig. 42), respectively. However, nitrogen concentrations were higher below Logwell Acres (nitrate: 8.60 mg N/L; TN: 8.77 mg N/L) than above (nitrate: 2.87 mg N/L; TN: 4.17 mg N/L) (nitrate: + 300 %; TN: + 214 %) (Fig. 42) indicating that the Logwell Arces CAFO is a likely source of nitrogen in the Wyoming Road subwatershed.

Bowhill Farms

Similar to Logwell Arces, TP and TSS concentrations decreased from above Bowhill Farms (TP: 102.2 µg P/L; TSS: 22.5 mg/L) to below (TP: 33.3 µg P/L; TSS: 3.7 mg/L) (Fig. 42). Nitrogen levels were higher downstream from Bowhill Farms (nitrate: 2.61 mg N/L; TN: 2.79 mg N/L) than upstream (nitrate: 0.35 mg N/L; TN: 1.59 mg N/L) (nitrate: + 746 %; TN: + 175 %) (Fig. 52). Similar to Logwell Acres, the Bowhill Farms CAFO is a probable source of nitrogen to the Wyoming Road subwatershed.

Stream Segment conclusions – Wyoming Road

The Bowhill Farms CAFO cow barn, which is just upstream of the retention pond (Fig. 36), drains runoff from the barn into the pond. This pond is a proximate source of nutrients and coliform bacteria in subwatershed 2a, while the Bowhill Farms CAFO site is likely the ultimate source. The Logwell Acres Inc. CAFO upstream from subwatershed # 6 and #7 and Victory Acres CAFO site were also sources of nutrients and sediment in the Wyoming Road subwatershed. The Wyoming Road subwatershed is mainly agriculture land use which is the ultimate cause for degraded water quality within this reach.

Roanoke Road Tributary

6 October 2010: A Segment Analysis of Roanoke Road Tributary (Fig. 43) (Under Event Conditions)

A segment analysis was performed on the Oatka Creek (OC) Roanoke Road tributary (Fig. 43) to identify point and nonpoint sources of pollution. Samples were taken over a 2-hour period (9:50 am to 11:37 am) under event conditions with air temperatures in the mid to upper 50s (13-15 ^{o}C) under cloudy skies. Roanoke Road tributary is made up of two subwatersheds (A and B) (Fig. 43). All sample sites (OC Roanoke Rd, A, B, B-1, B-3, C, C-1, D, D-1, D-2, D-3) were sampled except for two (B-2: no sample taken; B-4: Dry).

Subwatershed #1: Subwatershed #1 consists of five sample sites (B, B-1, B-2, B-3, B-4), two of which were not sampled (B-2, B-4) (Fig. 43). Site B-4 had no flow and site B-2 was under construction (ditch repair) and no sample was taken at the time of sampling. Soluble reactive phosphorus and TP concentrations were low at site B-3 (SRP: 8.3 µg P/L; TP: 55.7 µg P/L) compared to downstream site B-1 (SRP: 74.8 µg P/L; TP: 140.1 µg P/L) (Fig. 44). This suggests a source of phosphorus is located upstream of site B-1 but downstream of site B-3. Soluble reactive phosphorus and TP concentrations decreased as the water flowed downstream to site B (SRP: 45.9 µg P/L; TP: 99.8 µg P/L) (Fig. 44). Nitrate and TN concentrations (Fig. 45) were slightly elevated at site B-3 (nitrate: 1.21 mg N/L; TN: 2.91 mg N/L) and decreased in concentration as water flowed to site B-1 (nitrate: 0.39 mg N/L; TN: 1.56 mg N/L), indicating a source of nitrogen upstream of site B-3. Concentrations increased slightly downstream at site B (nitrate: 0.73 mg N/L; TN: 1.83 mg N/L) (Fig. 45) suggesting a small source of nitrogen between sites B and B-1 (Fig. 45). Total suspended solid concentrations remained consistently low from site B-3 (5.1 mg/L) to downstream site B-1 (3.6 mg/L) to furthest downstream site B (5.3 mg/L). Similar to phosphorus, total coliform abundances were low at site B-3 (11,900 CFU/100 mL) when compared to downstream site B-1 (50,000 CFU/100 mL) (Fig. 45). Abundances decreased as the water flowed to site B (14,100 CFU/100 mL) suggesting a noticeable source of coliform bacteria only exists between site B-1 and upstream site B-3 (Fig. 45).

Subwatershed #2: Subwatershed #2 is located next to subwatershed #1 in which they both merge at one location on the mainstem. Subwatershed #2 branches off into two separate smaller subwatersheds (2a and 2b) (Fig. 43). One sampling site is located at the mouth of subwatershed #2 (site A) which is downstream from both smaller subwatersheds. Subwatershed 2a is located on the western most segment of main subwatershed #2 which has two sites (C and C-1). Subwatershed 2b located on the eastern most segments of main subwatershed #2 occupies four sampling sites (D, D-1, D-2, D-3).

Subwatershed 2a: Soluble reactive phosphorus and TP concentrations were highest at site C (SRP: 362.4 µg P/L; TP: 528.6 µg P/L) and upstream site C-1 (SRP: 421.9 µg P/L; TP: 728.0 µg P/L) (Fig. 44). Concentrations decreased as the water flowed from site C-1 to site C, indicating a source of phosphorus upstream of site C-1. Similar to phosphorus, nitrate and TN concentrations were also highest at site C and C-1 (Fig. 45). Nitrogen concentrations decreased from site C-1 (nitrate: 4.21 mg N/L; TN: 7.20 mg /L) to downstream site C (nitrate: 3.94 mg N/L; TN: 6.02 mg /L), indicating a source of nitrogen upstream of site C-1. Upstream of site C-1 is a CAFO (Barniak Farms) that is a likely source for nutrients (Fig. 44). Total suspended solid and total coliform abundances were also highest at site C-1 (TSS: 16.5 mg/L; coliform: 64,000 CFU/100 mL) but decreased slightly as the water flowed to site C (TSS: 9.0 mg/L; coliform: 56,000/CFU 100 mL) suggesting Barniak Farms is a likely source of TSS and coliform bacteria. A Digital Elevation Map illustrates that precipitate falling within Barniak Farms would flow directly downhill into the stream (Fig. 46).

Subwatershed 2b: Soluble reactive phosphorus and TP concentrations were highest at upstream site D-3 (SRP: 132.4 µg P/L; TP: 174.1 µg P/L) then decreased to downstream site D-2 (SRP: 53.0 µg P/L; TP: 94.7 µg P/L) (Fig. 43). Similar to phosphorus, site D-3 was elevated in both nitrate (1.82 mg N/L) and TN (2.75 mg N/L) when compared to downstream site D-2 (nitrate: 1.41 mg N/L; TN: 2.14 mg N/L). Nitrogen concentrations had very little variation as water flowed downstream; indicating the likely source for nutrients is upstream of site D-3 (Figs. 44 and 45). Different from phosphorus and nitrogen, TSS concentrations were low at site D-3 (2.7 mg/L) and progressively became higher as the water flowed downstream (site D-2: 9.3 mg/L; site D-1 10.0 mg/L) (Fig. 44) until it reached the furthest downstream sample site (site D: 12.6 mg/L). Total coliform abundances were variable throughout subwatershed 2b. Abundance increased from site D-3 (32,000 CFU/100 mL) to downstream site D-2 (52,000 CFU/100 mL) (Fig. 45), suggesting either a possible source upstream of site D-2 or a slug of water from upstream of site D-3 reached site D-2. A source of coliform bacteria is likely present upstream of site D-3. Abundance then decreased slightly at downstream site D-1 (21,400 CFU/100 mL) and then increased to furthest downstream site D (34,000 CFU/ 100 mL) (Fig. 45).

No increases in nutrients, TSS, or total coliform abundances were found from subwatersheds 2a and 2b to downstream site A (outlet of subwatershed #2) (Figs. 44 and 45). Increases in analyzed analytes from site D to downstream site A were likely from extremely high nutrient concentrations and total coliform abundances from subwatershed 2a.

Stream Segment Conclusions – Roanoke Road

Main sources of nutrients, sediment, and coliform bacteria were from subwatershed 2a where Barniak Farms is located upstream of site C-1. Barniak Farms is a likely cause for elevated nutrient and bacteria levels in the Roanoke Tributary.

Parmelee Road Tributary

27 July 2010: Segment Analysis of Parmelee Road Tributary (Fig. 47)

A segment analysis was performed on the Oatka Creek Parmelee Road tributary (Fig. 47) to identify sources of coliform abundances previously encountered (12 July 2010). Samples were taken under nonevent conditions with air temperatures in the low 80s (28 ^{o}C) under sunny skies.

OC Parmelee Road had high coliform abundances (7,500 CFU/100 mL) (Fig. 47) indicating sources of coliform upstream. Sites A and B, which are located in different upstream segments, had elevated coliform abundances (site A: 14,300 CFU/100 mL; site B: 3,000 CFU/100 mL) (Fig. 47). Site A had very low flow but high coliform abundances suggesting sources upstream. Site B-1 had elevated coliform abundances (10,400 CFU/100 mL) compared to downstream site B indicating coliform sources upstream but not downstream from site B-1. An agricultural field is located just upstream from OC Parmelee Road but manure smell was not present during the period of sampling.

3 August 2010: Segment Analysis of Parmelee Road

A segment analysis was performed on the Oatka Creek Parmelee Road to identify sources of coliform bacteria and point and nonpoint sources of pollution. Samples were taken over a 5-hour period (10:35 am to 3:19 pm) under nonevent conditions with air temperatures in the mid to upper 70s (23-26 ^{o}C) under fairly cloudy skies.

From upstream to downstream location, total coliform abundances decreased. Site B-3 had an abundance of 46,000 CFU/100 mL total coliform and dropped to 1,400 CFU/100 mL at site B-1 and then increased at site B to 29,000 CFU/100 mL (Fig. 48). Sources of coliform abundance are still unknown, but a few possible areas might be contributing coliform bacteria into the tributary. Two private ponds are located upstream of site B (29,000 CFU/100 mL) (Fig. 48). The ponds, which are located on private property, cannot be observed from the road. Agricultural practices surround both ponds, suggesting that these ponds could be used for retention purposes. Runoff from the farm field into the retention pond could cause increased abundances of total coliform due to manure spread on the fields for fertilizer. However, manure smell was not present during the time of collection. Another possible source is an occupied mobile home which is located just upstream of site B-3. This area was not maintained, and garbage was located in multiple places outlining the edges of the stream.

7 June 2011: A Segment Analysis of Parmelee Road subwatershed (Fig. 49) (Under Nonevent Conditions)

A second segment analysis was conducted on the Oatka Creek (OC) Parmelee Road sub-watershed (Fig. 49) to further identify sources of elevated nutrients. Ten sampling sites (OC Parmelee Road, B, B-1, B-3 to B-5 and A to A-3) (Fig. 49) were sampled over 3.5- hour period (2:18 pm to 5:49 am) under nonevent conditions with air temperatures in the mid-70s (24 ^{o}C) under sunny skies.

Sites A to A-3

Soluble reactive phosphorus, TP, and TSS concentrations were highest at furthest upstream site A-3 (SRP: 115.0 µg P/L; TP: 218.7 µg P/L; TSS: 14.9 mg/L) (Fig. 50), suggesting a small source of phosphorus and TSS upstream from site A-3. Soluble reactive phosphorus, TP, and TSS levels also increased from upstream site A-1 (SRP: 0.3 µg P/L; TP: 7.4 µg P/L; TSS: 2.7 mg/L) to downstream site A (SRP: 3.8 µg P/L; TP: 12.3 µg P/L; TSS: 6.1 mg/L) (Fig. 50), suggesting a likely source upstream from site A, but downstream from A-1.

Similar to phosphorus and TSS, nitrogen concentrations were high at site A-3 (nitrate: 2.11 mg N/L; TN: 3.05 mg N/L) when compared to downstream site A-2 (nitrate: 1.29 mg N/L; TN: 1.96 mg N/L) (Fig. 51). Nitrogen concentrations also increased from upstream site A-1 (nitrate: 1.46 mg N/L; TN: 3.53 mg N/L) to downstream site A (nitrate: 1.95 mg N/L; TN: 3.53

mg N/L) (nitrate: + 34 %; TN: + 119 %) (Fig. 51). Total coliform abundances increased from upstream site A-3 (1,500 CFU/100 mL) to downstream site A-2 (3,900 CFU/100 mL) (Fig. 51) suggesting a likely source of coliform bacteria between sites A-3 and A-2. Further observations were made upstream from site A-3 and between sites A and A-1 on 10 August 2011 to determine likely sources of nutrients.

Sites B, B-1, and B-3 to B-5

Soluble reactive phosphorus, TP, and TSS concentrations were highest at site B-3 (SRP: 11.7 µg P/L; TP: 44.1 µg P/L; TSS: 7.4 mg/L) (Fig. 51) suggesting a source of phosphorus and TSS upstream from site B-3. The stream segment analysis performed on 3 August 2010 (Fig. 48) concluded that a small residence was a source of high coliform bacteria and a likely source for nutrients. Similar to phosphorus and TSS, nitrogen levels were highest at site B-3 (nitrate: 2.11 mg N/L; TN: 2.98 mg N/L) (Fig. 51) indicating that the residence is also a source of nitrogen. Total coliform abundances ranged from low (site B-1: non-detectable) to high (site B-4: 6,000 CFU/100 mL) (Fig. 51), suggesting a coliform bacteria source upstream from site B-4 but downstream from site B-5. A visit to the residence was conducted on 10 August 2011 to determine the treatment system used at the residence.

Stream Segment conclusions – Parmelee Road

Agriculture (corn) is the dominate land use in this area and a windshield survey of operations next to source areas in the Parmelee Road tributary concluded that agricultural practices, which is the only visible source, was the cause of elevated nutrients and coliform abundances.

The residence found to be a source of coliform bacteria on 7 June 2011 is also a likely source of nutrients. The residence was visited on 10 August 2011 and determined the waste treatment method implemented was a septic system.

Big Spring Creek

12 July 2010: Genesee Country Village Culvert Results *(Table 17)*

Big Spring Creek is located upstream of the Genesee Country Village (Fig. 2), in which the water flows separately into two small culverts around the village. From a reconnaissance of the watershed, a sulfur smell was present at the west culvert. Samples were taken at both culverts to determine if differences in analyzed nutrient and TSS concentrations were present as the water flowed separately around the village.

Soluble reactive phosphorus and TP concentrations were low at site 1A (SRP: 6.1 µg P/L; TP 16.3 µg P/L) and site 1B (SRP: 5.2 µg P/L; TP 35.2 µg P/L) (Table 17) when compared to other sampling sites on 12 July 2010 (range – SRP: 5.2 to 69.7 µg P/L; TP: 17.1 to 132.6 µg P/L) (Fig. 15). Nitrate (site 1A: 2.1 mg N/L; site 1B: 1.93 mg N/L) and TN (site 1A: 2.44 mg N/L; site 1B: 2.22 mg N/L) (Table 17) concentrations were generally elevated compared to all other sites (range - nitrate: 0.05 to 2.40 mg N/L; TN: 0.88 to 3.17 mg N/L) in the Oatka Creek subwatershed on 12 July 2010 (Fig. 16). Just upstream from these two sample sites (sites 1A and 1B) is a CAFO site (Hubert W. Stein & Sons, Inc) which is a likely source for nitrogen. Similar to phosphorus, TSS, and total coliform abundances were also low at site 1A (TSS: 3.75 mg/L; coliform: 1,500 CFU/100 mL) and at site 1B (TSS: 4.14 mg/L; coliform: 1,600 CFU/100 mL) (Table 17) in comparison to all other sampling sites on 12 July 2010 (range – TSS: 2.17 to 23.67 mg/L; coliform: 800 to 16,000 CFU/100 mL) (Fig. 17). These results suggest that during low flow conditions, sources of nitrogen upstream from site 1 (Village of Caledonia) could be impacting the Oatka Creek subwatershed. Because the results were similar for both culverts, the decision was made to combine these segment sites into one sample site by just taking 500 mL of sample from each culvert and combine it into one composite sample.

Stream Segment Conclusions – Genesee Country Village Culverts

A stream segment analysis was performed upstream from tributary site 1 in the village of Caledonia on 4 January 2011 to identify sources of nitrogen. A SPDES (Caledonia Fish Hatchery) and CAFO (Hubert W. Stein & Sons, Inc) are located upstream from site 1 which may be likely sources of nitrogen.

4 January 2011: A Segment Analysis of Big Spring Creek (Fig. 52)
(Under Nonevent Conditions)

A segment analysis was conducted on the Oatka Creek (OC) Big Spring Creek tributary (Fig. 52) to further identify sources of nitrogen that were observed on 12 July 2010. A SPDES (Caledonia Fish Hatchery) and CAFO site (Hubert W. Stein & Sons Inc.) are located upstream and could be contributing to elevated levels of nitrogen. Three sites (A-C) (Fig. 52) were sampled over a 35-minute period (10:18 am to 10:43 am) under nonevent conditions with air temperatures in the low to mid 30s (0-2 ^{o}C) under sunny skies.

Soluble reactive phosphorus and TP concentrations decreased from upstream site C (SRP: 4.3 µg P/L; TP: 35.9 µg P/L) (Fig. 53) to downstream site B and then increased slightly as the water flowed past the SPDES site (Caledonia Fish Hatchery) at downstream site A (SRP: 10.7 µg P/L; TP: 15.9 µg P/L). Nitrate and TN concentrations varied little from upstream site C (nitrate: 2.73 mg N/L; TN: 2.86 mg N/L) (Fig. 53) to downstream site A (nitrate: 2.58 mg N/L; TN: 2.76 mg N/L). Total suspended solid concentrations increased slightly from upstream (site C: 1.6 mg/L) to downstream (site B: 2.1 mg/L; site A: 3.6 mg/L) (Fig. 53), while total coliform abundances were non-detectable at sites B and C are then increased slightly at downstream site A

(400 CFU/100 mL) (Fig. 53). These results suggest that the Caledonia Fish Hatchery is a likely source for phosphorus.

3 May 2011: A Segment Analysis of Big Spring Creek (Fig. 54) (Event Conditions)

A second segment analysis was conducted on the Oatka Creek (OC) Big Spring Creek tributary (Fig. 54) to further identify sources of nutrients. A SPDES (Caledonia Fish Hatchery) and CAFO site (Hubert W. Stein & Sons Inc.) are located upstream and maybe sources of nutrients. Four sites (A-D) (Fig. 54) were sampled over a 22-minute period (9:13 am to 9:35 am) under event conditions with air temperatures in the low to mid 60s (16-17 ^{o}C) under rainy skies.

Soluble reactive phosphorus, TP, and TSS concentrations increased from upstream the Caledonia Fish Hatchery (site B – SRP: 1.0 μg P/L; TP: 5.8 μg P/L; TSS: 3.0 mg/L) to downstream (site A – SRP: 5.1 μg P/L; TP: 17.0 μg P/L; TSS: 11.1 mg/L) (Fig. 54) the SPDES site suggesting that the Caledonia Fish Hatchery is a likely source of phosphorus and TSS under event conditions. However, nitrogen concentrations varied slightly (range – nitrate: 2.78 to 3.06 mg N/L; TN: 2.85 to 3.17 mg N/L) (Fig. 54) between sites in Big Spring Creek. Total coliform abundances were highest at upstream site D (36,000 CFU/100 mL) (Fig. 54).

Samples were taken at the Caledonia Fish Hatchery on two separate days (1 September 2011 and 7 September 2011) to investigate if the hatchery is a point source for nutrients. Both samples (1 September 2011 and 7 September 2011) were taken at the intake and outtake pipes. Soluble reactive phosphorus and TP concentrations increased from the intake to the effluent pipe (Table 5), while nitrate and TN concentrations decreased from the intake to effluent pipe. Similar to phosphorus, total coliform abundances increased from intake to the effluent pipe (Table 5). On 1 September 2011, TSS concentrations decreased from the intake (2.0 mg/L) to the effluent pipe (1.1 mg/L).

Stream segment conclusions – Big Spring Creek

The Caledonia Fish Hatchery is a likely source of phosphorus and TSS under event conditions. A visit to the Caledonia Fish Hatchery was conducted on 10 August 2011 to discuss any management techniques that are implemented before discharging effluent into Big Spring Creek. The Hubert W. Stein & Sons Inc. CAFO is the likely source of nitrogen and coliform bacteria in Big Spring Creek.

Wastewater Treatment Plant Results (Fig. 2, Table 18)

17 August 2010: Warsaw Water Treatment Plant

Soluble reactive phosphorus, TP, nitrate, and TN were statistically ($p < 0.001$) higher in concentration below the WWTP than above (Table 18). There was no significant difference ($p= 0.16$) in TSS above (mean = 3.10 mg/L) and below (mean = 2.25 mg/L) the WWTP. Total coliform abundances were higher above the WWTP (13,050 CFU/100 mL) than below (7,875 CFU/100 mL) but were not statistically different ($p = 0.059$) (Table 18). This secondary treatment plant is the second largest in the Oatka Creek watershed (discharge: 2,650 m^3/day; 4.9 kg P/day) with high effluent concentrations (SRP: 1,780.8 μg P/L; TP: 1,843.0 μg P/L; nitrate: 16.04 mg N/L; TN: 29.68 mg N/L) (Table 18).

20 October 2010: Leroy Water Treatment Plant

Soluble reactive phosphorus, TP, nitrate and TN were statistically ($p = 0.005$) higher in concentration below the WWTP outfall than above (Table 18), effluent pipe sample concentrations were high (SRP: 2,372.9 μg P/L; TP: 2,436.9 μg P/L; nitrate: 12.50 mg N/L; TN: 28.39 mg N/L) and total coliform abundances (450,000 CFU/100 mL) (Table 18). No significant difference ($p= 0.072$) in TSS occurred above (mean = 2.72 mg/L) and below (mean = 1.66 mg/L) the WWTP, while total coliform abundances were higher below the WWTP (850 CFU/100 mL) than above (725 CFU/100 mL) but were not statistically different ($p = 0.334$) (Table 18). This secondary treatment systems maximum discharge (3,785 m^3/day) and estimated TP load (9.0 kg P/day) were the highest in Oatka Creek.

2 November 2010: Pavilion Water Treatment Plant

Soluble reactive phosphorus, TP, nitrate, TN and total coliform abundances were statistically ($p < 0.05$) higher in concentration below the Pavilion WWTP than above (Table 18), while total suspended solid were statistically ($p=0.027$) higher in concentration above the Pavilion WWTP (TSS: 4.30 mg/L) than below (2.60 mg/L) (Table 18). This secondary treatment system had high concentrations of nutrients and total coliform from the effluent pipe (SRP: 3,425.9 µg P/L; TP: 3,591.8 µg P/L; nitrate: 19.09 mg N/L; TN: 20.44 mg N/L; total coliform: 52,000 CFU/100mL) (Table 18). The Pavilion WWTP is the smallest in the Oatka Creek watershed (discharge: 303 m^3/day; TP load: 1.1 kg P/day).

4 January 2011: Scottsville Water Treatment Plant

Soluble reactive phosphorus, TN and total coliform abundances were statistically ($p<0.05$) higher in concentration below the Scottsville WWTP than above (Table 18). Total phosphorus, nitrate and TSS were not statistically ($p>0.05$) higher in concentration below the Scottsville WWTP than above (Table 18). Effluent concentrations were lowest at the Scottsville WWTP (SRP: 1,405.7 µg P/L; TP: 1,597.8 µg P/L; nitrate: 4.13 mg N/L; TN: 6.98 mg N/L; total coliform: 150,000 CFU/100mL) (Table 18). Scottsville WWTP is a secondary treatment system that discharges 2,461 m^3/day and releases roughly 3.9 kg P/day.

SWAT Model Results

Sources of Phosphorus

After the calibration and validation of the SWAT12 model was completed, point and nonpoint source phosphorous allocations were then quantified. These sources were broken down into specific landuse/activity groups: Agricultural crops, tile drainage, farm animals (Confined Animal Feeding Operations), streambank erosion, wetlands, fish hatchery (Caledonia), groundwater, forest, urban runoff, sewage treatment and septic systems. More than 70 % of the annual TP load from Oatka Creek watershed at Garbutt resulted from anthropogenic sources: agricultural operations [crops – 2,305 kg TP/yr (17.9 %); farm animals – 1,310 kg TP/yr (10.2 %); tile drainage – 438 kg TP/yr (3.4%)] and urban/wastewater [urban runoff – 439 kg TP/yr (3.4 %); sewage treatment – 3,375 kg TP/yr (26.2 %); septic systems – 890 kg TP/yr (6.9 %); fish hatchery– 260 kg TP/yr (2.0 %)] (Table 12). Groundwater phosphorus contributes the second largest annual load [3,244 kg TP/yr (25.2 %)] along with minimal contributions from other natural sources [wetlands – 2 kg TP/yr; forest: 35 kg TP/yr (0.3 %)] (Table 12). This allocation of TP loading in Oatka Creek allows for organization of sources to target remediation scenarios. Data from this study can then be utilized to construct a total maximum daily load (TMDL) for Oatka Creek.

Effectiveness of Best Management Practices (BMPs)

Several remediation scenarios were simulated with the SWAT model to suggest the best method to reduce TP and TSS loading. A total of 23 different remediation scenarios were simulated in SWAT12 to determine concentration and load percent reduction from all management practices (Table 19). For example, if Oatka Creek was transferred to a natural watershed (all forest and wetlands), the TP load would be reduced by roughly 60.5 % and the TSS load by 8.5 % (Table 19), while TP concentration would decrease from 51.6 µg P/L to 22.9 µg P/L (55.6 % reduction). The TP concentration of 22.9 µg P/L represents the lowest possible nutrient concentration that is attainable in the Oatka Creek watershed.

Multiple agricultural remediation scenarios effectively reduced annual TP loads at the outlet site in Garbutt (buffer strips, contouring, grassed waterways, cover crops, terracing, strip cropping and nutrient management (reducing fertilizer application) and reducing manure application from CAFO locations). The most effective best management practices included: buffer strips (8.4 %), grassed waterways (18.1 %), terracing (8.8 %) and reducing manure applied to CAFO operations (9.7 %) (Table 19).

Residental and urban management was also implemented in the SWAT12 model (removal of WWTPs, upgrading all WWTPs, removal of point sources, septic systems and streambank armoring). Upgrading or removing all WWTPs in Oatka Creek had substantial improvements to water quality reducing TP loads by 24.9 and 25.0 %, respectively (Table 19). Removing septic systems from Oatka Creek had minimal impact on water quality reducing TP loads by 6.6 %, but increasing the annual average TP concentration from 51.6 µg P/L to 58.1 µg P/L. Armoring the streambank throughout the Oatka Creek watershed would reduce TSS loading by 87.0 % (5,094 MT TSS/yr to 655 MT TSS/yr), but TP increased slightly (Table 19). This same result was identified by Tuppad *et al.* (2010) and Winslow (2012) where large reductions in sediment were observed from streambank armoring but only a slight reduction in TP resulted. The SWAT model lacks the connection of phosphorus to sediment because only peak flow rates influence the transport of nutrients in the QUAL2E model (Brown an Barnwell 1987). Phosphorus is physically bound to sediment so indicating a large soil loss and increased phosphorus loading is unrealistic. Based on the correlated TP and TSS measured data, the actual TP concentration would be 3.1 µg P/L (Fig. 55) which would be over a 90% reduction in TP concentration.

Upon completion of all remediation scenarios, the most beneficial and applicable BMPs were implemented on Evans Road and Wyoming Road. Remediation of Evans Road and Wyoming Road segments included implementing buffer strips, grassed water waterways, cover crops and manure removal from CAFO locations to all agricultural landuse. All remediation efforts had reductions in TP loads with grassed waterways being the most effective BMP in both Evans Road (24.0 % reduction) and Wyoming Road (75.4 % reduction) (Table 20).

Basin-wide remediation targeted lowering the average annual concentration to the 45 μg P/L target concentration. Five management scenarios were developed including upgrading all four WWTPs, implementing agricultural management and remediating the two most impacted tributaries in Oatka Creek (Wyoming Road and Roanoke Road). The first two BMPs were upgrading all four WWTPs and then implementing grassed waterways on all agricultural land uses which reduced TP loading by 24.9 % and 18.1 %, respectively (Table 19). Additionally, a strenuous management scenario (45 Target Scenario 1) was implemented which upgraded all four WWTPs, and implemented grassed waterway, and buffer strips on all agricultural land reducing TP loads by 55.3 % (Table 19). The fourth remediation scenario targeted both Wyoming Road and Roanoke Road tributaries "only" (45 Target Scenario 2) by implementing grassed waterways and buffer strips on all agricultural land in both segments and then implementing cover crops to the entire watershed which reduced TP loads by 17.9 %, respectively (Table 19). Lastly, implementing cover crops and buffer strips to the entire watershed (45 Target Scenario 3) on agricultural land reduced TP loads by 14.7 % (Table 19).

Discussion

Watershed management recommendations should be made knowing the causes, size, and extent of impacted areas within a watershed. The Genesee River Watershed study focused on two separate but interrelated aspects: identification of sources of nutrients and soil loss from the basin and the development of remediation strategies and utilizing SWAT. The Rochester Embayment of Lake Ontario provides recreation to thousands of Rochesterians who visit Charlotte Beach and Durand Eastman Beach. Due to the large amount of phosphorus, soil and bacteria delivered from the Genesee River to the Rochester Embayment, beneficial use impairments such as beach closings, aesthetics, and nuisance algae are a current issue. For example, nutrients and sediment discharging from the Genesee River Basin at Charlotte are implicated in the deterioration of water quality in the Rochester Embayment of Lake Ontario (Makarewicz 2000). Thus, results from the Genesee River Watershed Study also have implications for the management of Lake Ontario. The larger study of the Genesee River is divided into six portions: Black Creek, Oatka Creek, Canaseraga Creek, Honeoye Creek, Upper Genesee and the Lower Genesee mainstem segments. Here I focus on Oatka Creek.

The main objective of the Oatka study was to identify and prioritize source areas and recommend management strategies for remediation of subbasins of the Oatka Creek watershed. Oatka Creek was spatially divided into weekly monitoring locations for discharge and water chemisty (nutrients and sediment) for one sampling year (1 June 2010 to 31 May 2011) in which relative nutrients losses were determined at four mainstem (Evans Road, Warsaw, Ellicott Road and Garbutt) and four tributary segments (Buck Road, Wyoming Road, Roanoke Road and Parmelee Road) (Fig. 2). The data collected from field measurements were integrated into the calibrated and validated Oatka Creek Soil Water Assessment Tool (SWAT12) model to develop a Total Maximum Daily Load (TMDL) and determine best management strategies for the Oatka Creek watershed.

Water Quality Targets

Water runoff and municipality discharge from surrounding tributaries influence nutrient load to and the overall health of the Great Lakes. Section 303(d) of the Clean Water Act requires states to locate and identify watersheds that fail to meet federal water quality standards (USEPA 2003, Cadmus Group Inc. 2007). An estimate of a total maximum daily load (TMDL) for a watershed has been used by the USEPA as the basis to manage the amount of nutrients, mainly phosphorus, being lost from a watershed and discharging into the nation's lakes and reservoirs. Although the determination of the actual or estimated loss (i.e., the load) from a watershed is the criterion used by USEPA, New York State has traditionally used a concentration of nutrient to set regulate standards.

For example, New York's recent general water quality standard for both phosphorus and nitrogen (6NYCRR 703.2) was originally "None in amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages" (NYSDEC 2011). The current phosphorus target for New York class A and B streams is 20 µg P/L, which is twice as high as the IJC phosphorus goal in Lake Ontario of 10 µg P/L (NYSDEC 2011). The 20 µg P/L regulatory standards have been viewed as potentially to strict and unreachable. New, regulatory targets have been suggested from various studies. For example, Smith *et al.* (2007) suggested a total phosphorus target of 65 µg P/L based on the nutrient biotic index developed from New York macro invertebrate communities, while a nutrient target goal of 45 µg P/L has been suggested as a logical median target goal between the 20 and 65 µg P/L proposed target concentrations (United States Environmental Protection Agency 2003). Compared to other states, New York has stricter numerical total phosphorus stream concentration standards (e.g., Arkansas

= 100 µg P/L, North Dakota = 100 µg P/L, Oklahoma = 37 µg P/L, Illinois = 50 µg P/L) (USEPA 2003).

The development of a phosphorus regulatory standard for streams in an entire state is difficult. Nutrient concentrations of streams are highly dependent on soil types and surrounding geologic characteristics of a watershed. For example, the export of phosphorus from igneous rock watersheds is significantly lower than from sedimentary rock watersheds (Dillon and Kirchner 1975). A study conducted by Kelly (1999) demonstrated that on the Tualatin River, the five highest TP concentrations were underlain with sedimentary rock while the ten lowest TP concentrations where underlain with volcanic rock. Such a situation is evident in New York State where forested granite dominated Adirondack watersheds have lower TP concentrations (TP = <10 µg P/L; Raquette River streams; personal communication, Dr. Daniel Kelting, Adirondack Watershed Institute of Paul Smith's College) than TP concentrations found in forested sedimentary rock watershed in Western New York (North McMillian Creek in the Conesus Lake watershed average TP = 21 µg P/L, Makarewicz *et al.* 2009). When developing statewide TMDL and P concentration regulatory criterion, background P from soil type and geology should be taken under consideration due to the different soil and geology characteristics found in New York State. A statewide regulatory concentration is not justifiable.

Over the past 40 years, an interest in determining natural background phosphorus loads and concentrations from forested watersheds rather than human impacted watershed has increased throughout the United States (Smith *et al*. 2003). Such data needed to develop regulatory standards has been stymied by the lack of "pristine" reference watersheds; that is watersheds not impacted by human kind. However, the development of sophisticated simulation tools, such as SWAT, allows background phosphorus to be estimated via modeling of the watershed. In the Oatka Creek watershed study, the Soil Water Assessment Tool (SWAT) model was utilized to determine P concentrations and loads when all human influenced land uses (agriculture and urban/residential areas) were removed from the simulation and converted to mature mixed forest/wetland habitats. Using this approach, a stream P concentration of 22.9 µg P/L (Table 19) was estimated for Oatka Creek with land use as natural cover (forest and wetlands). This value of 22.9 µg P/L is suggested as the lowest attainable or background P concentration of Oatka Creek. Considering the likely variability in the data, it is surprising and perhaps coincidental that baseline P concentration for Oatka Creek is not likely significantly different from the once proposed 20 µg P/L standard for streams in New York State.

Determining a nutrient regulatory concentration allows targets and goals to be set for remediation and management applications appropriate to achieve the overall long term health improvement of a stream and its watershed. Since New York State has not created a strict phosphorus concentration goal, three proposed phosphorus levels (20, 45, and 65 µg P/L) were considered when determining management scenarios based on the Oatka Creek TMDL. Within the Oatka watershed, the average annual SWAT simulated (S) and measured (M) TP concentration at mainstem sites were similar at Evans Road (S: 65.1 µg P/L; M: 63.2 µg P/L), Warsaw (S: 81.4 µg P/L; M: 58.4 µg P/L), Ellicott (S: 49.2 µg P/L; M: 97.1 µg P/L) and Garbutt, NY (S: 51.6 µg P/L; M: 41.3 µg P/L), while TSS concentrations were also similar at Evans Road (S: 15.1 mg N/L; M: 17.5 mg N/L), Warsaw (S: 95.0 mg N/L; M: 60.3 mg N/L), Ellicott (S: 12.6 mg N/L; M: 24.5 mg N/L) and Garbutt, NY (S: 21.1 mg N/L; M: 10.5 mg N/L). When the Oatka watershed is simulated in its natural state, forest and wetland, the simulated average annual phosphorus and sediment concentrations ranged from 20.2 µg P/L at Evans Road to 41.5 µg P/L at Warsaw to 22.9 µg P/L at Ellicott Road to 22.9 µg P/L at Garbutt and TSS ranged from 0.3

mg/L at Evans Road to 96.5 mg/L at Warsaw to 12.0 mg/L at Ellicott Road to 20.8 mg/L at Garbutt (Table 21). As mentioned previously, these are the predicted minimum average expected concentrations of phosphorus and suspended solids of water in Oatka Creek.

If the regulatory standard for P is 65 µg P/L, no further management recommendations would be required in the Oatka Creek watershed. Five management scenarios were developed to attain the suggested 45 µg P/L TP concentration target. Perhaps the most effective management to a stream TP concentration of 45 µg P/L is the upgrading of all secondary waste water treatment plants to tertiary plants - which decreased the TP load by 24.9% (Table 19). Other management strategies include grassed waterways (18.1 % reduction), buffer strips (8.4 % reduction), and cover crops (3.2 % reduction) (Table 19) to specific areas, mainly agriculture, within Oatka Creek. Lastly, a 45 µg P/L target concentration was achieved by focusing on remediating agricultural runoff at the major tributaries where CAFO operations are found (Roanoke Road and Wyoming Road). A target concentration of 20 µg P/L, the currently proposed phosphorus target in New York State, is not easily attainable as all human impact would have to be removed.

Oatka Creek in Comparison to Other Tributaries

Comparing areal phosphorus loads with other Lake Ontario subbasins allows an evaluation of the impact of land use in a watershed. For example, areal phosphorus loss from forested watersheds are often low (Bobolink Creek: 0.01 kg/ha/yr; First Creek: 0.10 kg/ha/yr) when compared to watersheds dominated by agricultural (Wolcott Creek: 1.37 kg/ha/yr; Glenmark Creek: 1.50 kg/ha/yr) (Makarewicz *et. al* In Press). At Garbutt NY, at the base of Oatka Creek watershed, a slightly higher TP areal weighted losses (0.51 kg/ha/yr) were observed compared to P loads from the forested watersheds of Boblink and First Creek, but lower than the multi-use Genesee River basin (0.65 kg P/ha/yr) (Makarewicz *et. al*, In Press); a NYSDEC area of concern (NYSDEC, Division of Water, Bureau of Watershed Assessment and Research 2003). Subbasins of Oatka Creek dominated by agriculture (Roanoke: 0.85 kg P/ha/yr; Wyoming: 1.09 kg P/ha/yr) compare closely to other regional agricultural sub-basins (Wolcott Creek and Glenmark Creek) indicating that portions of the Oatka watershed have nonpoint sources that could be remediated via agricultural BMPs. In agricultural watersheds, total phosphorus concentrations are a function of discharge which levels increase as precipitation falls on the soil. Makarewicz *et al.* (2012) also concluded that in the Conesus Lake watershed where agriculture is primarily dominant, that concentrations increased at discharge increased due to storm events. This is also evident in the Oatka Creek watershed (Fig. 56) suggesting that creating a TMDL and nutrient targets to remediate Oatka Creek should focus on high flow conditions during the winter and spring months. Also in Oatka Creek, total phosphorus is highly correlated with TSS (Fig. 55) indicating BMPs targeting soil loss should be successful.

Within the Oatka watershed, the Roanoke and Wyoming subbasins are areas of concern that are impacting the entire Oatka watershed. These areas of concern identified through segment analysis were used as input data to the Oatka Creek Soil Water Assessment Tool (SWAT 12) model to represent the measured nutrient and sediment losses from Oatka Creek.

Efficacy and Limitations of SWAT

Since the ArcSWAT model is a real-time predictor of hydrologic processes, many default input limitations are based on the quality of input data used to start the model. The main limitations observed in SWAT12 were: SCS curve number application, manual input of WWTPs and SPDES and CAFO sites, Karst water inputs and default settings with groundwater P, and operation management scenarios. The SWAT model is an equation and theoretically based simulation, where data other than the basic three main datasets (digital elevation, soils and land use) are needed to appropriately calibrate the model and be able to recommend remediation strategies based on realistic watershed characteristics.

One of the calibration issues with SWAT12 was the application of the SCS Curve Number. The empirically based SCS curve number is calculated based on soil type and land use but lacks elevation data of the watershed. Reductions in the typical SCS curve number (-6.0% to -29.0%) have been applied across the Northeast due to watershed characteristics such as soil and topography that internally drain precipitation more efficiently (Richards *et al.* 2010). For example, a study conducted by Richards *et al.* (2010) at Oak Orchard Creek, an area west of Oatka Creek, had highly drained soils; as a result a reduction of 23.0% in the SCS curve number was applied to the model. A reasonable alternative, the SWAT model could incorporate the variable source area concept to predict surface runoff (Frankenberger *et. al* 1999).

Another issue became very evident during the discharge calibration of the SWAT12. An underground "aquifer" also known as the Onondaga Escarpment runs across the Northern part of the Oatka Creek watershed (Fig. 2). During the initial SWAT12 run, a large water deficit was noticed in the stream in December through May. Winslow (2012) discovered a similar situation in the nearby Black Creek watershed. To adjust this for water deficit, the SWAT model was utilized to predict the average flow deficit over a ten year simulation run and this average deficit was added to balance the measured and the predicted discharge (Winslow 2012). Several assumptions are made in this approach. One major one is the hydrologic model capability to predict reliable outside groundwater flow when the model initially has no real-time data to support the results. Also, this approach can only result an "average" value for water deficit and lacks the ability to predict year to year water table fluctuations. A second approach used here is based on real-time USGS flow gauges in Oatka Creek to estimate potential flow increases from the Karst region during the deficit months (December to May). By comparing discharge at two USGS gauges within the Oatka Creek watershed [one upstream (Warsaw), one downstream (Garbutt)] of the Karst Region to calculate abnormal flow increases due to water table rise could be calculated. From this regression, the deficit of water occurring due to the SWAT model not considering groundwater introduced from the Karst region could be estimated from rises in the water table (Fig. 7). These Karst water flows were manually inputted to the SWAT12 model where under predicted flows were established aiding in the calibration to the model. The benefit of the Oatka Creek approach, as opposed to the method used by Winslow (2012), is the real-time documented flow data up and downstream from the Karst region to increase reliability and the ability to predict flow changes from a year to year basis by documenting the monthly average discharge at the USGS station in Garbutt, NY.

A third limitation or requirement of SWAT is related to point sources. Point source inputs such as WWTPs and SPDES sites need to be manually inputted to the SWAT model. If manual action is not taken, the SWAT model will not produce loading and stream chemistry results from all point sources with the study watershed. Like point sources, Confined Animal Feeding Operations (CAFO) were taken into account by the model and had to be manually added. Data from soil and water districts on manure application is required to improve predictive capacity. Information on the location of point and nonpoint sources found in the study watershed can save the modeler time and have greater applicability as an assessment tool of the remediation scenarios. Since the objective of the Oatka Creek study was to identify source areas, it was important to include all potential sources into the model to better represent the real field conditions. This was achieved through a segment analysis conducted prior to the development of the SWAT model.

SWAT was developed for Texas watersheds and some of the defaults do not apply well to the Northeast. SWAT default inputs such as groundwater P concentration and the MUSLE P factor (Contour Farming, Strip Cropping and Terracing) for remediation practices do not readily fit Northeast USA watersheds and their hydrologic characteristics. Richards *et al.* (2010) in a study on the Onondaga Escarpment reported total phosphorus groundwater concentrations ranging from roughly 20 µg P/L to 90 µg P/L suggesting a range of groundwater concentrations maybe inputted to the SWAT12 model. Well water samples were also taken at sixteen different locations across Western New York to determine the average TP concentration of groundwater. Total phosphrous concentrations ranged from 0.7 to 162.7 µg P/L with an average level of 22.1 µg P/L (Table 22). This suggests that a total phosphorus concentration of 20 µg P/L employed in the SWAT12 model was appropriate. Actual values, as opposed to the default values increase the SWAT models effectiveness as a tool for management.

Finally in SWAT, the MUSLE P factor calculates soil and nutrient loss, and was a problem when running certain management scenarios. In the Oakta Creek SWAT model, default options for the MUSLE P factors (contour farming, strip cropping and terracing) resulted in large increases in TP loading. However, contour farming, strip cropping and terracing options (all MUSLE P factors) are greatly influenced by elevation and at high slopes as these practices fail. (Arabi *et al.* 2007). Because the upper reach of Oatka Creek has high slopes (greater than 25 %), this remediation was limited to the lower reaches of Oatka Creek where slopes of land were in acceptable ranges (less than 25% slope) (Arabi *et al.* 2007). This application had a major factor in affecting P loads.

SWAT Loading Allocations

Oatka Creek annual loading allocations were determined by utilizing SWAT12 to determine individual TP load contributions per source. Management suggestions were based on the information determined by the individual natural and anthropogenic sources that were either known or discovered via segment analysis of the Oatka Creek watershed. Much of the discussion focuses on identifying the extent and quantity of phosphorus load to maintain and improve the overall health of Oatka Creek and ultimately, the Genesee River.

In the Oatka Creek subwatershed, agriculture [Agriculture Fields – 2,305 kg TP/yr (17.9 %); Farm Animals (CAFO) – 1,310 kg TP/yr (10.2 %) and Tile Drainage – 438 kg TP/yr (3.4 %)] was the largest contributor to downstream transport of phosphorus (31.5 %, 12,861 kg TP/yr total, Table 12). Another large source of phosphorus to the stream was the sewage treatment plants of Warsaw, Pavilion, Leroy and Scottsville (26.2 %), (Table 12) contributing 3,375 kg of TP/yr out of the total 12,861 kg of TP estimated in the 2010-2011 sampling year. Septic systems (890 kg TP/yr: 6.9 %) and urban runoff (439 kg TP/yr: 4.4 %) (Table 12) accounted for another 11.3 % of the total 12,861 kg TP/yr annual allocated phosphorus load, while the Caledonia Fish Hatchery was estimated to allocate 2.0 % (260 kg TP/yr) (Table 12) of the total TP in Oatka Creek, respectively. As anthropogenic sources, natural phosphorus sources also occur with Oatka Creek. Roughly, about 3,844 kg TP/yr of the total 12,861 kg P/yr were allocated to natural sources [Groundwater – 3,244 kg TP/yr (25.2 %); Stream bank Erosion – 563 kg TP/yr (4.4 %); Forest – 35 kg TP/yr (0.3 %); Wetlands – 2 kg TP/yr (0.03 %)] (Table 12). Roughly, about 70 % of the total phosphorus load is from anthropogenic sources while only 30 % is due to natural sources. The allocation analysis demonstrated that management of anthropogenic sources may significantly reduce the TP load discharging from Oatka Creek.

Relative losses from subbasins, identification of source areas and model implications

In the Oatka Creek subwatershed there are twenty registered CAFOs (Table 6). Confined animal feeding operations are practices that raise livestock for marketing in confined areas and contribute large amounts of nutrients, pathogens, and residues to watersheds (Wing *et al*. 2002). Nutrients from animal wastes such as nitrogen, phosphorus, and *E.coli* bacteria can contribute to the eutrophication of lakes, rivers, and streams and endanger human health by contaminating the ground water supply (Wing *et al*. 2002). Transport pathways to streams include runoff, erosion, and air discharges (Steeves 2002). Confined animal feeding operations create 13 times more nutrient waste (133 million tons per year) than human wastewater treatment plants (Burkholder *et. al* 2007). However, nitrogen and phosphorus fertilizers are important factors in crop growth and when managed properly via best management practices (BMPs), minimal impacts are evident in surrounding water bodies (Burkholder *et al.* 2007, Makarewicz *et al.* 2009).

Since the SWAT model allocated roughly 70% of the load towards anthropogenic sources, calculated total annual and areal (kg/ha/yr) loadings identified areas of concern among the four mainstem and four tributaries of Oatka Creek. Such an approach allows a priority ranking of the mainstem and tributary sites of Evans, Warsaw, Ellicott, and Garbutt with the Buck, Wyoming, Roanoke, and Parmelee tributaries and provides direction for the segment stream analysis by analyzing nutrient, sediment, and bacteria abundances within a reach. To determine areas of concern within the Roanoke and Wyoming reaches, priority was given to identify sources within each tributary.

Relative nutrient and sediment losses were evident in specific mainstem (Warsaw) and tributary locations (Roanoke and Wyoming Roads) with Oatka Creek. Priority was given to those potential source areas to determine the likely causes and extent of pollution. By identifying likely source areas and calibrating outlet sampling sites for sediment and nutrients, management implications could be then simulated via the SWAT model. A method called segment analysis was utilized to identify point and nonpoint source areas within the Oatka Creek watershed. Segment analysis is a systematic method that divides a watershed into smaller sections in an attempt to pinpoint localized source areas by taking multiple samples (Makarewicz and Lewis 2004a). A discussion follows that describes main sources within Oatka Creek and likely remediation techniques based on the SWAT model.

Evans Road (Relative losses, source areas with remediation implications)

The mainstem segment at Evans Road (Fig. 2) represents the most upstream (headwater) location that was sampled weekly for water chemistry and discharge. Although total annual load indicated that the section upstream from Evans Road contributed a small fraction to the total load calculated at the furthest downstream mainstem site at Garbutt (SRP: 3.6 %; TP: 5.2 %; nitrate: 3.2 %; TN: 3.3 %; TSS: 5.8 %), areal load suggested a major impact of land use on the stream water quality (Table 14). Evans Road had the third highest SRP (117 g/ha/yr), TP (460 g/ha/yr), and TSS (171.0 kg/ha/yr) areal load of the four mainstem locations, indicating evident nutrient and sediment losses from this watershed. Unidentified areas upstream from Evans Road are sources of nutrient and sediment losses from the watershed to Oatka Creek and were investigated further.

In this Evans Road subwatershed of Oatka Creek, one CAFO (Confined Animal Feeding Operation) site is known to exist (Double B Farms: 266 head of cattle) and is characterized as a medium-sized site by the New York State Department of Environmental Conservation (NYSDEC). At baseline low flow conditions, the CAFO site does not impact the Evans Road tributary. However, during a rain event (5 October 2011), elevated nutrient concentrations increased in stream water above and below the CAFO site for nitrogen (nitrate: +2,108 %; TN: +469 %), phosphorus (SRP: +15 %; TP: +40 %), and coliform bacteria (+96 %) (Fig. 19). During rain events, the stream overflows its banks along Double B Farms carrying nutrients such as nitrogen from the CAFO site downstream. Nutrient rich soils have high concentrations of nitrogen, phosphorus, and coliform bacteria (Eghball *et al.* 2002).

The agricultural field just upstream from the weekly sampling site at Evans Road, which was identified as a source for nutrients in 2004 (Makarewicz and Lewis 2004a) (Fig. 25), was also identified as a source area on 19 October 2010. Nitrate concentrations greatly increased (+125%) from above to below the agricultural field, suggesting that nonpoint source agriculture has been an issue upstream from Evans Road for several years.

Even though major sources were found in the Evans Road segment, nutrient sinks were also evident. In the Oatka Creek subwatershed, one wetland (Site D-1, Fig. 22) significantly decreased the amount of nutrients flowing downstream. An agricultural site is located upstream of Site D-1 and flows downstream through the wetland to downstream Site D (Fig. 22). Under event and nonevent conditions, phosphorus loading was significantly reduced as the water flowed from upstream Site D-2 to downstream wetland Site D-1 (5 October 2010 – SRP: -79.1%; TP: -60.8%; 19 October 2010 - SRP: -96.4%; TP: -81.8%). The difference in phosphorus concentrations at Site D-1 under event and nonevent conditions is minimal, suggesting that this wetland is acting as a nutrient sink. Wetlands are known to serve as nutrient sinks and retain available nutrients needed for plant growth (phosphorus and nitrogen) reducing the amount that travels downstream (Braskerud 2002). During high loading periods, small wetlands can significantly reduce the amount of phosphorus and sediment loads traveling downstream

(Braskerud 2002) via plant up-take of available nutrients and settling out of the sediment (Braskerud 2002, Mitsch and Gosselink 2000).

Remediation Scenarios of Evans Road

Several remediation scenarios were simulated using the SWAT12 model to identify management recommendations. As noted, two major nutrient sources were identified with the Evans Road segment (Agriculture and Double B Farms CAFO operation) along with one nutrient sink (wetland). According to the allocated loads from the SWAT12 model, 28.1 % of the total P load from Oatka Creek is due to agricultural crops and farm animals (Table 12). Management scenarios such as buffer strips, contouring, grassed waterways, conservation tillage, cover crops, terracing, strip cropping and nutrient fertilization reduction were simulated to determine reductions across the entire watershed. Data collected from several segment analyses and the SWAT12 determined remediation by buffer strips to be an appropriate approach. A simulation adding buffer strips to the entire watershed resulted an 8.4 % reduction in total phosphorus loading reducing the P load from 13,477.4 kg P/yr to 12,347.9 kg P/yr (Table 19) suggesting that the management strategy may be appropriate for just the Evans Road segment. Adding buffer strips just on the Evans Road segment resulted in a 9.9 % reduction in TP load from 657.9 kg P/yr to 592.5 kg P/yr (Table 20).

Similar to buffer strips, grassed waterways (24.0% reduction), cover crops (17.5% reduction) and CAFO remediation (23.9% reduction) (Table 20) had a beneficial impact on the Evans Road segment but based on field observations and source locations, buffer strips would be the most appropriate strategy because the close proximity of agricultural practices to the stream beds. Buffer strips are vegetative areas that surround the stream to reduce overland and subsurface runoff (Dorioz *et al.* 2006). Over the past three decades since the Clean Water Act was implemented and under Section 303(d), buffer strips have been a common recommendation to reduce the effect of diffuse pollution to waterways in an attempt to reduce the extent of eutrophication (Dorioz *et al.* 2006). Other studies have shown that buffer strips have proved to be an effective way to reduce the transport of nutrient and sediment to stream bed. Blanco-Canqui *et al.* (2003) noted reductions of 92% of sediment and 71 % of the nutrients leaving the source area, being sequestered within the first four meters of buffer strips.

Warsaw Segment (Relative losses, source areas with remediation implications)

The Warsaw Segment is located downstream from the mainstem segment Evans Road (Fig. 2) but upstream from the Ellicott Road segment at the Warsaw USGS station (Fig. 2). One tributary monitoring segment (Buck Road) (Fig. 2) discharges into the mainstem just upstream from Warsaw but downstream from Evans Road. Major losses of sediment and nutrients occur upstream from Warsaw but downstream from Evans Road. Total annual SRP, TP, nitrate, TN, and TSS loads increased substantially from the upstream mainstem site Evans Road to downstream mainstem site at Warsaw [e.g., TP: 787 to 5,231 kg P/yr (+ 565%); TN: 22,658 to 139,828 kg N/yr (+ 517%); TSS: 292,147 to 5,791,046 kg/yr (+ 1,882%) (Table 14)]. The Buck Road tributary, which enters the mainstem of Oatka Creek just upstream of Warsaw, contributed a fraction of the TP (16.1 %), nitrate (20.9 %), TN (16.2 %) and TSS (6.4 %) to the total annual load (kg/yr) of the Warsaw site, indicating mainstem rather than tributary nutrient and sediment sources (Table 14). Areal losses from the Buck Road tributary were also relatively low (Table 14). In summary, a substantial amount of sediment and nutrients, especially nitrogen, is present just upstream from Warsaw which was investigated further via segment analysis.

The Warsaw segment (Fig. 2) had the highest total annual TSS load out of the eight monitoring locations (Table 14). In this segment of the entire watershed, the land area upstream from Warsaw is very hilly with steep sloping hillsides (Fig. 57). One of the main causes of soil erosion is slope steepness: the steeper the slope, the more runoff potential a watershed exhibits (Morgan 2005, Al-Kaisi 2008). Soil erosion causes pollution through the transport of phosphorus, sedimentation, and eutrophication to the downstream system including lakes (Morgan 2005, Julien 2010). A segment analysis conducted on 8 March 2011 indicated an erosion source area upstream from site OC Warsaw but downstream from site C (Fig. 29). Similarly, total annual loading suggested the same problem with huge sediment increases from Evans Road to Warsaw (260,304 to 5,791,046 kg/yr, + 1,725%). To determine the severity of erosion along the mainstem between these two sampling locations (OC Warsaw and site C), a sediment erosion inventory was performed on 28 July 2011. Between sites OC Warsaw and site C, 30.4 % of the mainstem was determined to be highly erodible and represents the likely cause of elevated TSS variables observed (Table 15, Fig. 29). Other variables that relate to erosion potential are vegetation, slope gradient/length, soil structure, rainfall intensity (impact), and management techniques (Ontario: Ministry of Agriculture, Food and Rural Affairs 1987). Major changes in elevation and decreased channel bank stabilization upstream from site OC Warsaw are the likely reason for erosion (Table 15, Fig. 29).

One objective of this study was to determine the cause of elevated nitrogen concentrations when compared to all other sampling locations along the Genesee River (Fig. 58). Nitrogen levels in excess cause human health issues long with increased eutrophication of lake ecosystems (Makarewicz and Lewis 2004a). Elevated nitrogen concentrations start in the headwater section upstream from site OC Warsaw and remain high to the furthest downstream site at OC Garbutt (Fig. 16). On 15 March 2011 samples were taken in the furthest upstream (Fig. 31) reaches to determine the cause for high nitrogen concentrations with the hypothesis that agriculture is the main cause. Wyoming County, which is rated as the #1 county in New York State for agriculture production, has twice as many nitrogen producing cows as people n (personal communication, Greg McKurth, Wyoming County Soil and Water manager). Two samples taken upstream and downstream of the Swiss Valley Farms CAFO on 15 March 2011 suggested that CAFO and agricultural practices were the main causes for elevated nitrogen levels in Oatka Creek. Nitrogen concentrations greatly increased upstream of the Swiss Valley Farms to downstream [(nitrate: 0.14 to 6.83 mg N/L (+ 4,779 %); TN: 0.37 to 6.85 mg N/L (+ 1,751 %)] (Fig. 31).

A similar situation was observe at the Broughton CAFO site (Fig. 31) where low nitrogen concentrations were also identified at upstream site A (nitrate: 0.04 mg N/L; TN: 0.46 mg N/L) when compared to an upstream site (B) just downstream from an agriculture field (nitrate: 8.54 mg N/L; TN: 10.44 mg N/L) (Fig. 31). Farm management should focus on CAFO sites and agricultural fields subject to runoff to minimize the effects of nutrient transport in Wyoming County. Management such as buffer strips, diversions, terraces, strip cropping, grassed waterways and no tillage are known to decrease the effects of runoff in agricultural landuses (Haith 1975, Makarewicz and Lewis 2004a). These agricultural management recommendations are known to reduce nitrogen input to degraded land areas within watersheds (Makarewicz and Lewis 2004a).

Remediation Scenarios of the Warsaw segment

The SWAT12 model is utilized to recommend remediation strategies on the mainstem source areas upstream from Warsaw (streambank erosion and Warsaw WWTP). The most effective best management practices simulated for these sources is streambank stabilization to combat streambank erosion and to upgrade the secondary wastewater treatment plant at Warsaw to tertiary treatment.

Streambank stabilization techniques such as channelization or rock armoring techniques (stone riprap, concrete pavement and asphalt mixes) maybe implemented depending on the severity and location of erosion (Li and Eddleman 2002). Federal agencies implement riprap management more often because more research has been conducted on the positive effects noticed over time (Li and Eddleman 2002). Due to the severity of the slopes upstream from Warsaw, riprap stabilization would be the best recommended management practice to reduce erosion in this source area of Oatka Creek. Since much of the sediment is lost upstream of Warsaw in Oatka Creek, a streambank stabilization simulation was conducted on this portion of the watershed to identify the overall affect. When implemented, sediment losses were reduced by 96.0 % from the Warsaw segment suggesting that armoring the streambank would significantly reduce TSS loads. When implemented to the entire watershed, relative sediment losses were reduced by 87.0% (Table 19). In fact, this management strategy has already been implemented in problem areas upstream to limit erosion and beneficial results have already been noted (personal communication – Greg McKurth, Wyoming County Soil and Water District manager).

One waste treatment plant (Warsaw WWTP, SPDES # NY 0021504, 700,000 gallons per day) is located downstream from the USGS monitoring station in Warsaw (Fig. 2). Wastewater treatment plants may be point sources for nutrients that are responsible for lake eutrophication and negatively impact water quality (Nichols 1983). On 17 August 2010, significantly (paired t-test: p-value < 0.001) higher concentrations of soluble reactive phosphorus, TP, nitrate and TN were observed downstream of the Warsaw Waste Treatment Plant, a secondary treatment plant, while total suspended solid concentrations and coliform abundances were not significantly higher (p-value; TSS = 0.16; coliform = 0.059) (Table 18) from upstream samples. Indeed Warsaw WWTP effluent was high for SRP (1.78 mg P/L), TP (1.84 mg P/L), nitrate (16.04 mg N/L) and TN (29.68 mg N/L). Having the third largest discharge of all waste treatment plants, the Warsaw plant contributes roughly 747 kg P/yr to the Oatka Creek watershed. The Warsaw WWTP is a point source of pollution for SRP, TP, nitrate, and TN. A trickling filter system, such as at Warsaw, fails to remove nutrients, such as phosphorus, from the effluent and is discharged back into the watershed via discharge pipe near the plant (Nichols 1983).

The Warsaw wastewater treatment represented a nutrient source in this segment. I simulated a remediation scenario to upgrade all waste water treatment plants in the entire watershed from secondary treatment to tertiary since the model allocated roughly 26.2 % of the total P load to the watershed from sewage plants (Table 12). A 24.9 % reduction in total phosphorus loading (13,477.4 kg P/yr to 10,117.4 kg P/yr) is predicted with an upgrade to tertiary treatment (Table 19). Upgrading wastewater treatment plants also reduced the average phosphorus concentration from 51.6 µg P/L to 38.8 µg P/L (24.8 % reduction) at the main outlet point at Garbutt.

A simulation that removed all sewage treatment plants to compare the effects of upgrading the waste water plant from secondary to tertiary or to remove them from Oatka Creek was completed. Removing all wastewater treatment plants (13,477 to 10,103 kg P/yr; 25% reduction) from Oatka Creek had a similar impact as upgrading the sewage treatment plant (13,477 to 10,117 kg P/yr; 24.9% reduction, Table 19). From the SWAT analysis, upgrading the Warsaw wastewater treatment plant would be a feasible option to decrease the overall phosphorus load in Oatka Creek. When upgrading currently existing treatment plants, different operation alternatives should be considered to determine the most cost effective approach.

Ellicott Segment (Relative losses, source areas with remediation implications)

The Ellicott Road mainstem segment represented the middle mainstem reach of Oatka Creek (Fig. 2). One tributary sampling segment (Wyoming Road) (Fig. 2) enters this segment and discharges just upstream from the Pavilion WWTP. The largest tributary areal loads for SRP, TP, nitrate, TN, and TSS were observed for the Wyoming Road segment (Table 14) indicating major source areas upstream in this subwatershed. Lastly, total annual and areal TSS load decreased from the upstream mainstem site at Warsaw to the downstream middle mainstem site at Ellicott [Total annual load –TSS: -51.4% from Warsaw to Ellicott; Total areal load – TSS: Warsaw (1,095.7) to Ellicott (0.0) kg/ha/yr)] (Table 14) suggesting sequestering of suspended solids as sediment: that is, settling of sediment and nutrients in this segment. In summary, the Wyoming Road tributary has the highest tributary areal loss of nutrients and soil in the Oatka Creek basin and thus a high priority for determining source areas.

In the Wyoming Road (Fig. 2) segment of Oatka Creek, three CAFO sites (Logwell Acres Inc.,Victory Acres, and Bowhill Farms) (Fig. 34) are known to exist. Logwell Acres Inc. (300 head of cattle) is located in the headwaters of subwatersheds #5 and #6 (Fig. 34). During a rain event and during a nonevent condition, Logwell Acres Inc. was identified as a major source of nutrients, TSS, and coliform abundances. Significant increases in nutrients (nitrate: +645.7 %; TN: +75.5 %) (Fig. 42) were identified from up to downstream from Logwell Acres. Confined animal feeding operations under event conditions release a higher load of nutrients and sediment to surface waters and can have immediate negative impacts on fish and macroinvertabrate communities (Burkholder *et al*. 2007). Similarly, two CAFO sites [Victory Acres (340 head of cattle) and Bowhill Farms (285 head of cattle)] (Fig. 42) had large increases in nitrate (Victory Acres: + 199.7 %; Bowhill Farms: + 342 %) and TN (Victory Acres: + 110.3 %; Bowhill Farms:

+ 206 %) from above to below each CAFO site under runoff rain event conditions. Releasing the nutrient-rich waste for fertilizer application on wet soils can cause an increase in nutrient runoff and a greater potential of contaminating the ground water supply (Burkholder *et al.* 2007). Since the Wyoming Road tributary has the greatest concentration of CAFO sites (3) and the highest tributary nutrient and sediment areal loads (SRP: 307 g/ha/yr; TP: 1,085 g/ha/yr; nitrate: 27.4 kg/ha/yr; TN: 34.1 kg/ha/yr; TSS: 684.5 kg/ha/yr, Table 14), management efforts should be focused on nonpoint source areas.

Two wastewater treatment plants are downstream from the Warsaw WWTP but upstream from the Garbutt USGS station (Pavilion WWTP and Leroy WWTP) (Fig. 2). Significantly (paired t-test: p-value < 0.05) higher concentrations of SRP, TP, nitrate, and TN were observed below the activated sludge secondary treatment Leroy and Pavilion Waste Treatment Plants (Leroy: SPDES # NY0030546, 1,000,000 gallons per day; Pavilion: SPDES # NY0020133, 80,000 gallons per day). Effluent SRP, TP, nitrate, and TN concentrations were very also high (Table 18). Being the smallest of all four waste treatment plants, Pavilion only contributes roughly 168 kg P/yr while Leroy is the largest of the treatments plant in Oatka Creek contributing 2,146 kg P/yr. Similar to the Warsaw WWTPs, the Leroy and Pavilion WWTP are point sources for SRP, TP, nitrate, and TN. Although the Warsaw WWTP implemented activated sledge systems, a secondary treatment that utilizes bacteria to remove phosphorus. The phosphorus removal efficiency is dependent on the microbial populations within the systems reactor (Bond *et al.* 1999) and it is not effective as a tertiary plant in removing phosphorus (Ellis 1987).

Remediation Scenarios of the Ellicott Road segment

Simulation of the two major source areas within this segment, Pavilion WWTP and the Wyoming Road segment (Fig. 2), were accomplished with the SWAT12 model. The Pavilion wastewater treatment is the smallest discharge plant in the Oatka Creek watershed. Remediation by upgrading the plant to a tertiary operation is possible, but will have only a small impact on P loads (168 kg P/yr) and may not be warranted. The high loading from Wyoming Road tributary which discharges nutrients just upstream from the Ellicott Road site (Fig. 2) was of high priority for remediation recommendations based on segment analysis and the loading results.

Segment analysis conducted on the Wyoming Road tributary suggested nutrient losses were mainly due to agricultural practices involving Confined Animal Feeding Operations. Being mainly agriculture, remediation techniques can range from implementing cover crops, grassed waterways and buffer strips. All three scenarios were tested through the SWAT model to determine the effectiveness of each practice. Out of the three management strategies, implementing grassed waterways had the most beneficial effect on reducing phosphorus loading throughout the entire watershed when applying the practice to agriculture [13,477 kg P/yr to 11,043 kg P/yr (18.0 % reduction)]. When applied to only the Wyoming Road segment, total TP load was reduced by 75.3 % (4,115 kg P/yr to 1,016 kg P/yr, Table 20) suggesting that grassed waterways have a significant impact on the Wyoming Road tributary. Similarly, a study conducted by Bracmort *et al.* (2006) on the effectiveness of BMPs using SWAT noted that under "good conditions" grassed waterways mixed with stabilization structures reduced sediment and phosphorus loading at the outlet by 24 to 32 %, respectively. Grassed waterways have been a proven remediation technique showing great potential in reducing runoff from agricultural fields such as those noted in the Wyoming Road tributary. For example, a study conducted by Fiener and Auerswald 2006 indicated that by implementing grassed waterways 290 meters long by 37 meter wide reduced runoff and sediment transport by 87 to 93 %, respectively. As most watersheds, the Bracmort (2006) study also indicated that high runoff periods existed between February through April. Over 70 % of the total outflow was due to storm events (Bracmort *et al.* 2006) which suggest management efforts to be focused on controlling overland flow during these periods.

Due to the severity of nutrient and sediment losses within the Wyoming Road tributary, a combination of remediation efforts may be needed. Another logical management practice in this impaired segment would be to introduce cover crops to all agricultural land uses with grassed waterways in the Wyoming Road tributary. However, the SWAT simulation suggested adding cover crop to agriculture land within the Oatka Creek watershed only incurred a 3.2 % decrease in total P loads (13,477.4 kg P/yr to 13,042.7 kg P/yr, Table 19). But according to the Zhu *et al.* 1988 study, cover crops usually reduce average annual dissolved nutrients by 7 to 77 %, respectively. Under-prediction of cover crop remediation to Oatka Creek could be due to the cover crop utilized during the simulation (rye). However, when applied to just the Wyoming Road tributary, a reduction of 10 % resulted suggesting that cover crops could act as an additive management recommendation within this segment.

Garbutt Segment (Relative losses, source areas with remediation implications)

The furthest downstream Oatka Creek mainstem segment at Garbutt (Fig. 2) is the second USGS location on the creek which (Fig. 2) records daily discharge and stream height. Two weekly sampling tributary segments are located upstream from Garbutt (Roanoke Road and Parmelee Road) (Fig. 2) but downstream from the middle mainstem segment at Ellicott. Total annual loads were lowest (Table 14) at the Parmelee Road tributary suggesting that a minimal contribution of nutrients and sediment was discharged from the tributary. The Roanoke Road tributary had high areal SRP (297 g/ha/yr), TP (850 g/ha/yr), nitrate (8.2 kg/ha/yr), TN (13.3 kg/ha/yr), and TSS (253.5 kg/ha/yr) load thus indicating areas of concern upstream from the sampling site on Roanoke Road (Table 14). The Garbutt segment, excluding the Parmelee Road and Roanoke Road tributaries (Fig. 2), accounted for 27.9 % of the SRP, 23.9 % of the TP, 46.1 % of the nitrate, 46.3 % of the TN, and 30.3% of the TSS loads suggesting other sources of nutrients and soil.

In the Roanoke Road subwatershed of Oatka Creek, a medium-sized (six acre) CAFO site with 498 cattle (Barniak Farms) exists (Fig. 44). The Barniak Farm CAFO appears to be a source for nutrients (SRP: 421.0 µg P/L; TP: 728.0 µg P/L; nitrate: 4.21 mg N/L; TN: 7.20 mg N/L) and coliform bacteria (64,000 CFU/100 mL) (Figs. 44 and 45). When compared to sub-watershed 2b (a reach lacking CAFOs), which is just east of Barniak Farm, significant increases in nutrients (SRP: +554.0 %; TP: +556.0 %; nitrate: +217.0 %; TN: +230.0 %) and coliform bacteria (+88.0 %) were observed at the CAFO site compared to the non-CAFO site. Elevated levels of nutrients and coliform bacteria are commonly observed downstream of CAFOs (Burkholder *et. al* 2007). Excessive phosphate and nitrogen levels, as observed on the Roanoke subwatershed, are the leading cause for water impairment in the U.S.A. (Steeves 2002).

Bariak Farms CAFO site is the ultimate cause for nutrient runoff in the Roanoke subwatershed which was remediated via the SWAT model. Removal of manure application to agricultural fields with Roanoke Road subwatershed reduced the overall P load by 13.7 % (Table 20) indicating CAFO remediation maybe a useful management technique. Confined Animal Feeding Operations also allocate about 10.2 % of the TP load (Table 12) within the Oatka Creek watershed suggesting CAFO management may reduce the overall TP load. Makarewicz and

Lewis (2004a) suggested that barnyard runoff management, manure storage containers and removing livestock from wooded areas may reduce nutrient-rich soil from reaching the stream bed. Substantial reductions in TP load (34.9 %) we identified when buffer strips were applied to all agricultural land within the Roanoke subwatershed. Remediation techniques such as CAFO management and buffer strips are implemented to reduce nutrient and soil transport to the stream improving the overall water quality of the watershed.

One wastewater treatment plant is located in the Garbutt segment at Scottsville, New York, just downstream from the USGS station at Garbutt [Scottsville Waste Treatment Plant (SPDES# NY0020133, 650,000 gallons per day)]. Effluent SRP, TN and total coliform bacteria abundances were very high (SRP: 1.41 mg P/L; TN: 6.98 mg N/L; total coliform: 150,000 CFU/100 mL) and, concentrations of SRP, TN, and total coliform abundances were significantly higher (paired t-test: $p\text{-value} < 0.05$) observed below the Scottsville Waste Treatment, a secondary treatment plant, during baseline conditions. The Scottsville WWTP is a point source for SRP, TN and coliform bacteria and is also the second largest of all four sewage plants contributing about 1,208 kg of P/yr to the Oatka Creek watershed. The Scottsville WWTP utilizes a diffused air system, which is a secondary treatment that can be effective if the oxygen transfer process within the activated sludge is evaluated and also can limit the effect of impurities that may be concentrated within the wastewater (Chern *et al.* 2001). Impurities in the wastewater may cause a reduction in oxygen transfer which is used by microbial communities in activated sledge systems to uptake phosphorus (Chern *et al.* 2001). Utilizing the SWAT12 model to remove all WWTPs in Oatka Creek solved this issue by reducing TP loads by 25.0% (Table 19).

Excluding the four waste water treatment plants, Oatka Creek has four sites (Caledonia Fish Hatchery, Markin Tubing, Lapp Insulator, and Pcore Electric Company) that have obtained SPDES permits. These permits are issued to places that discharge nutrients and waste into lakes or streams. In New York, the Environmental Protection Agency (EPA) is able to monitor and control the amount of pollutants being discharge daily (DEC 2006). These permit holders are also required to maintain site-specific water quality standards given by the EPA. Water quality standards are important to regulate the amount of contaminants being discharged to the stream which further degrades the water quality.

Fish hatcheries as point sources of phosphorus via effluent pipe discharging from the aquaculture operation are known (Cain and Garling 1995). A segment analysis conducted concluded a 328% increase in SRP concentrations and a 354% increase in TP concentrations from above to below the Caledonia Fish Hatchery (Fig. 54). To determine the impacts of the Caledonia Fish Hatchery, samples were taken at the intake and outtake pipe of the hatchery in order to quantify the amount of phosphorus being discharged. The Caledonia Fish Hatchery under NYS SPDES regulations is able to discharge a maximum of 7.26 million gallons per day into Big Spring Creek (personal communication, Alan Mack, manager of the Caledonia Fish Hatchery). The samples taken from the intake and outtake pipe on both dates (1 September 2011 and 7 September 2011) resulted in increases in SRP and TP concentrations (1 September 2011 – SRP: + 159%; TP: + 255%; 7 September 2011 – SRP: + 336%; TP: + 596%) (Table 5). The main source of phosphorus in hatchery systems is via fish food and fecal matter (Ruiz and Hall 1996). At the Caledonia Fish Hatchery in 2010, 187,866 lbs (85,215 kg) of Melick aquaculture food was fed to fish. This is equivalent to 2,442 lbs (1,108 kg) of pure phosphorus (personal contact: Alan Mack, manager of the Caledonia Fish Hatchery).

The Caledonia Fish Hatchery was used as an input source in the SWAT12 model to determine the overall impact the hatchery had on the watershed. When the input point source was removed, the overall phosphorus load was decreased by 260 kg P/yr which makes up roughly 2.0 % of the total P loss from Oatka Creek (Table 12). With the amount of nutrients in the Oatka Creek watershed allocating from agriculture and wastewater treatment plants, the Caledonia Fish Hatchery is not a major area of concern in Oatka Creek.

Target Concentrations with Management Recommendations

Oatka Creek is currently below the 65 µg P/L level and the 20 µg P/L is not feasibly attainable unless all human presence is removed. Five remediation strategies were developed to attain the 45 µg P/L target in the SWAT12 model to determine the best management practice approach to improve the water quality of the watershed. First of the five management scenarios is upgrading all four secondary wastewater treatment plants to tertiary plants. After implementing tertiary treatment plants, a 24.9 % reduction in total annual TP load was identified lowering the average TP concentration from 51.6 to 38.8 µg P/L (24.8 % reduction in concentration) (Table 19). More intensive agricultural management recommendations such as grassed waterways, cover crops and filter strips also reduced the TP concentration and TP load in the entire watershed. When applied throughout Oatka Creek, grassed waterways reduced the annual TP load by 2,434.5 kg P/yr (18.1 % reduction) and lowering the TP concentration to 42.3 µg P/L (18.0 % reduction) (Table 19).

Combined management, a utilization of several BMPs, also attained the 45 µg P/L concentration target goal. The most strenuous management implication included upgrading all four WWTPs and included implemented grass waterways and filter strips. This management technique [45 Target Scenario (1)] (Table 19) significantly reduced TP load (55.3 % reduction) and concentration (42.6 % reduction to 29.6 µg P/L). This management scenario utilizes several land uses and would not be recommended for basin-wide management due to the cost and time it would take to implement; rather it may be utilized in areas of impairment where intensive remediation is needed. For the two areas with elevated runoff (Roanoke and Wyoming), a management scenario [45 Target Scenario (2)] (Table 19) was implemented with cover crops (rye) throughout Oatka Creek then focused grassed waterways and filter strips on all agricultural land uses within Roanoke and Wyoming tributaries. The 45 µg P/L concentration target for Garbutt and the entire watershed was reached with Target Scenario (2) adequately reducing TP load (13,477.4 to 11,067.5 kg P/yr: 17.9 % reduction) and concentration (51.6 µg P/L to 44.3 µg P/L: 14.1 % reduction) (Table 19). Lastly, two management practices were implemented (cover crop and filter strips) [45 Target scenario (3)] to agricultural land uses throughout Oatka Creek to attain an average annual TP concentration of 44.4 µg P/L [14.0 % reduction (Table 19)].

Conclusions and Recommendations

Anthropogenic sources due to human interactions have made a great impact on the hydrology and stream chemistry of Oatka Creek (Figs. 59 and 60) with over 70% of the attributed phosphorus load from non-natural sources. Runoff from nonpoint sources (Confined Animal Feeding Operation sites, agricultural practices and urban areas) and point sources (Wastewater treatment plants and State Pollution Discharge Elimination Sites) lead to impaired water quality in most watershed and lake systems. Nutrients from runoff such as phosphorus and sediment being transported downstream can have a long lasting negative impact on the overall environmental health of the Oatka Creek watershed ecosystem. Not only do these sources have a negative impact on the stream ecosystem, but the nutrients from the Genesee River are then transported to the near shore of Lake Ontario causing issues such as eutrophication, beach closings, harmful algae blooms, reduced homeowner aesthetics and reduce habitat for organisms (Makarewicz 2010). Due to the negative impacts on lake ecosystems, it is important to locate and manage nutrient and sediment sources within the subwatersheds of Lake Ontario.

Oatka Creek in the second largest tributary of the Genesee River and a very important trout fishery making it important to locate the extent and size of the sources to determine the best remediation approach. This study focused on identifying nonpoint and point sources, quantify the nutrient and sediment loads from Oatka Creek and to suggest the best management strategies based on the Soil Water Assessment Tool (SWAT) model. A water quality target of 45-µg P/L for phosphorus stream concentration is the most logical target for Oatka Creek because the stream is below the 65-µg P/L proposed target (modeled concentration: 51.6 µg P/L) and would allow for attainable management recommendations. The most effective management recommendation to reduce the overall TP loading in Oatka Creek is to upgrade all four (Warsaw, Pavilion, Leroy and Scottsville) wastewater treatment plants from secondary to tertiary treatment systems. Other nonpoint source recommendations is to implement management such as grassed waterways, buffer strips and cover crops within the two most impaired tributaries (Wyoming Road and Roanoke Road) in the Oatka Creek watershed. Both suggestions would significantly improve the water quality in the Oatka Creek watershed by reducing the average annual P concentration to below the 45 µg P/L target. Another issue to manage is the large amount of soil that is transported to the site in Warsaw, NY along the mainstem. Streambank stabilization techniques have already been implement in areas upstream from Warsaw, but including more in the highly erodible areas will have a beneficial impact on reducing the TP and TSS loading in this segment of Oatka Creek.

This study determined many different management recommendations through the utilization of the SWAT12 model that could potentially reduce the amount of nutrients and sediment being transported downstream. By making remediation recommendations, not only will the water quality of Oatka Creek improve significantly, but it will have a positive impact on the Genesee River and the nearshore of Lake Ontario. To achieve a TMDL for Oatka Creek, best management practices should be implemented to meet possible water quality targets. Once this is achieved, the nearshore of Lake Ontario can be restored from beneficial use impairments caused by human influences.

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Table 1. Oatka Creek subwatershed Sewage Treatment Plant (WWTP) information (Fig. 2**).**

WWTP Site	Location	Contact #	SPDES #	Daily Maximum Discharge (m^3/day)	Treatment System
Scottsville WWTP	Scottsville, NY	(585)-889-1002	NY0020133	2,461 (Average:2,068)	Secondary
Leroy WWTP	Leroy, NY	(585)-768-2234	NY0030546	3,785 (Average:2,410)	Secondary
Pavilion WWTP	Pavilion, NY	(845)-677-3839	NY0247197	303 (Average: 128)	Secondary
Warsaw WWTP	Warsaw, NY	(585)-786-8575	NY0021504	2,650 (Average: 1,113)	Secondary

Table 2. Weekly sampling site locations (Fig. 2).

Site	Latitude	Longitude
Garbutt USGS (Union Street)	N 43^{O} 00.613'	W 77^{O} 47.502'
Parmelee Road	N 43^{O} 00.891'	W 77^{O} 58.240'
Roanoke Road	N 42^{O} 57.478'	W 78^{O} 01.422'
Ellicott Road	N 42^{O} 52.853'	W 78^{O} 01.769'
Wyoming Road	N 42^{O} 50.909'	W 78^{O} 02.592'
Warsaw USGS (Court Street)	N 42^{O} 44.575'	W 78^{O} 08.237'
Evans Road	N 42^{O} 41.071'	W 78^{O} 06.076'
Buck Road	N 42^{O} 43.677'	W 78^{O} 09.696'

Table 3. Analysis methods used from Standard Methods for the Examination of Water and Wastewater (APHA 2005) and 3M (3M 2010).

Analyte	***Standard Method***
Total Phosphorus (TP)	***4500-P B.#5*** *Persulfate Digestion Method*
Soluble Reactive Phosphorus (SRP)	***4500-P F.*** *Automated Ascorbic Acid Reduction Method*
Total Suspended Solids (TSS)	***2540 D.*** *Dried TSS 103 to 105^{o}C*
Total Nitrogen (TN)	***4500-N C.*** *Persulfate Method*
Nitrate-Nitrite (NO_3 + NO_2)	***4500-NO_3^- F.*** Automated Cadmium *Reduction Method*
Total Coliform	***3M Petrifilm*** *Count Plate*

Table 4. Weather station datasets utilized in the Oatka Creek SWAT model.

COOP ID	NAME	LAT	LONG	ELEVATION (m)
300343	Avon	42.92083	-77.75556	50.6
300443	Batavia	43.03028	-78.16917	84.7
308962	Warsaw	42.68333	-78.21667	169.2
305597	Mount Morris	42.73056	-77.90444	81.7

Table 5. Water quality of influent and effluent from Caledonia Fish Hatchery on 23 August 2011, 1 September 2011, and 7 September 2011. Three samples were taken at the effluent and two at the intake pipe. Percentages indicate changes in analyte concentrations from influent to effluent pipe.

Site	Date	TP	Nitrate	TSS	SRP	TN	Coli
Caledonia Fish Hatchery Effluent pipe	8/23/2011	33.0	1.76	2.9	7.3	2.09	1,700
Caledonia Fish Hatchery Influent pipe	9/1/2011	9.3	1.54	2.0	4.1	1.86	700
Caledonia Fish Hatchery Effluent pipe	9/1/2011	32.9 (+255%)	1.49 (-3%)	1.1 (-45%)	10.6 (+159%)	1.77 (-5%)	3,600 (+414%)
Caledonia Fish Hatchery Influent pipe	9/7/2011	7.2	1.62	0.6	3.6	1.92	11,800
Caledonia Fish Hatchery Effluent pipe	9/7/2011	50.1 (+596%)	1.58 (-3%)	0.6 (±0%)	15.7 (+336%)	2.11 (+10%)	46,000 (+290%)

Table 6. A list of all Oatka Creek CAFO sites and the amount of dairy fresh manure applied (kg/ha)*30 day frequency) to specific HRU's (hydrologic response units) within selected subbasins. ha = hectares and transferred = CAFO sites that transfer 100% of the manure out of Oatka Creek.

SPDES	Site	County	HRU's used	ha used	kg/ha *30 day
NYA001455	Broughton Farms Operation, LLC	WYOMING	subbasins 78-81 (all corn and hay)	873.0	4044.9
NYA001443	Double B Farms (Broughton owned)	WYOMING	subbasin 76 (hay)	634.0	491.4
NYA000228	Swiss Valley Farms	WYOMING	subbasins 72-73 (all corn and hay)	461.8	3966.6
NYA001515	East Hill Farm, LLC	WYOMING	subbasin 64-65 (all hay and corn)	851.4	1923.2
NYA000278	Bowhill Farm	WYOMING	subbasin 59 (all corn and hay)	419.0	2395.5
NYA001413	Victory Acres	WYOMING	Transferred outside watershed	transferred	transferred
NYA000440	Highland Farms	WYOMING	subbasin 62 (hay)	1054.0	1456.8
NYA000139	Logwell Acres Inc.	WYOMING	subbasin 55 (all corn and hay)	409.8	1583.4
NYA001492	Craig T. Harkins	WYOMING	subbasin 43 (all corn and hay)	238.1	2655.9
NYA000257	Synergy, LLC	WYOMING	Transferred outside watershed	transferred	transferred
NYA000098	Hildene Farms, INC.	GENESEE	subbasin 37 (all hay and corn)	248.1	1818.7
NYA000359	Cottonwood Farms	GENESEE	subbasin 41 (all hay and corn)	160.0	3359.9
NYA001421	Barniak Farms	GENESEE	subbasin 39 (all hay and corn)	830.7	1656.6
NYA000102	Hy Hope Farms, INC.	GENESEE	subbasin 30 (all hay and corn)	317.1	3874.5
NYA000241	Hubert W. Stein & Sons	LIVINGSTON	subbasin 27 (hay)	605.5	2038.9
NYA000246	Pagen Farms, INC.	GENESEE	subbasin 38 (all hay and corn)	1040.0	1555.2
NYA000555	Stein Farms, LLC	GENESEE	subbasin 10 (all hay and corn)	758.6	2291.1
NYA000459	Udderly Better Acres	GENESEE	subbasin 10 (generic agriculture)	68.9	15886.7
NYA000099	Mowarces Farm II, LLC	GENESEE	subbasin 27 (corn)	364.9	3980.5
NYA000578	D & D Dairy	MONROE	subbasin 19 (hay)	210.8	2222.4

Table 7. Karst water input regression equations by month (December through May) which was calculated over a 40 year time period (1970-2009) (Fig. 9 and 10). The (x) represents the average flow measured at the USGS monitoring station at Garbutt, NY while the (y) represents karst water input.

Month	Regression equation
January	$y = 1852.2x - 511792$
February	$y = 1835.7x - 497321$
March	$y = 1974.4x - 555879$
April	$y = 1919.5x - 520688$
May	$y = 1847.9x - 484439$
December	$y = 2036.1x - 567921$

Table 8. Calibration results (1 June 2010 to 31 May 2011) of the Oatka Creek SWAT model. PBIAS = Percent bias.

Garbutt	Water	TSS	Phosphorus
Nash-Sutcliffe	0.94	0.90	0.71
PBIAS	5.1	2.5	10.3
r^2	0.95	0.90	0.80

Table 9. A summary of percent bias (PBIAS) by comparing SWAT simulated total suspended solid (TSS) loads (1 June 2010 through 30 May 2011) to the observed TSS loads at all eight monitoring locations. M= mainstem, T = Tributary, MT = Metric tons.

Site	Watershed Area (ha)	Observed TSS (MT/yr)	Simulated TSS (MT/yr)	PBIAS (%)
Evans Road (M)	1,712	292.1	284.2	-2.7
Warsaw (M)	8,518	5,791.0	6,531.8	12.8
Ellicott Road(M)	16,706	2,811.8	1,962.7	-30.2
Garbutt (M)	26,159	4,969.6	5,094.1	2.5
Buck Road (T)	2,126	370.9	457.2	23.3
Wyoming Road (T)	3,496	2,393.1	2,335.8	-2.4
Roanoke Road (T)	2,367	600.0	780.6	30.1
Parmelee Road (T)	4,014	73.9	70.7	-4.3

Table 10. A summary of percent bias (PBIAS) by comparing SWAT simulated total phosphorus (TP) loads (1 June 2010 through 30 May 2011) to the observed TP loads at all eight monitoring locations. M= mainstem, T = Tributary, MT = Metric tons.

Site	Watershed Area (ha)	Observed TP (kg/yr)	Simulated TP (kg/yr)	PBIAS (%)
Evans Road (M)	1,712	787.2	657.9	-16.4
Warsaw (M)	8,518	5,230.9	5,079.9	-2.9
Ellicott Road(M)	16,706	9,210.8	6,923.1	-24.8
Garbutt (M)	26,159	15,017.6	13,477.4	-10.3
Buck Road (T)	2,126	840.9	815.0	-3.0
Wyoming Road (T)	3,496	3,792.5	4,115.0	8.5
Roanoke Road (T)	2,367	2,012.0	2,347.0	16.7
Parmelee Road (T)	4,014	215.2	270.5	25.7

Table 11. Results of the validation run (June 2003 – May 2004) of the Oatka Creek SWAT model.

Garbutt Validation	2003-2004 Water Year
Nash-Sutcliffe	0.73
PBIAS	4.8
r^2	0.84

Table 12. Oatka Creek SWAT model average annual allocation of total phosphorus (TP) per source (June 2010 – May 2011).

Land Use/Activity	Current Load kg TP/yr	Percent of Total Predicted Load (%)	Method of Determination
Agricultural Crops	2,305	17.9	Subtraction
Tile Drainage	438	3.4	Subtraction
Farm Animals (CAFO only)	1,310	10.2	Subtraction
Stream bank Erosion	563	4.4	Subtraction
Wetlands	2	0.0	HRU Table
Fish Hatchery	260	2.0	Subtraction
Groundwater	3,244	25.2	HRU Table
Forest	35	0.3	HRU Table
Urban Runoff	439	3.4	Subtraction
Sewage Treatment	3,375	26.2	Subtraction
Septic Systems	890	6.9	Subtraction
Sum of Allocated Loads	12,861		
Total Predicted Load (From SWAT)	13,477		
Allocation Error	-616		

Table 13. Event versus Nonevent concentrations for SRP, TP, nitrate, TN, TSS, and total coliform at all weekly sampling locations from June 2010 through May 2011 (Fig. 2).

Buck Road	TP (µg P/L)	Nitrate (mg N/L)	TSS (mg/L)	SRP (µg P/L)	TN (mg N/L)	Coliform (CFU/100 mL)
Nonevent	16.7 ± 1.3	1.53 ± 0.12	1.9 ± 0.3	9.0 ± 1.3	1.82 ± 0.11	1,381 ± 369
Event	114.8 ± 26.9	1.34 ± 0.19	51.9 ± 17.8	25.3 ± 5.1	2.01 ± 0.18	23,352 ± 9,003
Evans Road						
Nonevent	15.9 ± 1.4	1.80 ± 0.11	2.5 ±0.4	6.7 ± 0.8	2.21 ± 0.11	2,405 ± 632
Event	189.9 ± 109.4	1.53 ± 0.20	57.8 ± 31.9	30.1 ± 11.0	2.26 ± 0.20	11,743 ± 2,901
Warsaw						
Nonevent	12.5 ± 1.4	1.58 ± 0.12	7.2 ± 1.5	3.1 ± 0.4	1.84 ± 0.12	2,782 ± 1,201
Event	182.7 ± 61.6	1.47 ± 0.17	207.7 ± 74.1	18.6 ± 5.0	2.20 ± 0.27	12,123 ± 4,510
Roanoke Road						
Nonevent	38.0 ± 4.8	1.00 ± 0.17	3.5 ± 0.5	15.5 ± 2.9	1.50 ± 0.16	3,374 ± 716
Event	198.4 ± 43.8	1.15 ± 0.17	63.6 ± 22.9	71.3 ± 13.3	2.21 ± 0.25	29,060 ± 8,759
Ellicott Road						
Nonevent	59.3 ± 3.7	2.09 ± 0.13	10.5 ± 1.8	28.7 ± 2.7	2.50 ± 0.13	4,450 ± 928
Event	175.5 ± 39.8	2.19 ± 0.14	53.3 ± 13.6	69.3 ± 9.5	2.93 ± 0.19	18,119 ± 3,219
Wyoming Road						
Nonevent	29.9 ± 2.3	3.32 ± 0.15	4.4 ± 0.5	12.2 ± 1.2	3.86 ± 0.15	2,722 ± 559
Event	191.6 ± 53.9	3.17 ± 0.31	106.7 ± 43.1	67.7 ± 16.7	4.32 ± 0.39	22,980 ± 6,950
Parmelee Road						
Nonevent	18.3 ± 1.1	0.77 ± 0.15	5.7 ± 1.1	4.1 ± 0.53	1.39 ± 0.13	4,748 ± 1,090
Event	26.2 ± 4.4	0.91 ± 0.24	8.3 ± 1.4	6.0 ± 1.6	1.40 ± 0.21	8,396 ± 2,173
Garbutt						
Nonevent	29.6 ± 2.9	2.11 ± 0.10	6.3 ± 1.1	13.2 ± 1.5	2.54 ± 0.12	1,238 ± 265
Event	74.3 ± 12.6	1.94 ± 0.16	22.3 ± 5.8	25.5 ± 4.1	2.44 ± 0.20	10,826 ± 6,306

Table 14. A. Total annual load (kg/ha) (1 June 2010 to 7 June 2011) of nutrients and sediments (kg/yr) at four mainstem (M) and four tributary (T) locations in the Oatka Creek watershed and **B.** total annual areal load was calculated for nutrients and sediments (kg/ha/yr) at four mainstem (M) and four tributary (T) locations in the Oatka Creek watershed. SRP = Soluble reactive phosphorous, TP = Total phosphorus, TN = Total nitrogen and TSS = Total suspended solids. Percent (%) signifies fraction contributed of total watershed load (Garbutt, NY).

A.	**Total Annual Load (kg/yr)**					
Site	Area (ha)	SRP	TP	Nitrate	TN	TSS
Parmelee Road (T)	4,014	47 (0.8%)	215 (1.4%)	11,878 (2.1%)	16,263 (2.4%)	73,900 (1.5%)
Roanoke Road (T)	2,367	702 (12.5%)	2,012 (13.4%)	19,511 (3.5%)	31,366 (4.6%)	600,035 (12.0%)
Wyoming Road(T)	3,496	1,075 (19.1%)	3,793 (25.3%)	95,864 (17.2%)	119,139 (17.6%)	2,393,098 (47.8%)
Buck Road (T)	2,126	169 (2.9%)	841 (5.6%)	23,917 (4.3%)	29,137 (4.3%)	370,903 (7.4%)
Evans Road (M)	1,712	201 (3.6%)	787 (5.2%)	17,538 (3.2%)	22,658 (3.3%)	292,147 (5.8%)
Warsaw (M)	8,518	592 (10.5%)	5,231 (34.8%)	114,164 (20.5%)	139,828 (20.6%)	5,791,046 (115.7%)
Ellicott Road (M)	16,706	3,314 (58.8%)	9,211 (61.3%)	268,733 (48.3%)	316,487 (46.7%)	2,811,827 (56.2%)
Garbutt (M)	26,159	5,635	15,018	556,686	677,504	5,006,876
B.	**Total Areal Load for Segment Area (kg/ha/yr)**					
Site	Area (ha)	SRP (g/ha/yr)	TP (g/ha/yr)	Nitrate	TN	TSS
Parmelee Road (T)	4,014	12	54	3.0	4.1	18.4
Roanoke Road (T)	2,367	297	850	8.2	13.3	253.5
Wyoming Road(T)	3,496	307	1,085	27.4	34.1	684.5
Buck Road (T)	2,126	79	396	11.2	13.7	174.4
Evans Road (M)	1,712	117	460	10.2	13.2	171.0
Warsaw (M)	8,518	47	770	15.5	18.8	1,095.7
Ellicott Road (M)	16,706	351	40	12.5	12.3	0.0
Garbutt (M)	26,159	512	1,165	83.5	102.0	495.2

Table 15. Results from the erosion inventory conducted on 28 July 2011. Above = upstream, Below = downstream. Sites refer to Fig. 29.

Site	Concentration above	Concentration below	Elevation Change	Distance Traveled	Erodible Stream Bank	Percent Erodible
Site C to OC Warsaw	40.8 mg/L	123.8 mg/L (+ 203 %)	17.9 m drop	4.00 km	1.09 km	30.4%
OC Evans Rd to Site H (reference location)	9.7 mg/L	13.3 mg/L (+ 37 %)	64.0 m drop	3.57 km	0.40 km	10.0%

Table 16. Soluble reactive phosphorus (SRP, µg P/L), total phosphorus (TP, µg P/L), nitrate (mg N/L), total nitrogen (TN, mg N/L) and total suspended solid (TSS, mg/L) seasonal loading at the USGS monitoring station at Garbutt, NY.

Garbutt, NY	TP	Nitrate	TSS	SRP	TN
Summer 2010	1,527	57,527	318,659	666	74,254
Fall 2010	1,920	70,037	540,302	774	85,886
Winter 2010-2011	5,725	226,765	1,446,821	1,984	270,819
Spring 2011	5,846	202,357	2,701,094	2,211	246,546
Total	15,018	556,686	5,006,876	5,635	677,504

Table 17. Comparison and results from both sampling locations near the Genesee Country Village (site 1) on 12 July 2010.

	SRP (µg P/L)	TP (µg P/L)	Total Coliform (CFU/100mL)	TSS (mg/L)	Nitrate (mg N/L)	TN (mg N/L)
Site1 A (East Culvert)	6.1	16.3	1,500	3.75	2.1	2.44
Site1 B (West Culvert)	5.2	35.2	1,600	4.14	1.93	2.22

Table 18. Results from samples taken above and below Warsaw, Leroy, Pavilion and Scottsville WastewaterTreatment Plants (WWTP). Distances samples were taken above and below the WWTP are listed. Asterisk represents a Wilcoxon statistical test was conducted.

Wastewater Treatment Plant (WWTP)		SRP (µg P/L)	TP (µg P/L)	Nitrate (mg N/L)	TN (mg N/L)	TSS (mg/L)	Total Coliform (CFU/100mL)
Above Warsaw WWTP	820m	1.1 ±0.24*	7.9 ±0.39*	0.82 ±0.01*	1.02 ±0.02	3.10 ±0.52	7875 ±550
Below Warsaw WWTP	1,200m	138.4 ±1.55*	148.7 ±3.68*	1.58 ±0.01*	1.95 ±0.04	2.25 ±0.59	13050 ±2357
Effluent pipe	10/19/2011	1780.8	1843.0	16.04	29.68	7.7	34,000
	P-value	0.05*	0.05*	0.05*	<0.001	0.16	0.059
Above Leroy WWTP	900m	18.2 ±0.41*	40.6 ±0.46	1.14 ±0.01*	1.62 ±0.03	2.72 ±0.37	725 ±111
Below Leroy WWTP	1,600m	64.9 ±0.42*	84.3 ±0.52	1.23 ±0.00*	1.79 ±0.02	1.66 ±0.24	850 ±278
Effluent pipe	10/19/2011	2372.9	2436.9	12.50	28.39	2.1	450,000
	P-value	0.05*	<0.001	0.05*	0.004	0.072	0.334
Above Pavilion WWTP	1,200m	14.9 ±0.19	40.2 ±0.52	1.30 ±0.01*	1.60 ±0.01	4.30 ±0.49	250 ±96
Below Pavilion WWTP	190m	21.0 ±0.71	45.2 ±0.83	1.40 ±0.00*	1.70 ±0.01	2.60 ±0.33	1725 ±132
Effluent pipe	10/19/2011	3425.9	3591.8	19.09	20.44	12.1	52,000
	P-value	<0.001	<0.001	0.05*	0.001	0.027	<0.001
Above Scottsville WWTP	50m	24.7 ±0.27	55.0 ±1.87	2.10 ±0.02	2.53 ±0.02	11.88 ±0.28	4875 ±225
Below Scottsville WWTP	200m	28.7 ±0.32	62.4 ±5.01	2.13 ±0.04	2.27 ±0.01	11.22 ±0.63	6600 ±635
Effluent pipe	10/19/2011	1405.7	1597.8	4.13	6.98	7.4	150,000
	P-value	0.002	0.15	0.128	0.001	0.098	0.042

Table 19. Oatka Creek SWAT management scenarios (SWAT Run Period: 1 Jan 2008 – 31 May 2011; SWAT Analysis Period: 1 June 2010 – 31 May 2011). Negative percent reduction indicates a net increase in TP and TSS loading in the stream. Kg = kilograms, µg = micrograms, MT = metric tons. 45 Target Scenario (1) = Upgrading all four WWTPs, grassed waterways and buffer strips to the entire watershed. 45 Target Scenario (2) = Cover crops to entire watershed and grassed waterways/buffer strips to Wyoming Road and Roanoke tributaries. Target Scenario (3) = cover crops and buffer strips to the entire watershed.

Management Scenarios	TP Load kg P/yr	Percent TP Load Reduction	TP Concentration µg P/L	Percent TP Concentration reduction	TSS Load MT TSS/yr	Percent TSS Load Reduction
Base Model	13,477	0	51.6	0	5,094	0
Forested	5,325	60.5	22.9	55.6	4,659	8.5
No CAFO	12,168	9.7	47.1	8.7	4,993	2.0
No WWTP	10,103	25.0	38.7	25.0	5,094	0.0
Upgrade WWTP	10,117	24.9	38.8	24.8	5,094	0.0
Upgrade Leroy and Warsaw WWTP	10,315	23.5	39.5	23.4	5,094	0.0
No Septic	12,687	6.6	58.1	-12.6	4,558	10.5
Stream bank Stabilization	14,042	-4.2	55.9	-8.3	665	87.0
No Agriculture	11,172	17.1	46.4	10.1	4,846	4.9
Buffer Strips	12,348	8.4	47.3	8.3	4,989	2.1
Contouring	12,611	6.4	48.4	6.2	5,265	-3.3
Grassed Waterways	11,043	18.1	42.3	18.0	5,315	-4.3
Conservation Tillage	17,453	-29.5	66.8	-29.5	5,022	1.4
No Fertilizer (100% Red.)	13,046	3.2	50.0	3.1	5,097	0.0
Cover Crops	13,043	3.2	50.4	2.3	5,210	-2.3
Terracing	12,285	8.8	47.1	8.7	5,281	-3.7
Strip Cropping	12,734	5.5	48.8	5.4	5,260	-3.3
25 % nutrient Management	13,206	2.0	50.6	1.9	5,106	-0.2
50% nutrient management	13,198	2.0	50.6	1.9	5,095	0.0
75% nutrient management	13,129	2.6	50.3	2.5	5,097	-0.1
Remove all point sources	9,847	26.9	37.7	26.9	5,094	0.0
45 Target Scenario (1)	6,028	55.3	29.6	42.6	5114	-0.4
45 Target Scenario (2)	11,068	17.9	44.3	14.1	5191	-1.9
45 Target Scenario (3)	11,493	14.7	44.4	14.0	5165	-1.4

Table 20. Agricultural management scenarios conducted on Evans Road and Wyoming Road subwatersheds. Percent TP load reductions are indicated for each scenario.

Management Scenario	Evans Road (Load kg P/yr)	Wyoming Road (Load kg P/yr)	Roanoke Road (Load kg P/yr)
Base Model	657.9	4,115.0	2,347.0
Buffer Strips	592.5 (9.9%)	3157.7 (23.3%)	1,527.9 (34.9%)
Grassed Waterways	500 (24.0%)	1016.4 (75.4%)	97.7 (95.8%)
Cover Crops	542.9 (17.5%)	3912.5 (4.9%)	2,816.2 (+20.0%)
CAFO remediation	500.6 (23.9%)	3975.8 (3.4%)	2,026.5 (13.7%)

Table 21. Mainstem total phosphorus (TP) and total suspend solid (TSS) concentrations from measured values, SWAT "base" model simulated, and SWAT natural forested simulated data.

Site Location	TP (µg P/L) Observed	TP (µg P/L) Base Simulation	TP (µg P/L) Natural	TSS (mg/L) Observed	TSS (mg/L) Base Simulation	TSS (mg/L) Natural
Garbutt	41.3	51.6	22.9	10.5	21.1	20.8
Ellicott Road	97.1	49.2	22.9	24.5	12.6	12
Warsaw	58.4	81.4	41.5	60.3	95	96.5
Evans Road	63.2	65.1	20.2	17.5	15.1	0.3

Table 22. Well water samples taken in the Western New York Region analyzed for total phosphorus (TP) concentrations in groundwater.

Sample	TP	Address	Depth of Well (ft)
	(µg P/L)		
Grimble Well	162.7	3117 Allens Bridge Rd Albion, NY 14411	N/A
Riddley Well	2.6	4000 Lake Rd Holley, NY 14470	N/A
Dansville water plant well	4.5	9980 Highland Ave. Dansville, NY 14437	72
Groveland well	7.5	6509 Groveland Hill Rd. Groveland, NY 14462	20
Mudrynski Well	3	6974 Norton Rd. Elba, NY 14058	30
Peter Lents Well (Caledonia)	3.8	907 Sandhill Rd. Caledonia, NY	23
Esther's Well (Pavilion)	0.7	11047 River Rd. Pavilion, NY	55-62
Maureen's Well (Oatka Trail Road)	3.7	3063 Oatka Creek Rd. Mumford, NY	23
Doran Well	3.1	11996 Roosevelt Highway, Lyndonville, NY	30
Comden Well	28.7	1801 Walker Lake Ontario Rd, Hilton NY 14468	N/A
Livingston Associates River Rd (Well)	2.8	River Rd. Caledonia, NY	55
Maxwell Farms (Well)	17.3	3977 Lakeville-Groveland Rd. Lakeville, NY	100
Springwater PWS (Well)	2.8	Kellegg Rd. Springwater, NY	35
Keshequa Bus Garage (Well)	64.3	Rt. 108 Dalton, NY	62
6290 Railroad Ave (Well)	42.2	6290 Railroad Ave, NY	50
McNinch Rd Ossian (Well)	4	McNinch Rd. Ossian, NY	47
Average well TP concentration (µg P/L)	22.1		

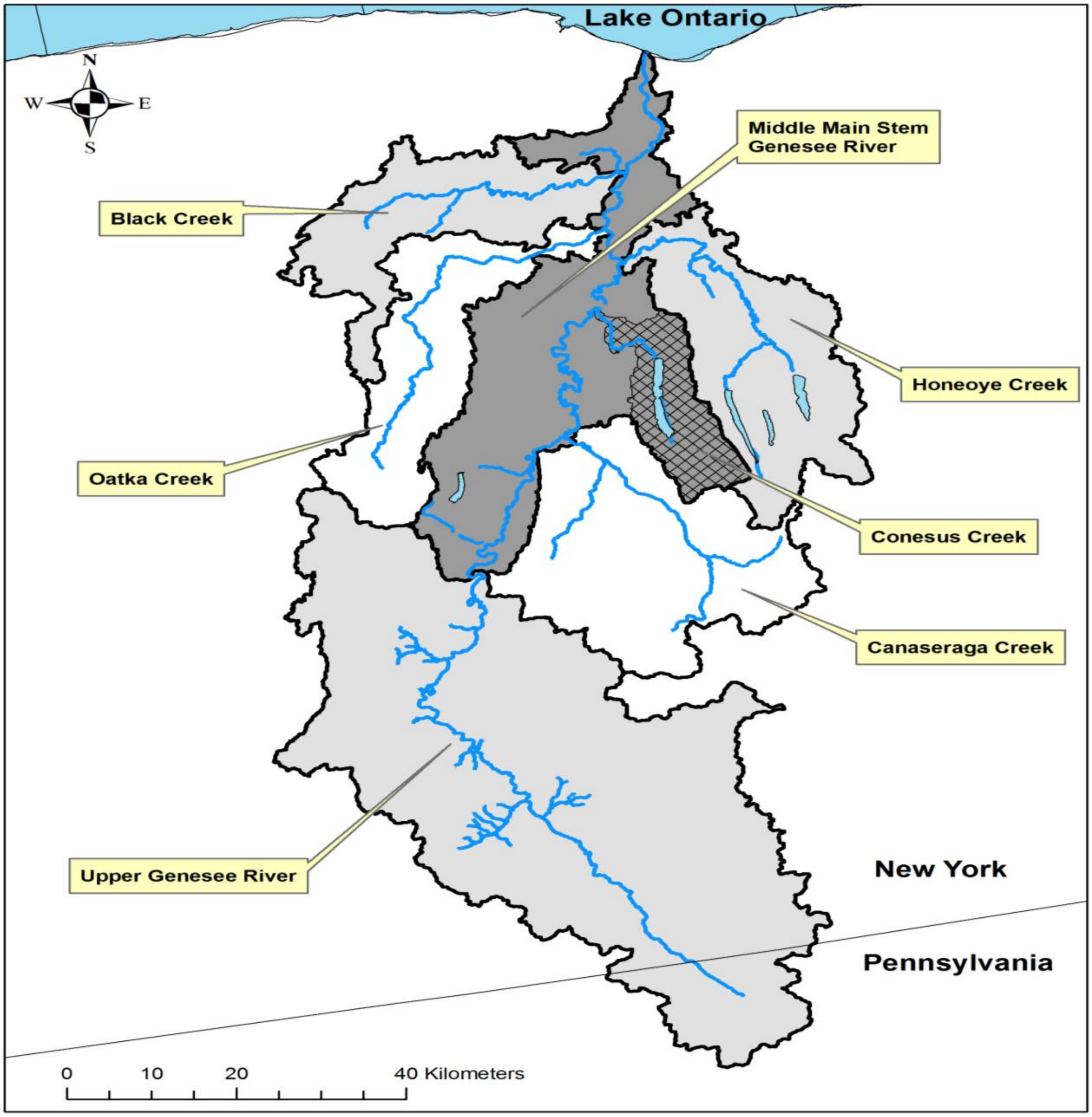


Figure 1. Genesee River watershed along with the major tributaries (Black Creek, Oatka Creek, Canaseraga Creek, Honeoye Creek)

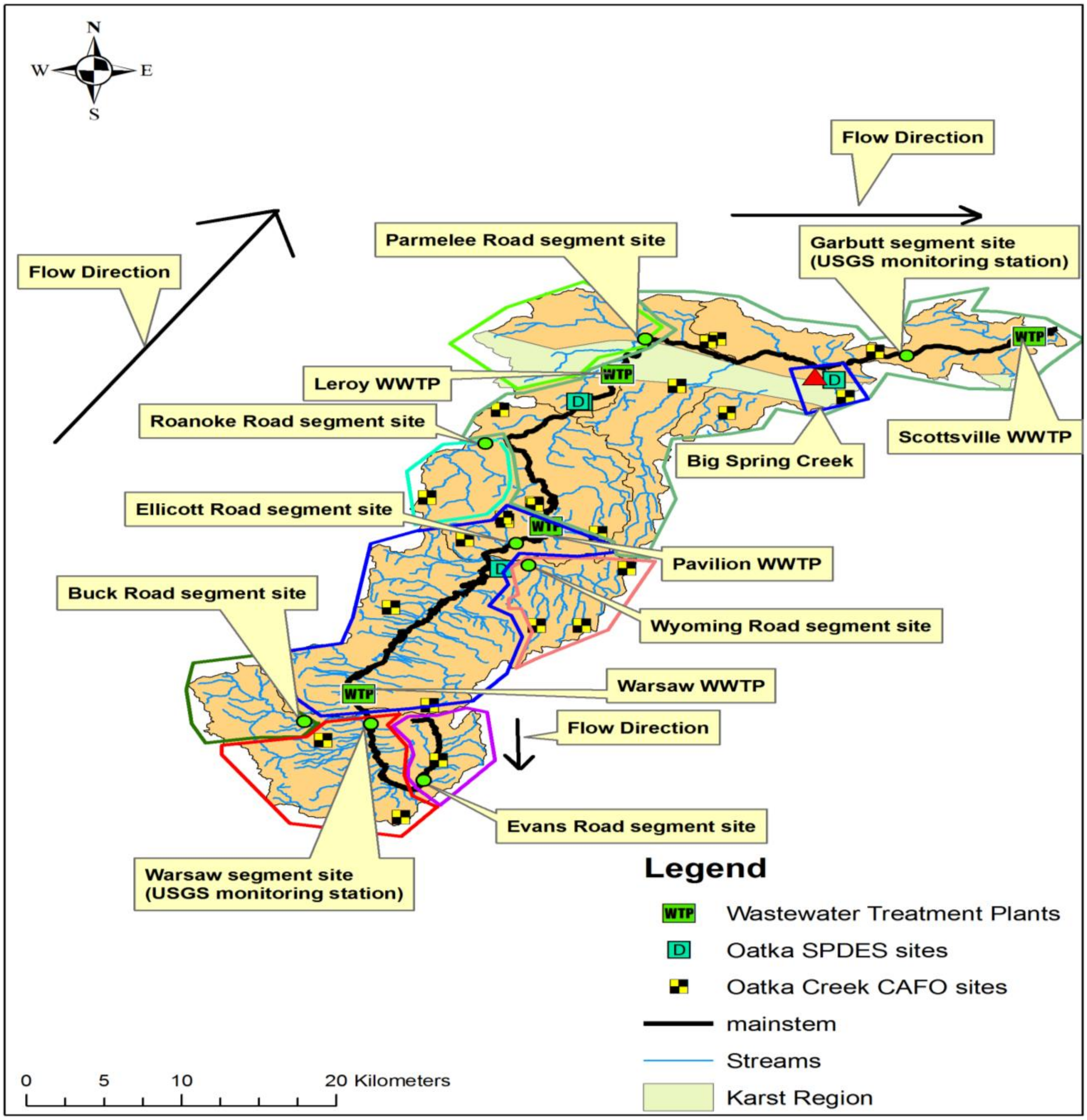


Figure 2. Map indicating the eight major study segments (Evans Road, Buck Road, Warsaw, Ellicott Road, Roanoke Road, Parmelee Road and Garbutt) in the Oatka Creek project. Arrows signify flow direction and outlined polygons show minor tributaries. Green dots are sampling locations within the polygon

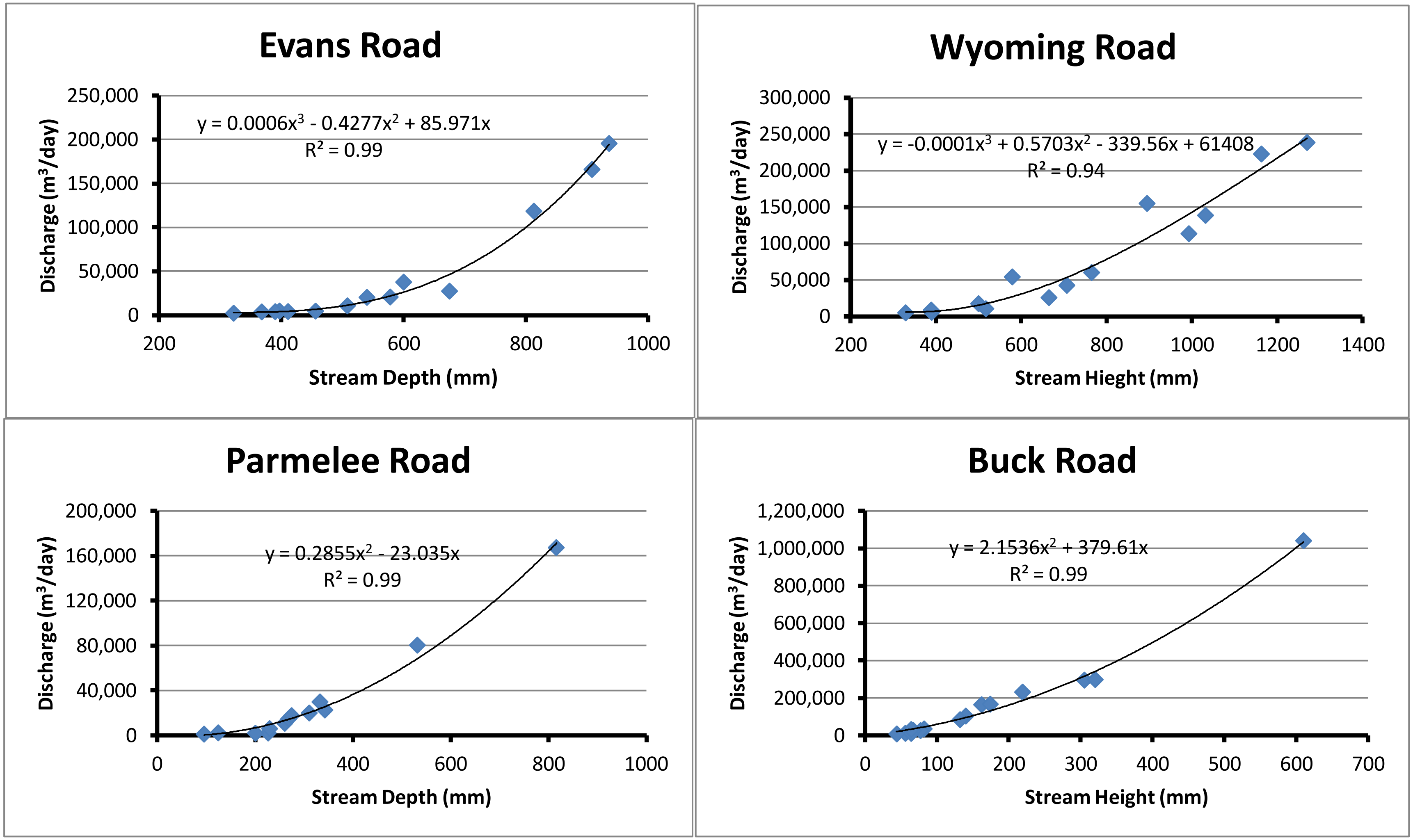


Figure 3. Rating Curves for discharge locations at Evans Road, Wyoming Road, Parmelee Road and Buck Road, Oatka Creek.

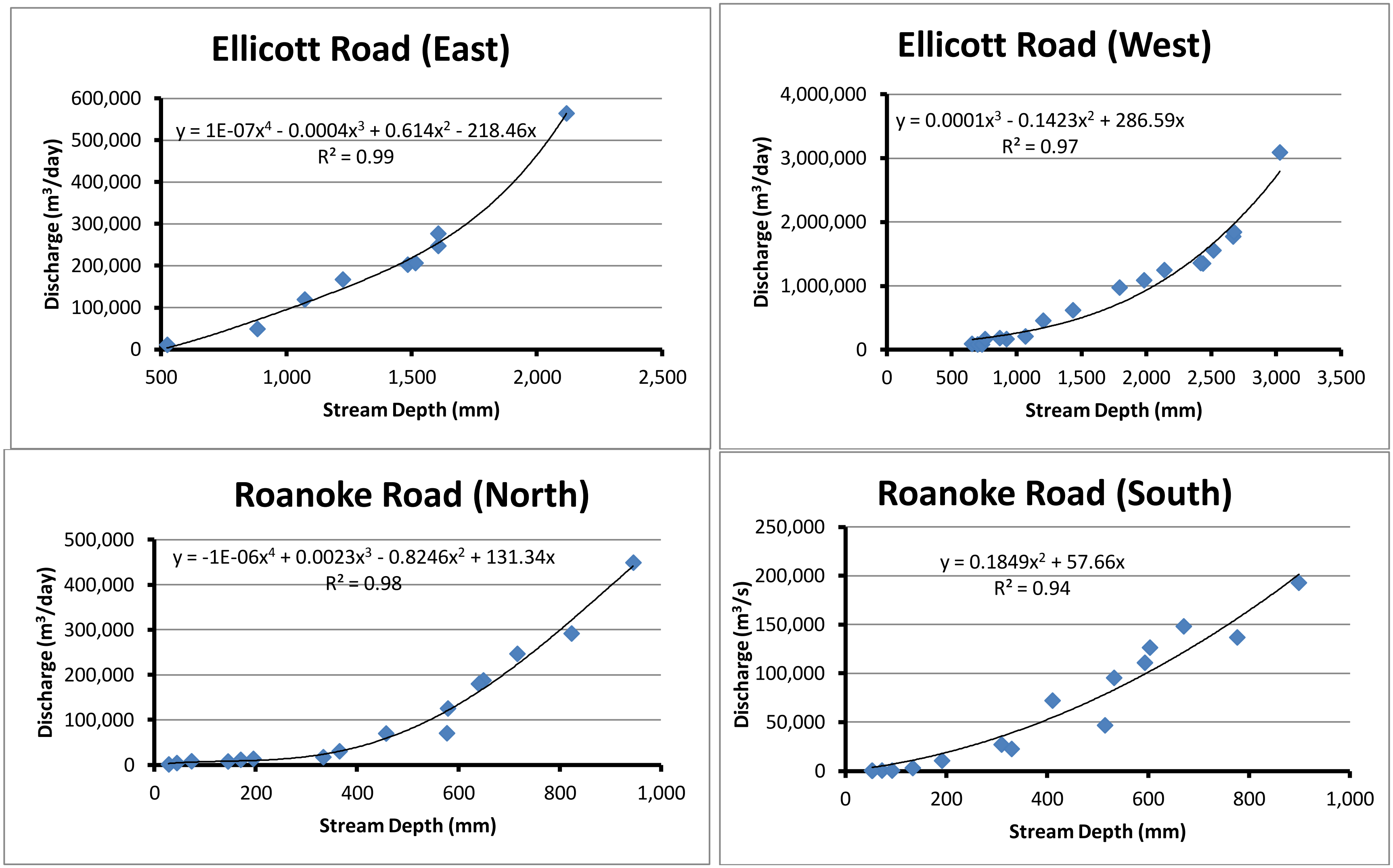


Figure 4. Rating Curves for discharge locations at Roanoke Road (North and South culverts) and Ellicott Road (East and West culverts), Oatka Creek.

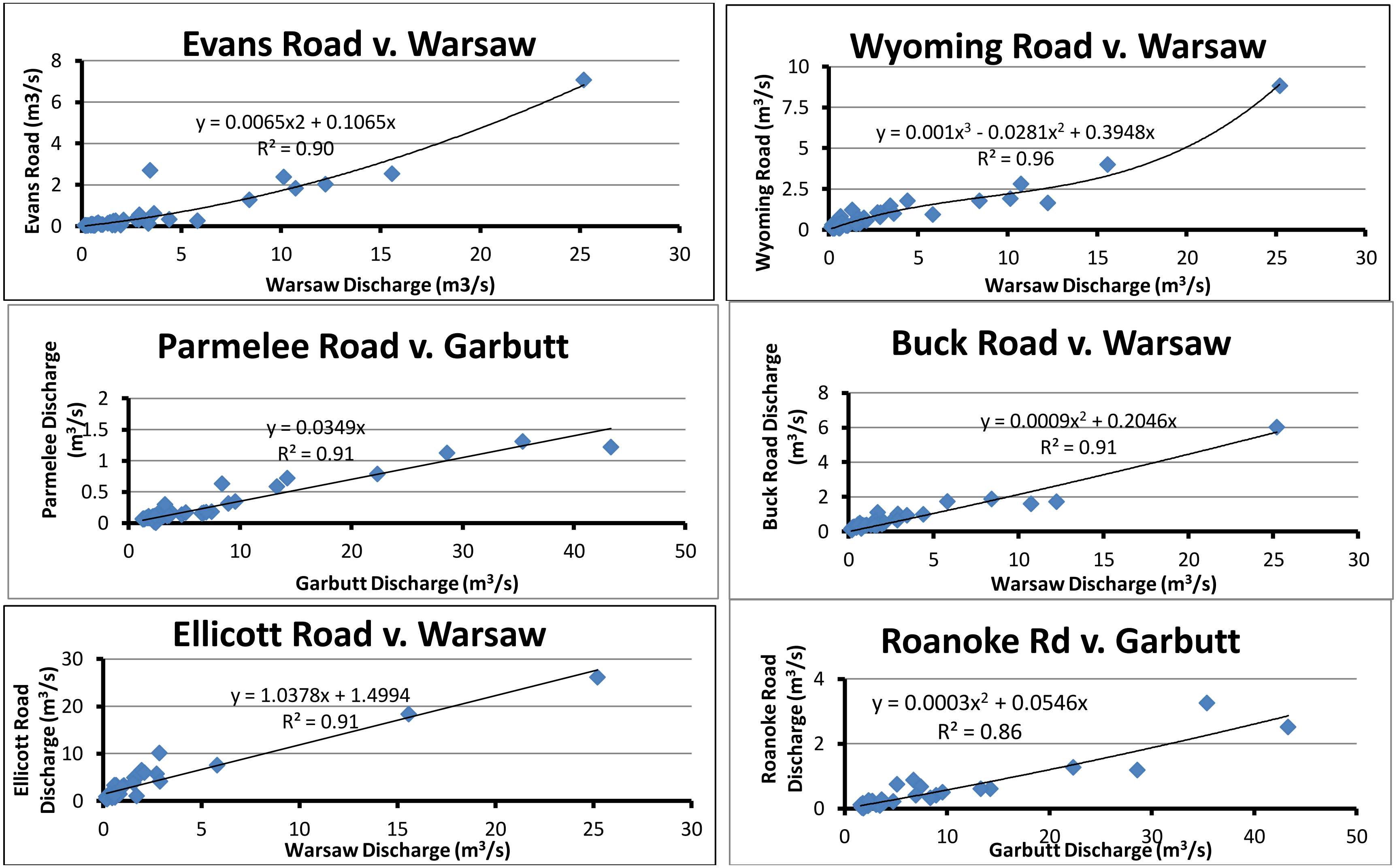


Figure 5. Regression of daily discharge (no lagtime for all monitoring locations) of Evans, Wyoming, Ellicott and Buck Roads with the USGS monitoring site at Warsaw while Roanoke and Parmelee Roads with the USGS monitoring site at Garbutt, NY.

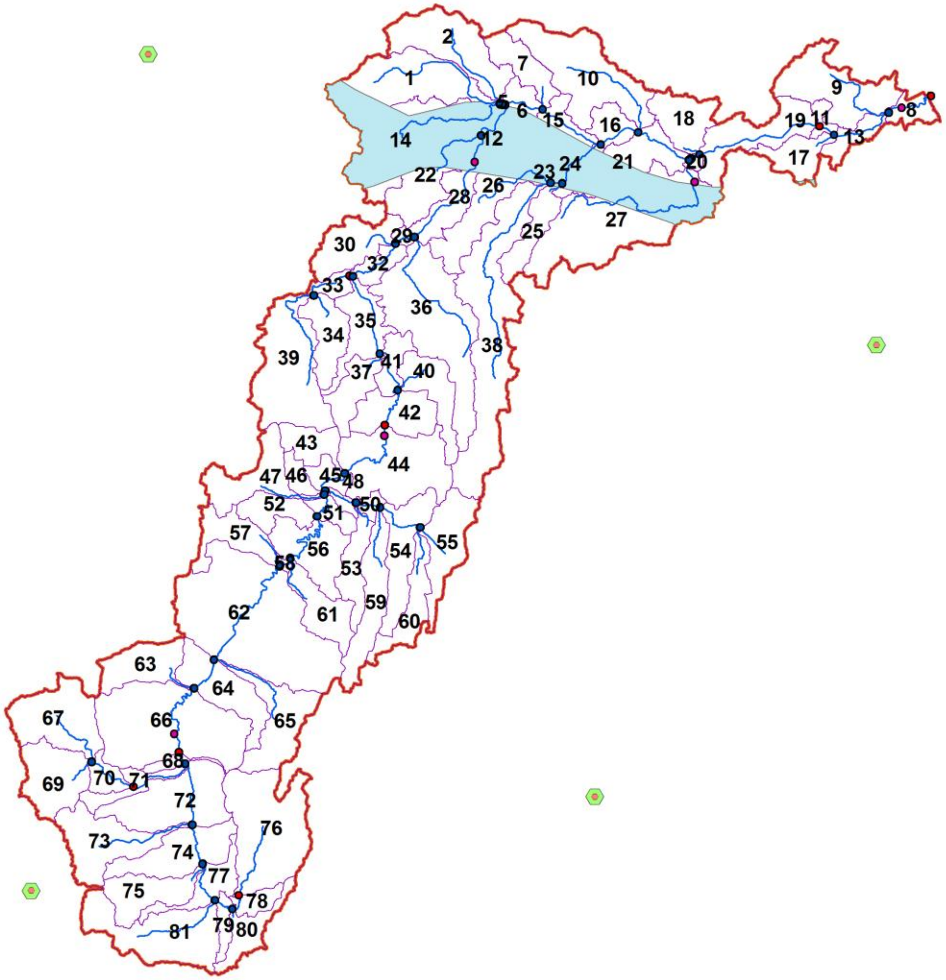


Figure 6. Oatka Creek showing the 81 subbasins used in the SWAT12 model. Shaded blue region symbolizes the carbonate rock aquifer.

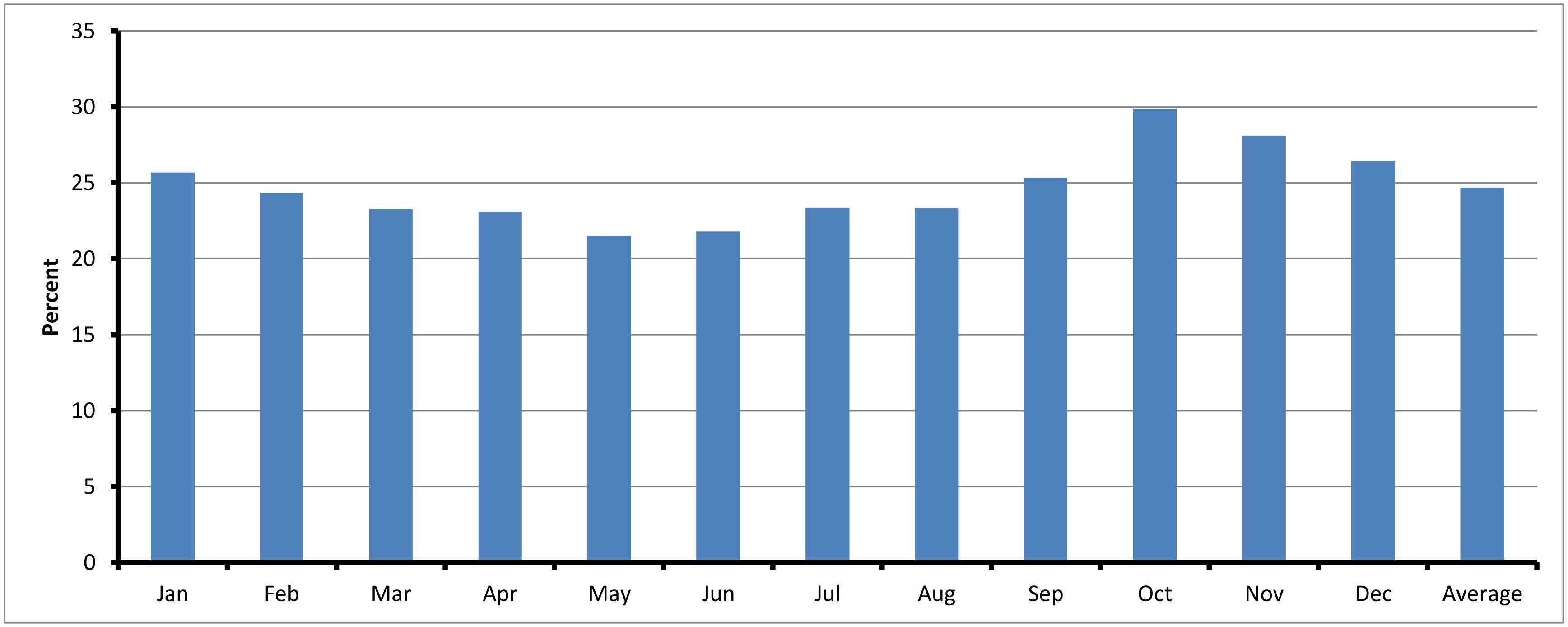


Figure 7. The ratio of average monthly discharge (1970 to 2009) from Warsaw, NY to average monthly discharge at Garbutt, NY expressed as a percentage, Oatka Creek.

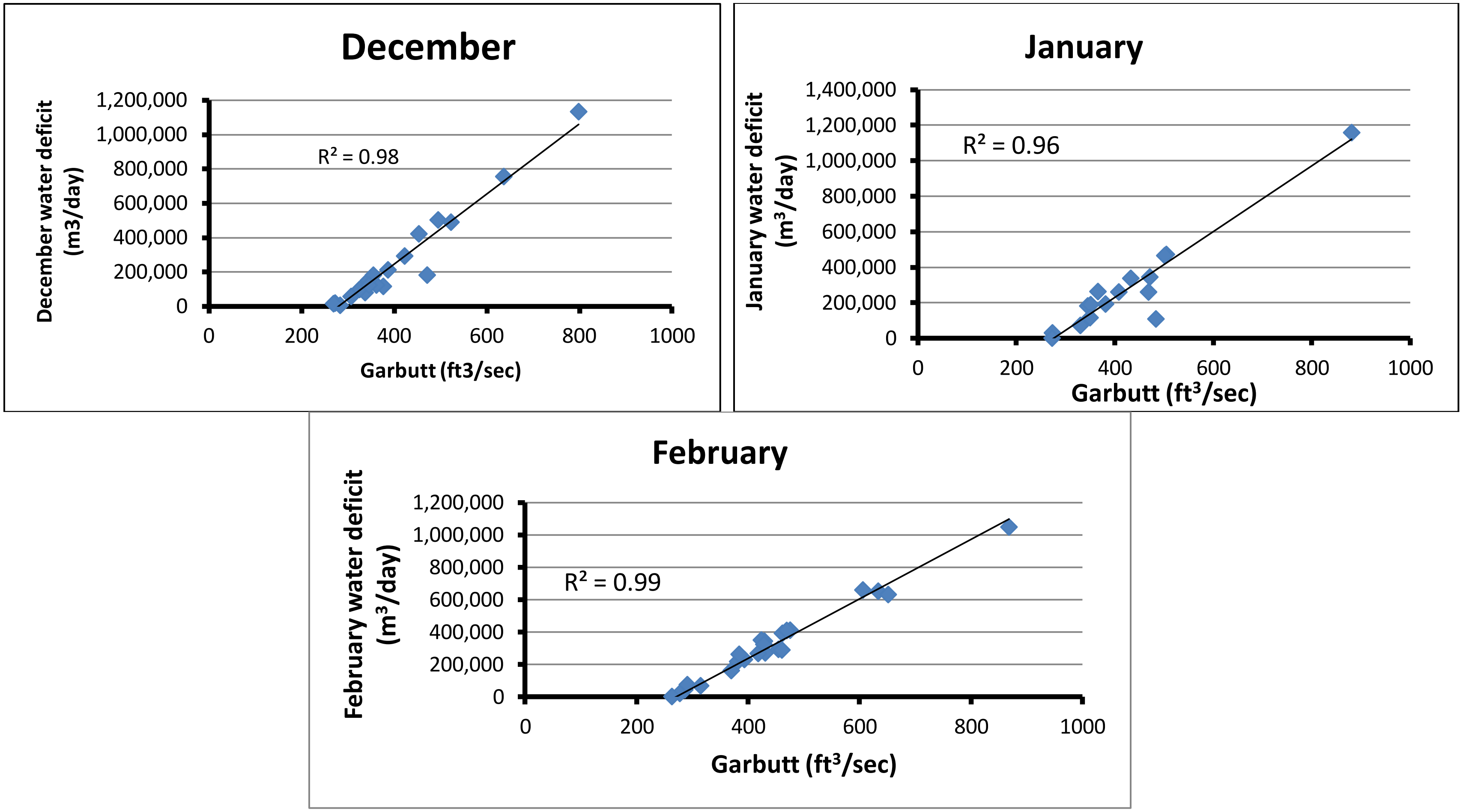


Figure 8. Regression of flow deficit (outside groundwater source) estimations based on flow measured at Garbutt, NY in December through February over a 40 year period (1970 – 2009), Oatka Creek. Flow deficits come from the line equation in Table 6.

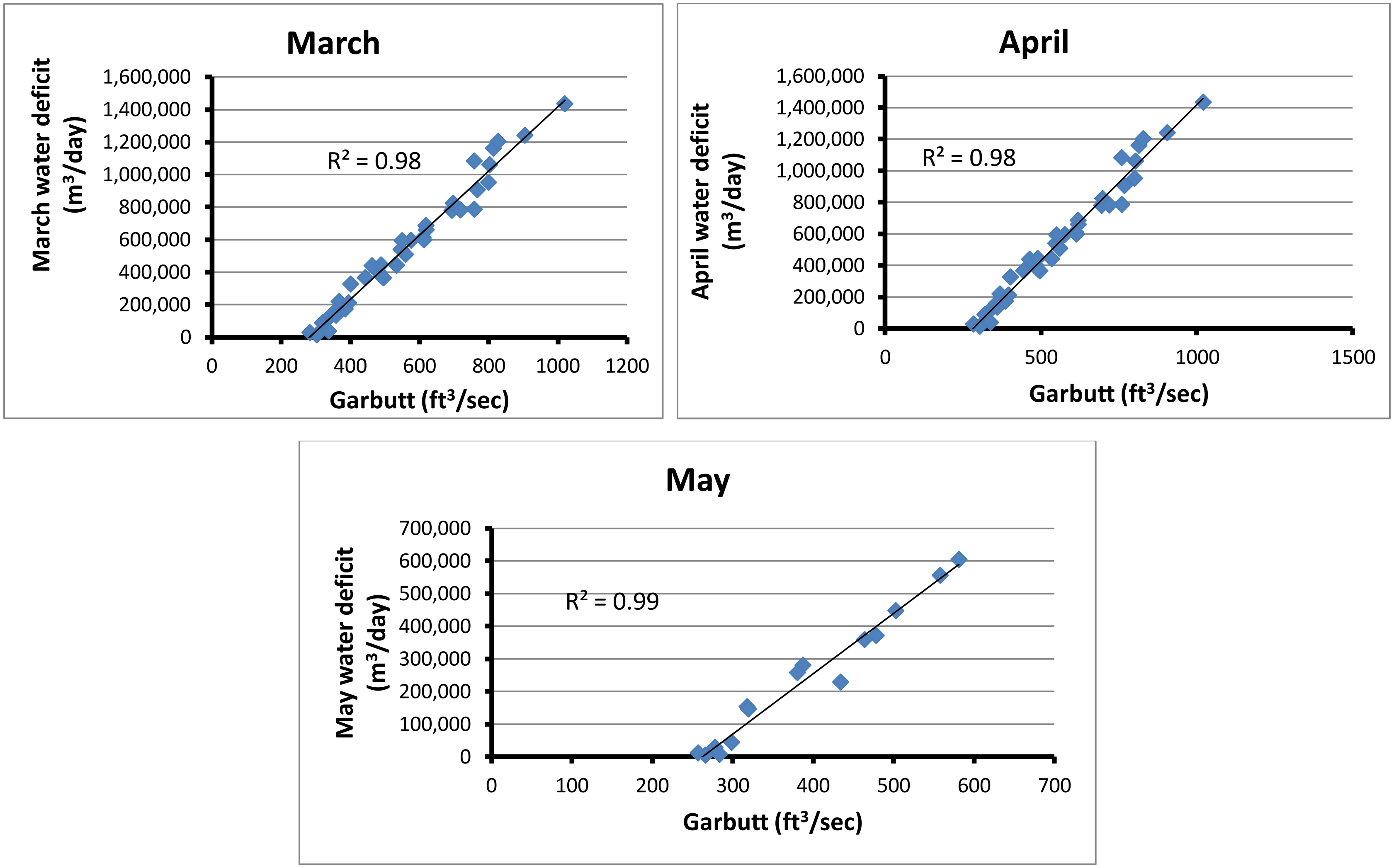


Figure 9. Regression of flow deficit (outside groundwater source) estimations based on flow measured at Garbutt, NY in March through May over a 40 year period (1970 – 2009), Oatka Creek. Flow deficits come from the line equation in Table 6.

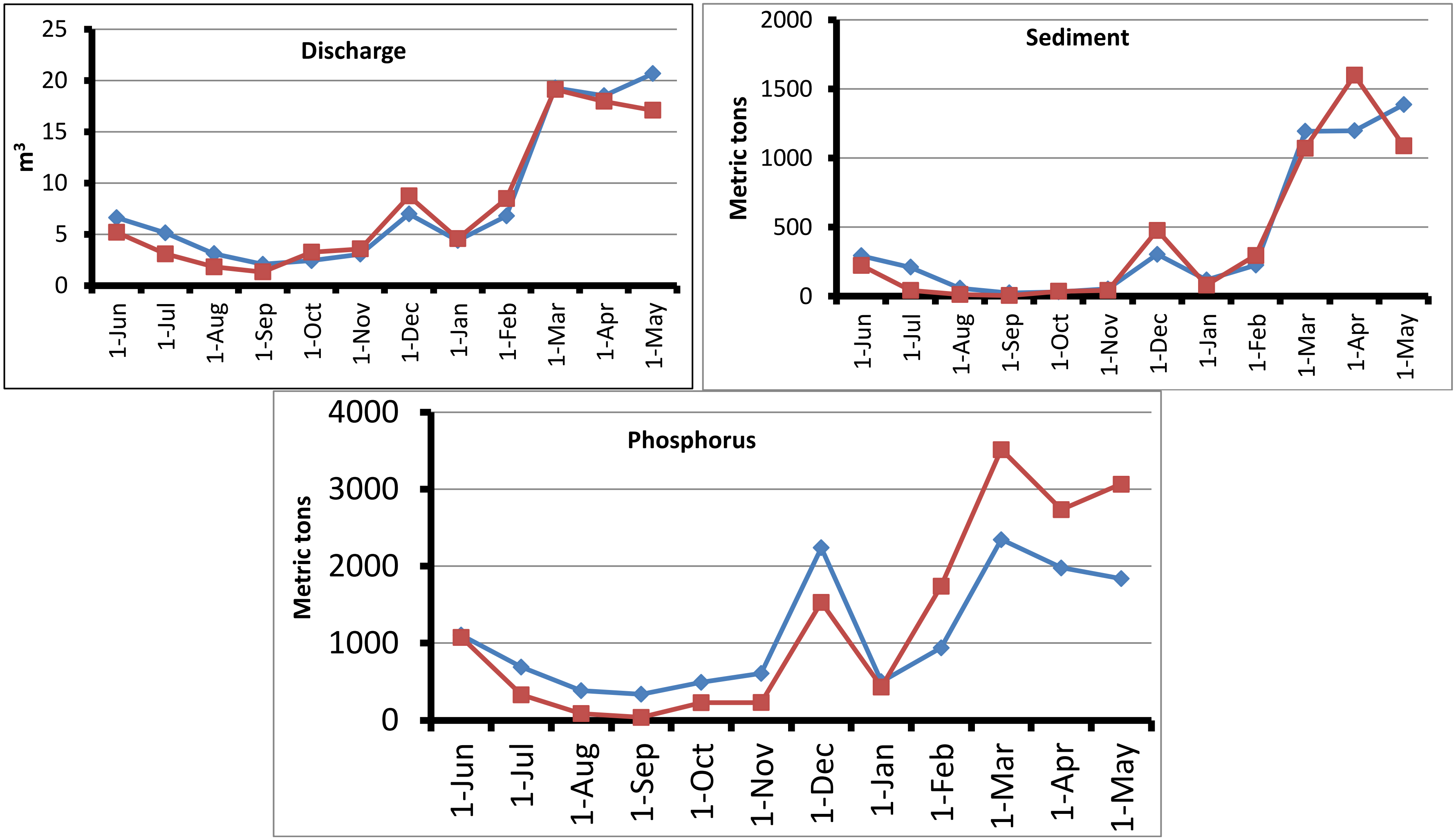


Figure 10. A comparison of SWAT12 model flow, sediment and phosphorus of observed (square points) to simulated (diamond points) resulting from the model run year (1 June 2010 through 30 May 2011), Oatka Creek.

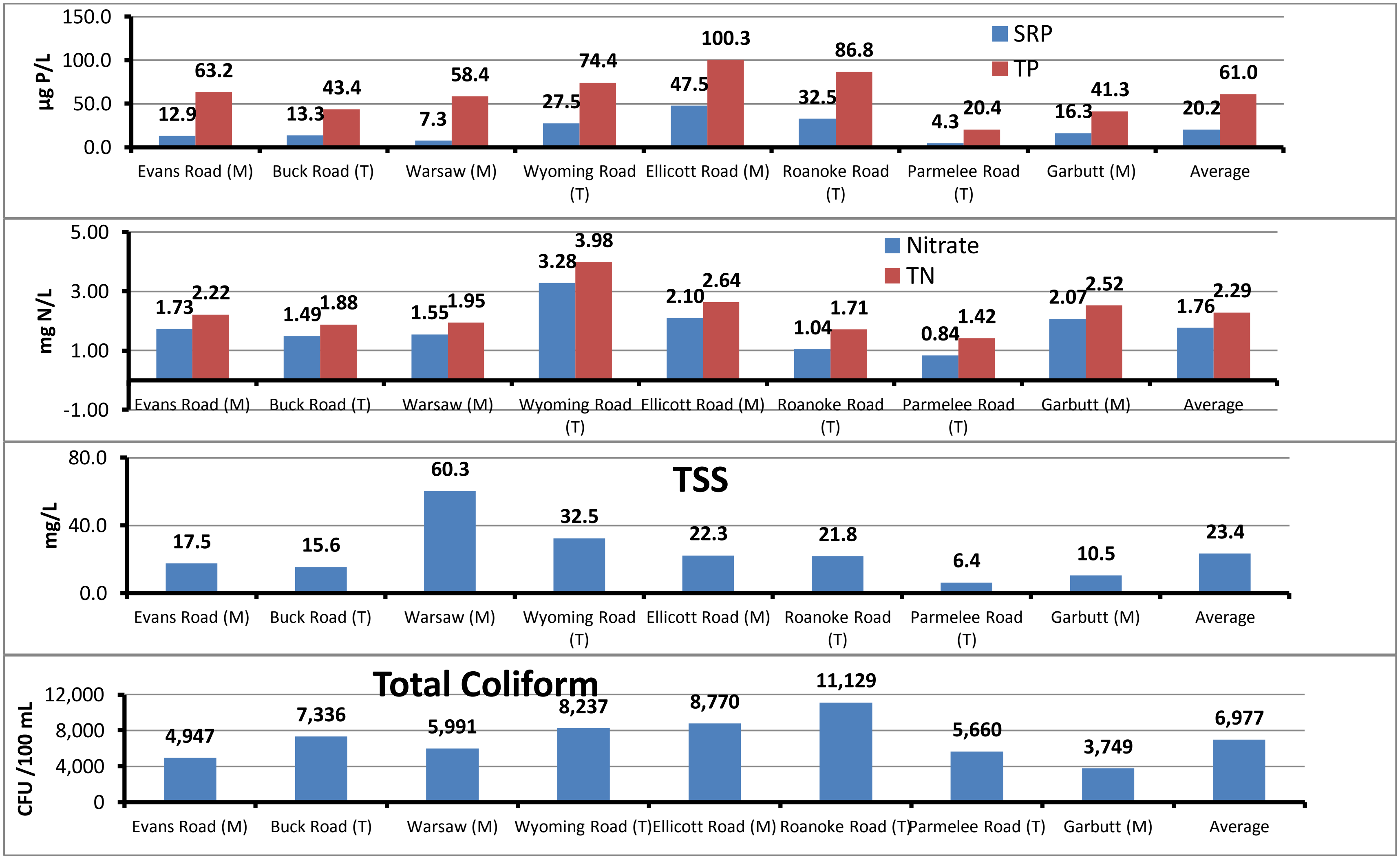


Figure 11. Average annual concentrations of soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate, total nitrogen (TN), total suspended solids (TSS) and total coliform abundances at all eight weekly monitoring locations from June 2010 to May 2011, Oatka Creek. M = mainstem. T = tributary

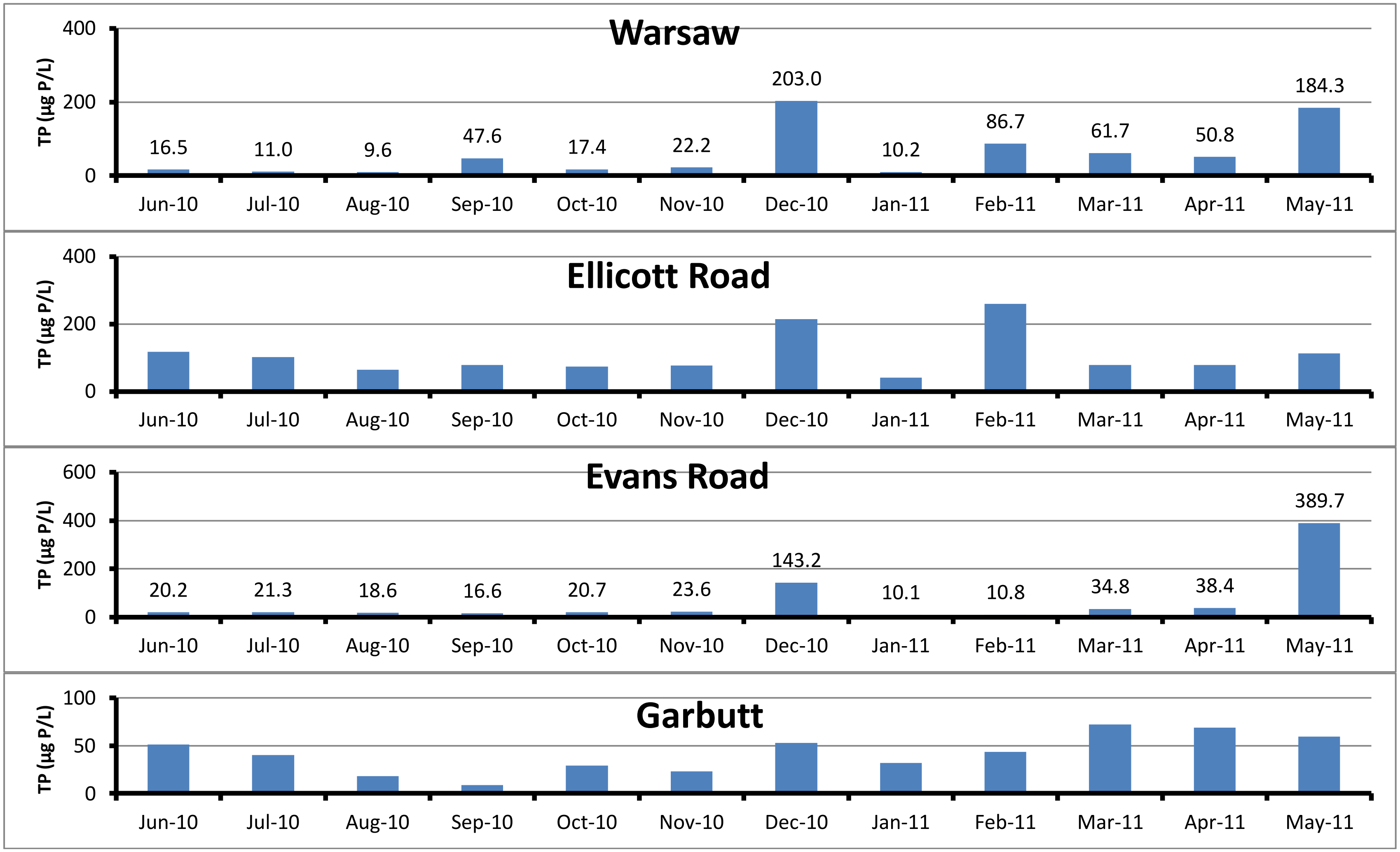


Figure 12. Average monthly TP concentrations at all eight (Fig. 2) weekly sampling sites, Oatka Creek.

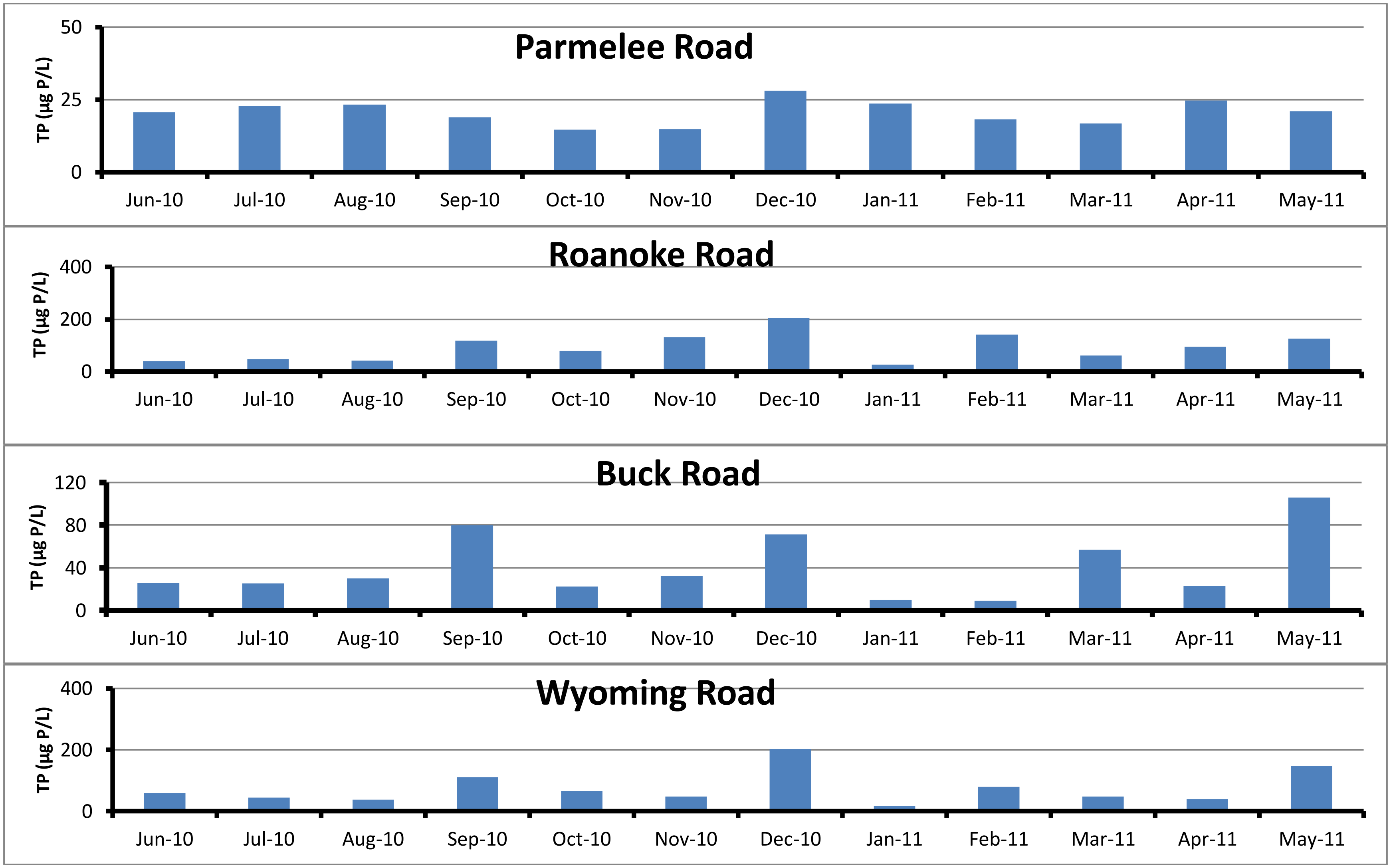


Figure 12. Continued

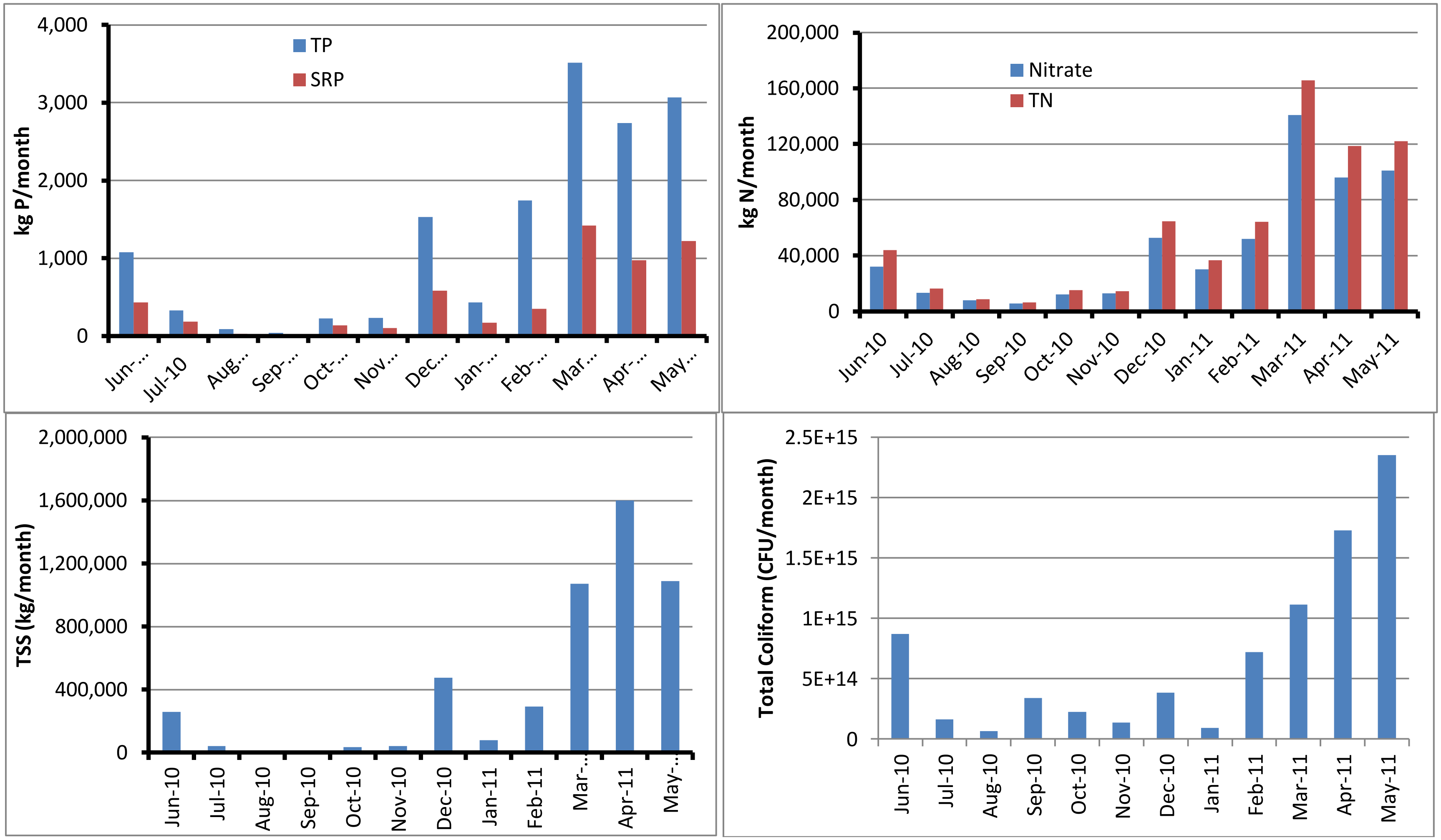


Figure 13. Measured monthly loads of soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate, total nitrogen (TN), total suspended solid (TSS), and total coliform at the USGS monitoring location at Garbutt, NY, Oatka Creek.

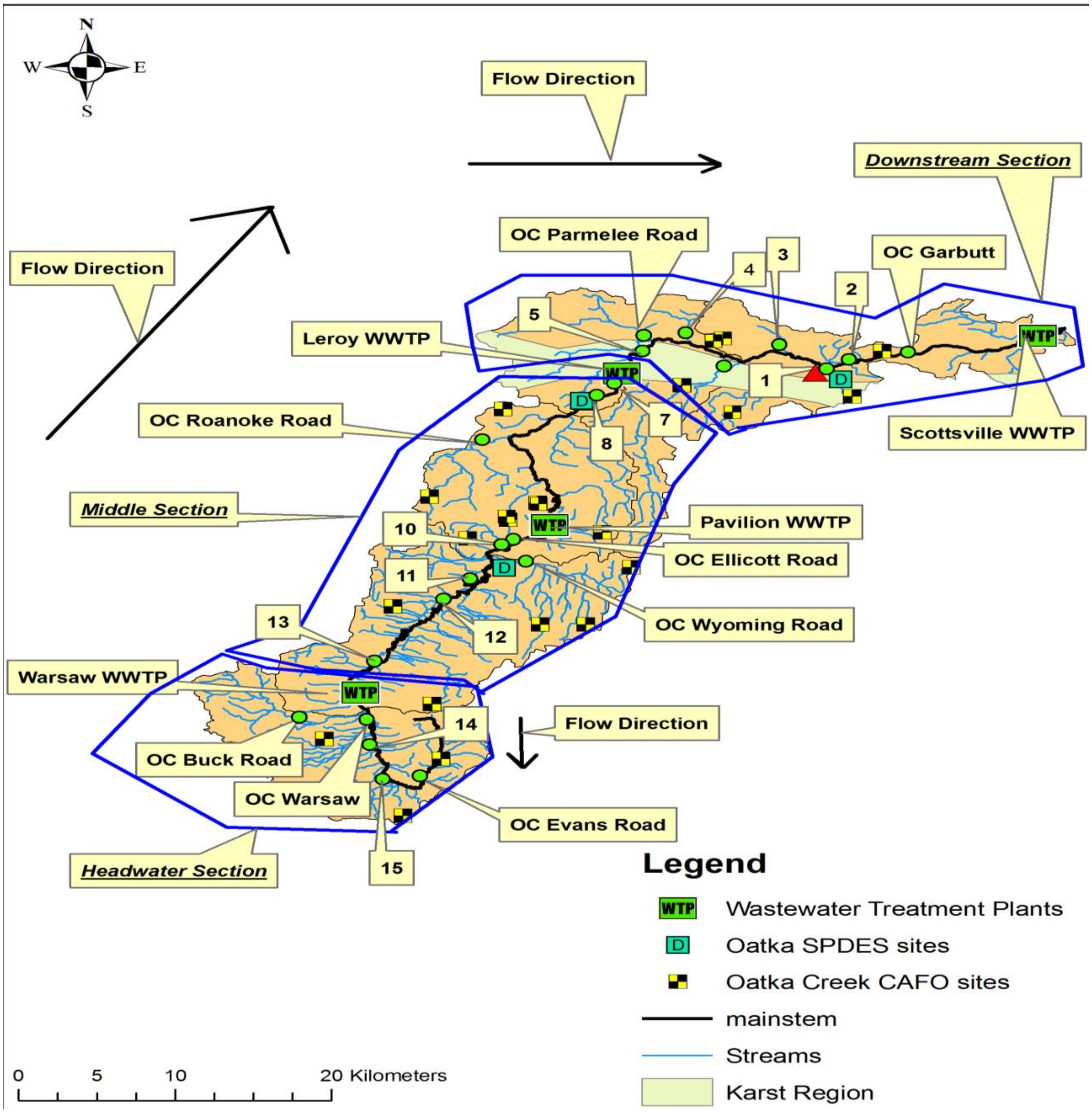


Figure 14. Initial stress stream sites (1-15) and the eight weekly discharge sites Evans Road, Buck Road, Warsaw, Wyoming Road, Ellicott Road, Roanoke Road, Parmelee Road and Garbutt on 12 July 2010. The arrows signify flow directions and the Oatka Creek sub-watershed is broken up into three sections (Headwater, Middle, and Downstream).

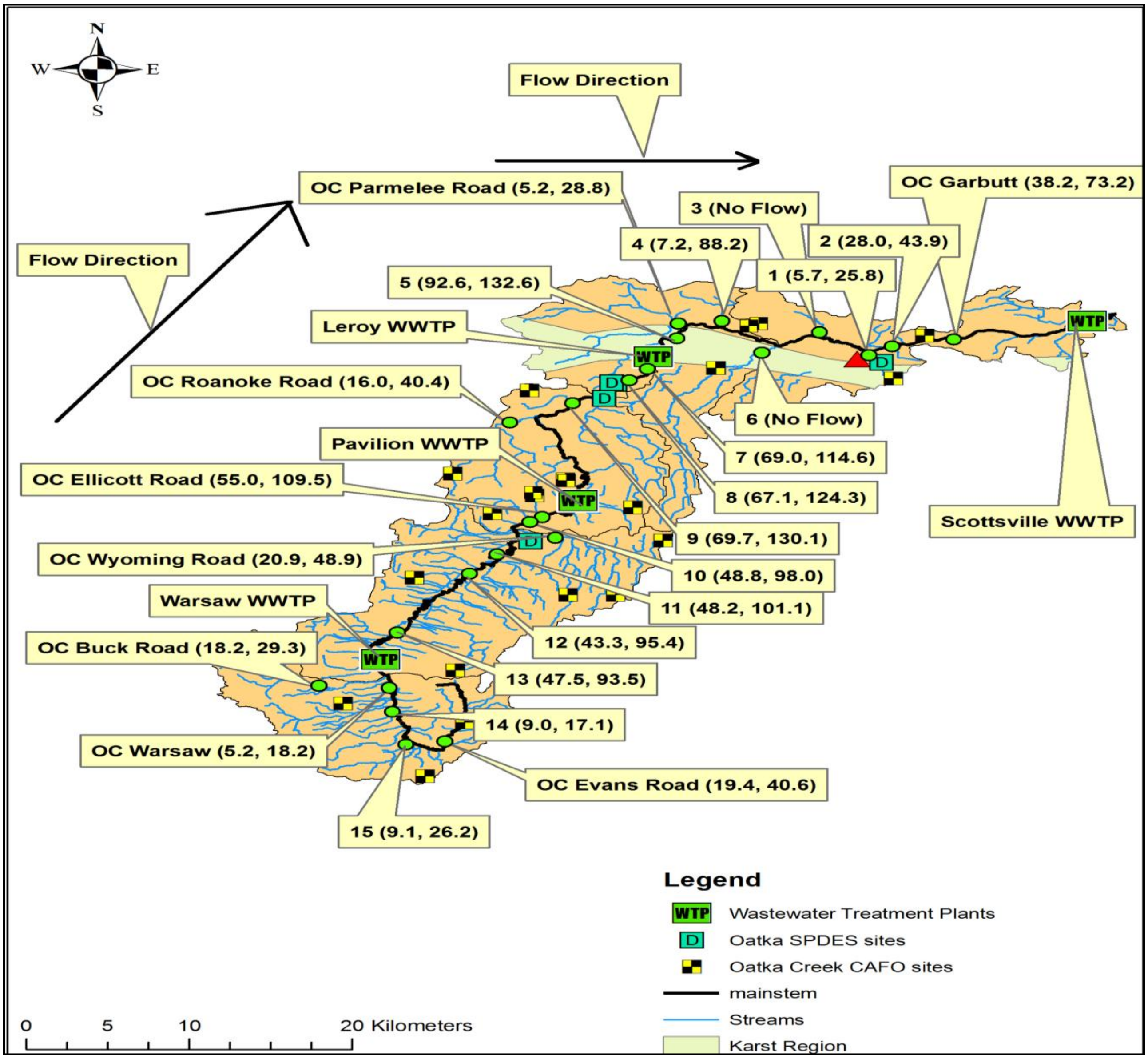


Figure 15. Soluble reactive phosphorus (SRP) and total phosphorus (TP) concentrations (µg P/L) at the Oatka Creek subwatershed on 12 July 2010. Green dots represent sample site.

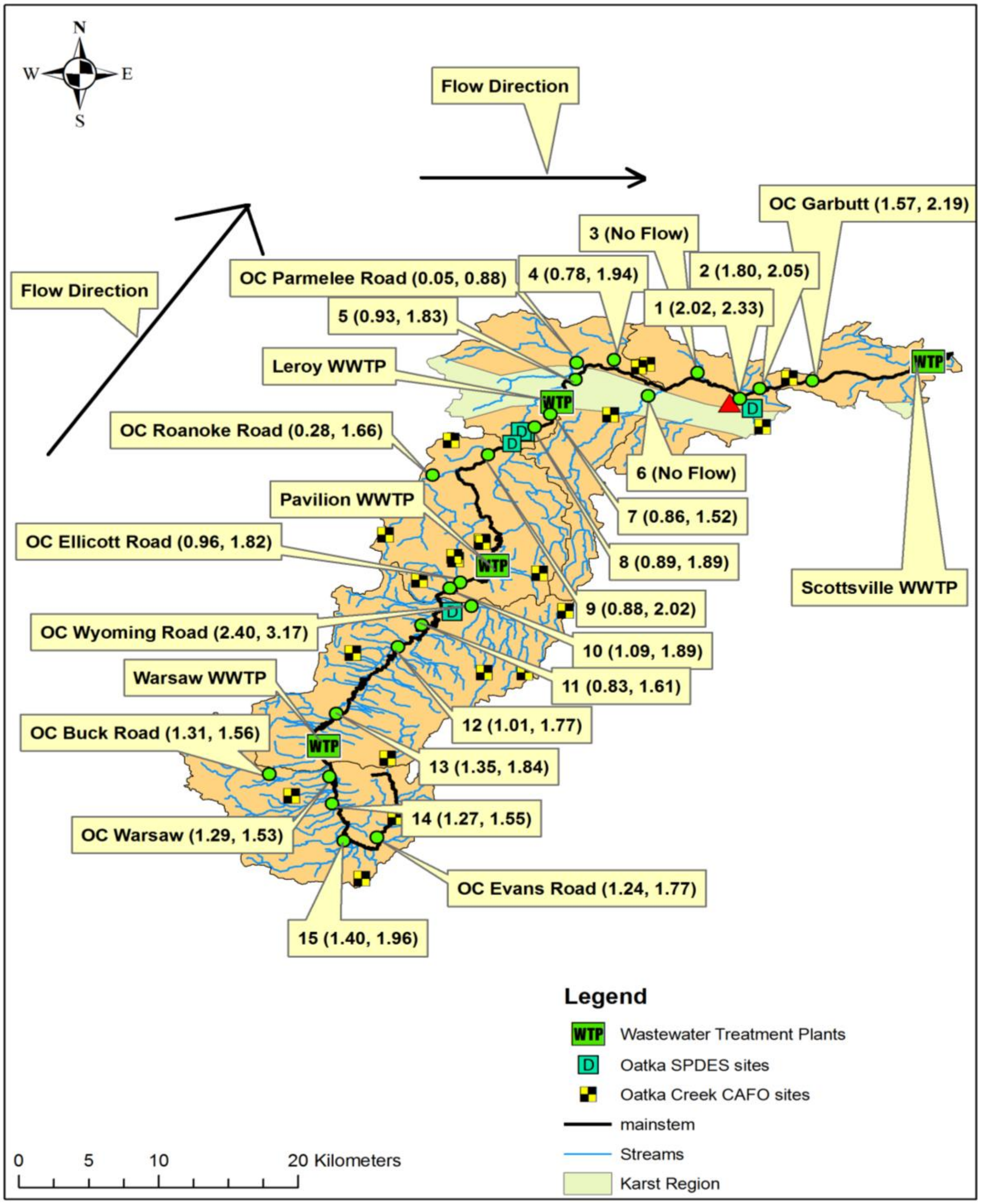


Figure 16. Nitrate and total nitrogen (TN) concentrations (mg N/L) at the Oatka Creek subwatershed on 12 July 2010. Green dots represent sample sites.

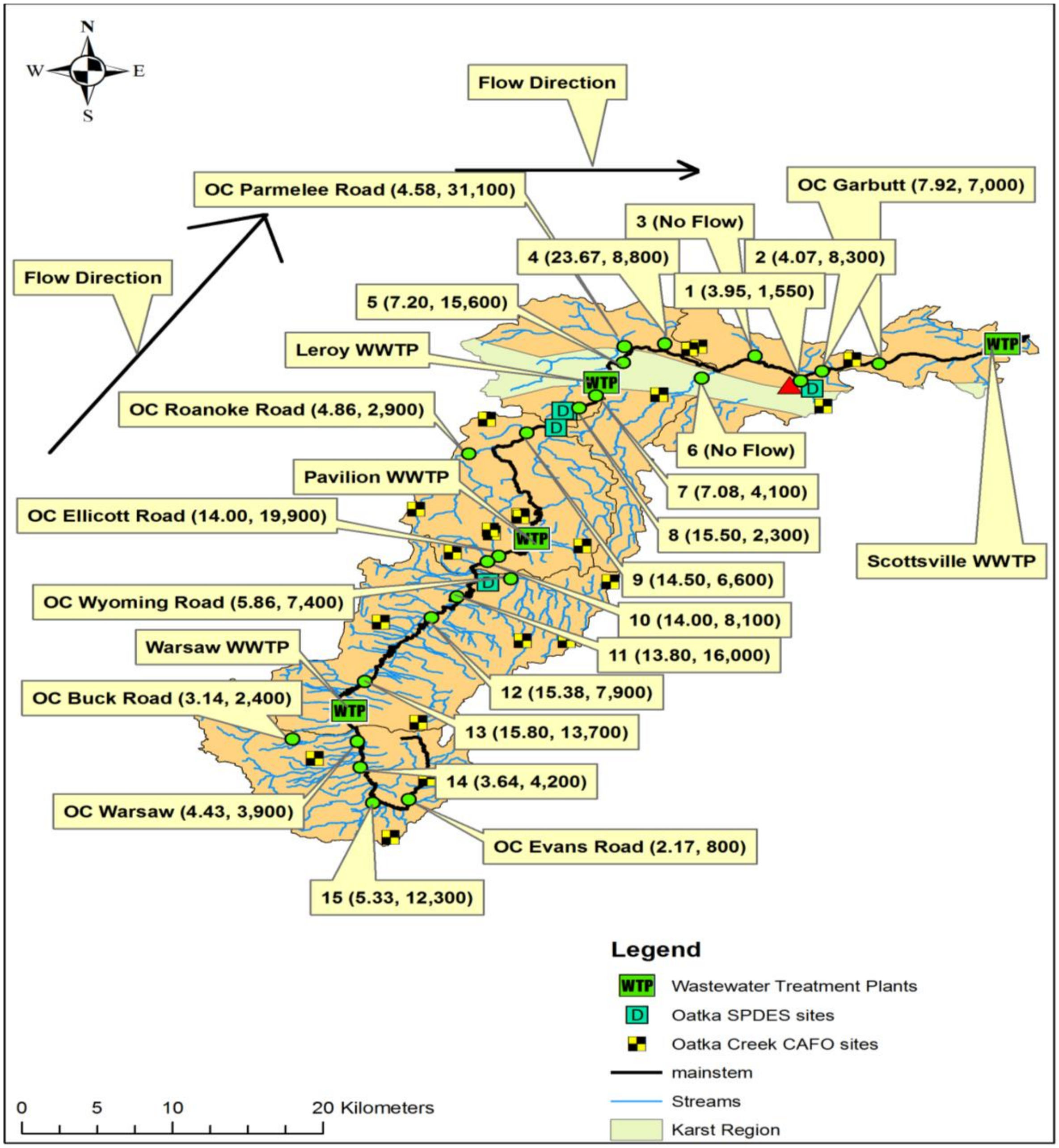


Figure 17. Total suspended solid (mg/L) and total coliform (CFU/100 mL) abundances at the Oatka Creek subwatershed on 12 July 2010. Green dots represent sample sites.

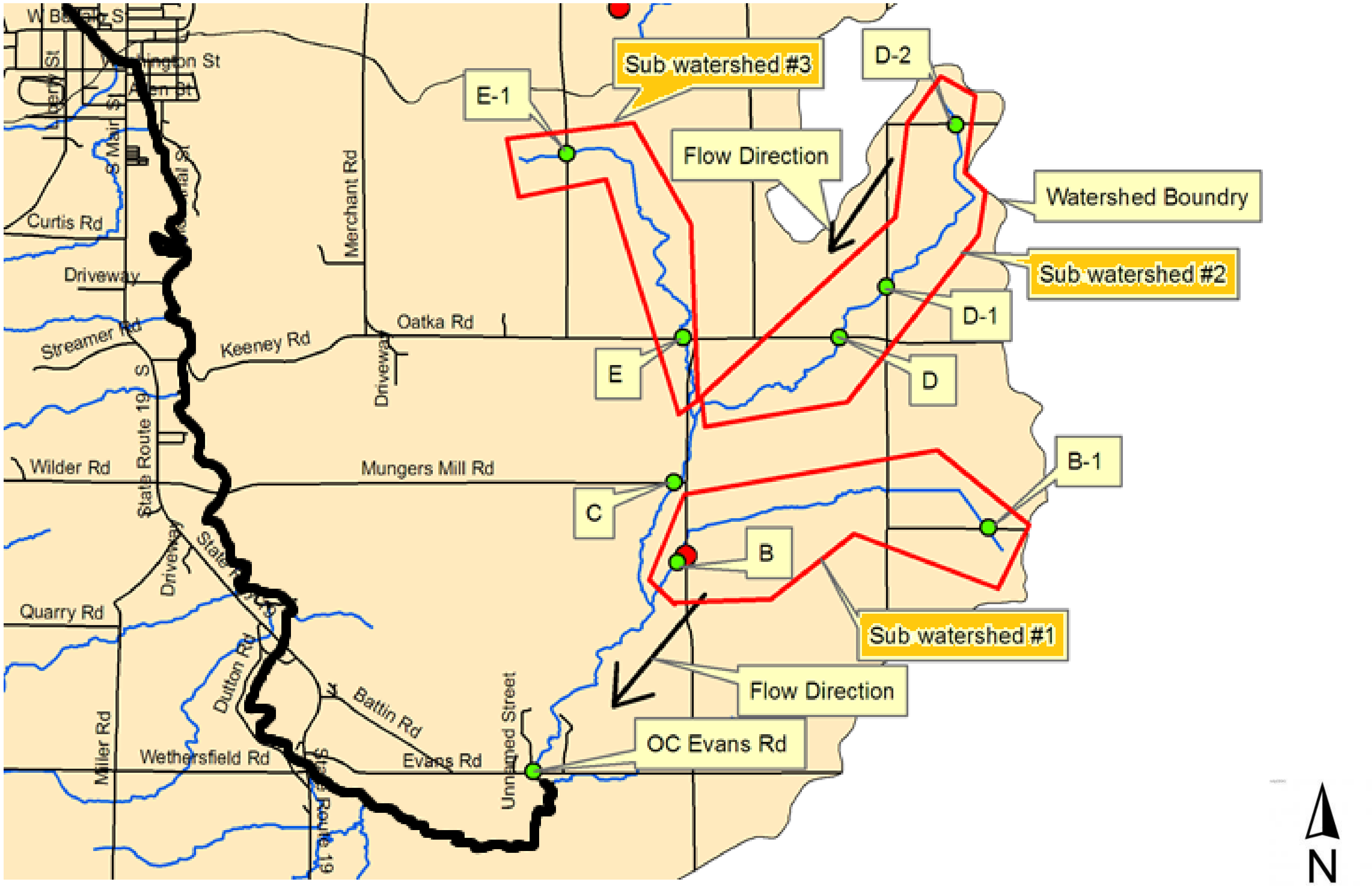


Figure 18. Segment analysis sites (B to E) for Evans Road subwatershed (Fig. 2) on 5 October 2010 (Event) and 19 October 2010 (Nonevent), Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red outlines show each individual subwatershed (1-3). Oatka Creek mainstem is bolded in black just downstream of Evans Road subwatershed.

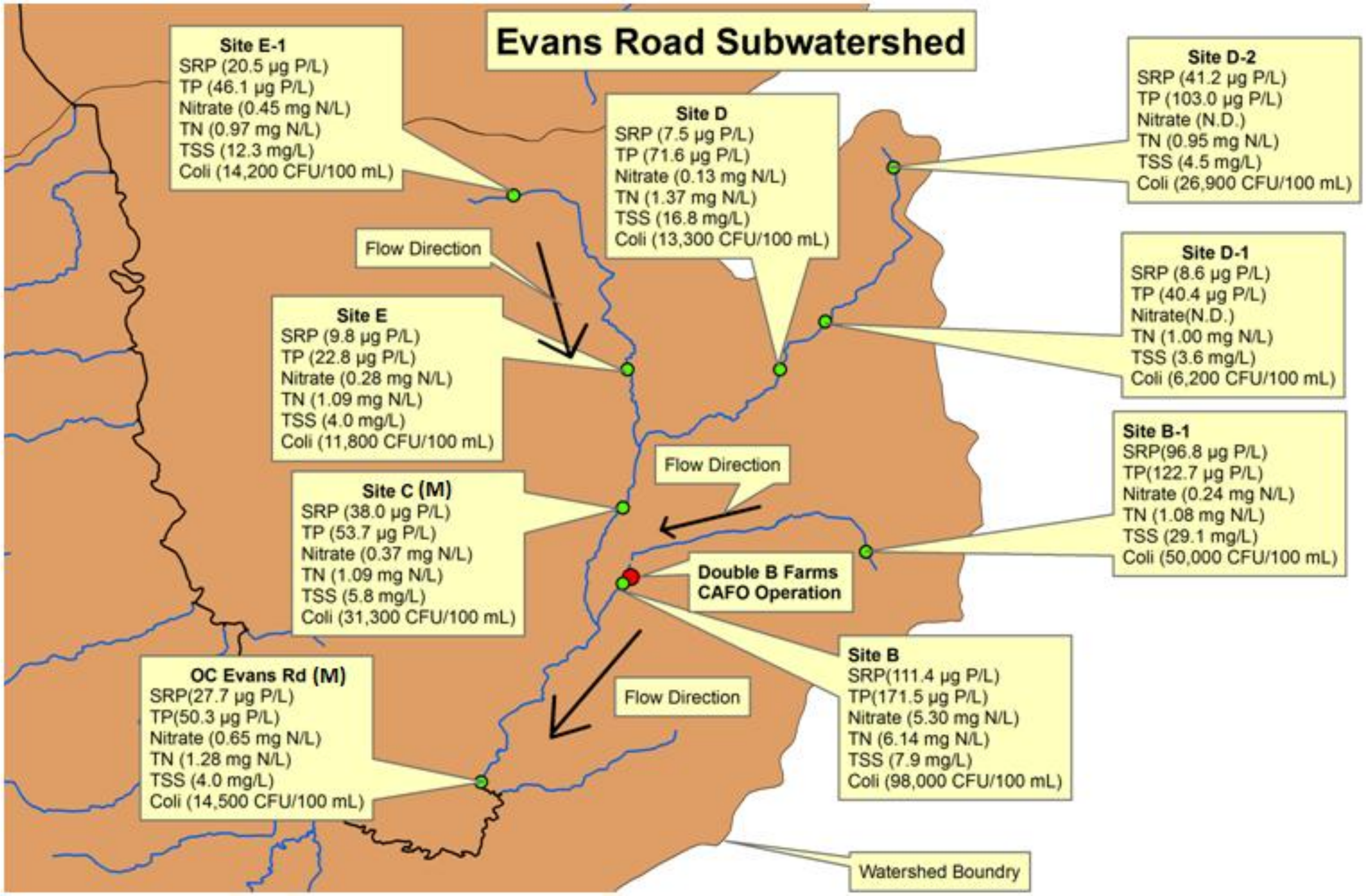


Figure 19. Soluble reactive phosphorus (SRP), total phosphorus (TP), total suspended solid (TSS), nitrate, total nitrogen (TN), and total coliform concentrations for Evans Road subwatershed (Fig. 2) on 5 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction. Oatka Creek mainstem is bolded in black just downstream of Evans Road subwatershed. M = Mainstem site in the Evans Road segment.

Figure 20. Picture of the Double B Farms CAFO (Fig. 19) located upstream of site B in subwatershed #1 in the Evans Road subwatershed, Oatka Creek.

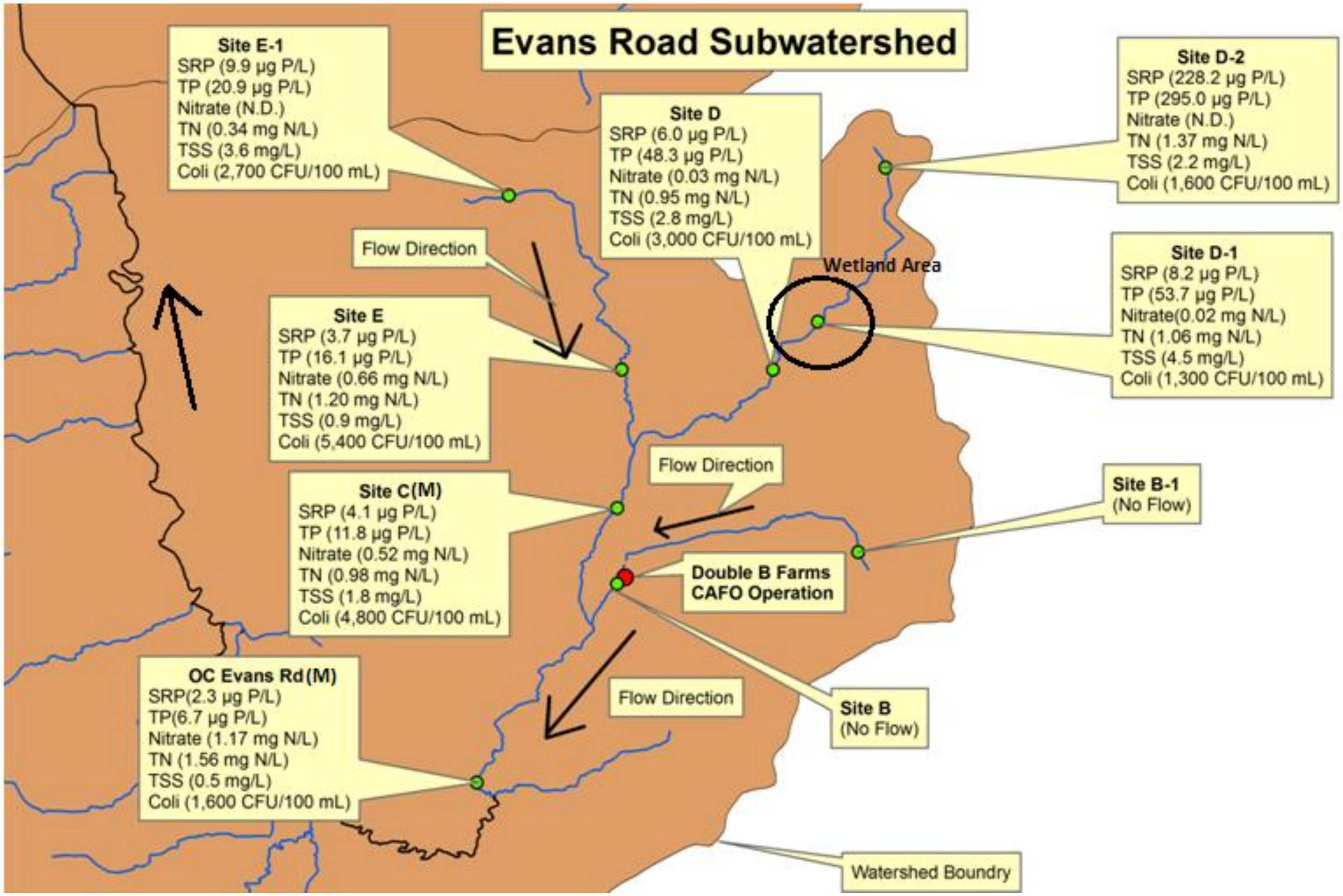


Figure 21. Soluble reactive phosphorus (SRP), total phosphorus (TP), total suspended solid (TSS), nitrate, total nitrogen (TN), and total coliform concentrations for Evans Road subwatershed (Fig. 2) on 19 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Oatka Creek mainstem is bolded black on left side of figure. Arrows signify flow direction. M = Mainstem site in the Evans Road segment.

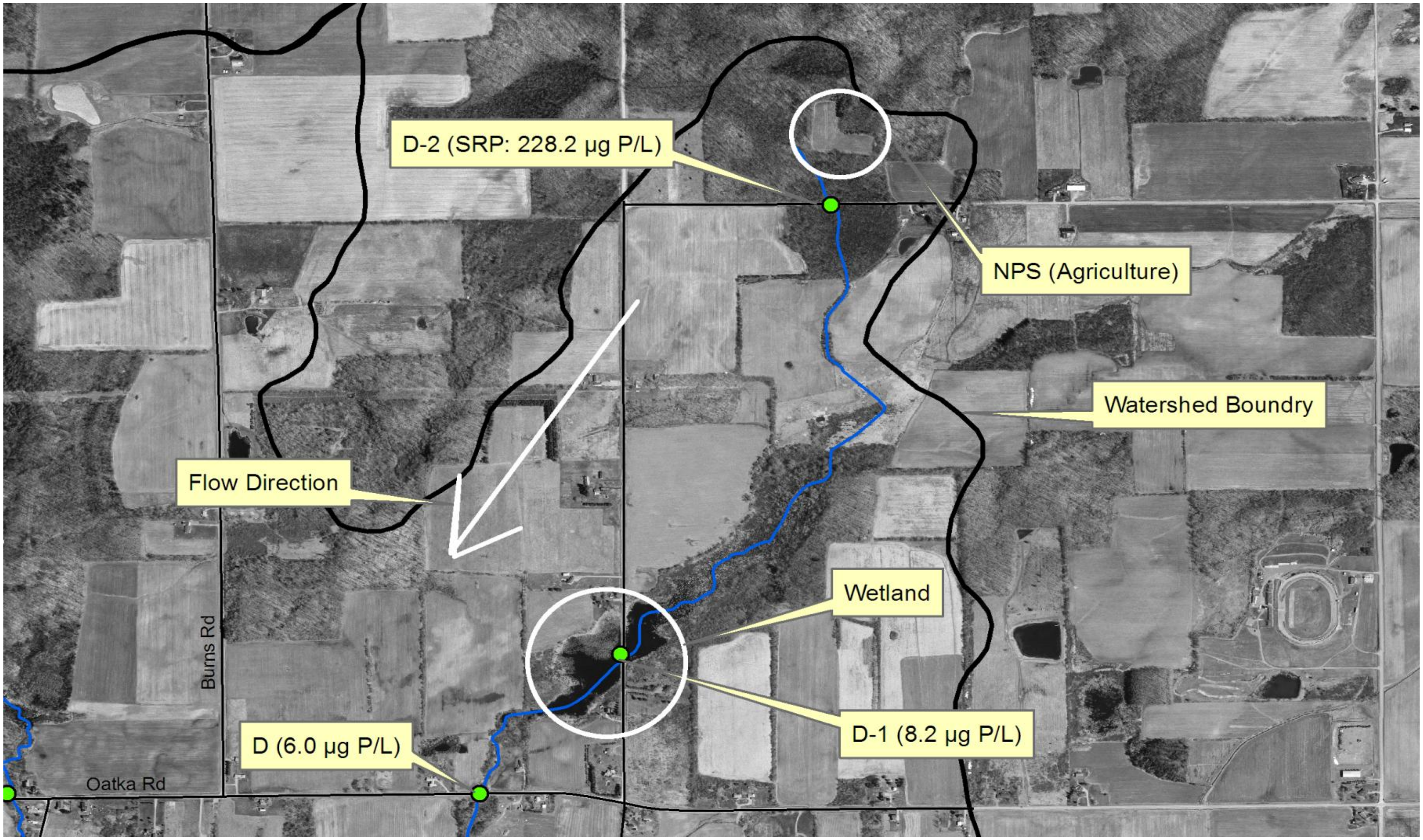


Figure 22. Soluble reactive phosphorus (µg P/L) concentrations at sites D, D-1, and D-2 (Fig. 21) in the Evans Road subwatershed on 19 October 2010, Oatka Creek. The wetland and agriculture sites are circled in white. Black line is the watershed boundary.

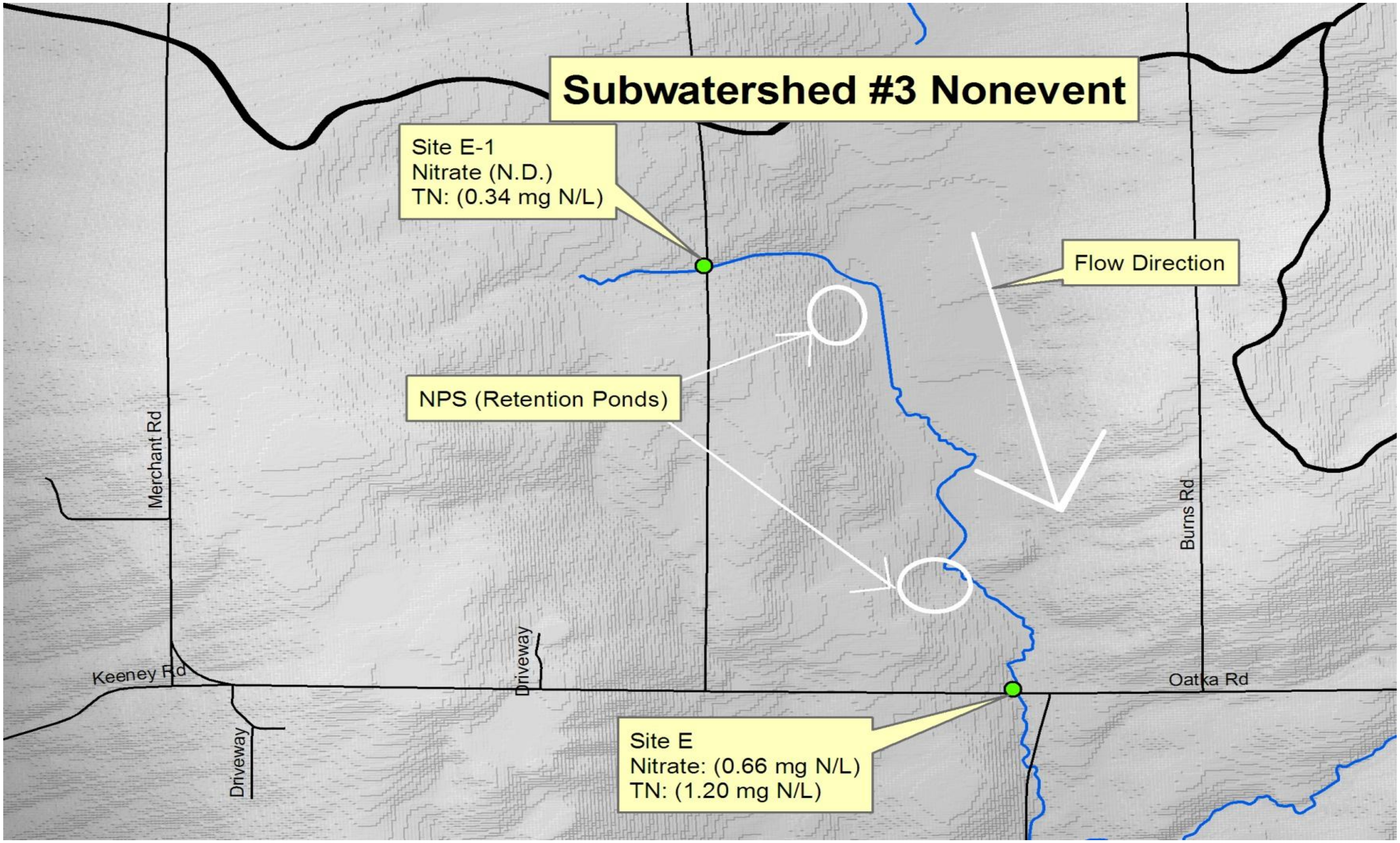


Figure 23. Digital Elevation Map (DEM) of sites E and E-1 (Fig. 21) in the Evans Road subwatershed on 19 October 2010, Oatka Creek. Both retention ponds are located on a downward slope towards the stream. Green dots signify sampling locations. White arrow illustrates flow direction.

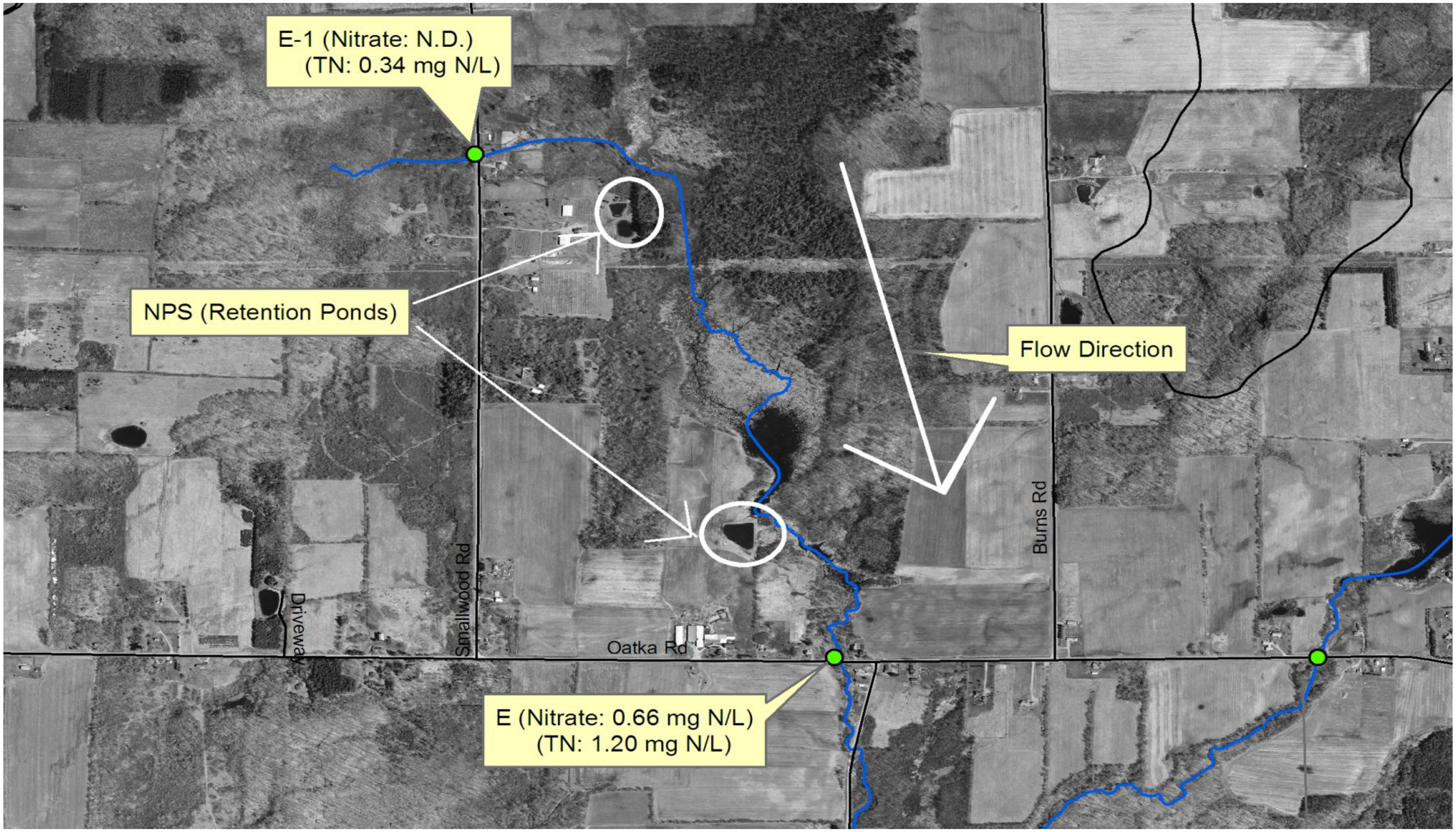


Figure 24. Nitrate and total nitrogen (mg N/L) concentrations at Sites E, E-1 (Fig. 21) in the Evans Road subwatershed on 19 October 2010, Oatka Creek. The retention ponds are circled in white. Black line is the watershed boundary.

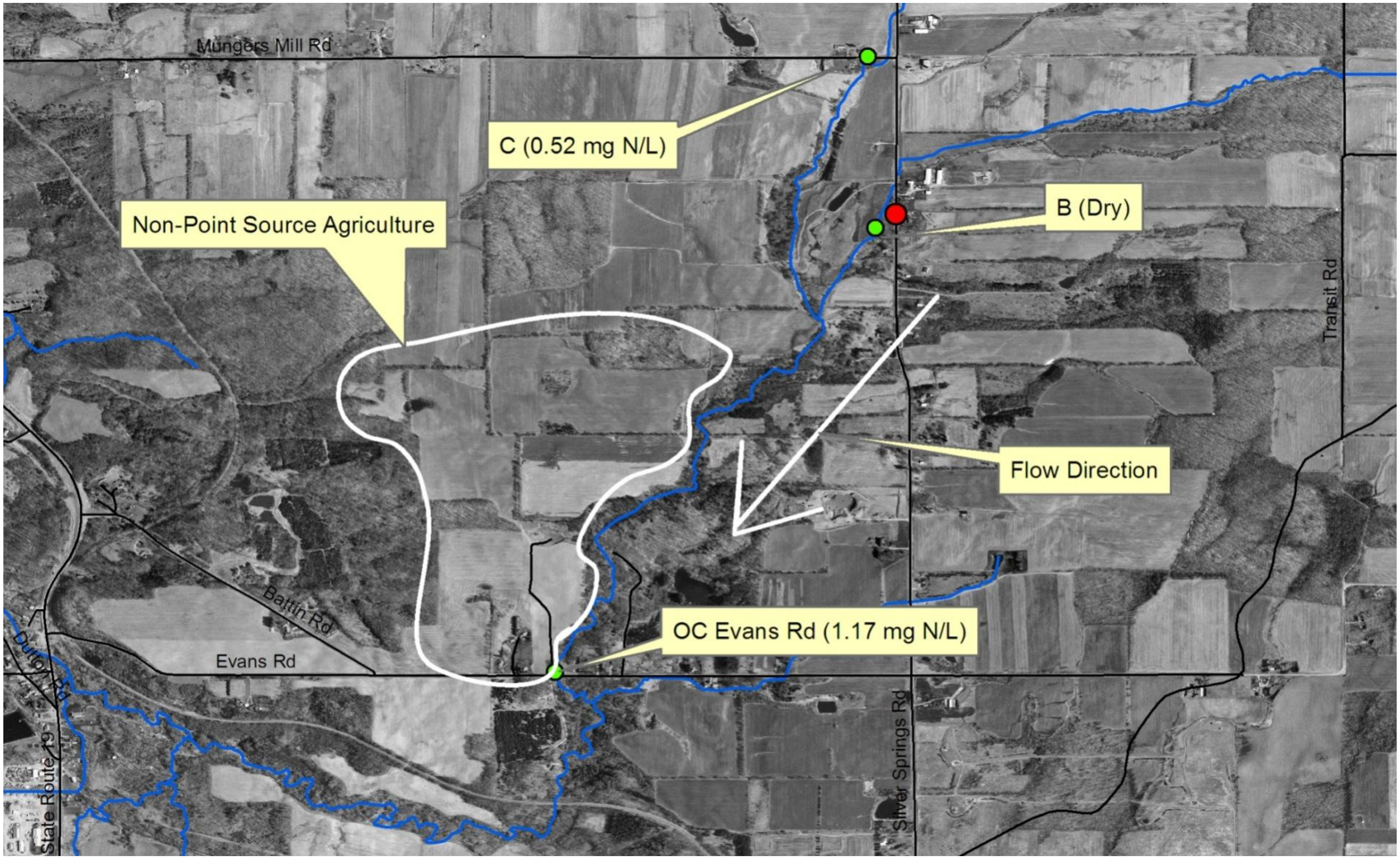


Figure 25. Nitrate (mg N/L) concentrations at Sites C, OC Evans Road (Fig. 21) in the Evans Road subwatershed on19 October 2010, Oatka Creek. The agriculture is circled in white. The red dot is a CAFO site. Black line is the watershed boundary.

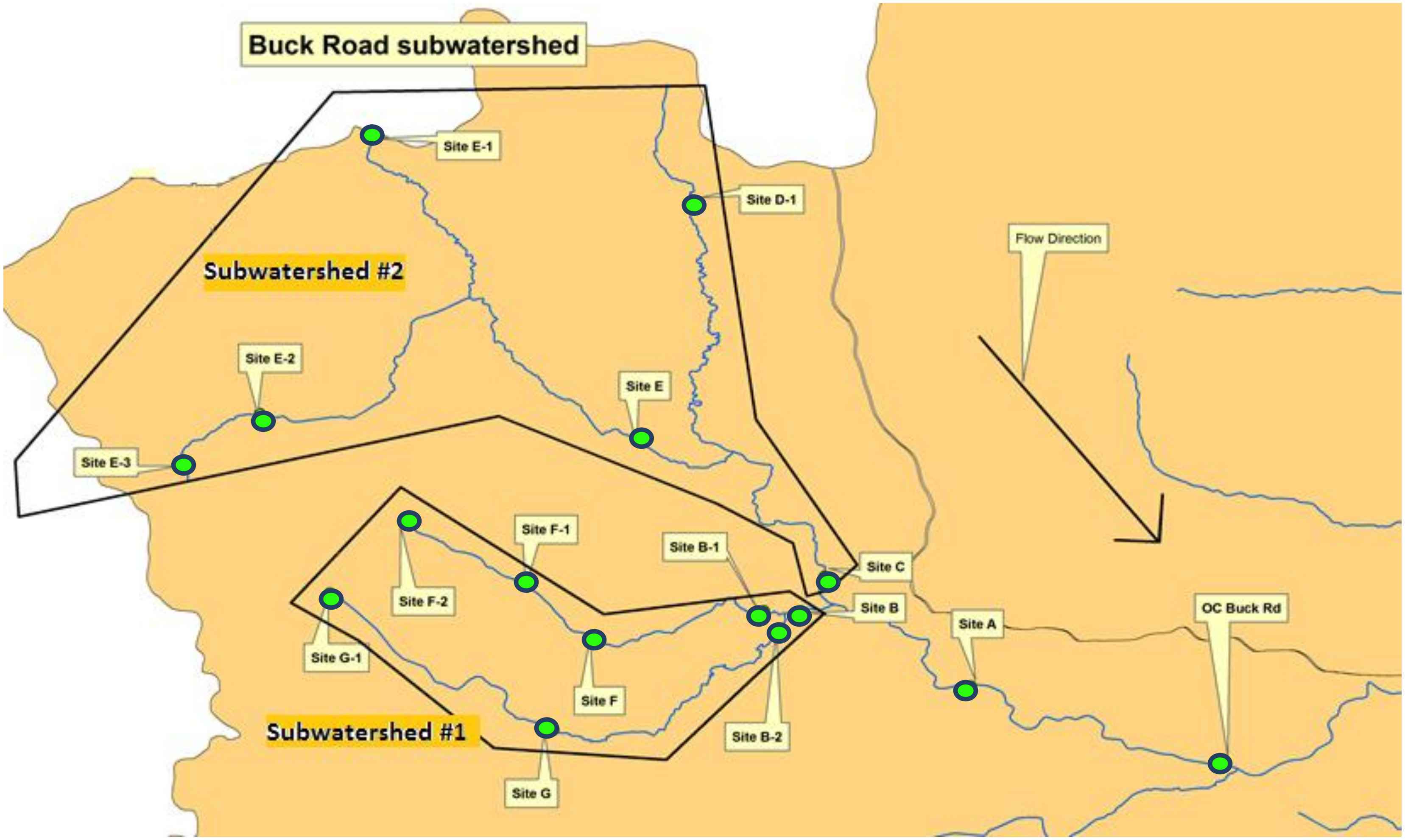


Figure 26. Segment analysis sites (OC Buck Road, A, B to B-2, C, D-1, E to E-3, F to F-2, G and G-1) for Buck Road subwatershed (Fig. 2) on 15 March 2011, Oatka Creek. Light green dots are sample sites. Arrows signify flow direction. Black outlines are watershed boundaries.

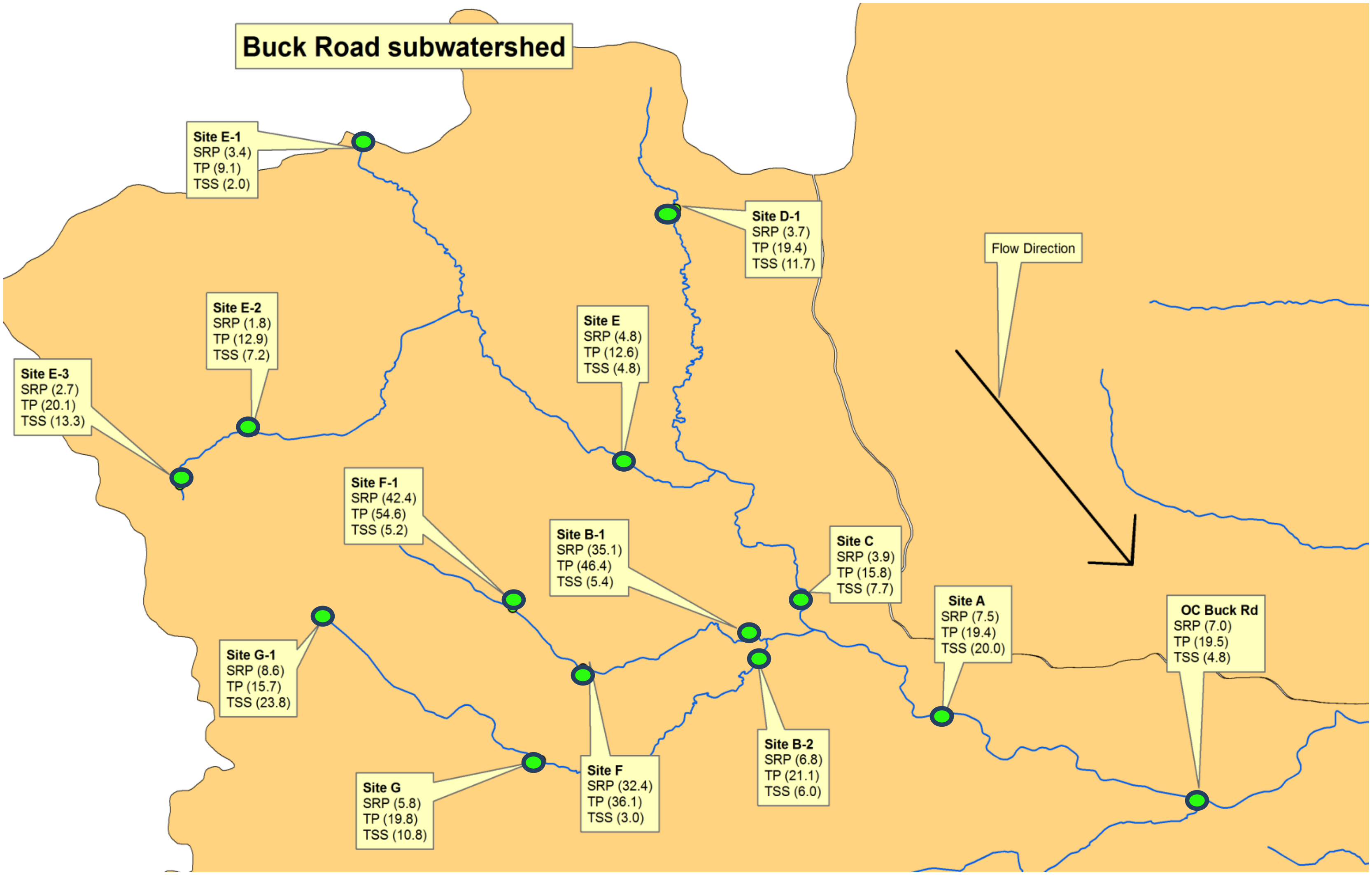


Figure 27. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), and total suspended solid (TSS: mg/L) for the Buck Road subwatershed (Fig. 2) on 15 March 2011, Oatka Creek. Light green dots are sample sites. Black arrow signifies flow direction.

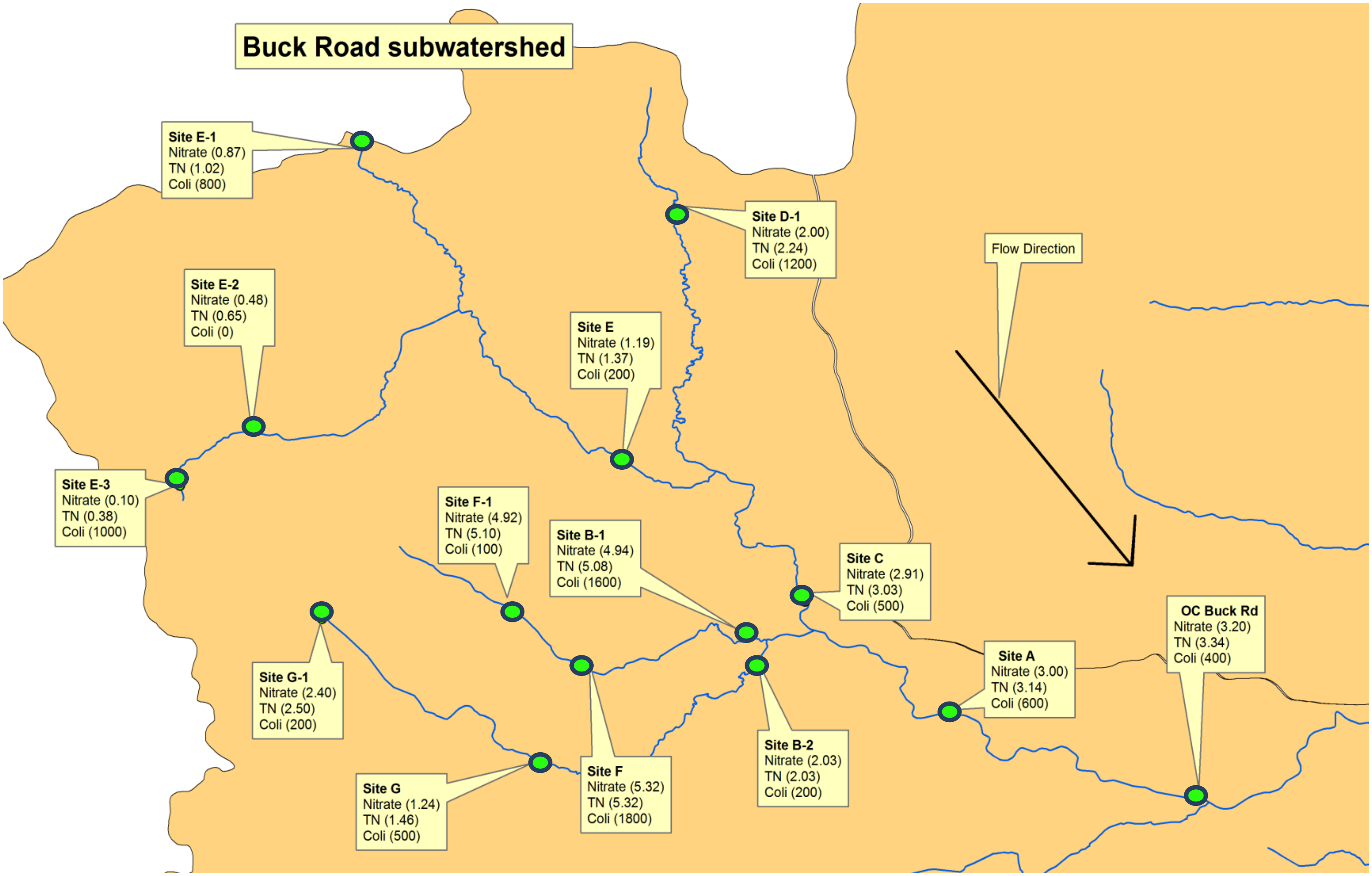


Figure 28. Nitrate (mg N/L), total nitrogen (TN: mg N/L), and total coliform abundances (CFU/100 mL) for the Buck Road subwatershed (Fig. 2) on 15 March 2011, Oatka Creek. Light green dots are sample sites. Black arrow signifies flow direction.

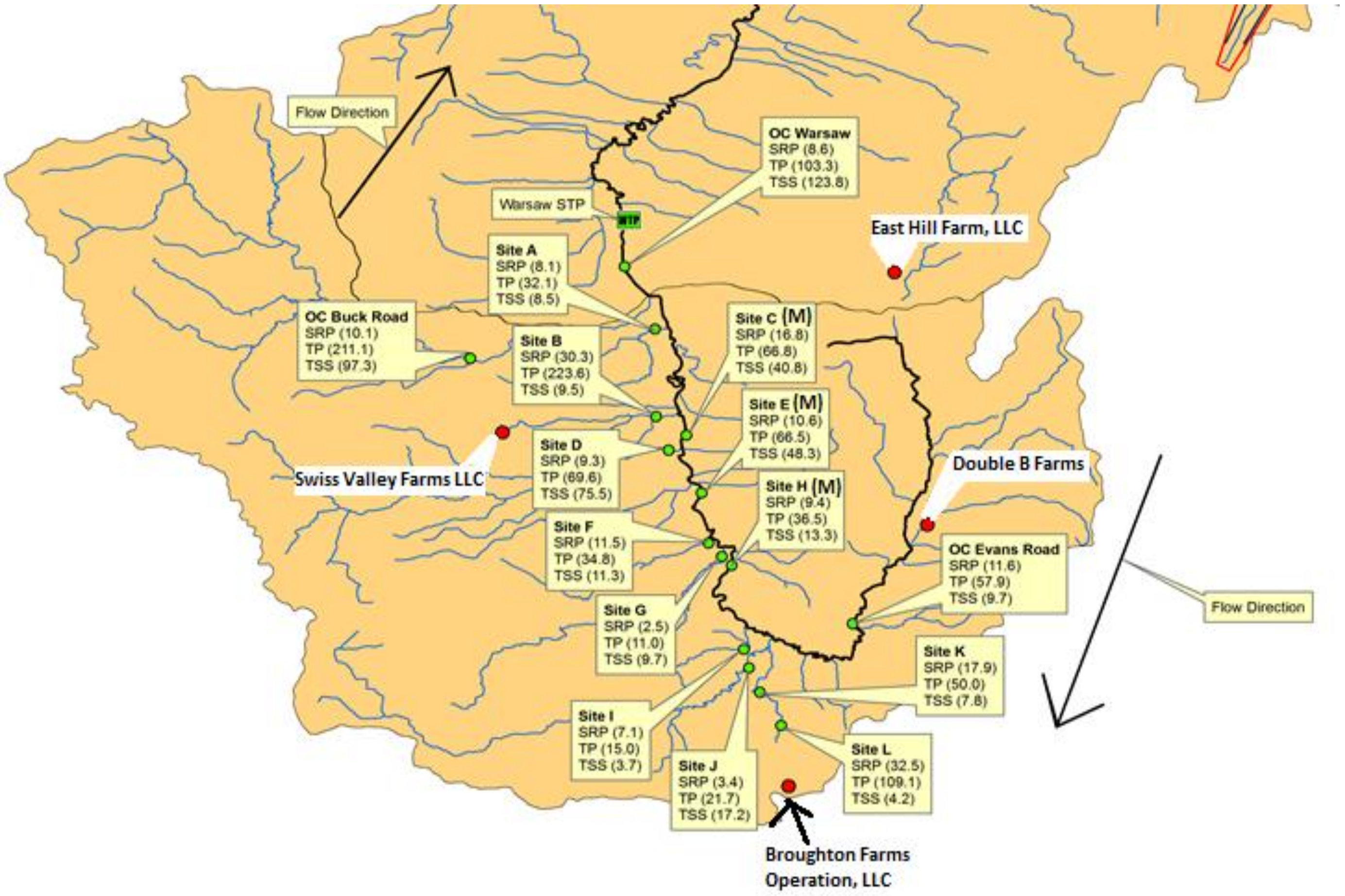


Figure 29. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), and total suspended solid (TSS: mg/L) for upstream from OC Warsaw on 8 March 2011, Oatka Creek (Fig. 2). Red dots are CAFO operations. Light green dots are sample sites. Black arrow signifies flow direction. Oatka Creek mainstem is bolded black and M = mainstem sampling sites with an addition to OC Warsaw and OC Evans Road.

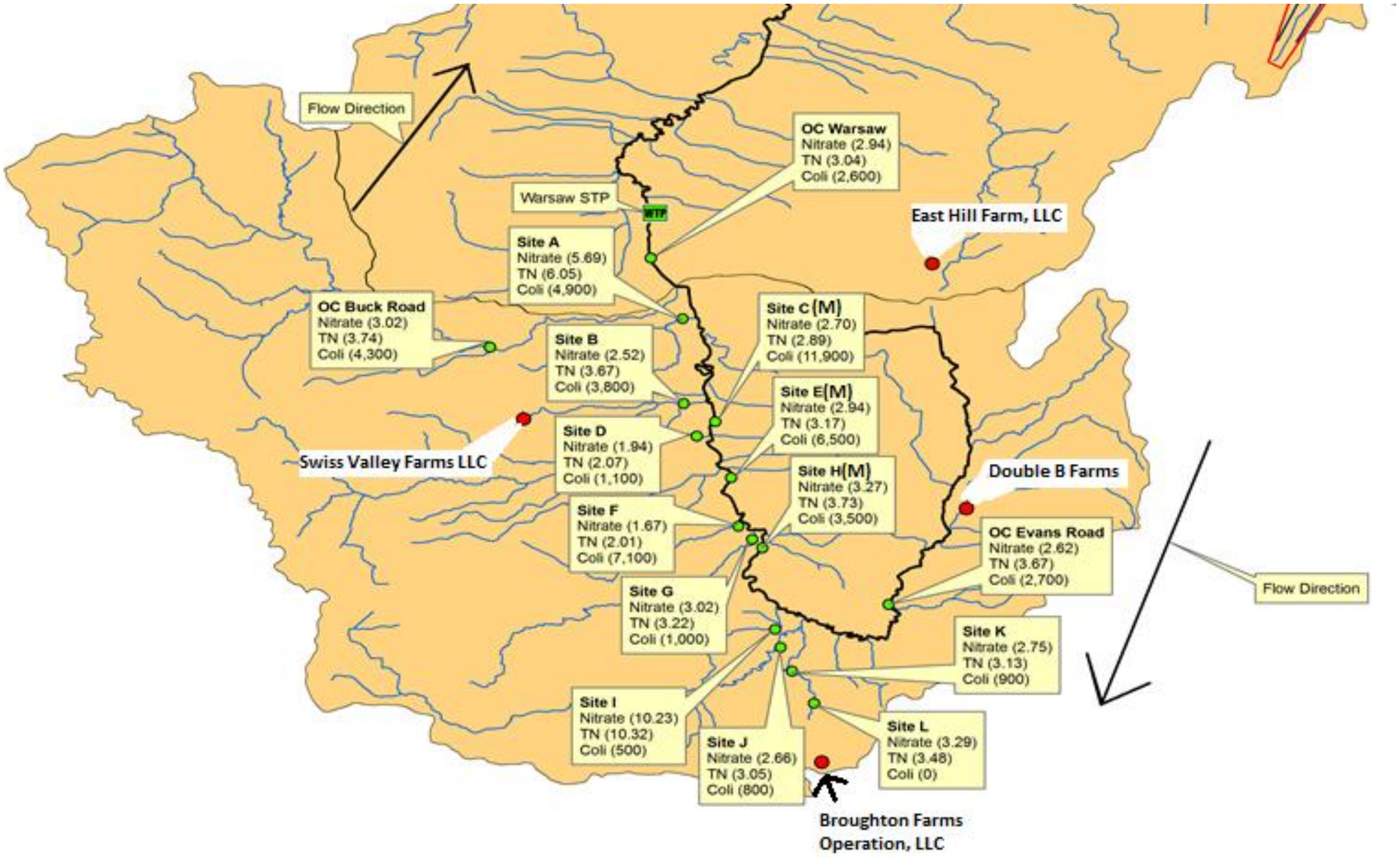


Figure 30. Nitrate (mg N/L), total nitrogen (TN: mg N/L), and total coliform abundances (CFU/100 mL) for upstream from OC Warsaw on 8 March 2011, Oatka Creek (Fig. 2). Red dots are CAFOs. Light green dots are sample sites. Black arrow signifies flow direction. Oatka Creek mainstem is bolded black and M = mainstem sampling sites with an addition to OC Warsaw and OC Evans Road.

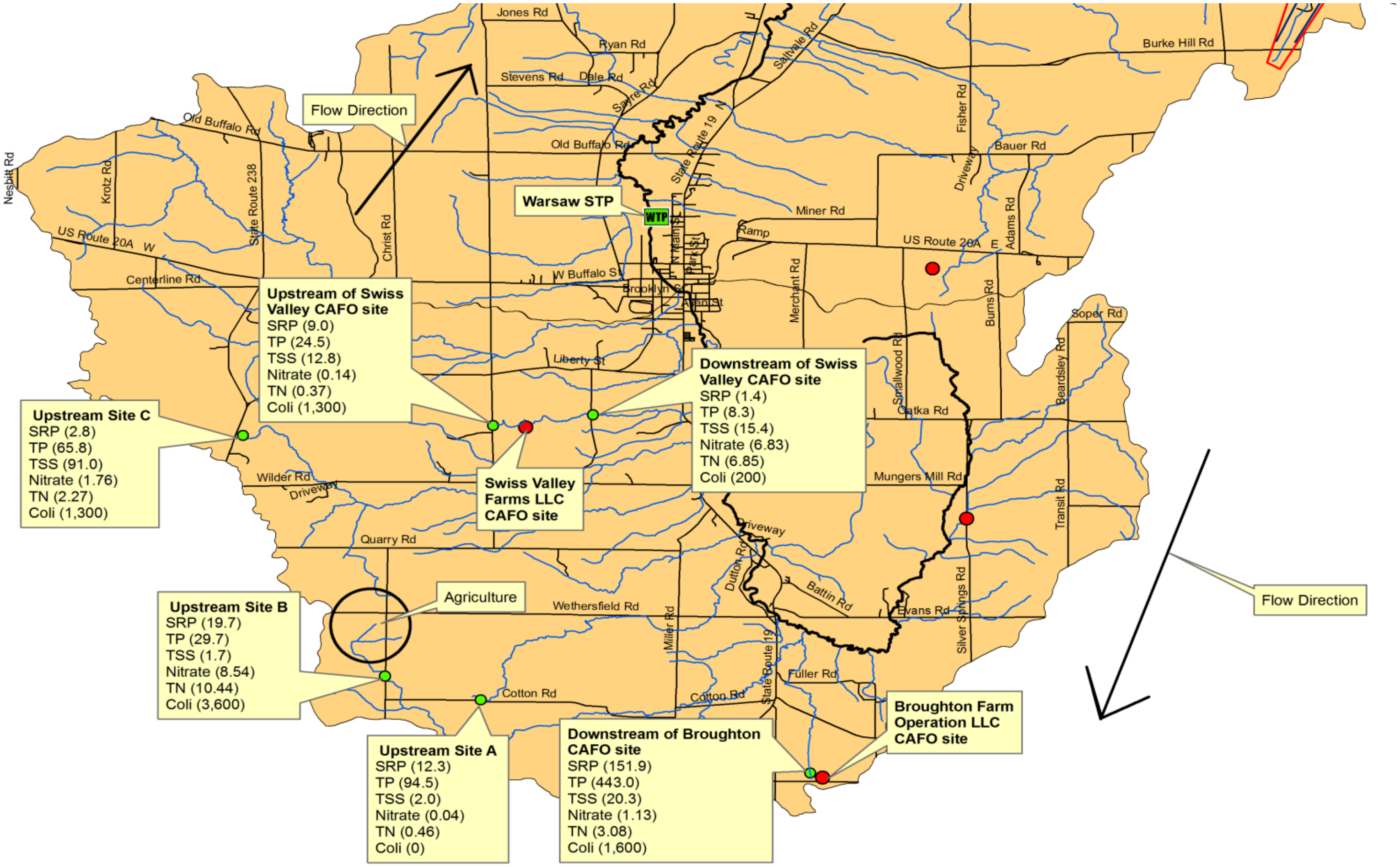


Figure 31. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), total suspended solid (TSS: mg/L), nitrate (mg N/L), total nitrogen (TN: mg N/L), and total coliform abundances (CFU/100 mL) for upstream from OC Warsaw CAFO operation and headwater sites on 15 March 2011, Oatka Creek (Fig. 2). Red dots are CAFOs. Light green dots are sample sites. Black arrow signifies flow direction. Oatka Creek mainstem is bolded black.

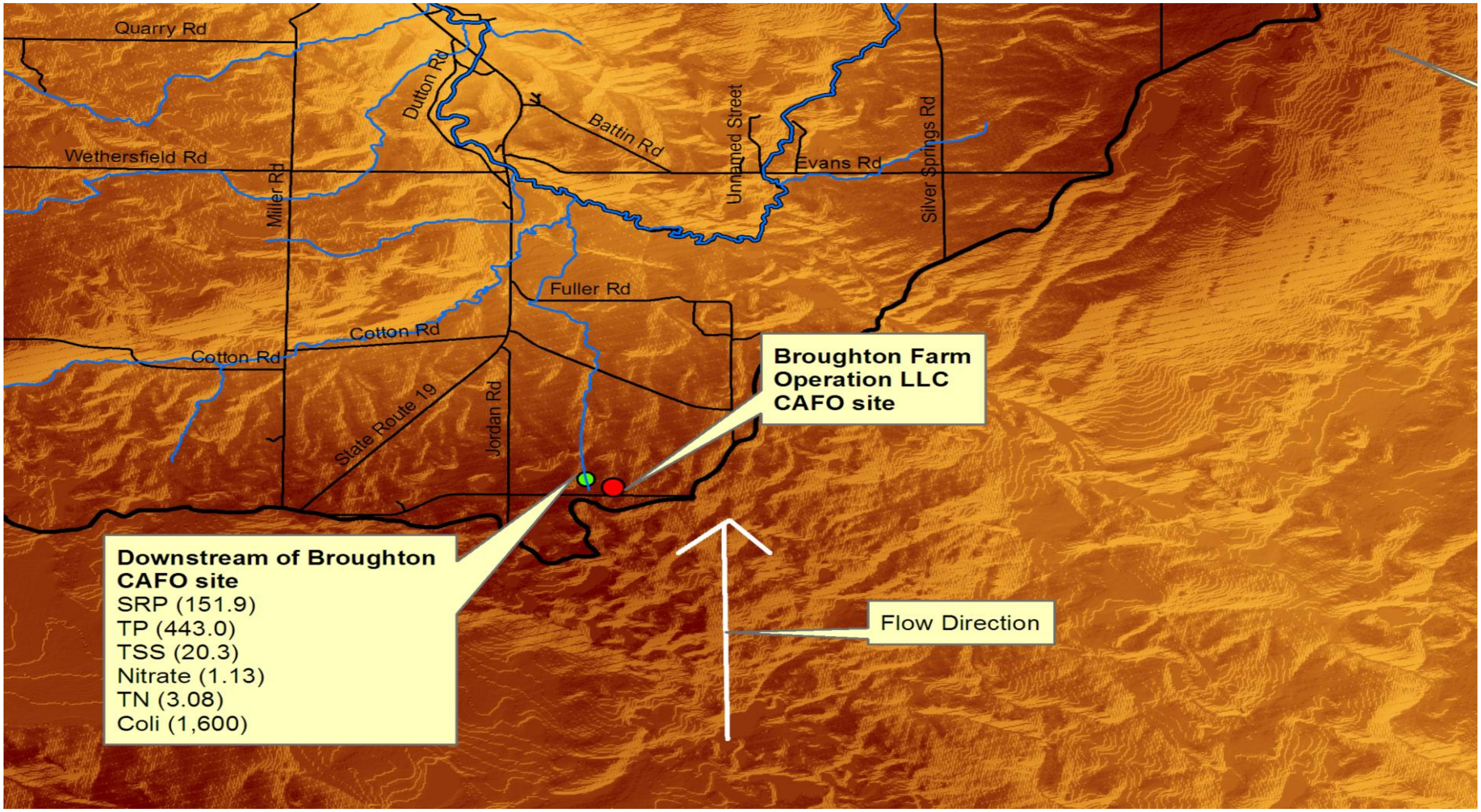


Figure 32. Digital Elevation Map (DEM) of the furthest upstream reach of Oatka Creek on 15 March 2011 (Fig. 31). Higher elevation is illustrated by the darker background. Green dot is a sampling location. White arrow illustrates stream flow direction.

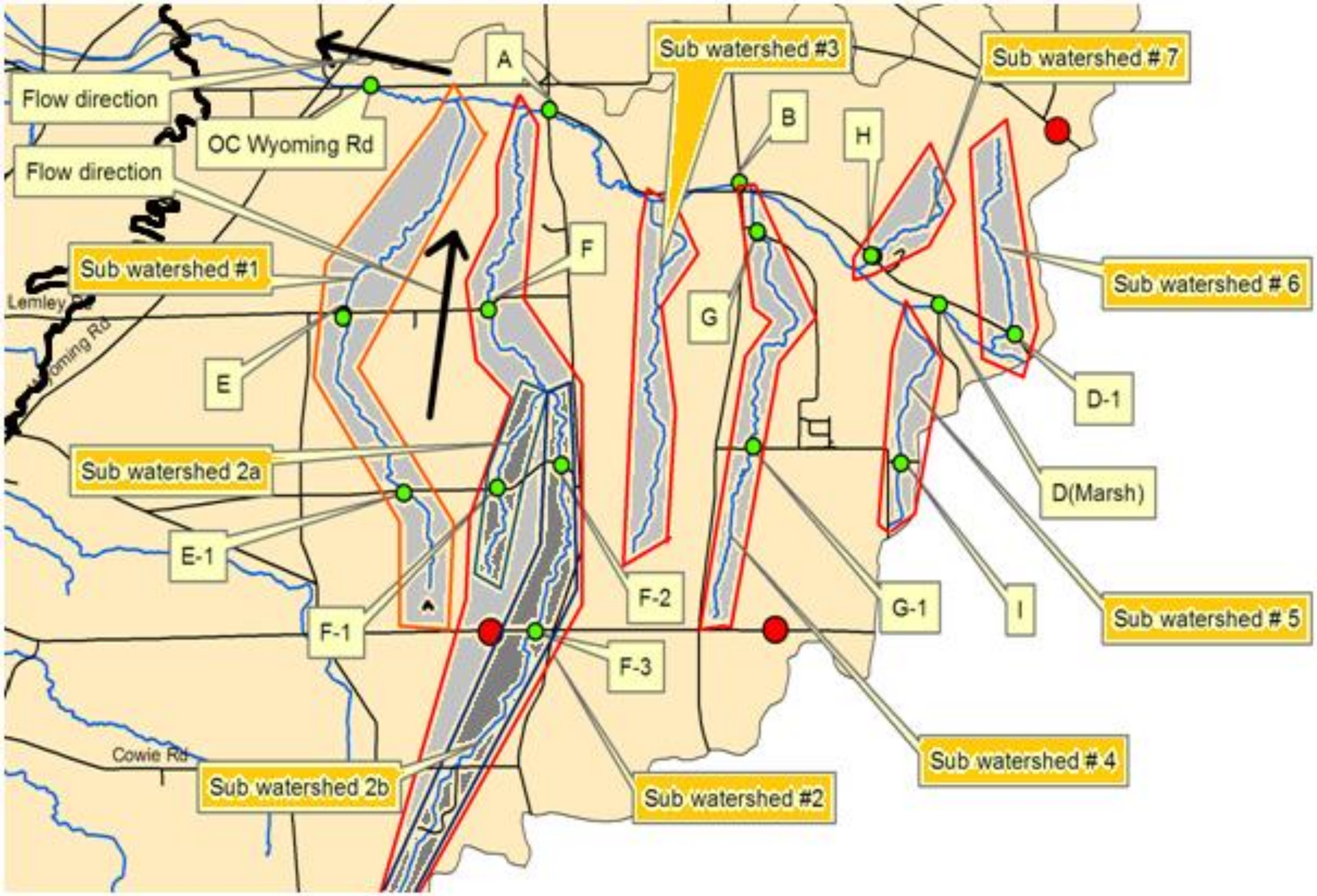


Figure 33. Segment analysis sites (A to H) for Wyoming Road subwatershed (Fig. 2) on 3 August 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red and blue outlines show each individual subwatershed (1-7). Oatka Creek mainstem is bolded in black on left side of figure.

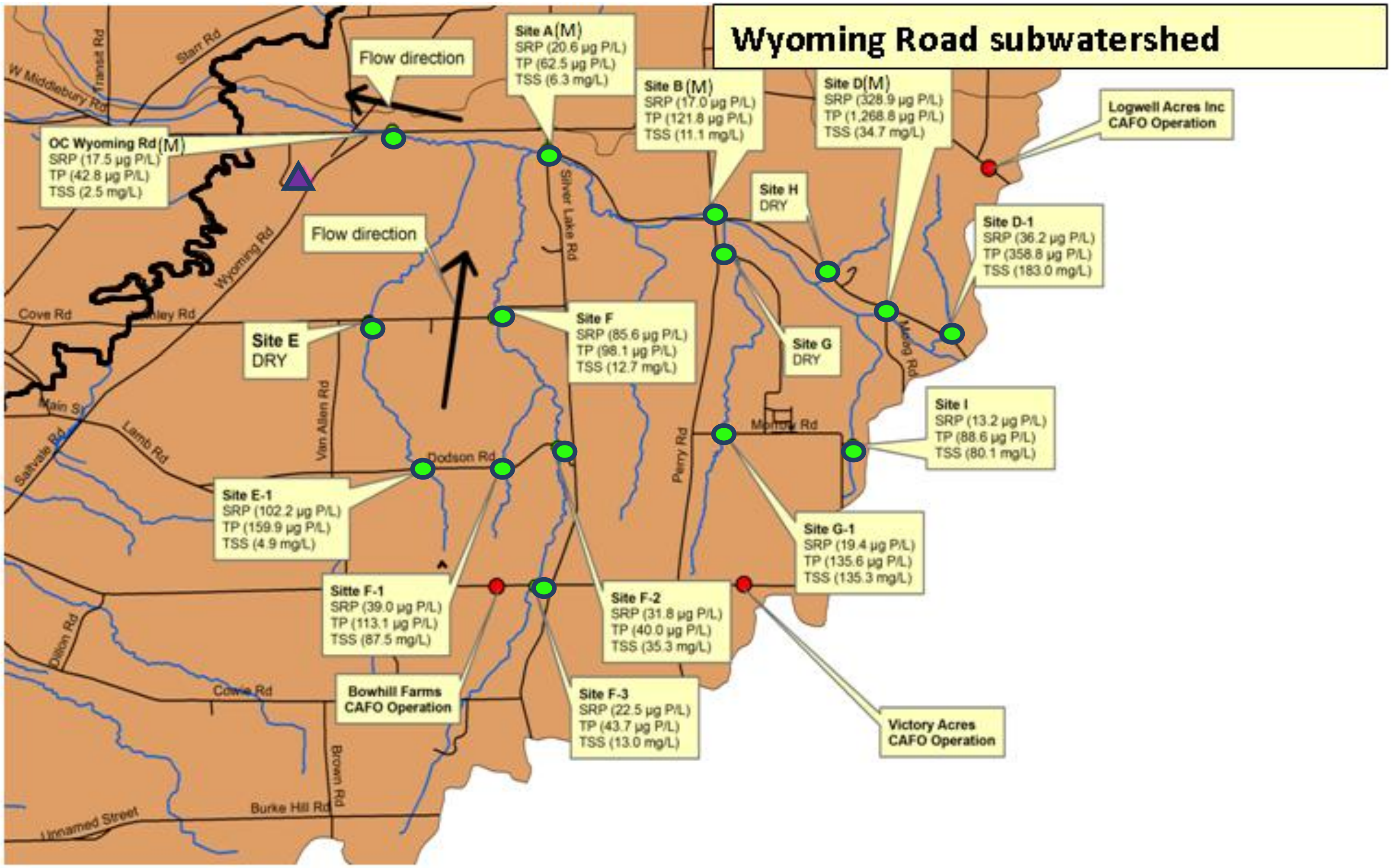


Figure 34. Soluble reactive phosphorus (SRP), total phosphorus (TP), and total suspended solid (TSS) concentrations for Wyoming Road subwatershed on 3 August 2010. Light green dots are sample sites. Purple triangle is a SPDES site. Arrows signify flow direction. Oatka Creek mainstem is bolded in black on left side of figure.

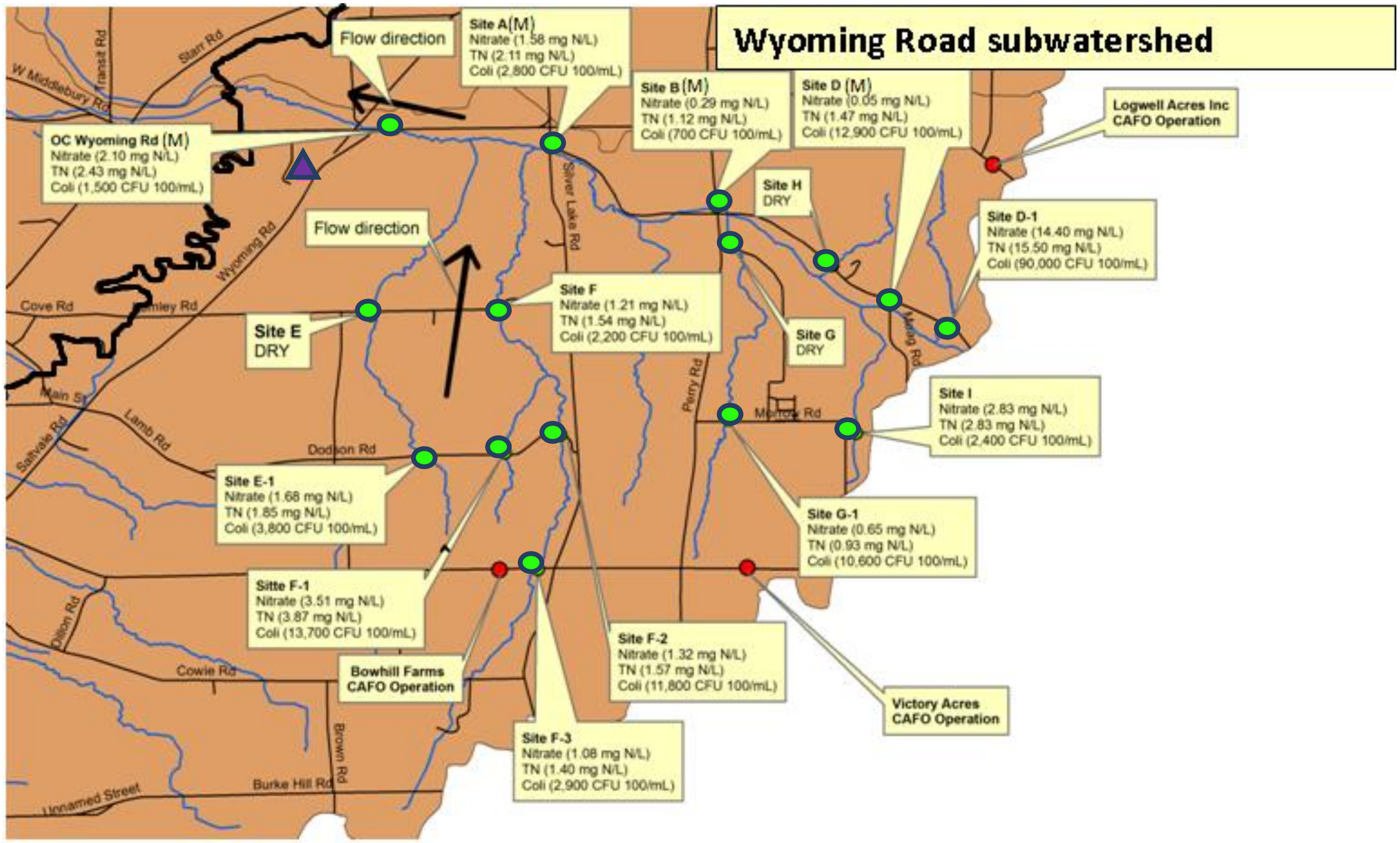


Figure 35. Nitrate, total nitrogen (TN), and total coliform concentrations for Wyoming Road subwatershed on 3 August 2010. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction. Oatka Creek mainstem is bolded in black on left side of figure.

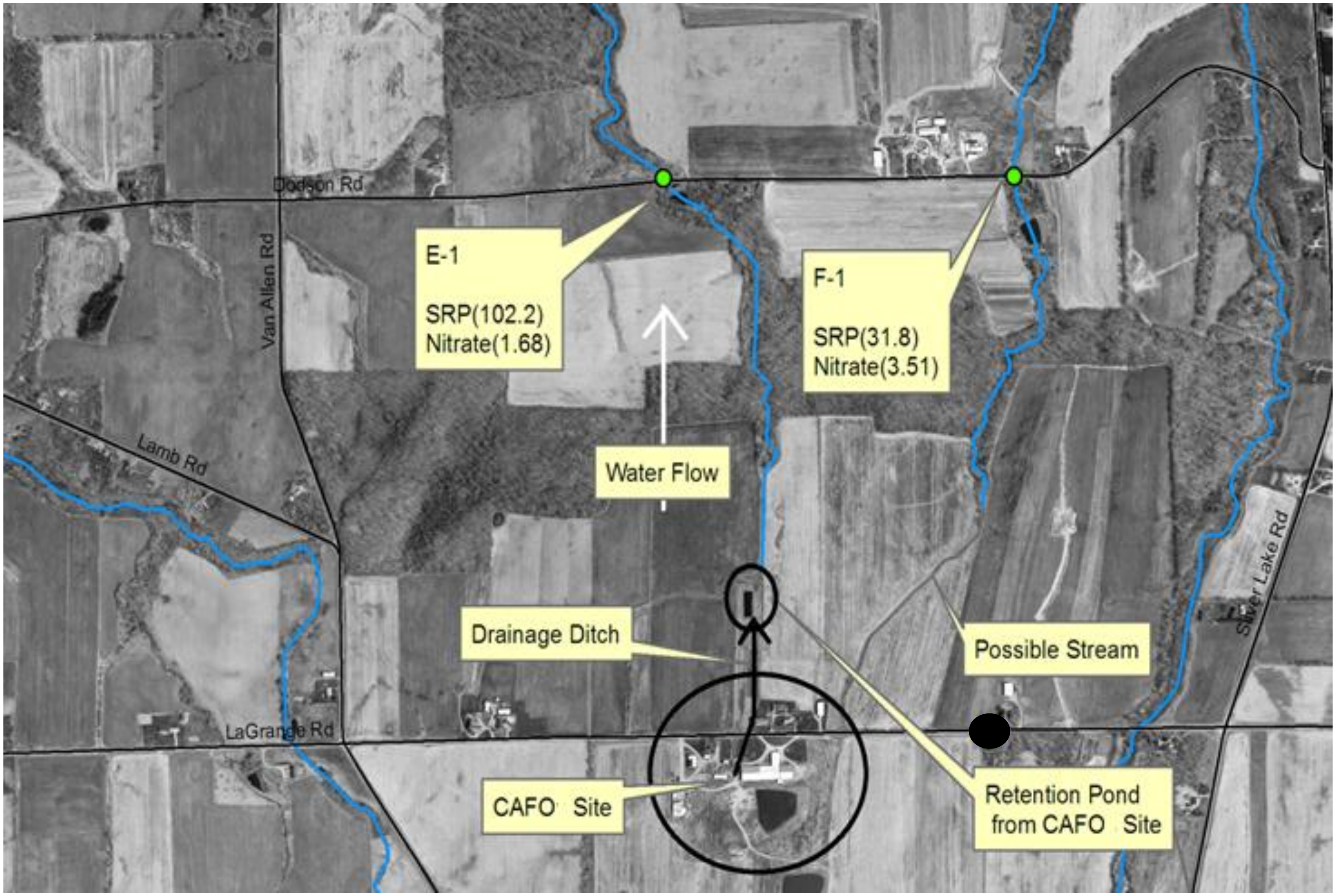


Figure 36. Soluble reactive phosphorus (µg P/L) and nitrate (mg N/L) in the Wyoming Road subwatershed at Sites E-1 and F-1 on 3 August 2010, Oatka Creek. CAFO site (Bowhill Farms) is circled and there is a retention pond that drains from Bowhill Farms to the center portion of a field.

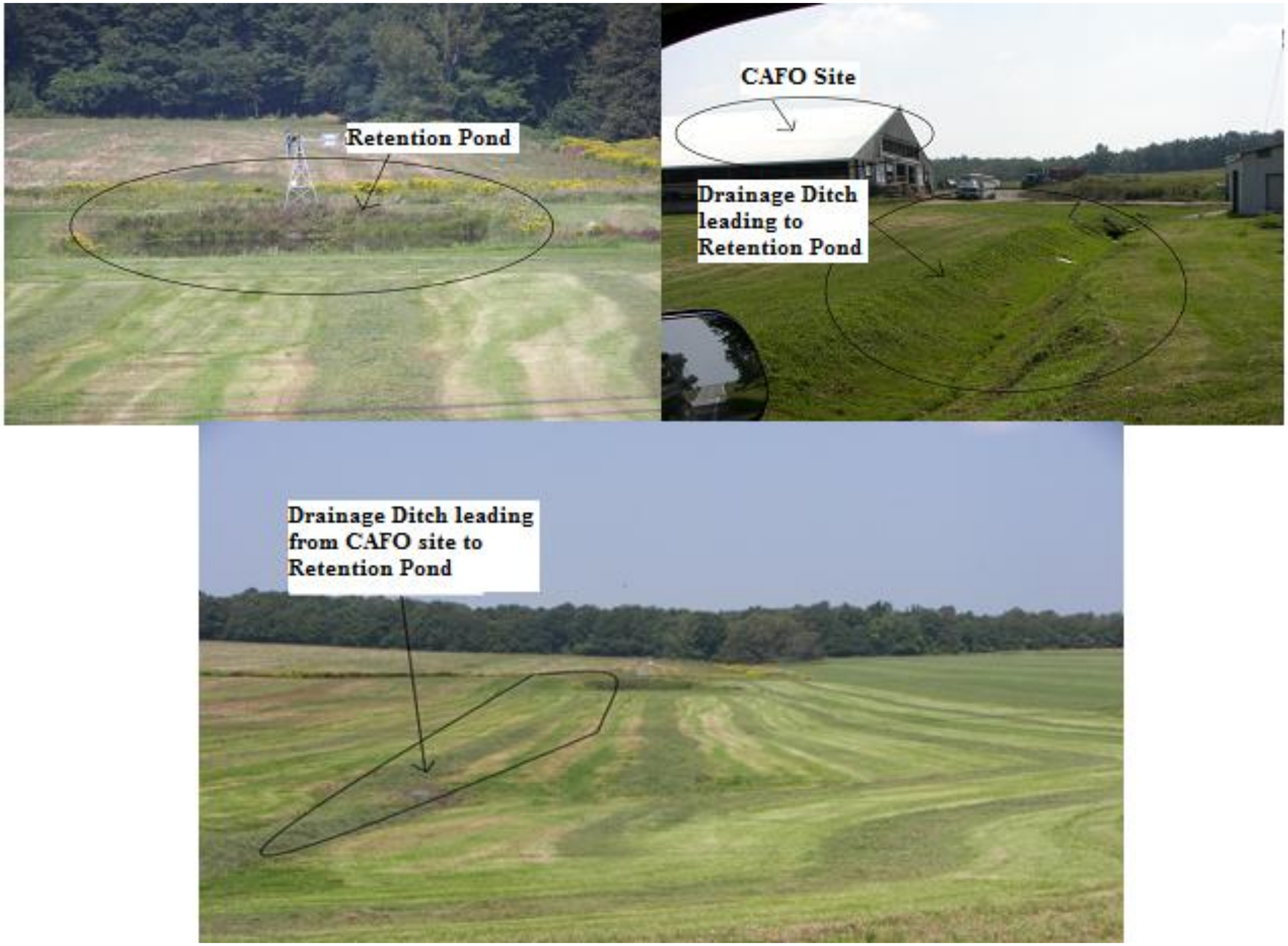


Figure 37. Pictures of the CAFO site (Bowhill Farms), drainage ditch, and retention pond located upstream of subwatershed #2 (Fig. 25) on 7 September 2010.

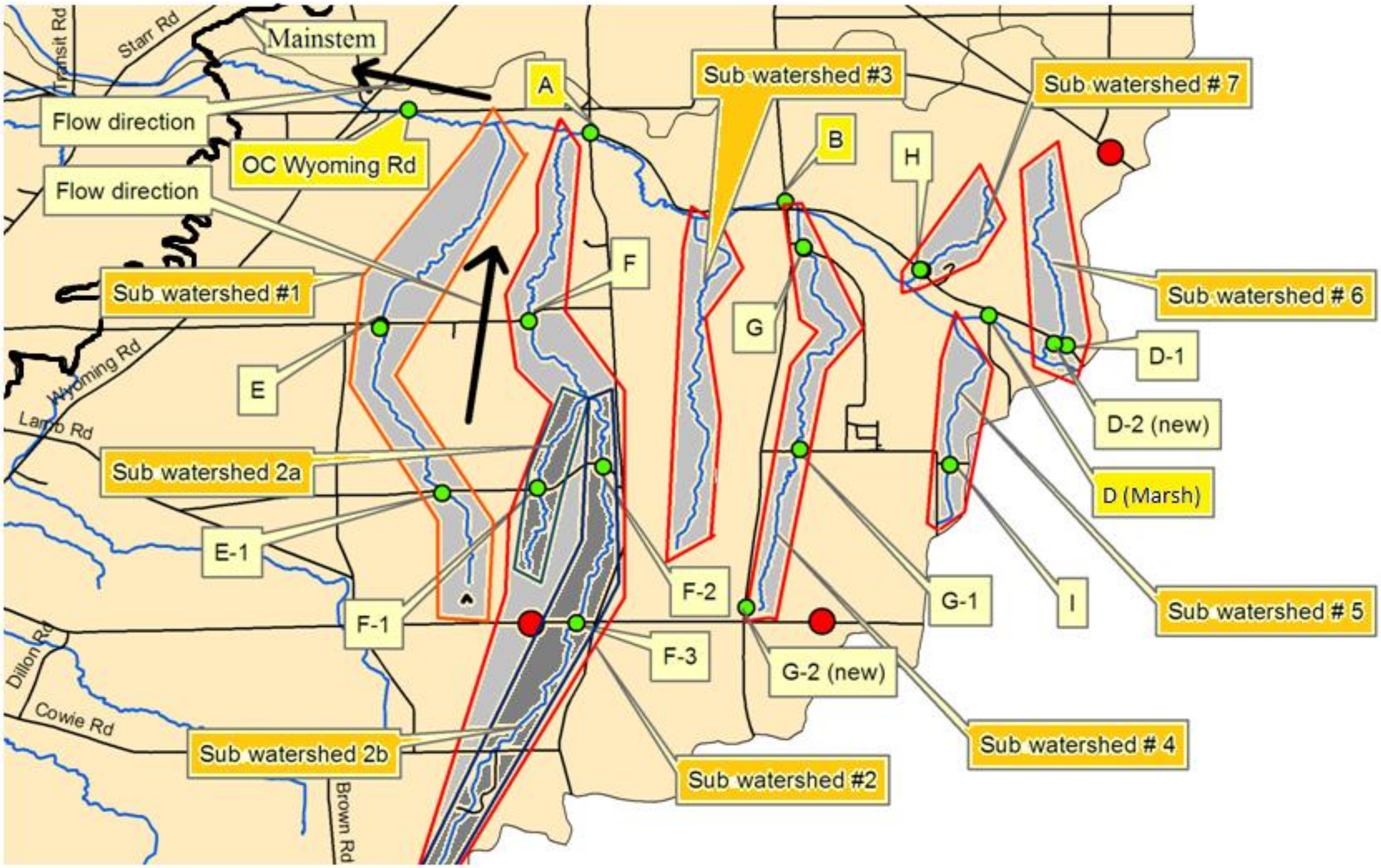


Figure 38. Segment analysis sites (A to H) for Wyoming Road subwatershed (Fig. 2) on 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red and blue outlines show each individual subwatershed (1-7). Sites bolded in yellow (OC Wyoming Road, A, B and D) are tributary mainstem sites.

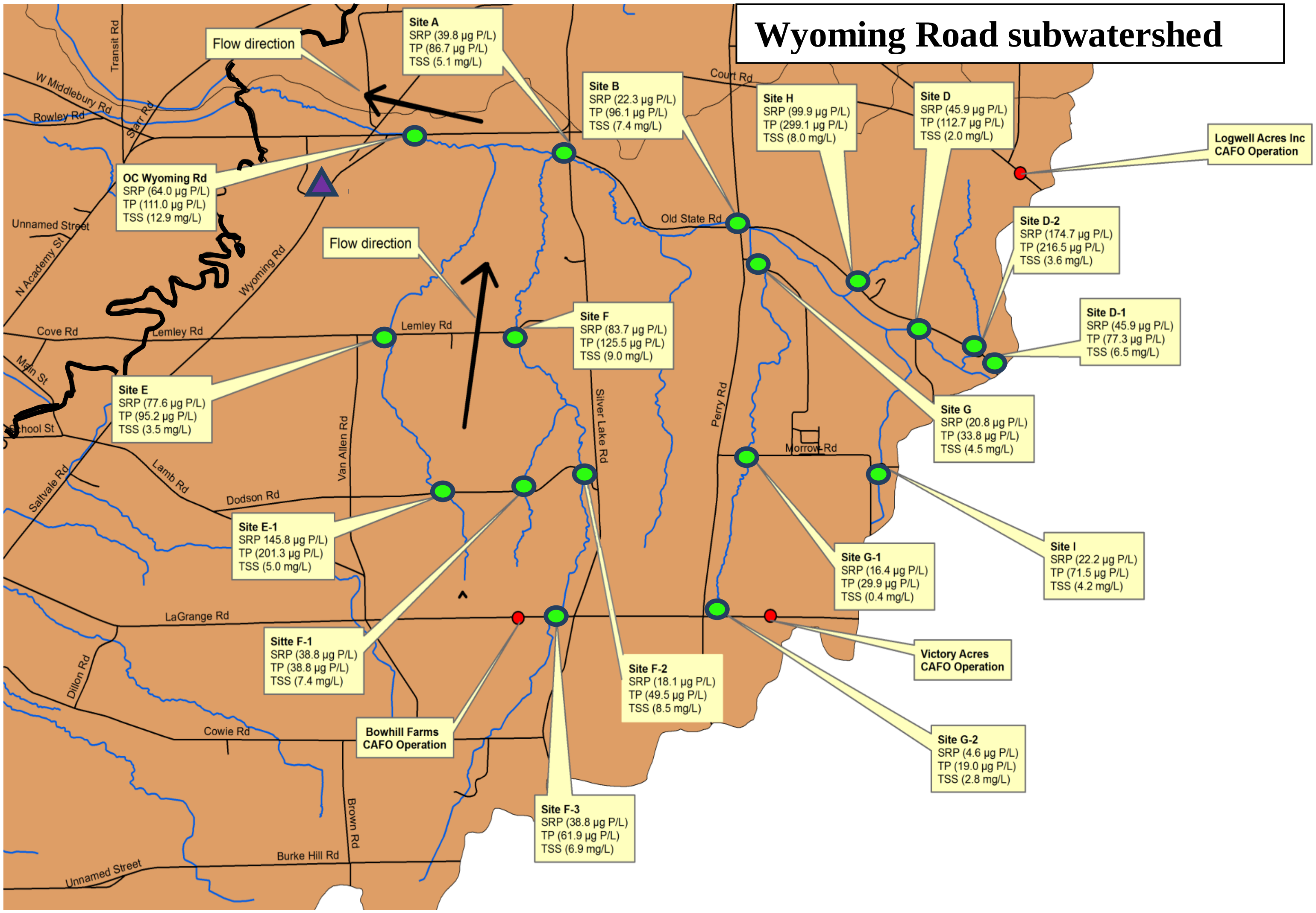


Figure 39. Soluble reactive phosphorus (SRP), total phosphorus (TP), and total suspended solid (TSS) concentrations for Wyoming Road subwatershed on 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Purple triangle is a SPDES site. Oatka Creek mainstem is bolded black on left side of figure. Arrows signify flow direction.

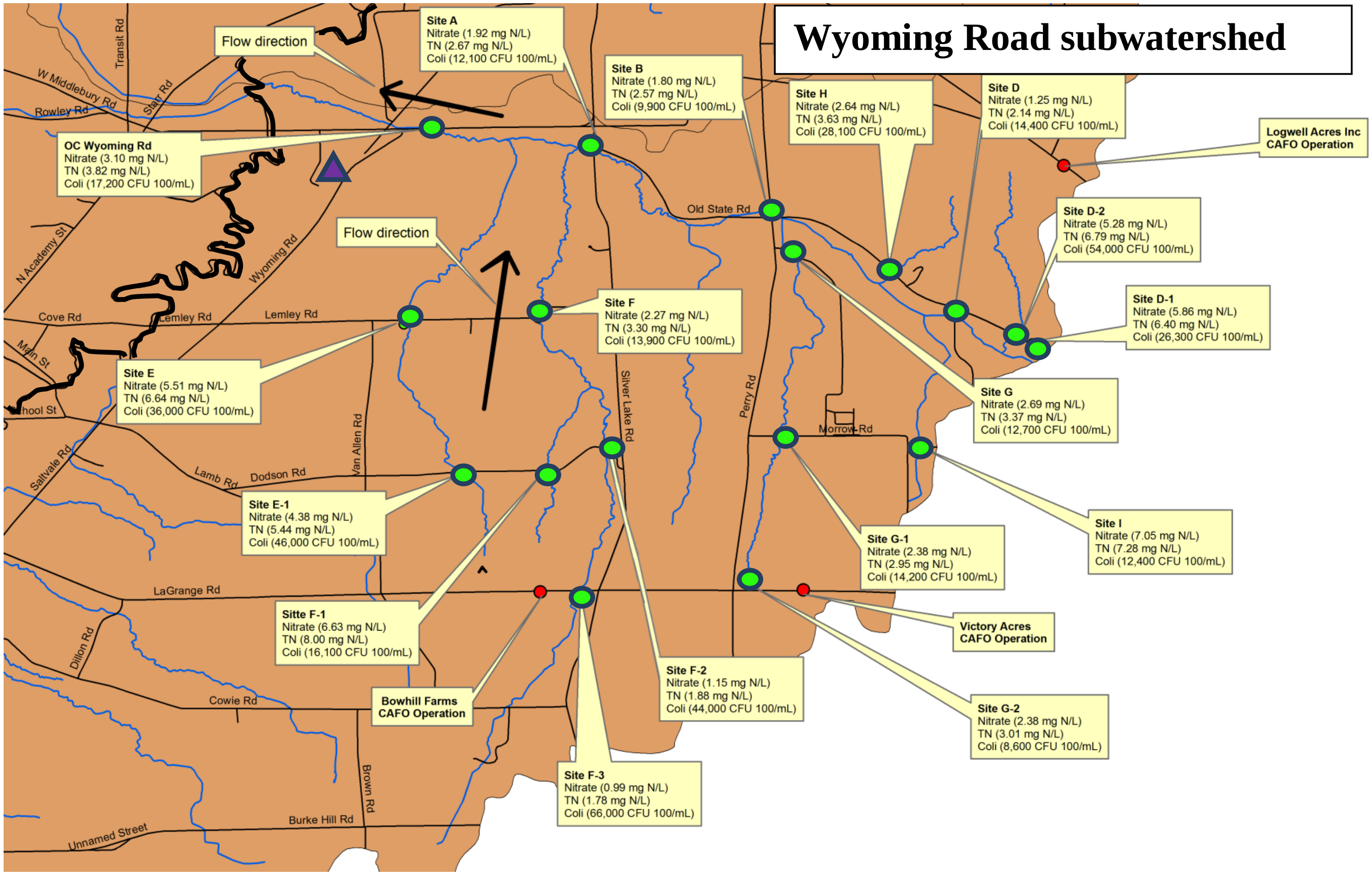


Figure 40. Nitrate, total nitrogen (TN), and total coliform concentrations for Wyoming Road subwatershed on 6 October 2010. Red dots are CAFO sites. Light green dots are sample sites. Purple triangle is a SPDES site. Oatka Creek mainstem is bolded black on left side of figure. Arrows signify flow direction.

Figure 41. Picture of Site D-1 in the Wyoming Road subwatershed (Fig. 38), Drainage pipe feeding out from under a residence.

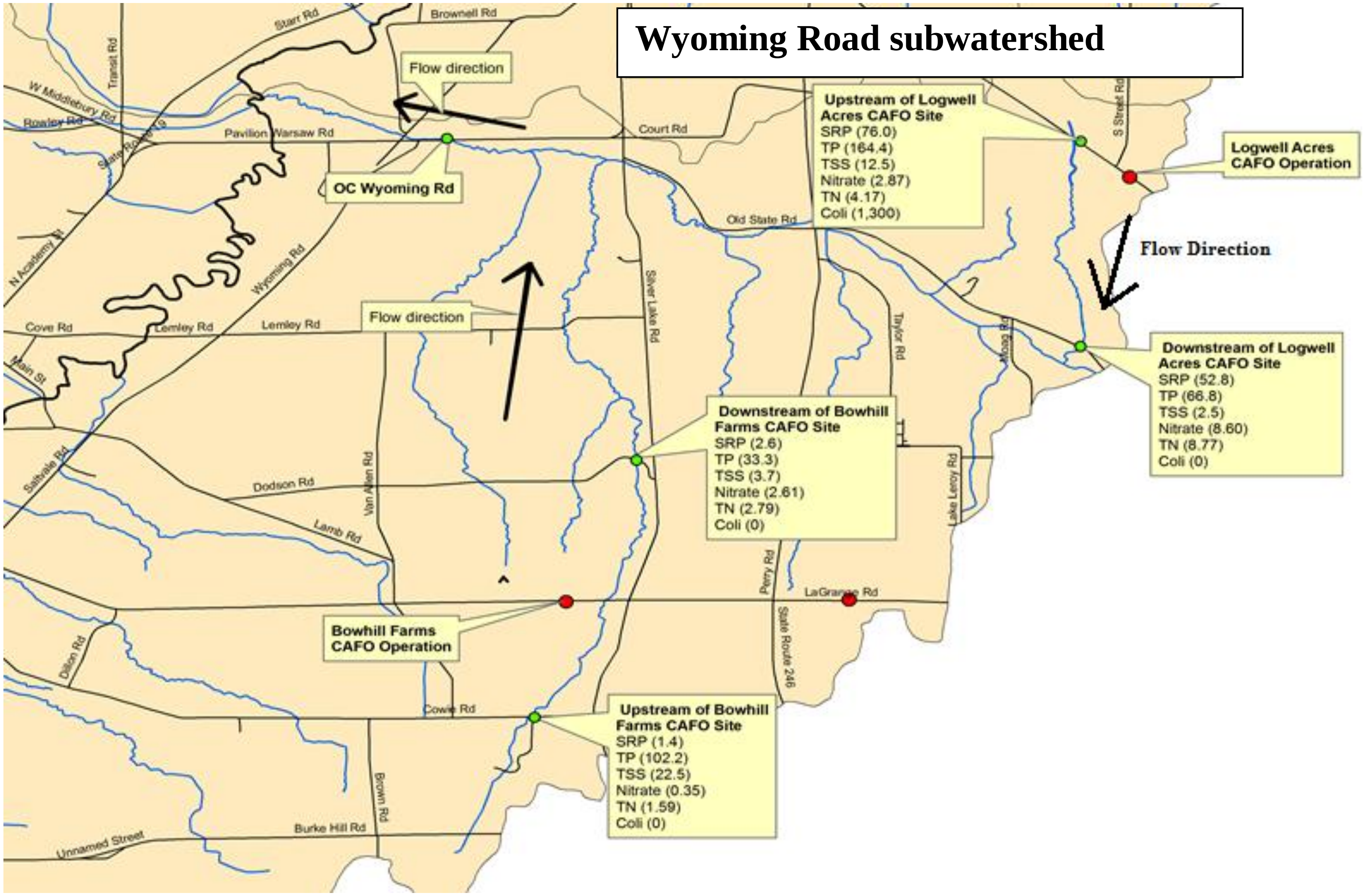


Figure 42. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), total suspended solid (TSS: mg/L), nitrate (mg N/L), total nitrogen (TN: mg N/L) and total coliform abundances (CFU/100 mL) for Wyoming Road (Fig. 2) CAFOs on 29 March 2011, Oatka Creek. Red dots are CAFOs. Light green dots are sample sites. Black arrow signifies flow direction. Oatka Creek mainstem is bolded black.

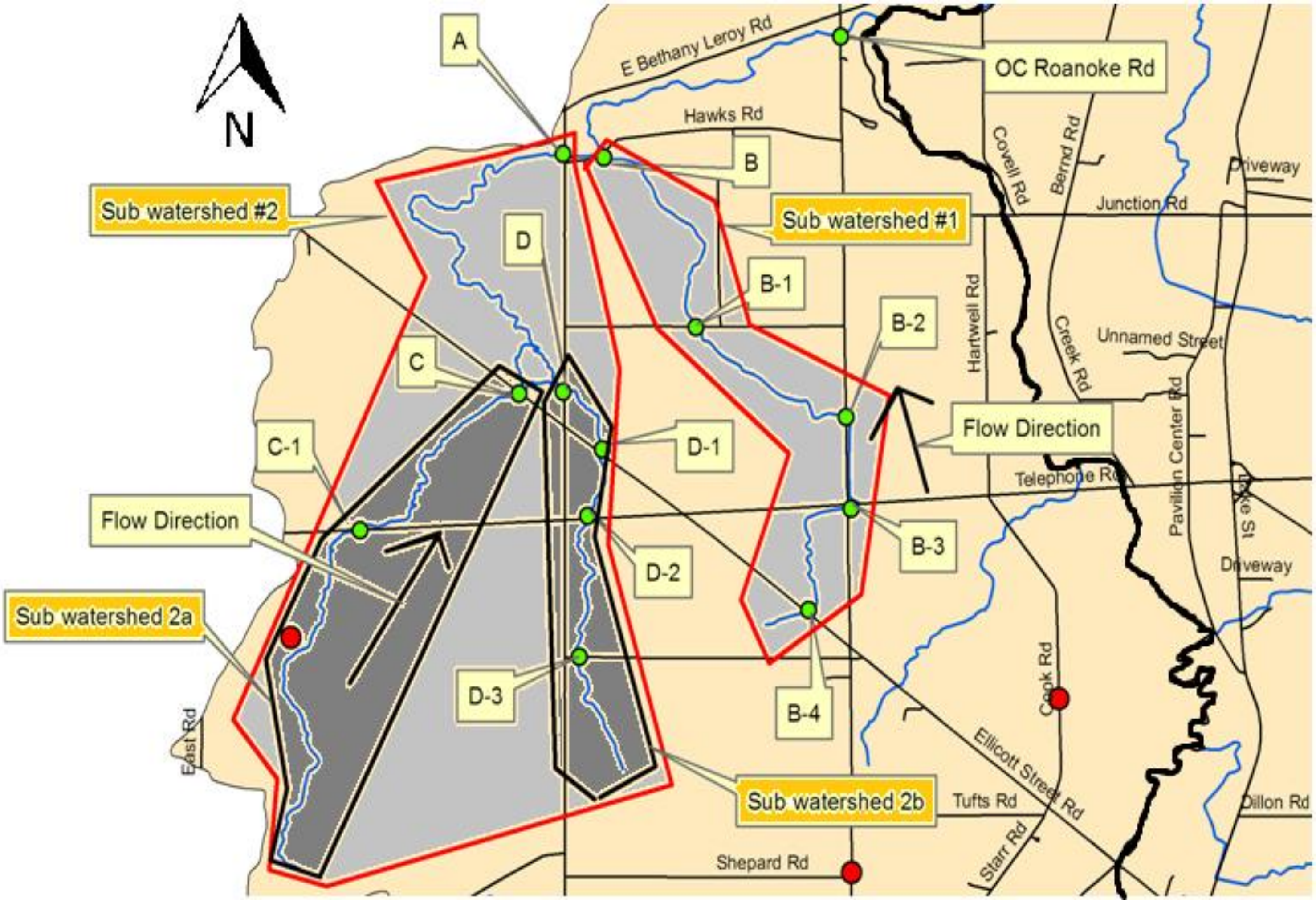


Figure 43. Segment analysis sites (A to D-3) for Roanoke Road subwatershed (Fig. 2) on 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red and black outlines show each individual subwatershed (1-2b). Oatka Creek mainstem is bolded in black on right side of figure.

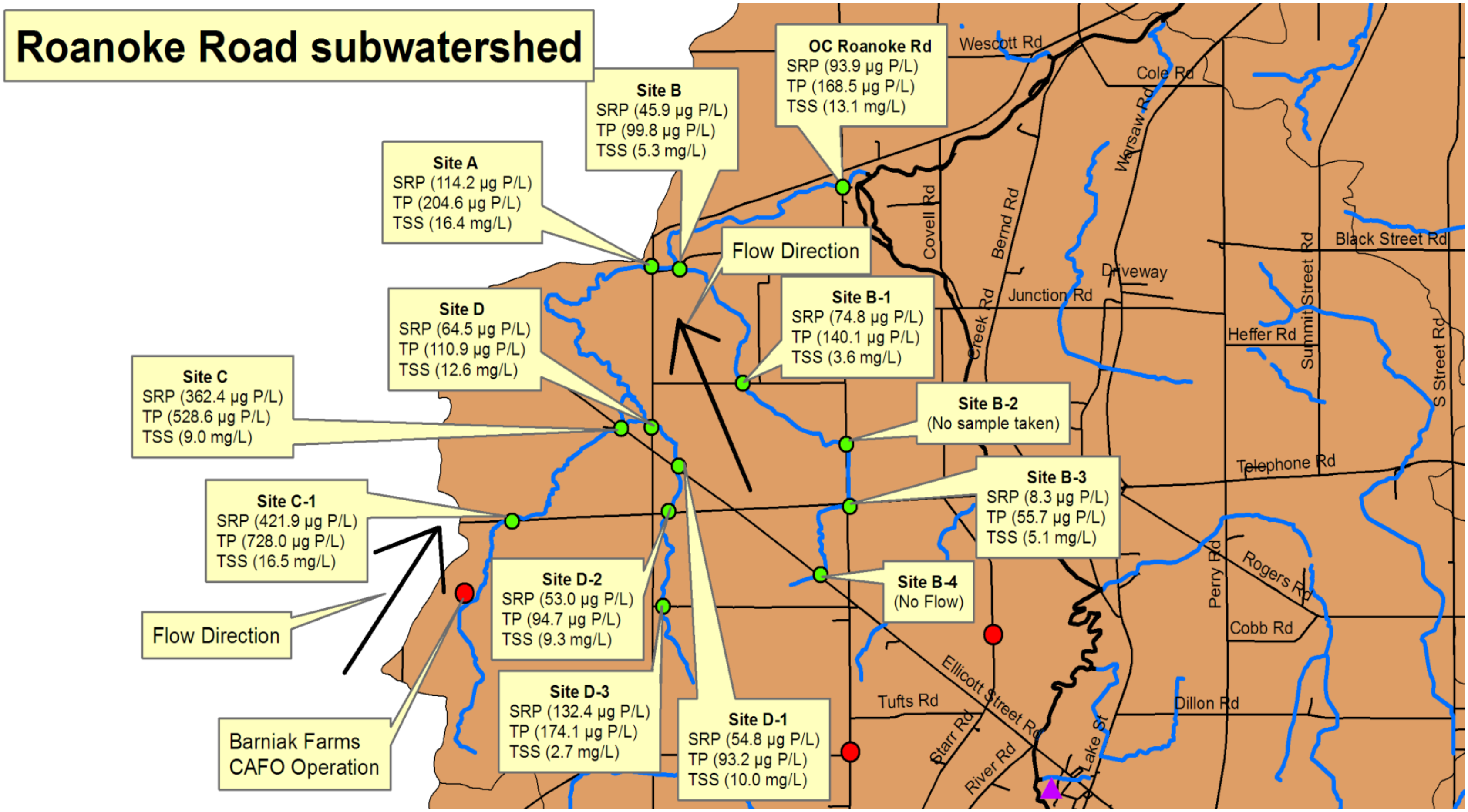


Figure 44. Soluble reactive phosphorus (SRP), total phosphorus (TP), and total suspended solid (TSS) concentrations for Roanoke Road sub-watershed on 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Purple triangle is a SPDES site. Arrows signify flow direction. Oatka Creek mainstem is bolded in black on right side of figure.

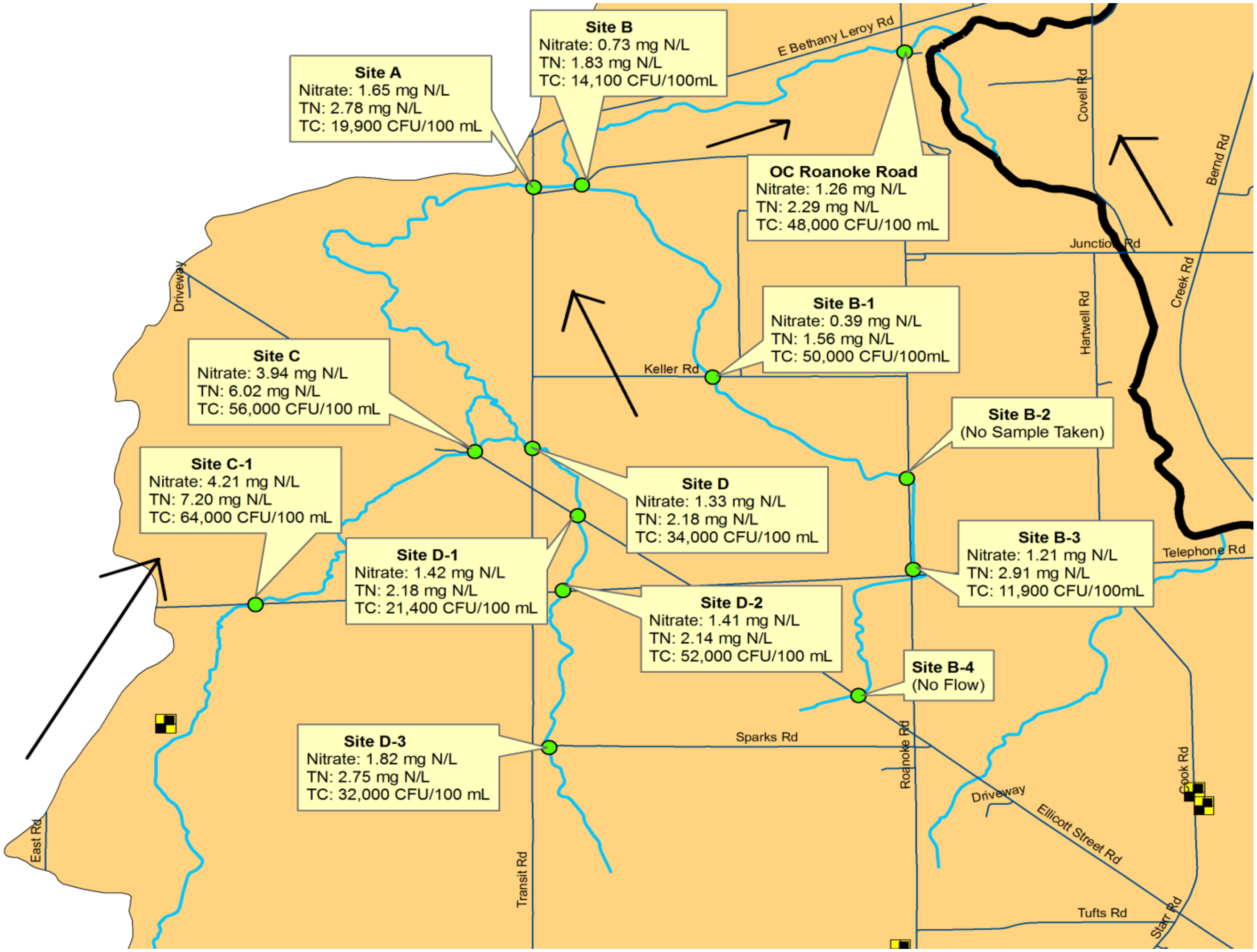


Figure 45. Nitrate, total nitrogen (TN), and total coliform concentrations for Roanoke Road subwatershed (Fig. 2) on 6 October 2010, Oatka Creek. Black/yellow squares are CAFO sites. Light green dots are sample sites. Arrows signify flow direction. Oatka Creek mainstem is bolded in black on right side of figure.

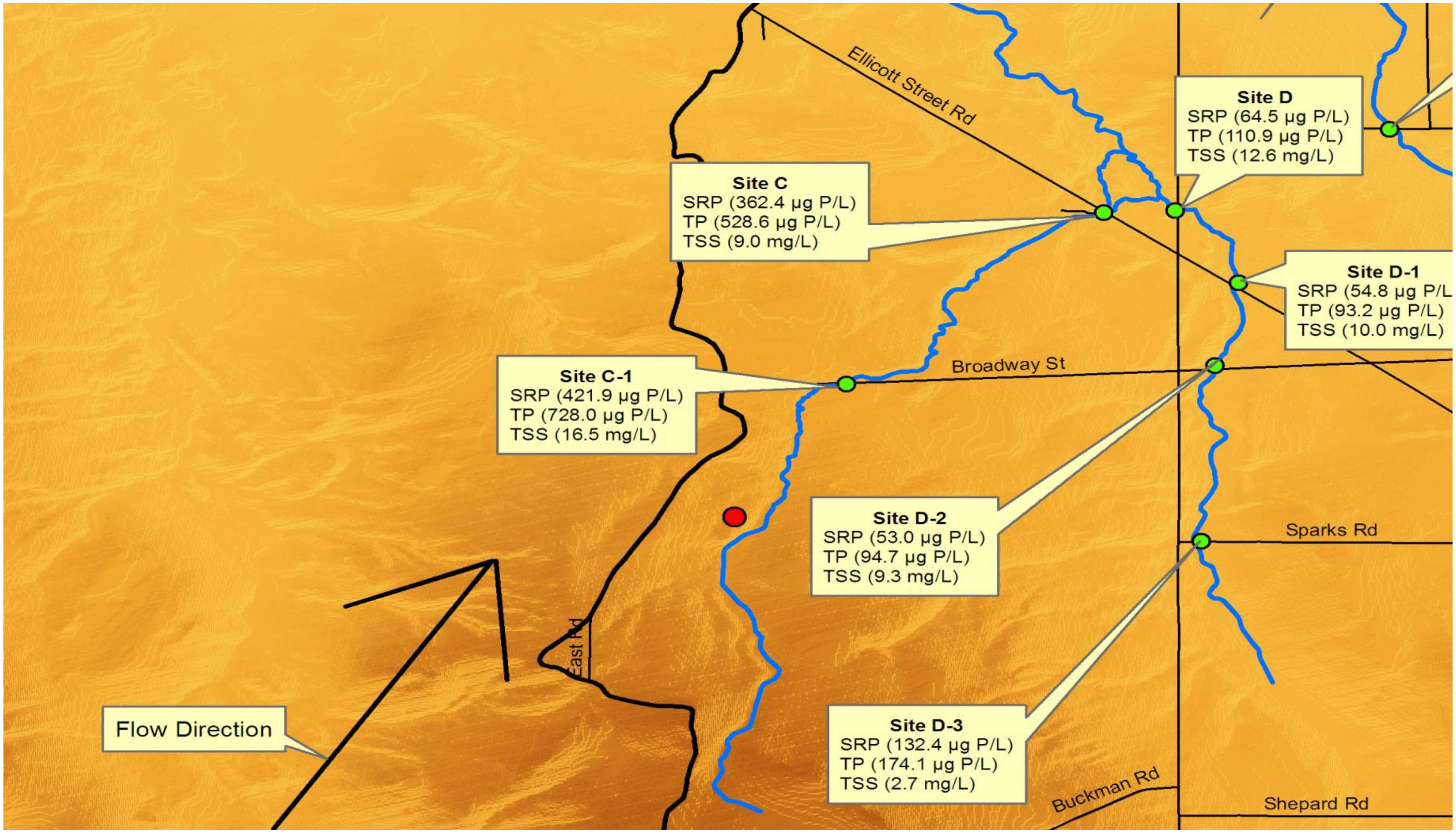


Figure 46. Digital Elevation Map (DEM) of Roanoke Road subwatershed (Fig. 2) on 6 October 2010, Oatka Creek. Darker orange signifies higher elevation while lighter orange illustrates lower elevations. Light green dots are sampling locations. Red dot is Barniak Farms CAFO (Fig. 45). Black Arrow signifies flow direction.

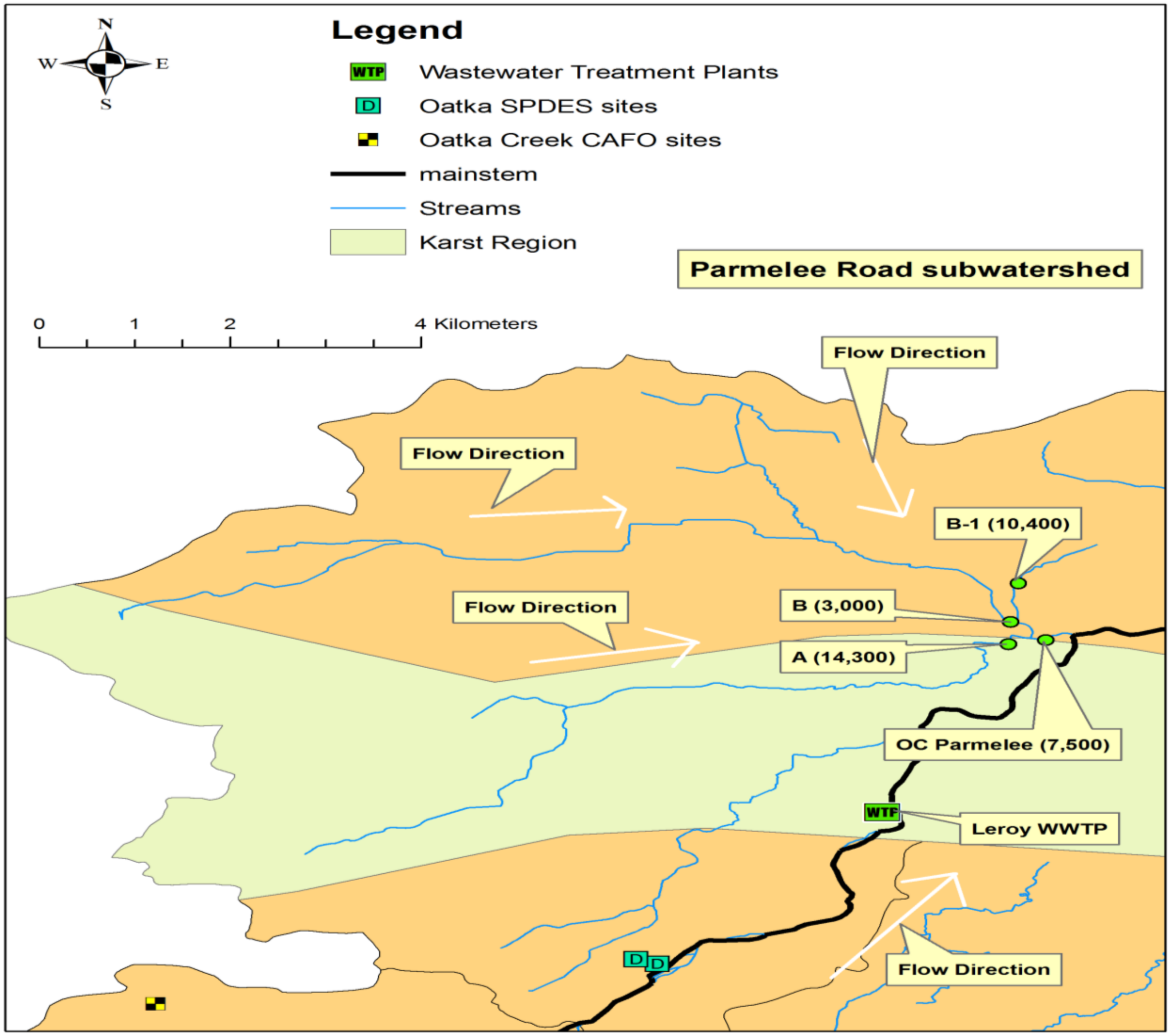


Figure 47. Total coliform abundance (CFU/100mL) at the Parmelee Road subwatershed (Fig. 2) on 27 July 2010, Oatka Creek. Green dots represent sample sites.

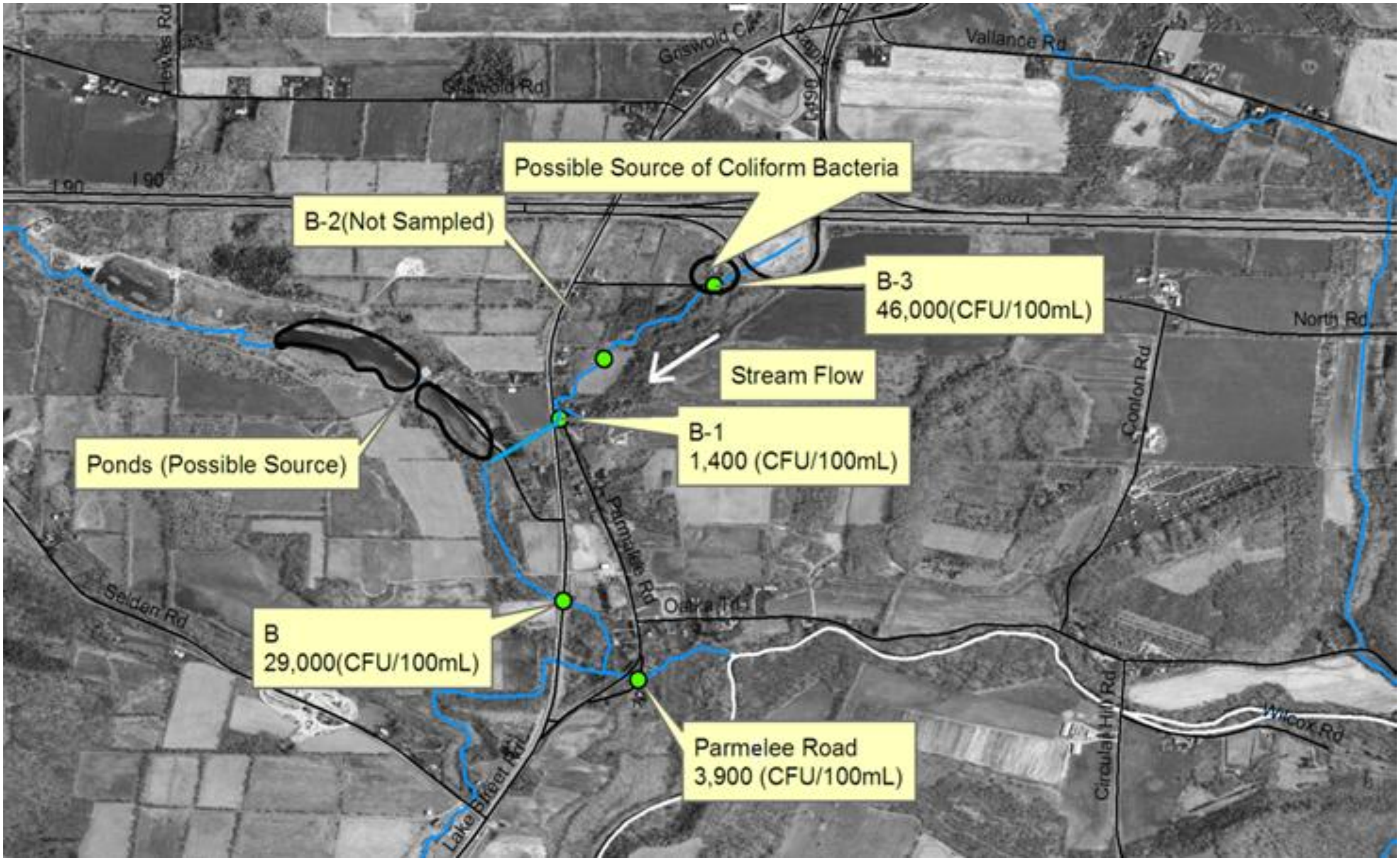


Figure 48. Total coliform abundances (CFU/100 mL) at the Parmelee Road subwatershed (Fig. 2) on 3 August 2010, Oatka Creek. Oatka Creek mainstem is bolded in white.

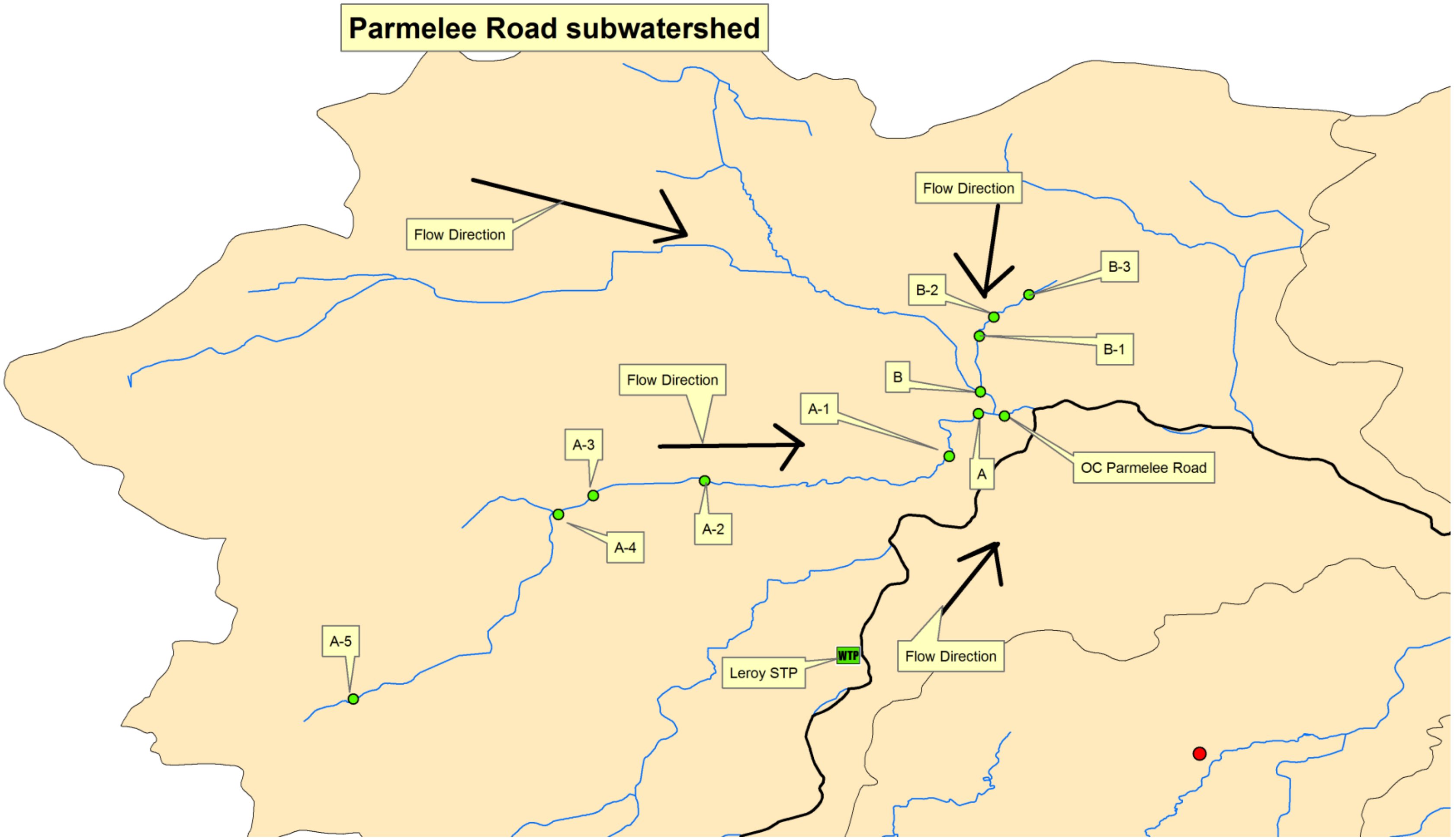


Figure 49. Segment analysis sites (OC Parmelee Road, A to A-5, B, B-1, B-3 to B-5) for Parmelee Road subwatershed (Fig. 2) on 7 June 2011, Oatka Creek. Light green dots are sample sites. Arrows signify flow direction. Red dot signifies a CAFO site. The Oatka Creek mainstem is bolded in black.

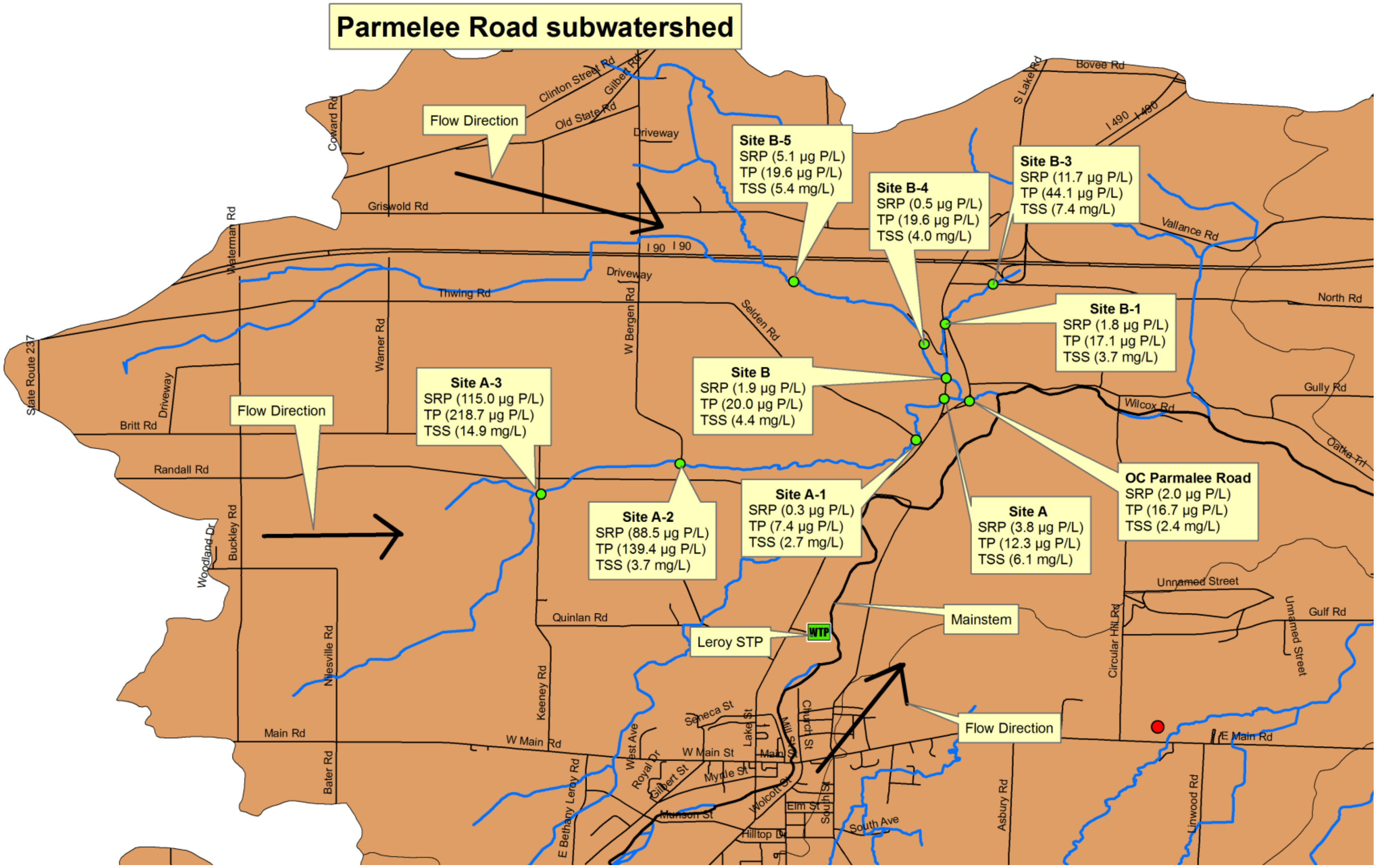


Figure 50. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), and total suspended solid (TSS: mg/L) for the Parmelee Road subwatershed (Fig. 2) on 7 June 2011, Oatka Creek. Light green dots are sample sites. Red dot is a CAFO site. Black arrow signifies flow direction. The Oatka Creek mainstem is bolded in black.

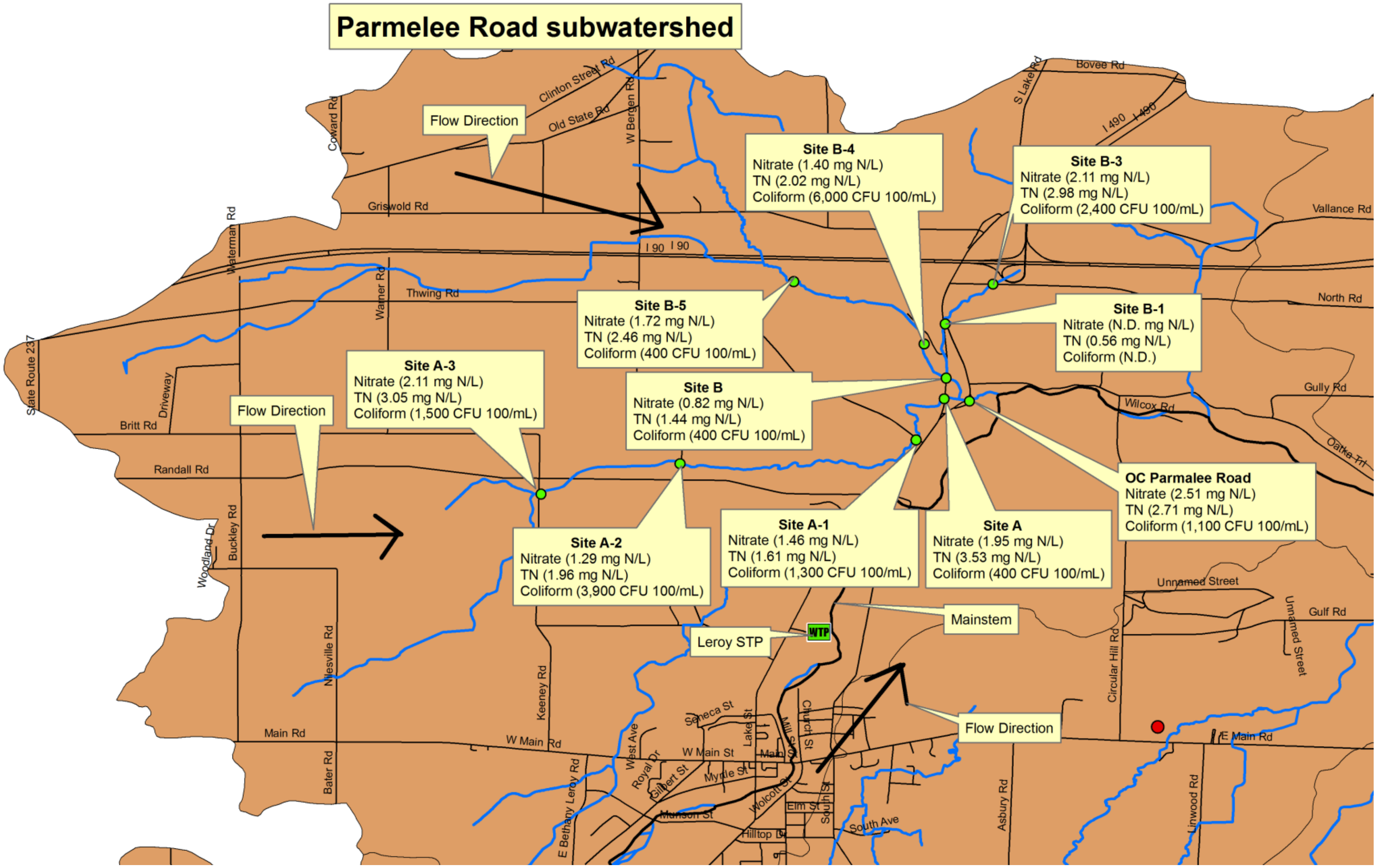


Figure 51. Nitrate (mg N/L), total nitrogen (TN: mg N/L), and total coliform abundances (CFU/100 mL) for the Parmelee Road subwatershed (Fig. 2) on 7 June 2011, Oatka Creek. Light green dots are sample sites. Red dot is a CAFO site. Black arrow signifies flow direction. The Oatka Creek mainstem is bolded in black.

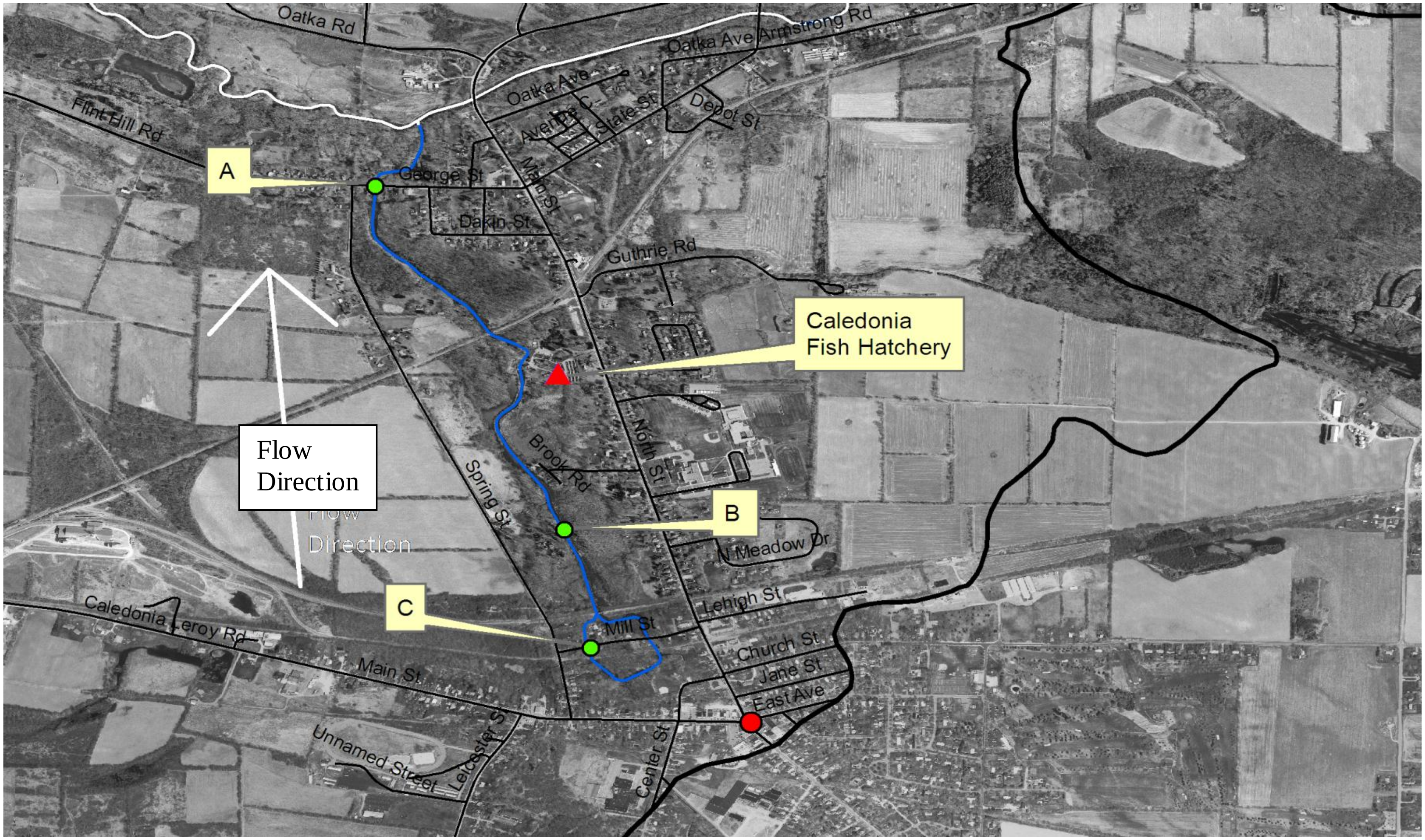


Figure 52. Segment analysis sites (A to C) for Big Spring Creek subwatershed (Fig. 2) on 4 January 2011, Oatka Creek. Red dot is a CAFO site. Light green dots are sample sites. Red triangle is the Caledonia Fish Hatchery. Arrows signify flow direction. Black line is the watershed boundary. Oatka Creek mainstem is bolded white on top of figure.

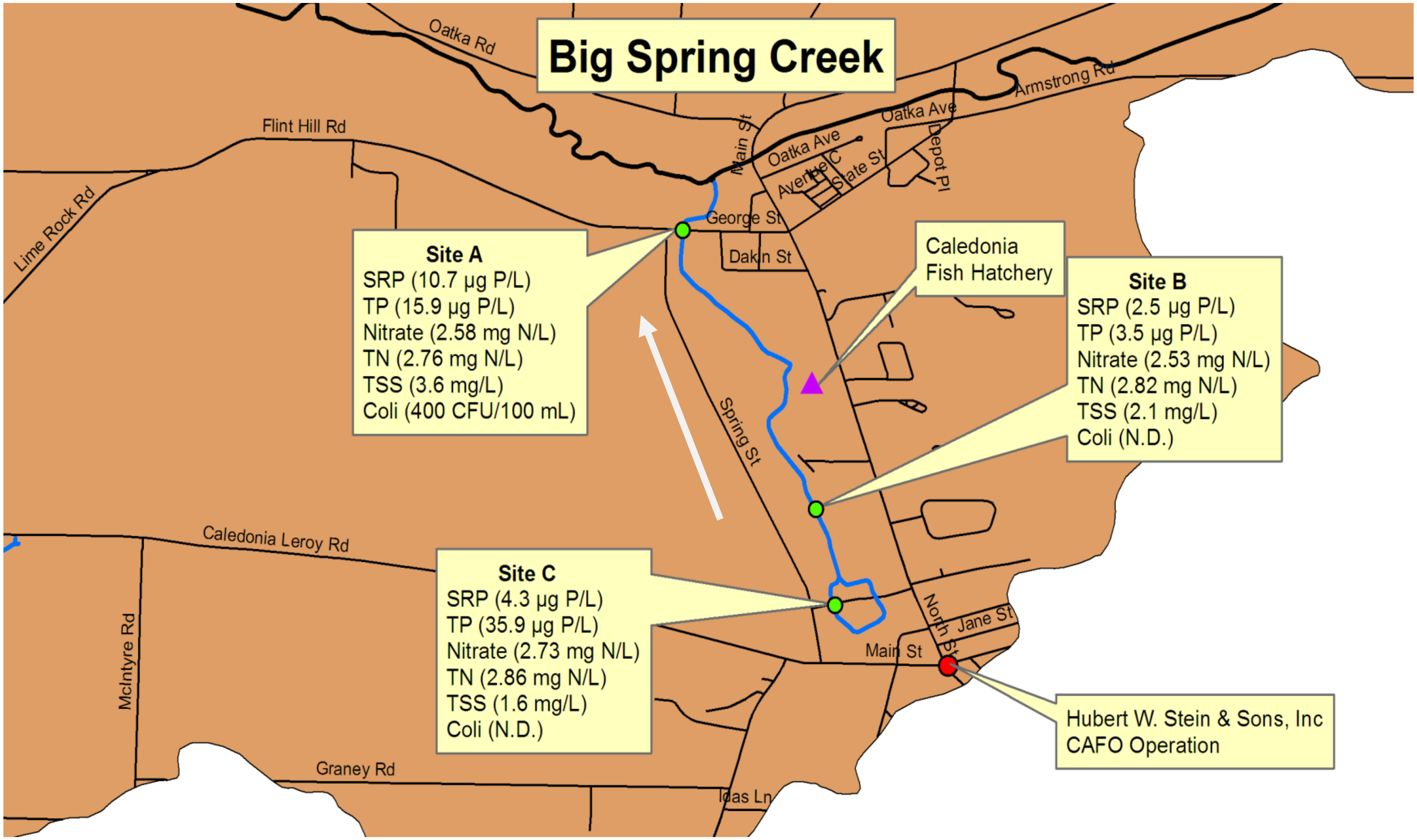


Figure 53. Soluble reactive phosphorus (SRP), total phosphorus (TP), total suspended solid (TSS), nitrate, total nitrogen (TN) and total coliform concentrations for Big Spring Creek subwatershed (Fig. 2) on 4 January 2010, Oatka Creek. Red dot is a CAFO operation. Light green dots are sample sites. Purple triangle is a SPDES site. White arrow signifies flow direction. Oatka Creek mainstem is bolded black on top of figure.

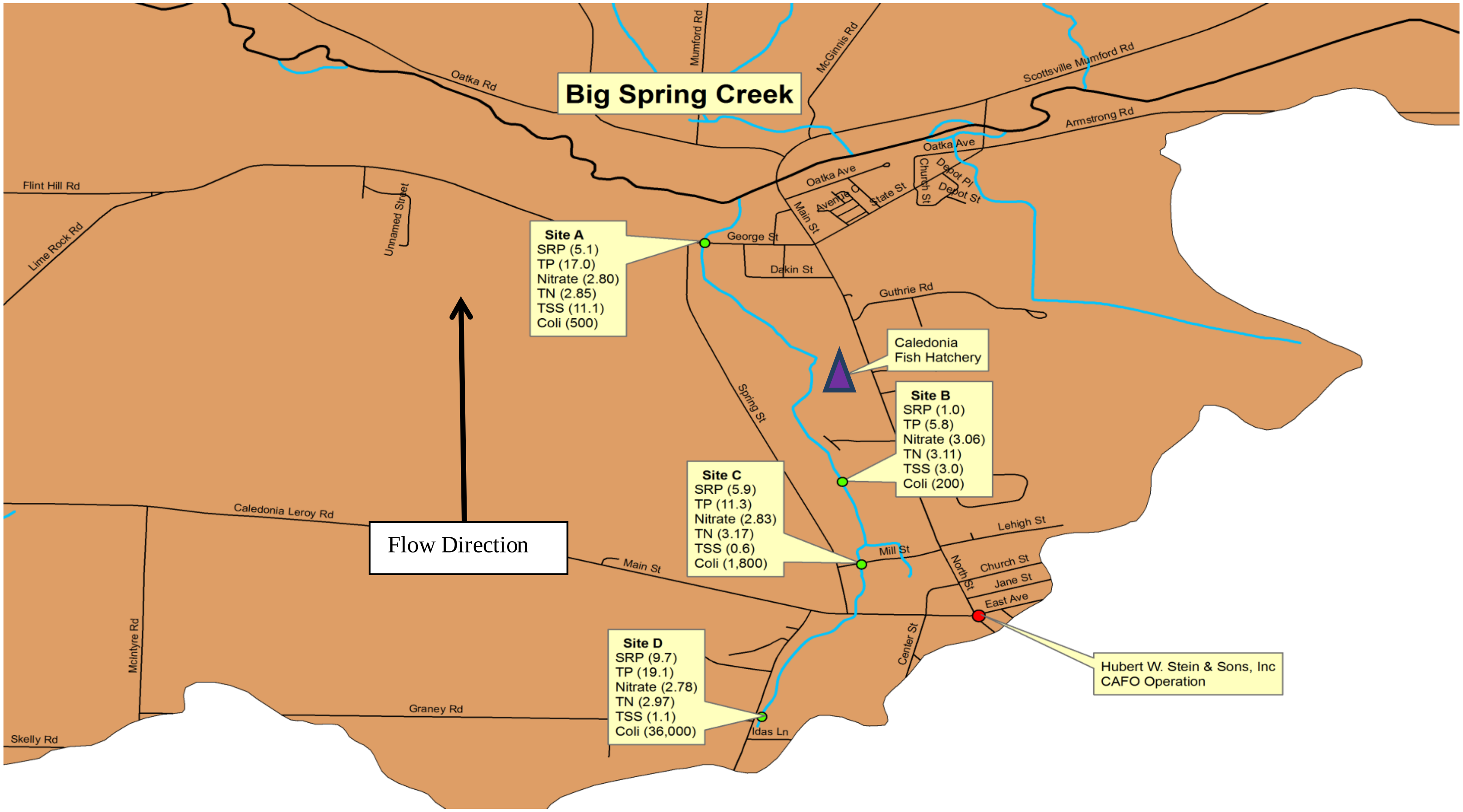


Figure 54. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), total suspended solid (TSS: mg/L), nitrate (mg N/L), total nitrogen (TN: mg N/L), and total coliform abundances (CFU/100 mL) for Big Spring Creek subwatershed (Fig. 2) on 3 May 2011, Oatka Creek. Red dots are CAFOs. Light green dots are sample sites. Black arrow signifies flow direction. Oatka Creek mainstem is bolded black.

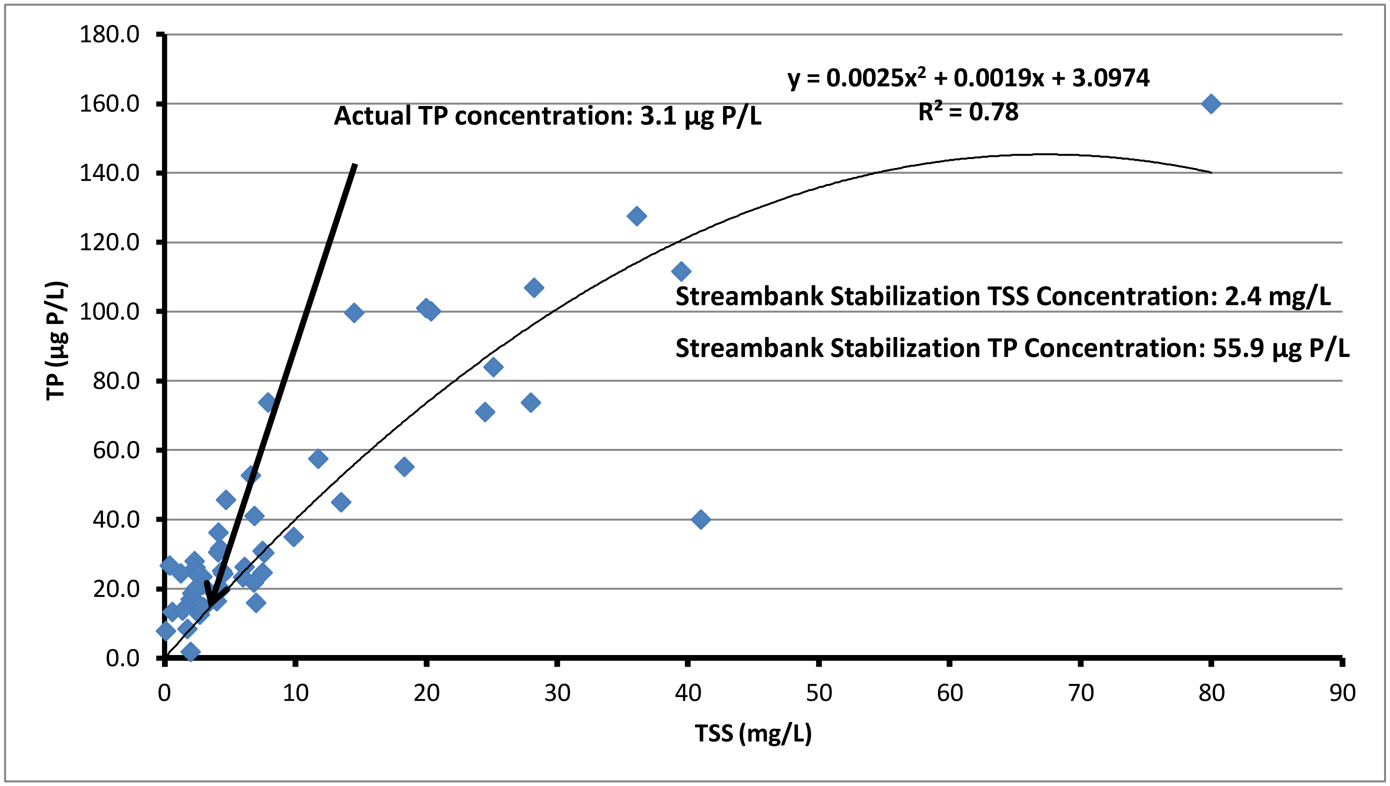


Figure 55. Regression of measured TP and TSS concentrations at Garbutt, NY.

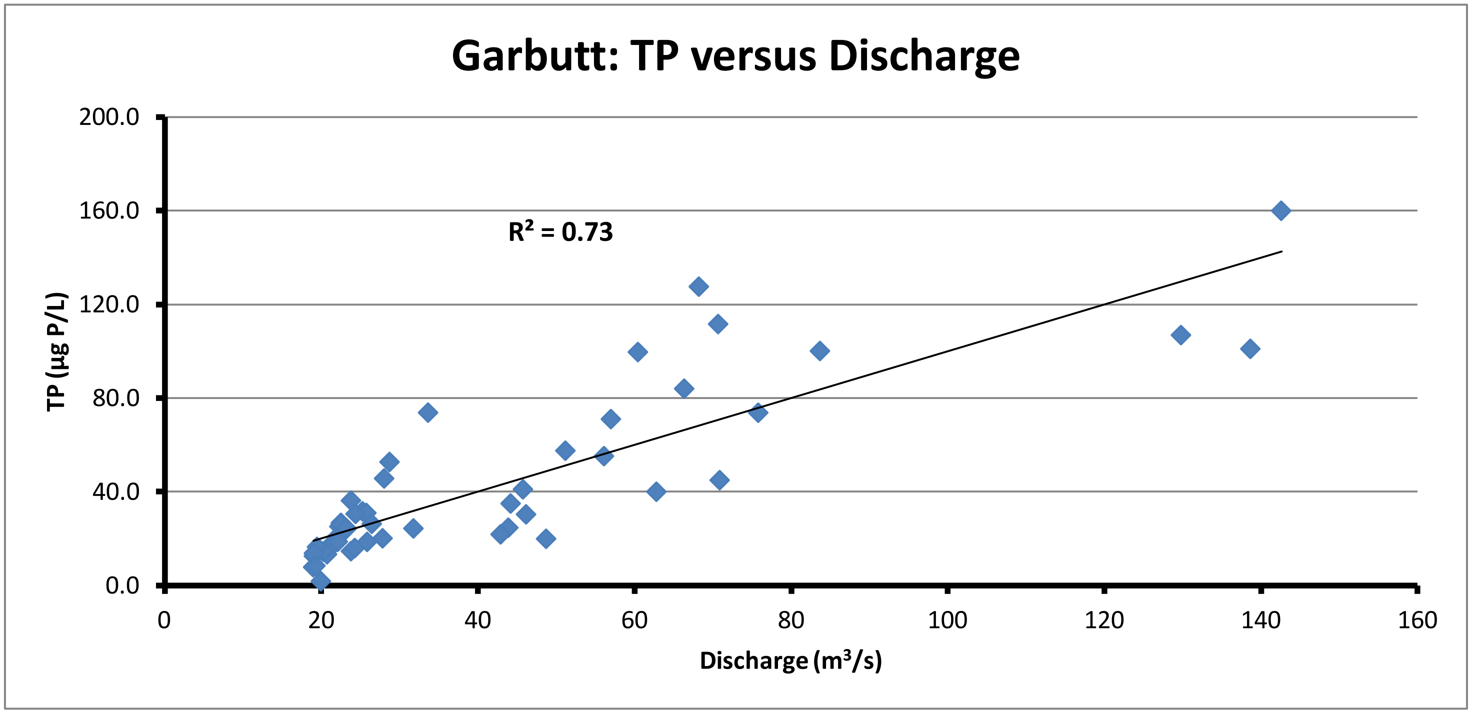


Figure 56. Graphic represents total phosphorous (TP) concentration versus discharge (m^3/s) at the USGS monitoring station located in Garbutt, NY.

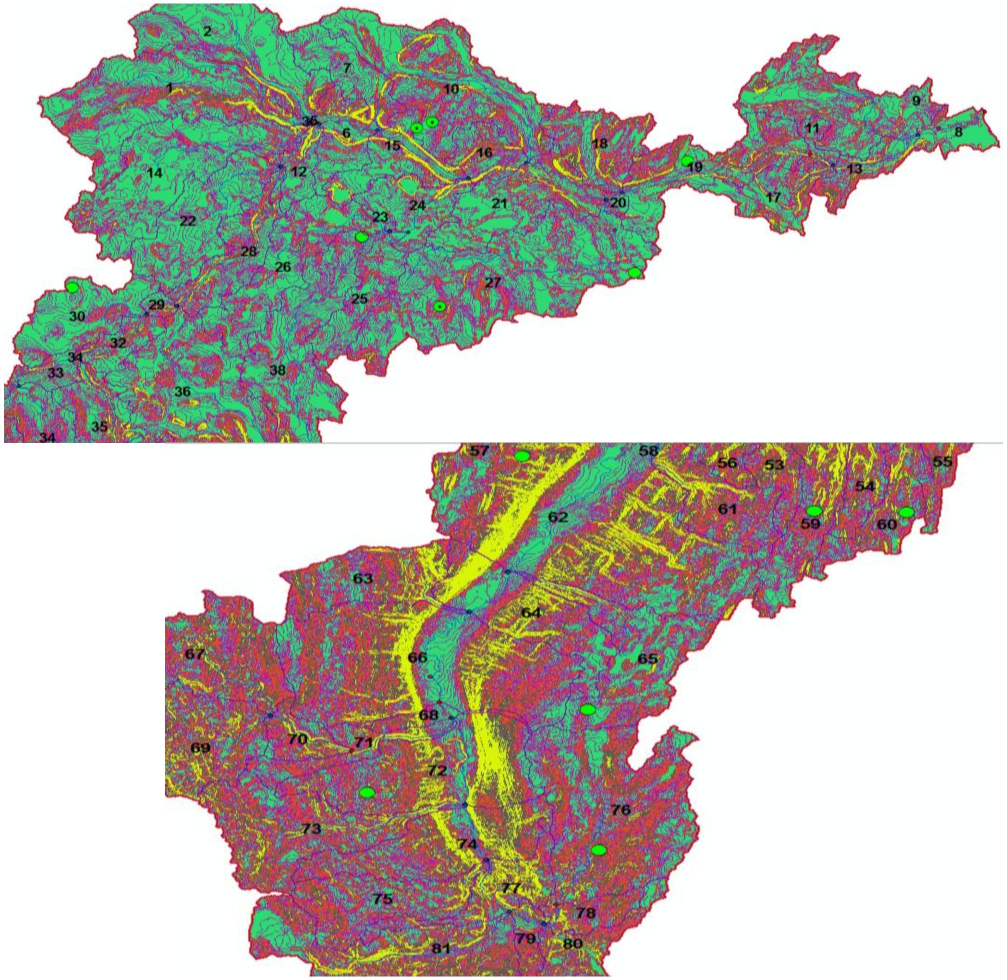


Figure 57. Percent slope of landscape from the Downstream Reach (top) and Headwater Reach (bottom) of the Oatka Creek watershed (Fig. 14). Green = 0-2% land slope, Maroon = 2-5% land slope, Orange = 5-8 % land slope, Gray = 8-15% land slope and Yellow = 15-100% land slope.

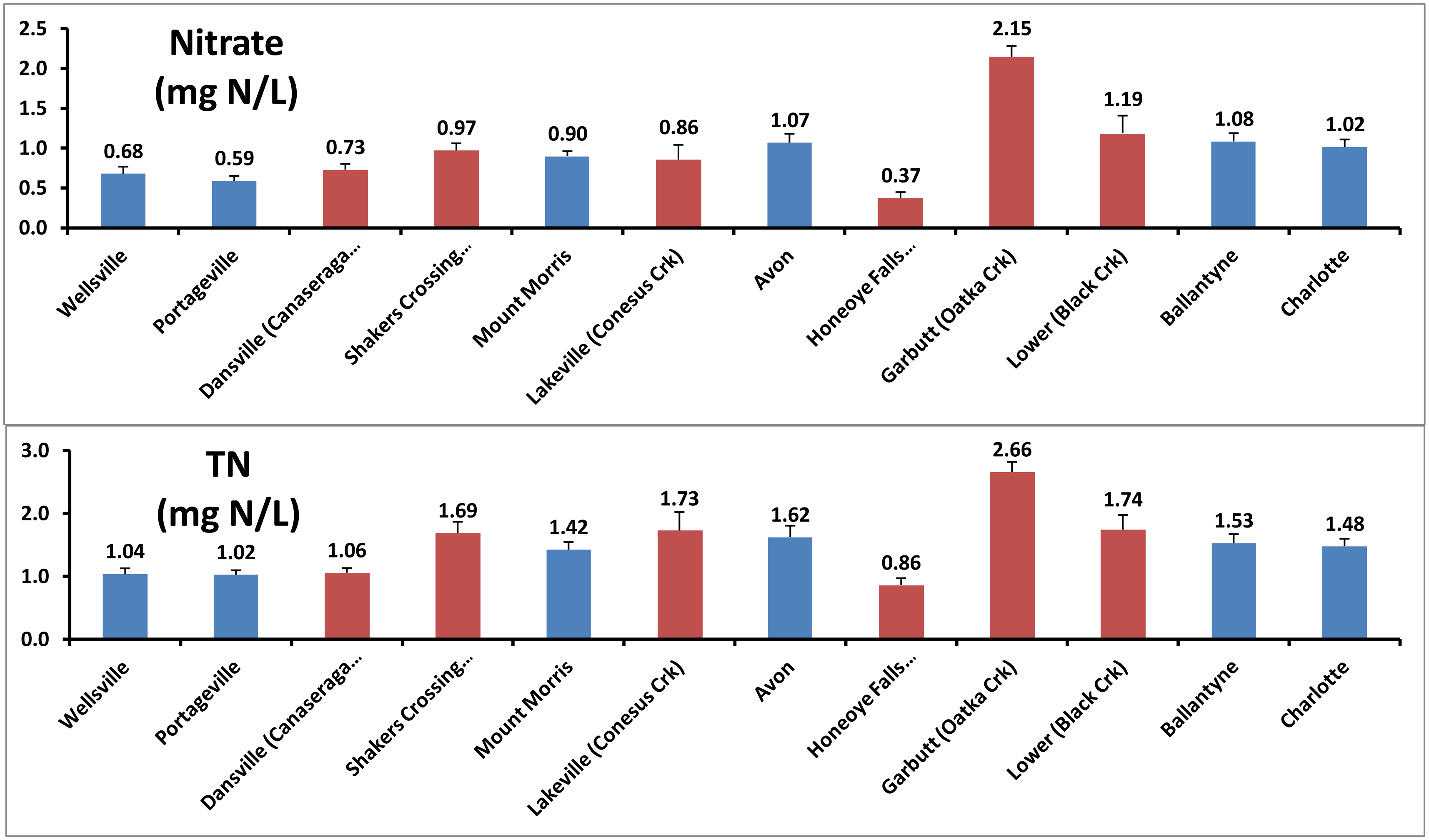


Figure 58. Average nitrate and total nitrogen (TN) concentrations from all the mainstem (blue) and tributary (red) weekly sampling locations along the Genesee River. Sites are in order from furthest up (Wellsville) to downstream.

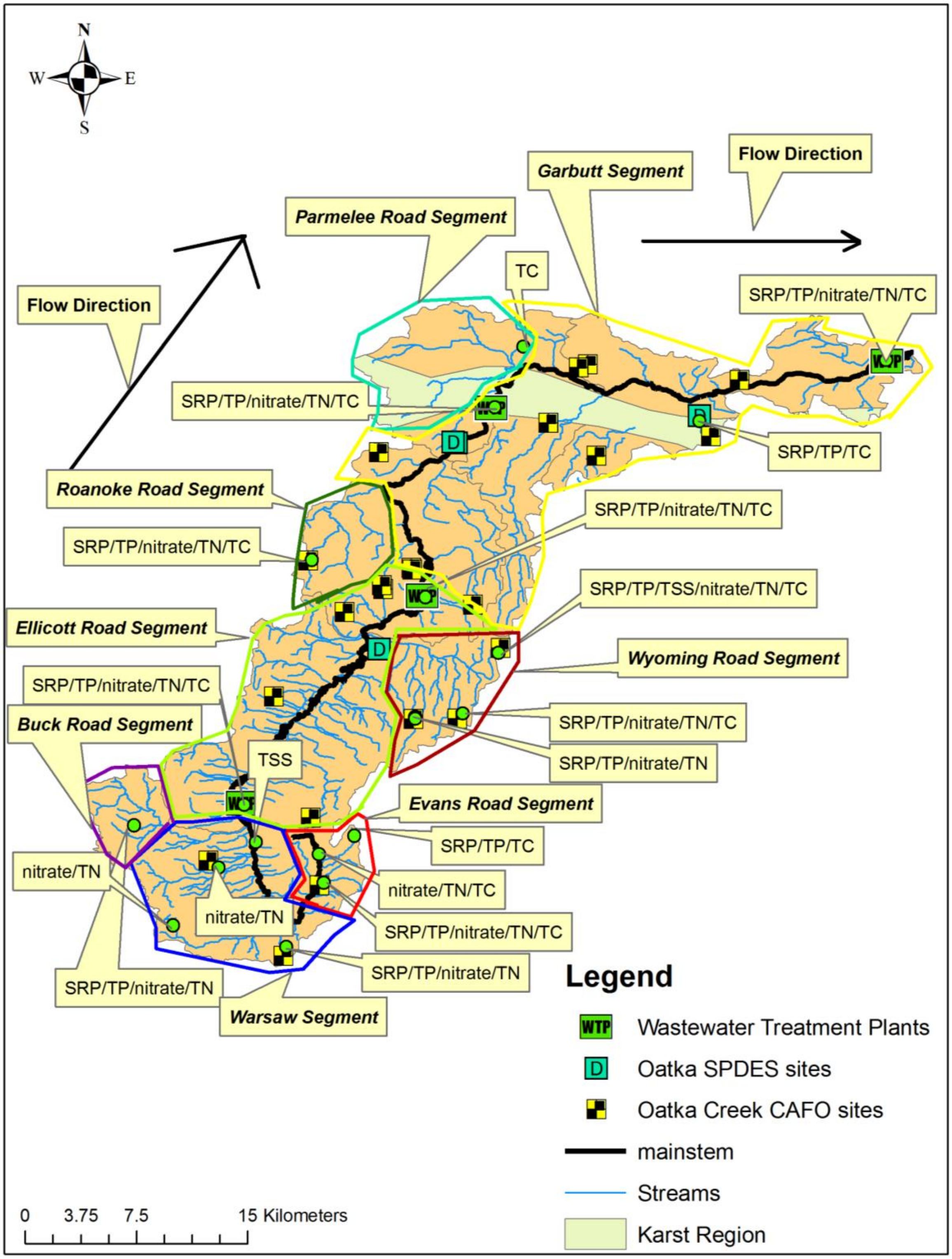


Figure 59. Oatka Creek watershed source map, Oatka Creek, NY.

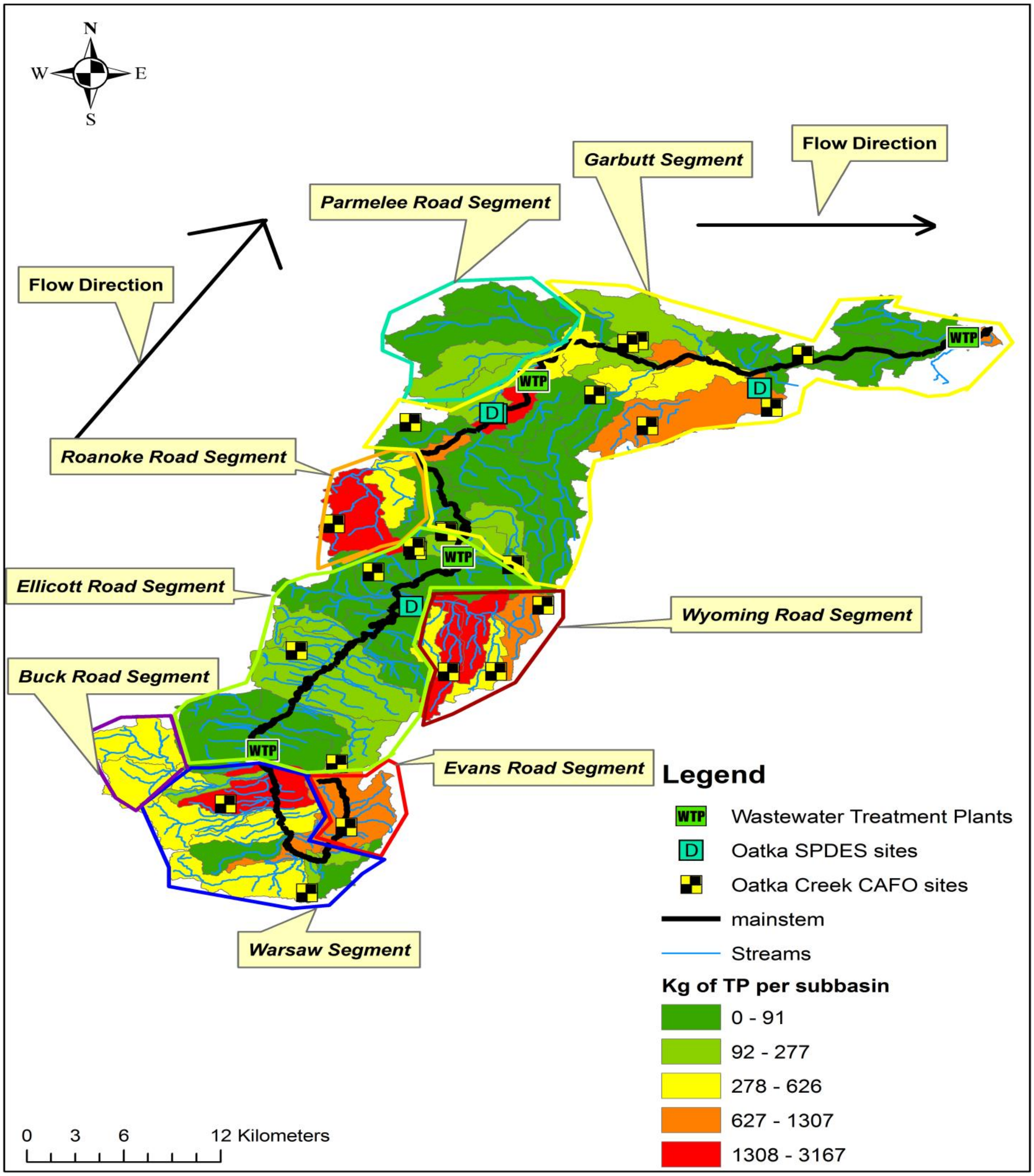


Figure 60. Map of annual total phosphorus (TP) loads from subbasins in the Oatka Creek watershed resulting from the SWAT12 model.

Appendix A

Extended table of SWAT calibration parameters. The parameter name, description of parameter, andvalue entered into the model are given. If a single value was applied to all Oatka Creek subbasins only a value is shown. If different parameter values were used for separate subbasins (A = Evans Road; B = Buck Road; C = Warsaw; D = Wyoming Road; E = Ellicott Road; F = Roanoke Road; G = Parmelee Road; H = Garbutt), all values are given.

Oatka Creek SWAT Calibration Parameters by Input Table

		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Soils (.sol)									
Parameter	*Description*	*Value*							
CN2	SCS Curve Number	-23%							
All Parameters	Soil Type Specific Parameters	Default							
SOL_AWC	Soil Anticedent Water Content	Default							
Subbasin (.sub)									
Parameter	*Description*	*Value*							
All Parameters	Subbasin Specific Parameters	Default							
HRU (.hru)									
Parameter	*Description*	*Value*							
RSDIN	Initial Residue Cover	*10,000*	*5,000*	*5,000*	*5,000*	*5,000*	*5,000*	*5,000*	*5,000*
ERORGN	Nitrogen Enrichment Ratio for Loading with Sediment	0							
ERORGP	Phosphorus Enrichment Ratio for Loading with Sediment	1.5	0	0.01	2.5	0	5	0.01	5
POT_FR	Fraction of HRU Area that Drains Into Pothole	0							
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	0							
OV_N	Manning's N value for Overland Flow	2.3	20	0.14	1	0.2	0.06	1	1
All Other	HRU Specific Parameters	Default							
Groundwater (.gw)									
Parameter	*Description*	*Value*							

SHALLST	Initial Depth of Water in the Shallow Aquifer	0.5							
DEEPST	Initial Depth of Water in the Deep Aquifer	1000							
GW_Delay	Groundwater Delay Time (days)	38							
ALPHA_BF	Baseflow Alpha Factor (days)	0.1							
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	1							
RCHRG_DP	Deep Aquifer Percolation Fraction	0.02							
GWHT	Initial Groundwater Height	1							
GW_SPYLD	Specific Yield of Shallow Aquifer	0.003							
SHALLST_N	Initial Concentration of Nitrate in Shallow Aquifer	0							
GWSOLP	Soluble Phosphorus in Groundwater	0.02							
HLIFE_NGW	Halflife of Nitrogen in Water	0							
LAT_ORGN	Organic Nitrogen in Lateral Flow	0.055							
GWLATP	Organic P in Baseflow	0.8							
Routing (.rte)									
Parameter	*Description*	Value							
CH_N2	Mannings 'n' Value for the Main Channel	0.15	0.08	0.16	0.02	0.19	0.08	0.8	0.15
CH_K2	Effective Hydraulic Conductivity in Main Channel	0							
CH_COV1	Channel Erodibility Factor	0							
CH_COV2	Channel Cover Factor	0.6							
ALPHA_BNK	Baseflow Alpha Factor for Bank Storage	1							
CH_BNK_BD	Bulk Density of Channel Bank Sediment	1.9	0						
CH_BED_BD	Bulk Density of Channel Bed Sediment	1.9	0						
CH_BNK_KD	Erodability of Channel Bank Sediment by Jet Test	0							
CH_BED_KD	Erodability of Channel Bed Sediment by Jet Test	0							
CH_BNK_D50	D50 Median Particle Size of Channel Bank Sediment	0							
CH_BED_D50	D50 Median Particle Size of Channel Bed Sediment	0							
CH_BNK_TC	Critical Stress Range for Bank Erosion	0							
CH_BED_TC	Critical Stress Range for Bed Erosion	0							

CH_EQN	Sediment Routing Method	2	1	2	2	1	4	1	1
All Other	Other Sediment Parameters	Default							
Management (.mgt)									
Parameter	*Description*	*Value*							
BIOMIX	Biological Mixing	0.55							
CN2	Curve Number Factor	Default							
USLE_P	USLE Eqn. Cropping Practices Factor	0.55							
BIO_MIN	Minimum Plant Biomass for Grazing	0							
FILTERW	Width of Edge-of-field Filter Strip	0							
All Other	Management Specific Parameters	Default							
Soil Chemical (chm.)									
Parameter	*Description*	*Value*							
SOL_NO3	Nitrate in Soil Layer	0							
SOL_ORGN	Organic Nitrogen in Soil Layer	0							
SOL_LABP	Labile Phosphorus in Soil Layer	0							
SOL_ORGP	Organic Phosphorus in Soil Layer	0							
PPERCO_SUB	Phosphorus Percolation Coefficient in Soil Layer	12							
Pond/Wetland (pnd.)									
Parameter	*Description*	*Value*							
All	Pond/Wetland Specific Parameters	Default							
Stream Water Quality (swq.)									
Parameter	*Description*	*Value*							
RS1	Local Algal Settling Rate in the Reach at 20C	1							
RS2	Benthic Sediment Source Rate for Dissolved P	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	0.05	0.001	0.1	0.05	0.1	0.1
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	0.1	0.7	0.1	0.1	0.7	0.05	0.7	0.5
Basin (.bsn)									
Parameter	*Description*	*Value*							
SFTMP/SMTMP	Snow Fall Temperature	1 / 0.5							
SMFMX	Snow Melt Factor Rate Maximum	10							
SMFMN	Snow Melt Factor Rate Minimum	2							
TIMP	Snow Pack Temperature Lag Factor	1.0							
SNOCOVMX	Minimum Snow Water Content of 100% Snow Cover	470							
SNO50COV	Fraction of Snow Volume That Corresponds To 50% Snow Cover	0.1							
PET	Potential Evapotranspiration Method	Hargreaves							
ESCO	Soil Evaporation Compensation Factor	0.4							
EPCO	Plant Evaporation Compensation Factor	1.0							
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	Curve Number for Frozen Soils	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	1
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	10
NPERCO	Nitrogen Percolation Coefficient	0.2
PPERCO	Phosphorus Percolation Coefficient	10
PHOS_KD	Phosphorus Soil Partitioning Coefficient	100
PSP	Phosphorus Availability Index	0.7
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	0.7

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
A	The subbasin from Evans Road (76)	
B	The subbasins from Buck Road (67,69,70)	
C	The subbasins from Warsaw (68,71-75,77-81)	
D	The subbasins from Wyoming Road (49.50,53-55,59,60)	
E	The subbasins from Ellicott Road (43-48,51,52,56-58,61-66)	
F	The subbasins from Roanoke Road (33,34,39)	
G	The subbasins from Parmelee Road (1-4,14)	
H	The subbasins from the Garbutt segment (5-7,10,12,16,18-29,31,32,35-37,40-42)	

Appendix B

Nutrient Biotic Index (NBI) results from macro-invertebrates collected at Garbutt, NY. Bottom left corner of Appendix is the average NBI P and N scores calculates from all macro-invertebrates along with average TP and nitrate concentrations at Garbutt, NY. Trophic state results are correlated with results.

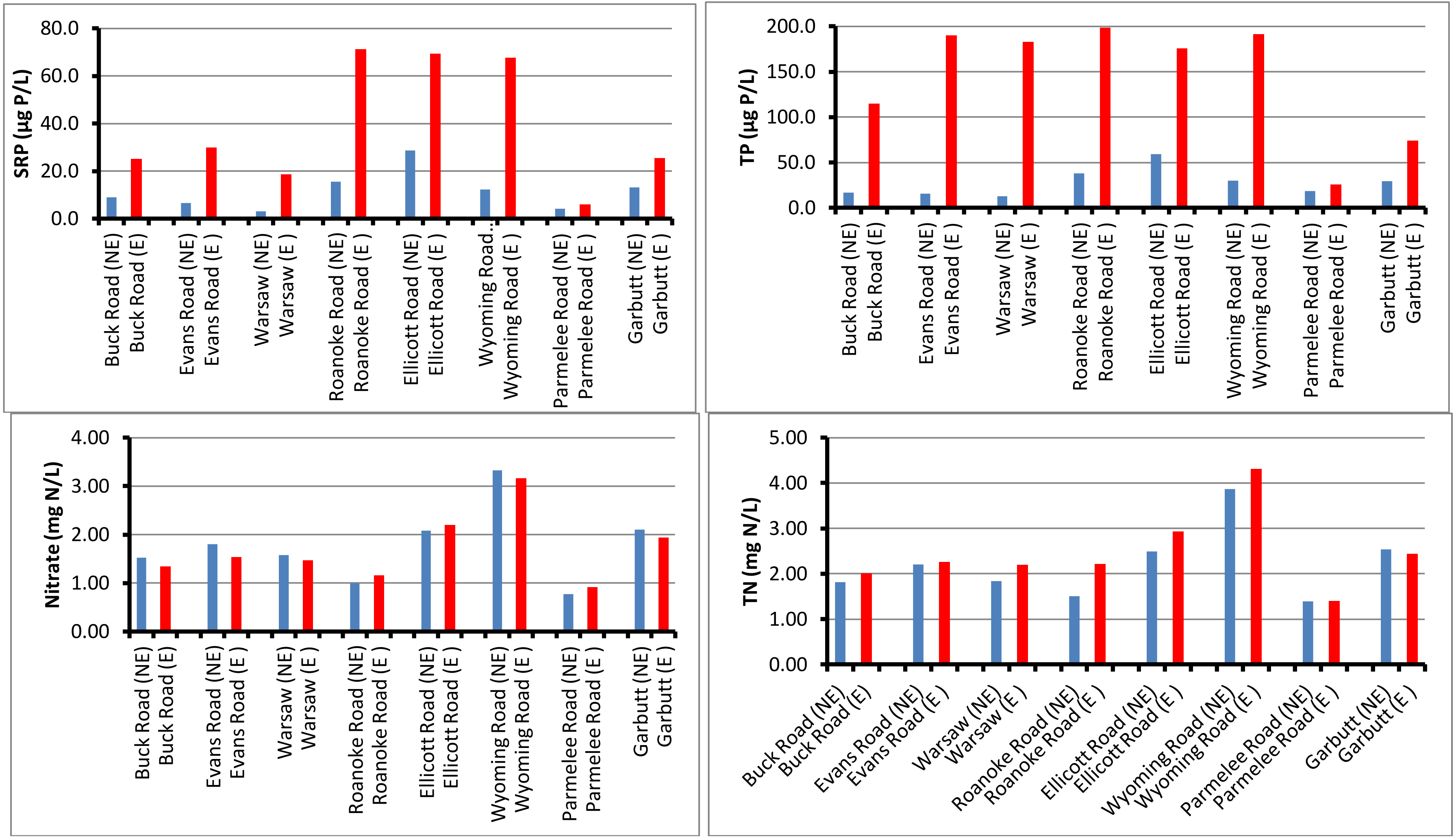
Placement	Order	Suborder	Family	Subfamily	Genus	Species	Count	NBI P Value	NBI N Value	NBI P Score	NBI N Score
H2	Coleoptera		Elmidae		Stenelmis		3	7	7	0.23	0.23
H3	Coleoptera		Elmidae		Promoresia	*elegans*	3	10	10	0.33	0.33
J2	Coleoptera		Elmidae		Optioservus		7	9	4	0.70	0.31
I2	Coleoptera		Elmidae		Optioservus (Adult)	*ovalis*	6	9	4	0.60	0.27
J5	Crustacea	Amphipoda	Gammaridae		Gammorus		1	8	9	0.09	0.10
J1	Diptera		Empididae (pupue)				1	No Score	No Score	0.00	0.00
H7	Diptera	Nematocera	Simuliidae		Simulium Latreille	*tuberosum*	1	1	0	0.01	0.00
I3	Diptera	Orthorhaphous-Brachycera	Athericidae		Atherix		6	8	5	0.53	0.33
H6#1	Diptera	Nematocera	Chironomidae	Orthocladiinae	Cricotopus	*trifascia gr.*	1	9	9	0.10	0.10
H6#2	Diptera	Nematocera	Chironomidae	Orthocladiinae	Eukiefferiella	*devonica gr.*	1	9	9	0.10	0.10
H6#3	Diptera	Nematocera	Chironomidae	Orthocladiinae	Parametriocnemus	*sp.*	1	No Score	No Score	0.00	0.00
G3	Ephemeroptera		Heptageniidae		(Damaged)		1	5	2	0.06	0.02
J7	Ephemeroptera		Ephemerellidae		Ephemerella		4	3	6	0.13	0.27
G6	Ephemeroptera		Baetidae		Acerpenna	*pygmaea*	4	3	3	0.13	0.13
G1	Ephemeroptera		Baetidae		Acentrella/Pseudocloeon		1	5	5	0.06	0.06
H5	Ephemeroptera		Caenidae		Caenis		5	0	4	0.00	0.22
I6	Ephemeroptera		Baetidae		Baetis		4	6	3	0.27	0.13
I7	Ephemeroptera		Ephemerellidae				2	3	6	0.07	0.13
J6	Ephemeroptera	DAMAGED					2	No Score	No Score	0.00	0.00
G2	Megaloptera		Sialidae		Sialis		1	5	6	0.06	0.07
H1	Megaloptera		Corydalidae		Nigronia		1	10	8	0.11	0.09
J3	Gastropoda		Physidae				1	No Score	No Score	0.00	0.00
I4	Gastropoda		Lymnaeidae		Radix	auricluria	1	No Score	No Score	0.00	0.00

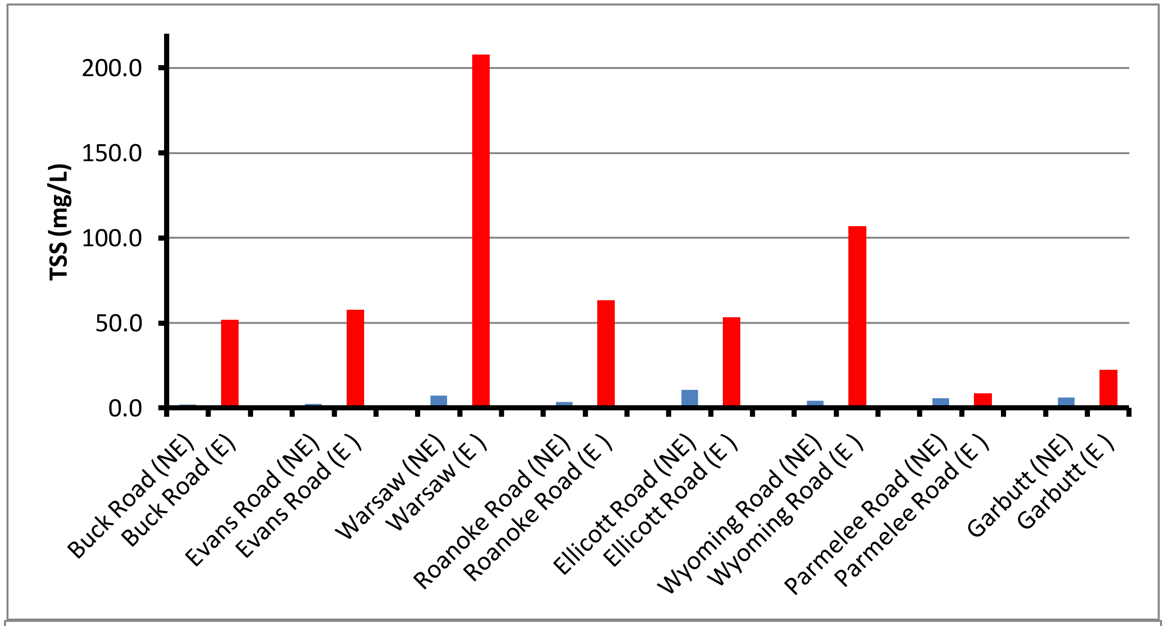
I1	Gastropoda		Planorbidae		Gyraulus		1	No Score	No Score	0.00	0.00
I5	Plecoptera		Perlidae		Paragnetina	*sp.*	1	1	6	0.01	0.07
J8	Plecoptera		Perlidae		Agnetina		3	No Score	No Score	0.00	0.00
J4	Trichoptera		Brachycentridae		Brachycentrus	*appalachia*	2	3	4	0.07	0.09
G7	Trichoptera		Hydropsychidae		Hydropsyche	*sparna*	5	6	7	0.33	0.39
G5	Trichoptera		Hydropsychidae		Cheumatosyche	*sp.*	21	6	6	1.40	1.40
G4	Trichoptera		Hydropsychidae		Hydropsyche	*sp.*	9	5	4	0.50	0.40
						Total	100		NBI Scores	5.89	5.24
						Total with NBI score	90				

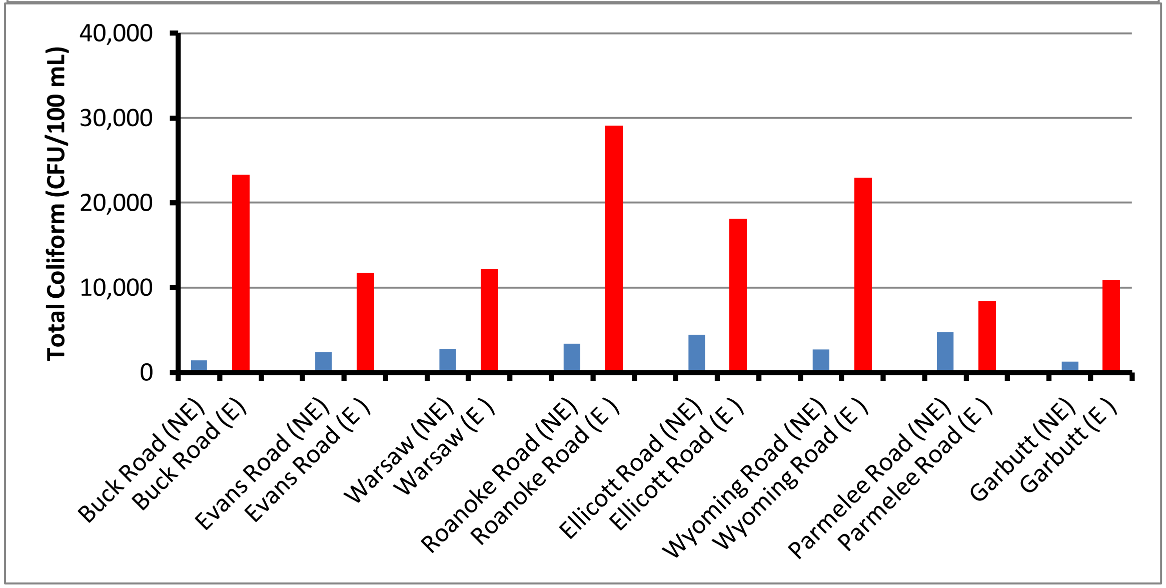
NBI Results	Oatka Creek	Trophic State
NBI-P	5.9	Mesotrophic
NBI-N	5.2	Mesotrophic
TP (µg P/L)	24.5	Mesotrophic
NO3- (mg N/L)	1.70	Eutrophic

Appendix C

Average annual event and nonevent SRP, TP, nitrate, TN, TSS and, total coliform concentrations. Red bars = event (E), blue bars = nonevent (NE).




TSS (mg/L)
200.0
150.0
100.0
50.0
0.0
Buck Road (NE)
Buck Road (E)
Evans Road (NE)
Evans Road (E)
Warsaw (NE)
Warsaw (E)
Roanoke Road (NE)
Roanoke Road (E)
Ellicott Road (NE)
Ellicott Road (E)
Wyoming Road (NE)
Wyoming Road (E)
Parmelee Road (NE)
Parmelee Road (E)
Garbutt (NE)
Garbutt (E)


Total Coliform (CFU/100 mL)
40,000
30,000
20,000
10,000
0
Buck Road (NE)
Buck Road (E)
Evans Road (NE)
Evans Road (E)
Warsaw (NE)
Warsaw (E)
Roanoke Road (NE)
Roanoke Road (E)
Ellicott Road (NE)
Ellicott Road (E)
Wyoming Road (NE)
Wyoming Road (E)
Parmelee Road (NE)
Parmelee Road (E)
Garbutt (NE)
Garbutt (E)