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Genesee River Watershed Project. Water Quality Analysis of the Oatka Creek Watershed. Volume 6. Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model. A report to the USDA.

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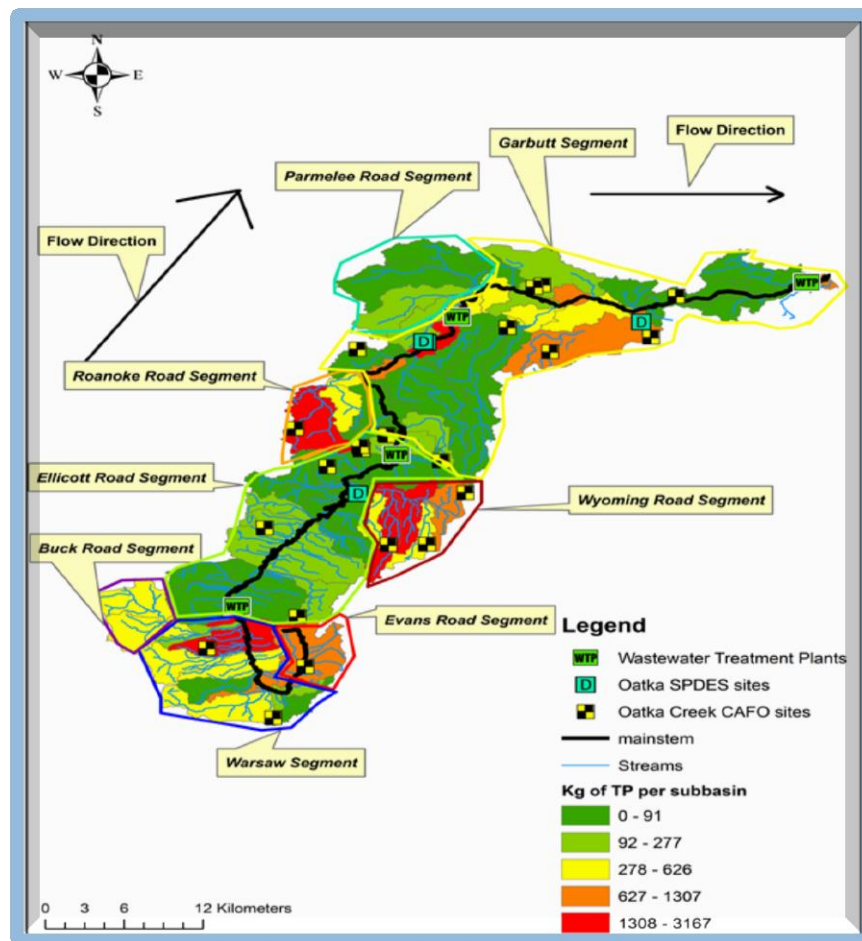
# Genesee River Watershed Project

## Volume 6

### Water Quality Analysis of the Oatka Creek Watershed

Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model

A Report to the United States Department of Agriculture



Phosphorus loads in the Oatka Creek

August 2013

Dale M. Pettenski, Joseph C. Makarewicz, Theodore W. Lewis

## **Abstract**

Oatka Creek is the second largest tributary of the Genesee River and is a highly prized trout fishery. The Oatka Creek portion of the Genesee River Project Study focused on identifying nonpoint and point sources, locating and quantifying the nutrient and sediment losses from Oatka Creek watershed, and through simulation identifying possible remediation or management practices. To accomplish this task, a multifaceted, integrated approach was taken by combining stream monitoring, segment analysis, and hydrologic modeling [Soil and Water Assessment Tool (SWAT)]. 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), all anthropogenic sources, accounts for ~70% of the phosphorus load of Oatka Creek, suggesting improvements in stream water quality are possible. The most effective management recommendation to reduce the overall total phosphorus loading in Oatka Creek is to upgrade all four wastewater treatment plants (Warsaw, Pavilion, Leroy, and Scottsville) to tertiary treatment systems. Other effective management recommendations focused on nonpoint sources 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. Either or both practices together would significantly improve the water quality in the Oatka Creek watershed by reducing the average annual P concentration to below the 45- $\mu\text{g}$  P/L target. Portions of the creek are experiencing stream bank soil erosion. Stream bank stabilization techniques, some already implemented, would have a beneficial impact on reducing the total phosphorus and total suspended solids loading in this segment of Oatka Creek.

## ***Executive Summary***

1. The Genesee River project encompasses six volumes (Makarewicz et al. 2013 a,b,c; Winslow et al. 2013, Rea et al. 2013, Pettenski et al. 2013). This volume focuses on the Oatka Creek subwatershed of the Genesee River.
2. The overall goal of this portion of the study was to assess the impact of the Oatka Creek watershed on the Lower/Middle main stem of the Genesee River by:
  - a) Determining the seasonal and annual nutrient and soil loss from the Oatka Creek watershed to the “Lower Middle main stem of the Genesee River” using routine water sample collection and analysis and discharge measurements from the USGS monitoring station at Garbutt, NY;
  - b) Identifying the location and magnitude of point and nonpoint sources of nutrients and sediments within the Oatka Creek watershed using segment analysis;
  - c) Constructing and calibrating the Soil and Water Assessment Tool (SWAT model) for water output, sediment, and total phosphorus loading for Oatka Creek;
  - d) Developing a Total Maximum Daily Load for Oatka Creek;
  - e) Developing a target phosphorus concentration for Oatka Creek by simulating a 100% forested land use in the SWAT model; and
  - f) Providing management scenarios to reduce the impact of Oatka Creek on the Lower Middle Genesee River Basin based on SWAT results.
3. Weekly water samples were taken at the four main stem (Garbutt, Warsaw, Ellicott Road, and Evans Road) and four tributary sites (Buck Road, Wyoming Road, Roanoke Road, and

Parmalee Road) for a period of 12 months under event and nonevent conditions. The samples were then analyzed for soluble reactive phosphorus (SRP) and nitrate+nitrite ( $\text{NO}_3 + \text{NO}_2$ ) with the filtered sample and for total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) and total coliforms (TC).

4. Discharge for the Oatka Creek subwatershed was obtained from the two USGS monitoring stations in Warsaw and Garbutt, New York. In addition to the two USGS sites, six other discharge sites (two main stem, four tributary) were added to calibrate the SWAT Model at several sites in the watershed.
5. Of the eight sites monitored, the average annual SRP and TP concentrations and total coliform abundances were highest at the Wyoming Road site (SRP: 27.5  $\mu\text{g P/L}$ ; TP: 74.4  $\mu\text{g P/L}$ ; total coliform: 8,237 CFU/100 mL), Ellicott Road (SRP: 47.5  $\mu\text{g P/L}$ ; TP: 100.3  $\mu\text{g P/L}$ ; total coliform: 8,770 CFU/100 mL), and Roanoke Road (SRP: 32.5  $\mu\text{g P/L}$ ; TP: 86.8  $\mu\text{g P/L}$ ; total coliform: 11,129 CFU/100 mL) compared to the average annual phosphorus concentration among all sampling locations (SRP: 20.2  $\mu\text{g P/L}$ ; TP: 61.0  $\mu\text{g P/L}$ ; total coliform: 6,977 CFU/100 mL). Based on concentration/abundance, the Wyoming, Ellicott, and Roanoke Roads segments within Oatka Creek appeared to be where most water quality issues occurred.
6. Average monthly main stem (Evans Road, Warsaw, Ellicott Road, and Garbutt) TP concentrations were highest in December 2010, February 2011, and May 2011 due to event runoff during the winter and spring months.
7. Water chemistry of headwater reaches tended to be more responsive to rain events [(nonevent to event) Buck Road (e.g., TP: 16.7 to 114.8  $\mu\text{g P/L}$ , + 587%), Evans Road (e.g., TP: 15.9 to 189.9  $\mu\text{g P/L}$ , + 1,094%), Wyoming Road (e.g., TP: 29.9 to 191.6  $\mu\text{g P/L}$ , + 541%), and Warsaw (e.g., TP: 12.5 to 182.7  $\mu\text{g P/L}$ , + 1,362%)] than the water chemistry of downstream reaches [Roanoke Road (e.g., TP: 38.0 to 198.4  $\mu\text{g P/L}$ , +422%), Ellicott Road (e.g., TP: 59.3 to 175.5  $\mu\text{g P/L}$ , +196%), Parmalee Road (e.g., TP: 18.3 to 26.2  $\mu\text{g P/L}$ , +43%), and Garbutt (e.g., TP: 29.6 to 74.3  $\mu\text{g P/L}$ , +151%)].
8. Total annual nutrient and sediment loading was calculated (kg/yr) for the 1 June 2010 to 31 May 2011 period at four main stem (Evans, Warsaw, Ellicott, and Garbutt) and four tributary sites (Buck, Wyoming, Roanoke, and Parmalee). Soluble reactive phosphorus, TP, nitrate, and TN load increased incrementally from the most upstream "main stem" site at Evans (TP: 787 kg P/yr) to Warsaw (TP: 5,231 kg P/yr) to Ellicott (TP: 9,211 kg P/yr) to the furthest downstream main stem site with the highest load at Garbutt (TP: 15,018 kg P/yr) .
9. Areal SRP and TP loads were higher in the tributaries (mean SRP= 177.5 g/ha/yr; mean TP=607 g/ha/yr) compared to the main stem segments (mean SRP=150 g/ha/yr; TP=544 g/ha/yr). Of the four tributary sites, the Parmalee tributary had the lowest areal contribution (SRP: 12 g/ha/yr; TP: 54 g/ha/yr; nitrate: 3.0 kg/ha/yr; TN: 4.0 kg/ha/yr) to the total losses of the watershed.
10. The Wyoming tributary, which is located just upstream from the main stem site at Ellicott, had the highest areal tributary load for SRP, TP, nitrate, TN, and TSS (SRP: 311 g P per ha/yr; TP: 1,098 g P per ha/yr; nitrate: 27.7 kg N per ha/yr; TN: 34.5 kg N per ha/yr; TSS: 692.4 kg per ha/yr). This tributary is clearly a source and an area of concern for nutrients and soil erosion. Similar to the Wyoming tributary, Roanoke tributary had high SRP (306 g P per ha/yr) and TP (877 g P per ha/yr) areal loads when compared to the Buck and Parmalee

Roads (mean SRP: 46 g P per ha/yr; TP: 226 g P per ha/yr). At both the Wyoming and Roanoke tributaries, these relatively high losses of phosphorus and other analytes indicate areas of concern on which to focus management practices.

11. On the main stem of Oatka Creek, areal loads of SRP (67 to 217 g/ha/yr), nitrate (13.0 to 21.4 kg/ha/yr), and TN (15.9 to 26.0 kg/ha/yr) increased from Warsaw to the main stem site at Garbutt, suggesting sources of nutrients are present between sites on the main stem. From Warsaw to Garbutt, NY areal TP (595 to 577 g/ha/yr) and TSS (658.6 to 192.5 kg/ha/yr) load decreased.
12. An erosion inventory was conducted between site C to OC Warsaw (4.00 km), and site H to OC Evans Road (3.57 km), to identify the cause of elevated TSS levels in the Warsaw segment. 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%). 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 was highly erodible while the stream bank between site H and OC Evans Road had only a 11.2 % (0.40 of 3.57 km) highly erodible portion, indicating the ultimate cause for soil loss in the Warsaw segment is due to stream bank erosion.
13. As a result of segment analysis, the Warsaw and Leroy Wastewater Treatments Plants (WWTPs) were significant sources of nutrients, total suspended solids, and coliform abundances on 12 July 2010 within the Oatka Creek watershed. Confined animal feeding operation (CAFO) sites may also be contributing nutrients, total suspended solids, and coliform bacteria to the Oatka Creek subwatershed.
14. During event conditions, the Double B Farms CAFO, which is just upstream of site B, appeared to be a likely source of nitrogen in the Evans Road tributary. Samples taken 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.
15. 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 the three sampling locations (sites G-1, F-1, and C) were likely due to manure applications on cropland .
16. Confined animal feeding operation sites upstream from sites B (Swiss Valley Farms) and L (Broughton Farms) are likely causes of elevated SRP 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). Also, the CAFO upstream from site B may be a proximate cause for high TP (211.1 µg P/L) and TSS (97.3 mg/L) concentrations observed at OC Buck Road site.
17. The Bowhill Farms CAFO cow barn, which is just upstream of the retention pond, 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 subwatersheds # 6 and #7 and the 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.
18. A segment analysis was performed on the Oatka Creek (OC) Roanoke Road tributary to identify point and nonpoint sources of pollution. The 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.

19. A segment analysis was performed on the Oatka Creek Parmalee Road tributary to identify sources of coliform abundances previously encountered on 7 June 2011, 12 July 2010, and 3 August 2011. Agriculture (corn) is listed as the dominate land use of this area, and a windshield survey in the Parmalee Road tributary confirmed that agricultural practices were widespread and the most likely cause of elevated nutrients and coliform abundances observed. However, a single residence was found to be a source of coliform bacteria and is also a partial source of nutrients in this tributary's watershed. The residence was again visited on 10 August 2011, and it was determined the waste treatment method here was a septic system.
20. A stream segment analysis was performed upstream from tributary site 1 in the Village of Caledonia on 4 January and 3 May 2011 to identify sources of nitrogen. Results from field work and actual measurement of P loads demonstrate that the Caledonia Fish Hatchery is a source of phosphorus and TSS under event conditions. For example, on 7 September 2011 SRP (336%) and TP (596%) concentrations and total coliform (290%) abundance increased from the intake to the effluent pipe (Table 5), while nitrate and TN concentrations did not increase significantly from the intake to the effluent pipe. Also, the Hubert W. Stein & Sons Inc. CAFO is the likely source of nitrogen and coliform bacteria in Big Spring Creek.
21. The Leroy, Scottsville, Warsaw, and Pavilion WWTPs were significantly elevating nutrient concentrations and total coliform abundance in Oatka Creek.
22. For the 2010-2011 water year, the OCSWAT model accurately predicted discharge: Nash-Sutcliffe: 0.94, coefficient of determination:  $r^2 = 0.95$ , and PBIAS (+ 5.1%). 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. 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%) (Moriassi *et al.* 2007). 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%) (Moriassi *et al.* 2007).
23. In the Oatka Creek subwatershed, agriculture [Agriculture Crops – 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 (31.5%) of the downstream transport of phosphorus (4,053 kg TP/yr of an annual 12,861 kg TP/yr total). Another large source of phosphorus to the stream was the sewage treatment plants of Warsaw, Pavilion, Leroy, and Scottsville (26.2%), 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%) 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) of the total TP in Oatka Creek, respectively. As anthropogenic sources, natural phosphorus sources also occur within 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%)]. Roughly,

about 70% of the TP 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.

24. Oatka Creek is currently below the 65- $\mu\text{g P/L}$  level, and the 20  $\mu\text{g P/L}$  is not feasibly attainable unless all human presence is removed. A 45- $\mu\text{g P/L}$  target in the OCSWAT model was attained in nine different management strategies. For example, upgrading all four secondary WWTPs to tertiary plants resulted in a 24.9% reduction in total annual TP load, lowering the average TP concentration from 51.6 to 38.8  $\mu\text{g P/L}$  (24.8% reduction in concentration). 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 kg P/yr (18.1% reduction) and lowered the TP concentration to 42.3  $\mu\text{g P/L}$  (18.0% reduction).
25. Combined management, a utilization of several BMPs, also attained the 45- $\mu\text{g P/L}$  concentration target goal. The most vigorous implementation included upgrading all four WWTPs and included implemented grass waterways and filter strips. This management technique [45 Target Scenario (1)] significantly reduced TP load (55.3% reduction) and concentration (42.6% reduction to 29.6  $\mu\text{g P/L}$ ). 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)] 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- $\mu\text{g P/L}$  concentration target for Garbutt and the entire watershed was reached, with [Target Scenario (2)] adequately reducing TP load (13,477 to 11,068 kg P/yr: 17.9 % reduction) and concentration (51.6  $\mu\text{g P/L}$  to 44.3  $\mu\text{g P/L}$ : 14.1 % reduction). 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  $\mu\text{g P/L}$  (14.0 % reduction).

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## *Introduction*

Excessive nutrient inputs from tributary watersheds are linked with persistent degradation in the nearshore waters of Lake Ontario (Makarewicz and Howell 2007). Key to understanding the nature of water quality issues in Lake Ontario is understanding the inputs and transport mechanisms of nutrient runoff in the subwatersheds (Sims *et al.* 1998). As the tributary with the second highest phosphorus load into Lake Ontario (Makarewicz *et al.* 2012), the Genesee River is of particular interest. In conjunction with the United States Department of Agriculture (USDA), SUNY Brockport's water quality laboratory has monitored the Genesee since August of 2010 in an ongoing study generally referred to as the Genesee River Watershed Project. Sampling has been conducted at numerous sites along the river and its tributaries, with analyses focused primarily on total suspended solids (TSS) and nutrient and bacterial concentrations throughout the system. This report is one of six reports (Makarewicz *et al.* 2013 a,b,c; Winslow *et al.* 2013, Rea *et al.* 2013, Pettenski *et al.* 2013) on this work and specifically focuses on the "Oatka Creek" portion of the Genesee River (Fig. 1).

With a drainage area of 557 km<sup>2</sup>, 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 2010a) (Fig. 2). Flows ranged from 0.57 m<sup>3</sup>/sec to 3.54 m<sup>3</sup>/sec at Warsaw and 1.70 m<sup>3</sup>/sec to 16.28 m<sup>3</sup>/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 NLCD 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) (Warsaw, Pavilion, LeRoy, and Scottsville) are stationed on the main stem



(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 total suspended solids (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 total phosphorus (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 soluble reactive phosphorus (SRP), TP, total Kjeldahl nitrogen (TKN), and TSS attributed to upstream nonpoint sources identified as agricultural and Concentrated Animal Feeding operations (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***

The overall goal of this portion of the study was to assess the impact of the Oatka Creek watershed on the Lower/Middle main stem of the Genesee River by:

- a) Determining the seasonal and annual nutrient and soil loss from the Oatka Creek watershed to the “Lower Middle main stem of the Genesee River” using routine water sample collection and analysis and discharge measurements from the USGS monitoring station at Garbutt, NY;
- b) Identifying the location and magnitude of point and nonpoint sources of nutrients and sediments within the Oatka Creek watershed using segment analysis;
- c) Constructing and calibrating the Soil and Water Assessment Tool (SWAT model) for water output, sediment, and total phosphorus loading for Oatka Creek;
- d) Developing a Total Maximum Daily Load for Oatka Creek;
- e) Developing a target phosphorus concentration for Oatka Creek by simulating a 100% forested land use in the SWAT model; and
- f) Providing management scenarios to reduce the impact of Oatka Creek on the Lower Middle Genesee River Basin based on SWAT results.

## *Methodology*

### *Sampling Sites*

#### *Four Main Stem Sites*

Four main stem 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<sup>o</sup>, W 78.133399<sup>o</sup>), 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<sup>o</sup>, W 77.79169<sup>o</sup>), Hydrologic Unit (HNU) 04130003] has discharge records dating back to October 1945 to present. A third main stem 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<sup>o</sup>, W 78.02925<sup>o</sup>). Lastly, the fourth main stem weekly sampling and discharge site (Evans Road) was located in the headwaters near Warsaw, New York (N 42.68447<sup>o</sup>, W 78.10132<sup>o</sup>) (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 (Parmalee Road) (Fig. 2). The one tributary located at the headwaters [Buck Road (N 42.72795<sup>o</sup>, W -78.16161<sup>o</sup>)] is just upstream of the USGS discharge station at Warsaw, New York. The middle tributary site on Wyoming Road (N 42.84858<sup>o</sup>, W 78.04319<sup>o</sup>) was upstream; the second middle tributary site on Roanoke Road (N 42.94206<sup>o</sup>, W 78.05186<sup>o</sup>) was downstream of the main stem site at Ellicott Road. The last tributary site at Parmalee Road (N 43.01498<sup>o</sup>, W -77.97026<sup>o</sup>) was 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 four main stem (Garbutt, Warsaw, Ellicott Road, and Evans Road) and four tributary sites (Buck Road, Wyoming Road, Roanoke Road, and Parmalee Road) for a period of 12 months under event and nonevent conditions. Samples were filtered on site with 0.45- $\mu\text{m}$  MCI Magna Nylon 66 membrane filters. Both the raw sample and filtered sample were transported on ice to maintain a temperature of 4<sup>o</sup>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<sub>3</sub>+NO<sub>2</sub>) 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 main stem, four tributary) were added to calibrate the SWAT Model at several sites in the watershed. At these six locations (Ellicott Road, Buck Road, Evans Road, Wyoming Road, Roanoke Road, and Parmalee 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 2<sup>nd</sup> and 3<sup>rd</sup> 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 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 (1.5-m increments), Buck Road (0.3-m increments), Evans Road (0.61-m increments), Wyoming Road (0.61-m increments), Roanoke Road (0.61-m increments), and Parmalee Road (0.30-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 multiplying the average velocity by the cross-section area of water that flowed through the culvert or bridge (m<sup>2</sup>/s) resulting in the discharge (m<sup>3</sup>/s). Rating curves were then developed based on multiple measurements throughout the sampling year (Figs. 3 and 4).

The discharge on days when sampling and water depth were not taken was 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 Parmalee Road were regressed against the USGS gauge at Garbutt (Fig. 5). Predictive regressions for daily discharge were good with r<sup>2</sup> ranging from 0.86 to 0.91. Annual loadings were estimated based on regresses discharge (Garbutt: Roanoke Road and Parmalee 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.

Loading was calculated at each of the eight weekly sampling locations from the concentrations of SRP, TP, nitrate, TN, and TSS and from daily discharge. The loading from Ellicott Road and Roanoke Road was calculated by adding the loadings from both culverts. Normalized loading for area of the subbasin (kg/ha/yr) for each segment (Evans Road, Buck Road, Warsaw, Wyoming Road, Ellicott Road, Roanoke Road, and Parmalee 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,  $\text{NO}_3 + \text{NO}_2$ , TN, TSS, and coliform analysis. Statistical difference was determined using a paired T-test ( $p = 0.05$ ) 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 main stem and at each of the five major discharge segments (Parmalee 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 an ice-filled cooler and transported at 4°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 chemistry 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 main stem 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 main stem. The areas of concern were measured using a rangefinder for length (m) and height (m) of eroded area and then entered 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.

## **Soil Water Assessment Tool (SWAT) Model**

### **Model Setup**

A Soil Water Assessment Tool (SWAT) model was created for the Oatka Creek subwatershed (OCSWAT 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 2010b), and National Weather Service (precipitation and temperature) (NOAA-NWS 2011). Weather data (daily precipitation and temperature) was obtained for the 29-month study duration (1 January 2008 to 31 May 2011) from four stations associated with OCSWAT (Warsaw, Batavia, Mount Morris, and Avon) (Table 4). The in-program generator for OCSWAT 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 Parmalee Road) (Fig. 2). In addition, outlets were placed at point source discharge locations and where CAFO sites existed. In the HRU (Hydrologic Response Unit) 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 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 Cooperative Extension 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 (OCSWAT), five point source locations known to have nutrient inputs to Oatka Creek (four WWTPs 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 SPDES permit database and the New York State Department of Environmental Conservation website 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<sup>3</sup>/day), Leroy WWTP (2,410 m<sup>3</sup>/day), Pavilion WWTP (128 m<sup>3</sup>/day), Scottsville WWTP (2,068 m<sup>3</sup>/day), Caledonia Fish Hatchery (est: 13,136 m<sup>3</sup>/day). The nutrient concentrations observed in three 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.

#### *Concentrated Animal Feeding Operations (CAFOs)*

Confined animal feeding operations are a nonpoint source of nutrients and sediments that were incorporated into OCSWAT. There are a total of twenty CAFOs (Table 6), eighteen of which were placed into eighteen subbasins of the Oatka SWAT model. 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). The total allocated area in

Oatka Creek that CAFOs were permitted to spread manure was 9,546 hectares, but only 7,480 hectares were used in OCSWAT. 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 manure produced by each farm (kg manure/d) as viable dairy manure for fertilizer was calculated using the number of cows and the amount of manure produced per cow per day (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 were 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 New York.

#### **Model Calibration and Validation**

The model was calibrated for flow, 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).

#### **Water Balance**

##### *Carbonic Rock Aquifer*

The initial OCSWAT simulation run, when compared to the measured USGS discharge at Garbutt, suggested that a deficit of water was present in OCSWAT from 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.* 2010a). 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.* (2010a and b). To estimate the quantity of water being added by the karst region, a regression of the average monthly discharge at Garbutt and the flow deficit calculated at Garbutt were developed with data from a 40-year period. Strong correlations ( $r^2 > 0.96$ ) between the average monthly discharge and the 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.

#### *Curve Number*

To predict surface runoff under peak flow conditions, the SCS curve number was changed in the OCSWAT model. Because curve number is based on soils and land use, some studies suggest that the curve number should stay within  $\pm 10\%$  of the initial curve number SWAT creates based on soils and land use (Richards *et al.* 2010a, 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.* 2010a). In the OCSWAT model, the curve number reduction closely resembled those of previous studies (Richards *et al.* 2010a) by reducing the value by 23%.

#### *Alpha Base flow*

ALPHA base flow, a groundwater base-flow parameter, greatly impacted the OCSWAT 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. Richards' calculations resulted in values ranging from 0.03 to 0.11 in which a value of 0.11 was used for the OCSWAT model.

#### *SWAT Model Calibration Criterion*

For the 2010-2011 water year, the OCSWAT model accurately predicted discharge: Nash-Sutcliffe: 0.94, coefficient of determination:  $r^2 = 0.95$ , and PBIAS: + 5.1% (Fig. 10, 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 phosphorus 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.* (2010a). 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%) (Moriassi *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%) (Moriassi *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 Parmalee 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  $\pm 26\%$  for all sites and the TSS PBIAS were within  $\pm 31\%$  (Tables 9 and 10). Total phosphorus PBIAS ranged from -24.8 to 25.7 with an average of -0.8 for 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 (Moriassi *et al.* 2007). Concentration calibration of TP along the main stem of Oatka Creek was also used to further increase the models predictive precision.

Once the OCSWAT 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 OCSWAT was calibrated and validated, management scenarios were simulated to determine their impact on sediment and phosphorus lost from the watershed.

### **Model Simulations**

With calibration and verification of OCSWAT 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 best management practices (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 WWTPs 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 WWTP TP concentration used for this scenario was based on other WWTPs 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 OCSWAT 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 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 has on streams through vegetation or structural techniques. To simulate the stabilization of stream banks in the SWAT model, several routing parameters were altered by decreasing channel erodibility (CH\_EROD), increasing stream bank vegetation cover (CH\_COV), and increasing Manning's n Stream Roughness Coefficient (CH\_N2) by 50%. This approach is consistent with previous studies in modeling stream bank stabilization (Tuppad *et al.* 2010; Narasimhan *et al.* 2007) and was applied at the basin scale (applied to the entire Oatka Creek watershed).

### *Oatka Creek Watershed Management*

When attempting to achieve the 45- $\mu$ g 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- $\mu\text{g}$  P/L concentration target consisted of land-use management techniques, tributary management, and point source remediation (upgrading WWTPs).

#### *Source P Load Allocation*

Based on OCSWAT, a TP load allocation table was created considering the following: 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 OCSWAT 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 from the entire contribution from residential/urban areas is identified. Septic systems were considered a separate entity and were derived from the difference in the calibrated model and a scenario where septic is inactive. Lastly, the phosphorus from sewage treatment was the difference between the calibrated P output and a scenario where all WWTPs are removed from the model. This analysis allows for identification and quantification of P from different sources in the watershed.

## ***Results***

### **Segment and Tributary Loading**

#### *Discharge Measurements*

Strong correlations existed ( $r^2 \geq 0.94$ ) between discharge and stream depth (rating curve) at Evans Road, Buck Road, Wyoming Road, Parmalee Road, Ellicott Road (East and West culverts), and Roanoke Road (North and South culverts) (Figs. 3 and 4).

#### *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 the Wyoming Road site (SRP: 27.5  $\mu\text{g}$  P/L; TP: 74.4  $\mu\text{g}$  P/L; total coliform: 8,237 CFU/100 mL), Ellicott Road (SRP: 47.5  $\mu\text{g}$  P/L; TP: 100.3  $\mu\text{g}$  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). Based on concentration/abundance, the Wyoming, Ellicott, and Roanoke Roads segments (Fig. 2) within Oatka Creek appeared to be where most water quality issues occurred. Further evidence suggesting that the Wyoming Road area is of concern is the elevated average nitrogen concentration (average - nitrate: 3.28 mg N/L; TN: 3.98 mg N/L) compared to the average of all '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 main stem (Evans Road, Warsaw, Ellicott Road, and Garbutt) (Fig. 12) TP concentrations were highest in 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 the absence of hydrometeorologic events. Similar to main stem sites, tributary locations (Parmalee, Roanoke, Buck, and Wyoming Roads) (Fig. 12) had elevated TP concentrations in winter and spring (December 2010, March 2011, and May 2011) and also in September 2010 due to an event.

#### *Event versus Nonevent Concentrations (Table 13, Appendix C)*

Water chemistry of 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 the water chemistry of 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%), Parmalee 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 also had large increases in concentration during nonevent to event periods (average of all eight monitoring locations – SRP: 11.6 to 39.2 µg P/L, +238%; TP: 27.5 to 144.2 µg P/L, +424%; TSS: 5.3 to 71.5 mg/L, +1,249%; total coliform: 2,888 to 17,075 CFU/100 mL, +491%) while this was not evident for 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%). Parmalee Road tended to be the least responsive to rain event periods.

#### *Measured Total Annual Nutrient and Sediment Load*

Total annual nutrient and sediment loading was calculated (kg/yr) for the 1 June 2010 to 31 May 2011 period at four main stem (Evans, Warsaw, Ellicott, and Garbutt) and four tributary sites (Buck, Wyoming, Roanoke, and Parmalee) (Table 14). Soluble reactive phosphorus, TP, nitrate, and TN load increased incrementally from the most upstream "main stem" site at Evans (TP: 787 kg P/yr) to Warsaw (TP: 5,231 kg P/yr) to Ellicott (TP: 9,211 kg P/yr) to the furthest downstream main stem site with the highest load at Garbutt (TP: 15,018 kg P/yr) (Table 14a). Total suspended solid load displayed a different spatial pattern. Total suspended solid annual load increased from the furthest upstream main stem site at Evans (TSS: 292,147 kg/yr) to Warsaw [(TSS: 5,791,046 kg/yr (+ 1,882%)] (Table 14a) 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 14a).

The monitored tributaries accounted for 35.3% (Buck: 2.9%; Wyoming: 19.1%; Roanoke: 12.5%; Parmalee: 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), contributed 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), suggests other source(s) of erosion, perhaps bank erosion, in the main stem 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 Parmalee 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 Parmalee) (Fig. 2) accounted for a small fraction of the total load at Garbutt (nitrate: 5.6%; TN: 7.0%). This suggests other tributary or main stem 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. Areal SRP and TP loads were higher in the tributaries (mean SRP= 177.5 g/ha/yr; mean TP=607 g/ha/yr) compared to the main stem segments (mean SRP=150 g/ha/yr; TP=544 g/ha/yr). Of the four tributary sites, the Parmalee tributary had the lowest areal contribution (SRP: 12 g/ha/yr; TP: 54 g/ha/yr; nitrate: 3.0 kg/ha/yr; TN: 4.0 kg/ha/yr) to the total losses of the watershed, while the Wyoming tributary, which is located just upstream from the main stem site at Ellicott (Fig. 2), had the highest areal tributary load for SRP, TP, nitrate, TN, and TSS (SRP: 311 g P per ha/yr; TP: 1,098 g P per ha/yr; nitrate: 27.7 kg N per ha/yr; TN: 34.5 kg N per ha/yr; TSS: 692.4 kg per ha/yr) (Table 14b). This tributary is clearly a source and an area of concern for nutrients and soil erosion. Similar to the Wyoming tributary, Roanoke tributary had high SRP (306 g P per ha/yr) and TP (877 g P per ha/yr) areal loads when compared to the Buck and Parmalee Roads (mean SRP: 46 g P per ha/yr; TP: 226 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 on which to focus management practices.

With the exception of SRP (116 to 67 g/ha/yr), areal main stem losses of TP, nitrate, TN, and TSS tend to increase from the main stem Evans segment (e.g., TP: 455 g/ha/yr) to the main stem Warsaw segment (e.g., TP: 595 g/ha/yr) (Fig. 2, Table 14b). In fact, areal TSS loading was high at the main stem Warsaw site (658.6 kg/ha/yr) compared to all tributary (range – 18.4 to 692.4 kg/ha/yr) and main stem (range – 167.2 to 192.5 kg/ha/yr) sites. Buck tributary (TP: 397 g/ha/yr; nitrate: 11.3 kg/ha/yr; TN: 13.7 kg/ha/yr) (Table 14b), which empties just downstream

of the Evans Road segment and into the Warsaw segment (Fig. 2), is a likely source of TP, nitrate, and TN in the Warsaw reach. Also, TSS areal losses increased from 168 to 658.6 kg P/ha/yr (+ 292 %) from the Evans Road to the Warsaw segment, while the Buck Road TSS tributary losses were low (174.9 kg P/ha/yr), suggesting an erosion issue along the main stem in this segment.

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 was highly erodible while the stream bank between site H and OC Evans Road had only a 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 main stem of Oatka Creek, areal loads of SRP (67 to 217 g/ha/yr), nitrate (13.0 to 21.4 kg/ha/yr), and TN (15.9 to 26.0 kg/ha/yr) increased from Warsaw to the main stem site at Garbutt (Fig. 2, Table 14b), suggesting sources of nutrients are present between sites on the main stem. From Warsaw to Garbutt, NY areal TP (595 to 577 g/ha//yr) and TSS (658.6 to 192.5 kg/ha/ yr) load decreased.

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: 636 g P/ha/yr; TSS: 424 kg/ha/yr) (Table 14) than the four downstream (Ellicott Road, Roanoke Road, Parmalee Road, and Garbutt) monitoring locations (mean –TP: 514 g P/ha/yr; TSS: 160 kg/ha/yr) (Fig. 2, Table 14). Major nutrient and erosion issues in Oatka Creek appear to begin upstream from the Ellicott segment (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**

#### **Segment Analysis: Entire Watershed: 12 July 2010 (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 °C) at all sites. Of these sites, two which were non-main stem 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.

### *Summary*

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.

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) 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 from both (Warsaw and Garbutt) downstream main stem USGS monitoring stations. The Parmalee Road subwatershed may also have a source of coliform bacteria.

### Detailed Analysis

**Upstream of Warsaw Sewage Treatment Plant:** 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 main stem (OC Warsaw), and two tributary sites (OC Evans Road and OC Buck Road) along with two main stem 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 = 1.30 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. In the headwaters, 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:** Downstream of the Warsaw WWTP site and upstream of the Leroy WWTP site is the “Middle Section” of the Oatka Creek subwatershed (Fig. 14). This middle segment has one main stem weekly monitoring location (OC Ellicott St), two monitoring tributary sites (OC Wyoming Road and OC Roanoke Road), and seven main stem segment sites (7-13).

Phosphorus: 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 main stem, 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 main stem site OC Ellicott Road (SRP: 55.0 µg P/L; TP: 109.5 µg P/L) to downstream main stem 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 concentrations 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 main stem.

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 this nitrogen. This tributary discharges water into the main stem 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 main stem increased substantially from above (OC Warsaw; TSS = 4.43 mg/L; total coliform = 3,900 CFU/100 mL) to below the Warsaw WWTP (Site 13: TSS = 15.80 mg/L; total coliform: 13,700 CFU/100 mL) (Fig. 17). The WWTP site appeared 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 a low at 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:** 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 Parmalee Road), two main stem 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.

Phosphorus: 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 main stem site 7 (SRP: 69.0 µg P/L; TP: 114.6 µg P/L) to below the WWTP at main stem 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 phosphorus and TP concentrations decreased consistently from upstream main stem site 5 to downstream main stem 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) concentrations, indicating a source of particulate phosphorus upstream. Soluble reactive phosphorus and TP concentrations also increased from site 2 to downstream main stem site OC Garbutt (SRP: 38.2 µg P/L; TP: 73.2 µg P/L) suggesting a source of phosphorus, probably the CAFO site (D & D Dairy).

Nitrogen: Nitrate did not have the same relationship as phosphorus below the Leroy WWTP. Nitrate concentrations were similar above (site 7: 0.86 mg N/L) and below (site 5: 0.93 mg N/L) the Leroy WWTP site (Fig. 16). 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 below the

WWTP (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 concentrations (site 4: 23.67 mg/L) (Fig. 17) but did not significantly impact the TSS concentrations on the main stem due to low tributary flow. Tributary site 4 also had low concentrations of SRP and high concentrations of TP, suggesting that a particulate source of phosphorus exists upstream. Total coliform abundances (31,100 CFU/100 mL) were high at tributary site OC Parmalee Road, a site between sites 5 and 2, but did not impact the main stem 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 Parmalee Road and was investigated more closely.

### **Segment Analysis: Headwaters (Evans Road) (Fig. 18)**

Segment analyses were performed upstream from Evans Road (Fig. 18) on 5 October 2010 during event conditions and on 19 October 2010 during a nonevent to identify point and nonpoint sources of pollution. On 5 October, samples were taken over a 2-hour period (1:53 pm to 3:59 pm) under nonevent conditions with air temperatures in the mid to upper 50s (13-15 °C) under cloudy skies. On 19 October 2010, 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 °C) under sunny 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.

### **Summary**

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 taken 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 the 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 main stem which is likely a source for nitrogen.

### **Detailed Analysis: 5 October 2010 (Event Conditions)**

**Subwatershed #1:** Subwatershed #1 consists of site B and upstream site B-1 (Fig. 18). Subwatershed #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 N/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 to 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. Subwatershed #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. Total phosphorus 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 and D-1 had no detectable nitrate (Fig. 19). 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 #3 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 (1.09 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.

*Detailed Analysis: 19 October 2010 (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 nonevent conditions with air temperatures in the mid to upper 50s (13-15 °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-1 and the Double B Farms CAFO due to the lack of flow in the stream.

**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 solids 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: 9.9 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, of coliform bacteria upstream from site E that is between sites E and E-1.

**Main Stem sites:** The main stem of the Evans Road subwatershed consists of two sampling sites (C and OC Evans Road). 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  $\mu\text{g P/L}$ ; TP: 11.8  $\mu\text{g P/L}$ ) (Fig. 21) to downstream site OC Evans Road (SRP: 2.3  $\mu\text{g P/L}$ ; TP: 6.7  $\mu\text{g P/L}$ ), 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 main stem 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).

### **Segment Analysis: Buck Road Tributary: 15 March 2011 (Fig. 26)**

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 to 1:16 pm) under nonevent conditions with air temperatures in the mid to upper 50s (13-14 °C) under sunny skies. A sample was not obtained at site B and site F-2 due to private property.

#### **Summary**

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 three sampling locations (sites G-1, F-1, and C) were likely due to manure applications on cropland (Figs. 26 and 27).

#### **Detailed Analysis**

##### **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  $\mu\text{g P/L}$ ; TP: 54.6  $\mu\text{g P/L}$ ) when compared to all other sites in subwatershed #1 (range – SRP: 5.8 to 42.4  $\mu\text{g P/L}$ ; TP: 15.7 to 54.6  $\mu\text{g P/L}$ ) (Fig. 27) and decreased in concentration to downstream site F. Nitrogen concentrations were high at site F-1, F, and B-1 (nitrate:  $\sim 5$  mg N/L; TN:  $>5$  mg N/L) when compared to all other sites in subwatershed #1 (range – nitrate: 1.24 to 2.40 mg N/L; TN: 1.46 to 2.50 mg N/L) (Fig. 28), suggesting a likely source of nutrients upstream from site B-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 (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 phosphorus 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 small 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).

## **Segment Analysis: Warsaw Segment: 8 March 2011 (Figs. 29 and 30)**

A segment analysis was conducted on the Oatka Creek (OC) main stem 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 °C) under cloudy skies. Out of the fifteen samples taken, five main stem (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.

### **Summary**

Confined animal feeding operation sites upstream from sites B (Swiss Valley Farms) and L (Broughton Farms) are likely causes of elevated SRP 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). Also, the CAFO upstream from site B may be a proximate cause for high TP (211.1 µg P/L) and TSS (97.3 mg/L) concentrations observed at OC Buck Road site (Fig. 29). This CAFO may operate in both subbasins and was further investigated on 15 March 2011 to identify any sources of pollution upstream from OC Buck Road. A major increase in TSS was observed between site C (40.8 mg/L) and OC Warsaw (123.8 mg/L). A stream bank erosion inventory was performed on 28 July 2011 to identify likely causes of erosion in this segment. Nitrate and TN concentrations were extremely high at tributary site A (nitrate: 5.69 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). This was further investigated.

### **Detailed Analysis**

Confined animal feeding operation sites upstream from sites B (Swiss Valley Farms) and L (Broughton Farms) are likely causes of elevated SRP 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 main stem 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 main stem site C and upstream main stem 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 main stem site E but downstream from main stem site H.

Similar to TP, high TSS concentrations were identified at the tributary site OC Buck Road (97.3 mg/L) and main stem 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 main stem were identified between upstream site H (13.3 mg/L) and downstream site E (48.3 mg/L) (+ 263.2%), and between upstream site C (40.8 mg/L) and downstream site OC Warsaw (123.8 mg/L) (+ 203.4%) (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: 5.69 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 main stem sites, a major increase in nitrate was identified between upstream main stem site OC Evans Road (2.62 mg N/L) to downstream main stem site H (3.27 mg N/L) (+ 24.8%) (Fig.30). The likely source of nitrate between these two main stem 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).

### **Segment Analysis: CAFOs upstream from Warsaw, NY: 15 March 2011 (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 °C) under sunny skies.

#### **Swiss Valley Farms**

Soluble reactive phosphorus, 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: + 4,779%; TN: + 1,751 %; TSS: + 20%) (Fig. 31), suggesting Swiss Valley Farms is a major source of nitrogen, but not 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 other 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.

### **Segment Analysis: Wyoming Road Tributary: 3 August 2010, 6 October 2010, 29 March 2011 (Fig. 33)**

Segment analyses were performed on the Oatka Creek Wyoming Road segment (Figs. 2, 33 to 42, and 35) to identify sources of coliform bacteria and point and nonpoint sources of pollution on three different dates. Samples were taken over a 5-hour period under nonevent conditions with air temperatures in the mid to upper 70s (23-26 °C) under fairly cloudy skies on 3 August 2010; 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 °C) under cloudy skies on 6 October 2010; and over a 35-minute period near Logwell Acres and Bowhill Farms under event conditions on 29 March 2011 with air temperatures in the upper 50s (14 °C) under partly cloudy skies.

### **Summary**

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 subwatersheds # 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.

### **Detailed Analysis: 3 August 2010**



**Subwatershed #1:** Subwatershed #1 consists of site E and upstream site E-1 (Fig. 33). 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). 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, located on the western most segment of main subwatershed #2, has only one site (F-1). Site F-2 and upstream site F-3 are located on subwatershed 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 were high TSS concentrations (87.5 mg/L) (Fig. 34) and high coliform abundances (13,700 CFU/100mL) at site F-1 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

concentration was 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, the most upstream main stem 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 relative to TP 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 the highest concentrations of nitrate (14.4 mg N/L) and TN (15.50 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.

**Detailed Analysis: 6 October 2010 (Fig. 38)**

**Subwatershed #1:** Both sites E and E-1 had flow on 6 October 2011 under event conditions. 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 significantly 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 suspended 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, has only one site (F-1). Site F-2 and upstream site F-3 are located on subwatershed 2b.

**Subwatershed 2a:** Soluble reactive phosphorus and TP concentrations increased slightly from site F-1 (SRP: 38.8 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 a small decrease in concentration from upstream site F-3 to site F-2 (Fig. 39), while nitrate and TN concentrations increased slightly 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).

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)(Fig. 40). 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). Subwatershed #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 subwatershed #6 is likely upstream from site D-2 and the short distance to site D-1. 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, located at the headwaters of subwatershed #6, 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 Main stem 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 at site B to 39.8 µg P/L at site A 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 Road (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 concentrations (5.51 mg N/L) 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 nutrients, TSS, and perhaps coliform bacteria to the Oatka Creek subwatershed.

**Detailed Analysis: 29 March 2011(Fig. 42)**

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 °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 significantly 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: + 200%; TN: + 110%) (Fig. 42), indicating that the Logwell Acres CAFO is a likely source of nitrogen in the Wyoming Road subwatershed.

#### *Bowhill Farms*

Similar to the values at Logwell Acres, TP and TSS concentrations decreased upstream from 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: + 646%; TN: + 75%) (Fig. 52). Similar to Logwell Acres, the Bowhill Farms CAFO is a probable source of nitrogen to the Wyoming Road subwatershed.

### **Segment Analysis: Roanoke Road Tributary: 6 October 2010 (Fig. 43)**

#### *Summary*

A segment analysis was performed on the Oatka Creek (OC) Roanoke Road tributary (Fig. 43) to identify point and nonpoint sources of pollution. The 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.

#### *Detailed Analysis*

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 °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. 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 and streams from both merge to form the main stem. 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 N/L) to downstream site C (nitrate: 3.94 mg N/L; TN: 6.02 mg N/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 of 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 the 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 reaching 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.

## **Segment Analysis: Parmalee Road Tributary: 7 June 2011, 27 July 2010, 3 August 2010**

### **Summary**

A segment analysis was performed on the Oatka Creek Parmalee Road tributary (Fig. 47) to identify sources of coliform abundances previously encountered on 7 June 2011, 27 July 2010, and 3 August 2010. Agriculture (corn) is listed as the dominate land use of this area, and a windshield survey in the Parmalee Road tributary confirmed that agricultural practices were widespread and the most likely cause of elevated nutrients and coliform abundances observed. However, a single residence was found to be a source of coliform bacteria and is also a partial source of nutrients in this tributary's watershed. The residence was again visited on 10 August 2010, and it was determined the waste treatment method here was a septic system.

### **Detailed Analysis: 7 June 2011**

A segment analysis was conducted on the Oatka Creek (OC) Parmalee Road sub-watershed (Fig. 48) to further identify sources of elevated nutrients. Ten sampling sites (OC Parmalee Road, B, B-1, B-3 to B-5 and A to A-3) (Fig. 48) were sampled over a 3.5- hour period (2:18 pm to 5:49 pm) under nonevent conditions with air temperatures in the mid-70s (24 °C) under sunny skies.

#### ***Sites A to A-3***

**Soluble reactive phosphorus**, TP, and TSS concentrations were highest at the furthest upstream site A-3 (SRP: 115.0 µg P/L; TP: 218.7 µg P/L; TSS: 14.9 mg/L) (Fig.49), 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: µg P/L; TSS: 6.1 mg/L) (Fig. 49), suggesting a likely source upstream from site A but downstream from A-1.

Similar to phosphorus and TSS, nitrogen concentrations were higher 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. 50). Nitrogen concentrations also increased from upstream site A-1 (nitrate: 1.46 mg N/L; TN: 1.61 mg N/L) to downstream site A (nitrate: 1.95 mg N/L; TN: 3.53 mg N/L) (nitrate: + 34%; TN: + 119%) (Fig. 50). 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. 50), suggesting a likely source of coliform bacteria between sites A-3 and A-2.

#### ***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. 49), suggesting a source of phosphorus and TSS upstream from site B-3. The stream segment analysis performed on 3 August 2010 (Fig. 51) 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. 50), 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. 50), 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 2010 to determine the treatment system used at the residence.

Detailed Analysis: 27 July 2010

Samples were taken under nonevent conditions with air temperatures in the low 80s (28 °C) under sunny skies. OC Parmalee 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 Parmalee Road, but there was no physical evidence of manure spreading (or aroma).

Detailed Analysis: 3 August 2010

Results from 27 July 2010 were not conclusive. A third segment analysis was performed on the Oatka Creek Parmalee Road subwatershed 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 °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. 51). 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. 51). 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 ponds 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.

**Segment Analysis: Big Spring Creek (Genesee Country Village Culvert): 12 July 2010, 4 January 2011, 3 May 2011 (Table 17)**

Summary

Big Spring Creek at George Street is east of the Genesee Country Village (Fig. 2) and just west of the Village of Mumford. Big Spring Creek flows through two small but spatially separate culverts several meters apart on George Street. An earlier reconnaissance of the watershed detected a sulfur smell 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. There were no major differences in analyte concentrations between culverts, except

perhaps for TP, where one culvert's TP was twice as high as the other (Table 17). For routine sampling, the decision was made to combine these segment sites into one sample site by taking 500 mL of sample from each culvert and combining them into one composite sample. The results suggest that during low flow conditions, sources of nitrogen upstream from site 1 (Village of Caledonia) could be impacting the Oatka Creek subwatershed.

#### Detailed Analysis: 12 July 2010

Soluble reactive phosphorus and TP concentrations were low at site 1A (east end of George Street) (SRP: 6.1 µg P/L; TP 16.3 µg P/L) and site 1B (west end of George Street) (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 92.6 µg P/L; TP: 17.1 to 132.6 µg P/L) (Fig. 15). Nitrate (site 1A: 2.10 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 31,100 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 dissimilar for both culverts, the decision was made to combine these segment sites into one sample site by taking 500 mL of sample from each culvert and combining them into one composite sample.

#### Detailed Analysis: 4 January 2011

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 (Fig. 52) 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 °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 and 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. With the assistance of NYDEC, we calculated P loading from the fish hatchery.

Although not high compared to a WWTP, there was small P load delivered to the Big Spring Creek by the fish hatchery.

**Detailed Analysis: 3 May 2011 (Fig. 54)**

A third 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 may be 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 °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 the downstream (site A – SRP: 5.1 µg P/L; TP: 17.0 µg P/L; TSS: 11.1 mg/L) (Fig. 54) of 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 on 7 September 2011. On 7 September 2011, SRP (336%) and TP (596%) concentrations and total coliform (290%) abundance increased from the intake to the effluent pipe (Table 5), while nitrate and TN concentrations did not increase significantly from the intake to effluent pipe. These results indicate that the Caledonia Fish Hatchery is a likely source for phosphorus. With the assistance of NYDEC, we calculated P loading from the fish hatchery. Although not high compared to WWTP (3,375 kg P/yr), there was a small but significant P load delivered to the Big Spring Creek by the fish hatchery (260 kg P/yr) (Table 12).

**Segment Analysis: Warsaw Water Treatment Plant (17 August 2010)**

Soluble reactive phosphorus, TP, nitrate, and TN were statistically ( $p < 0.05$ ) 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 below the WWTP (13,050 CFU/100 mL) than above (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<sup>3</sup>/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).

**Segment Analysis: Leroy Water Treatment Plant (20 October 2010)**

Soluble reactive phosphorus, TP, nitrate and TN were statistically ( $p = 0.05$ ) 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) as were 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 system maximum discharge (3,785 m<sup>3</sup>/day) and estimated TP load (9.0 kg P/day) were the highest in Oatka Creek.

#### **Segment Analysis: Pavilion Water Treatment Plant (2 November 2010)**

Soluble reactive phosphorus, TP, nitrate, and total coliform abundances were statistically ( $p < 0.05$ ) higher in concentration below the Pavilion WWTP than above (Table 18), while total suspended solids 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<sup>3</sup>/day; TP load: 1.1 kg P/day).

#### **Segment Analysis: Scottsville Water Treatment Plant (4 January 2011)**

Soluble reactive phosphorus, TN and total coliform abundances were statistically ( $p < 0.05$ ) higher in concentration below the Scottsville WWTP than above (Table 18). At the Scottsville WWTP, effluent concentrations were the lowest of the Oatka WWTPs (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<sup>3</sup>/day and releases roughly 3.9 kg P/day.

### **SWAT Model Results**

#### **Model Performance**

For the 2010-2011 water year, the OCSWAT model accurately predicted discharge: Nash-Sutcliffe: 0.94, coefficient of determination:  $r^2 = 0.95$ , and PBIAS (+ 5.1 %) (Fig. 10, 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.*

(2010a). 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%) (Moriassi *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%) (Moriassi *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 Parmalee 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  $\pm 26\%$  for all sites and the TSS PBIAS were within  $\pm 31\%$  (Tables 9 and 10). Total phosphorus PBIAS ranged from -24.8 to 25.7 with an average of -0.8 at all eight sites while TSS PBIAS ranged from -30.2 to a high of 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 (Moriassi *et al.* 2007). Concentration calibration of TP along the main stem of Oatka Creek was also used to further increase the model’s predictive precision.

Once the OCSWAT 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).

### **Sources of Phosphorus (Table 12)**

After the calibration and validation of the OCSWAT model was completed, point and nonpoint source phosphorus allocations were then quantified. These sources were broken down into specific land use/activity groups: agricultural crops, tile drainage, farm animals (Confined Animal Feeding Operations), stream bank erosion, wetlands, fish hatchery (Caledonia), groundwater, forest, urban runoff, sewage treatment and septic systems. More than 70% of the annual TP load from the 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).

### **Effectiveness of Best Management Practices (BMPs)**

Several remediation scenarios were simulated with the OCSWAT model to determine the best scenario of management practices to reduce TP and TSS loading in the Oatka Creek watershed. A total of 23 different remediation scenarios were simulated in OCSWAT to determine concentration and load percent reduction from several management scenarios (Table 19). For example, if Oatka Creek was transformed 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) at Garbutt, NY (Table 22). 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 to reduce P loss from the watershed included: buffer strips (8.4%), grassed waterways (18.1%), terracing (8.8%), and reducing manure applied to CAFO operations (9.7%) (Table 19).

Residential and urban management was also implemented in the OCSWAT model (removal of WWTPs, upgrading all WWTPs, removal of point sources, septic systems, and stream bank stabilization). Upgrading or removing all WWTPs in Oatka Creek resulted in 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 stream bank throughout the Oatka Creek watershed would reduce TSS loading by 87.0% (5,094 MT TSS/yr to 665 MT TSS/yr), but TP increased slightly (Table 19). A similar result was identified by Tuppard *et al.* (2010) and Winslow *et al.* (2013) where large reductions in sediment were observed from stream bank stabilization, but only a slight reduction in TP resulted. Phosphorus is physically bound to sediment so indicating a large soil loss and increased phosphorus loading is unrealistic. 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 and Barnwell 1987). 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.

To determine if a 45-µg P/L target concentration could be achieved, four basin-wide management scenarios and one partial subbasin scenario were simulated. Target Scenario 45 #1 upgraded WWTPs and implemented grassed waterways and buffer strips on all agricultural land. Target Scenario 45 #2 implemented grassed waterways and buffer strips in the Wyoming and Roanoke tributaries of Oatka Creek and cover crops to the entire watershed. Target Scenario 45 #3 implemented cover crops and buffer strips to agriculture land in the entire watershed. Target Scenario 45 #4 simulated grassed waterways in the entire watershed, while Target Scenario 45 #5 removed all SPDES sources (Table 19) and reduced TP loading by 26.9% and 18.1%, respectively (Table 19) and resulted in stream TP concentrations of less than 45 µg P/L. Target Scenario 45 #1 provided the greatest reduction in TP load (55.3%), resulting in a

stream TP concentration of 29.6  $\mu\text{g P/L}$  (Table 19). Both Target Scenario 45 #2 and #3 resulted in stream TP concentrations of less than 45  $\mu\text{g P/L}$  (Table 19). Clearly, the OC SWAT simulation suggests that with “vigorous management” stream target TP concentration of less than 45  $\mu\text{g P/L}$  is achievable.

Vigorous management of the entire watershed could be considered to be excessively intrusive. What if BMPs were implemented to subbasins that have been identified as major sources of phosphorus. Best management practices were implemented on the Evans Road and Wyoming Road subbasins including the implementation of buffer strips, grassed waterways, cover crops, and manure removal from CAFO locations to all agricultural land use. All remediation efforts had reductions in TP loads with grassed waterways being the most effective BMP in both the Evans Road (24.0% reduction) and Wyoming Road subbasins (75.4% reduction) (Table 20). Implementation of these two scenarios to Wyoming and Evans Roads only resulted in a 24% TP decrease for the entire watershed

## Discussion

An assessment of the Oatka Creek watershed was undertaken to determine the nutrient and sediment contribution of Oatka Creek to the Genesee River and to determine sources of nutrient and sediment loss geospatially within the watershed. To accomplish this task, a multifaceted, integrated approach was taken by a combination of monitoring, segment analysis, and modeling (Soil and Water Assessment Tool). Thus, the creek was monitored for discharge, water chemistry, and loss of nutrients and soil for an entire year (1 June 2010 to 31 May 2011) at four main stem (Evans Road, Warsaw, Ellicott Road, and Garbutt) and four tributary segments (Buck Road, Wyoming Road, Roanoke Road, and Parmalee Road) (Fig. 2). Based on these data, the Oatka Creek Soil and Water Assessment Tool (OCSWAT) model was created, calibrated, and verified for discharge, sediment, and phosphorus loss. Based on the loading data to a subbasin outlet and the SWAT model, segment analysis (Makarewicz and Lewis 1994) was performed on selected subwatersheds to determine sources of material loss. Together these two bodies of information, the total amount of nutrients, sediments, and bacteria lost from the watershed and the sources of these losses, served as a valuable tool for directing watershed management. Lastly, the OCSWAT model was employed to test the effectiveness of best management practices (BMPs) on land use and to determine the minimum potential phosphorus concentration expected in a forested Black Creek watershed as a nutrient target for TMDL development.

### Oatka Creek in Comparison to Other Tributaries

By determining annual areal sediment and nutrient loads ( $\text{kg/ha/yr}$ ), tributary catchments of varying watershed size may be compared, allowing a quantitative perspective on land use and prioritizing management within a watershed. Field-observed total (MT) and areal ( $\text{kg/ha}$ ) TP loading from various tributaries to Lake Ontario were obtained (Makarewicz *et al.* 2012) to compare to the observed areal loads from Oatka Creek watershed (Table 21). Throughout the Lake Ontario basin, tributaries with the highest percentage of agriculture tend to have the highest areal loads (Table 21). Phosphorus losses from the agricultural dominated Oatka Creek are lower compared to losses from other agricultural watersheds. For example, areal TP loads

from Oatka Creek (0.51 kg P/ha/yr) were lower than other agriculturally dominated Lake Ontario tributaries (Golden Hill and Wolcott Creeks: 0.88 and 1.37 kg TP/ha/yr, respectively; Table 21) but similar within the range of values observed for Genesee River watersheds (0.18 to 0.90 kg P/ha/ yr (Table 21). Such comparisons point out the loose connection between land-use practices and water quality issues within the Lake Ontario watershed and help to prioritize different subwatersheds. Because the high areal loads of portions of Oatka Creek are comparable to other impacted tributaries of Lake Ontario, they are of concern, and management efforts should be initiated.

### **Efficacy and Limitations of OCSWAT**

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 OCSWAT 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.

A calibration concern with OCSWAT 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.* 2010a). For example, a study conducted by Richards *et al.* (2010a) 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 OCSWAT. An underground “aquifer” also known as the Onondaga Escarpment runs across the Northern part of the Oatka Creek watershed (Fig. 2). During the initial OCSWAT run, a large water deficit was noticed in the stream in December through May. Winslow *et al.* (2013) 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 *et al.* 2013). 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, increases in stream flow 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 OCSWAT model where underpredicted 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 *et al.* (2013), 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 within the study watershed. Like point sources, CAFOs 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 and magnitude of point and nonpoint sources, as done in this study, 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 a, b) in a study on the Onondaga Escarpment reported total phosphorus groundwater concentrations ranging from roughly 20  $\mu\text{g P/L}$  to 90  $\mu\text{g P/L}$ , suggesting a range of groundwater concentrations may be inputted to the OCSWAT model. Well-water samples were also taken at sixteen different locations across Western New York to determine the average TP concentration of groundwater. Total phosphorus concentrations ranged from 0.7 to 162.7  $\mu\text{g P/L}$  with an average level of 22.1  $\mu\text{g P/L}$  (Table 23) and suggested that the TP concentration of 20  $\mu\text{g P/L}$  employed in the OCSWAT model was appropriate. Actual values, as opposed to the default values, increase the SWAT model's 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 Oatka 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 OCSWAT 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 crops – 2,305 kg TP/yr (17.9%); farm animals (CAFO) – 1,310 kg TP/yr (10.2%); tile drainage – 438 kg TP/yr (3.4%)] was the largest contributor (31.5%) of the downstream transport of phosphorus (4,053 kg TP/yr of an annual 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 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 groundwater 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 BMPs, minimal impacts are evident in surrounding water bodies (Burkholder *et al.* 2007, Makarewicz *et al.* 2009a).

Since the OCSWAT model allocated roughly 70% of the P load to anthropogenic sources, calculated total annual and areal (kg/ha/yr) loadings identified areas of concern among the four main stem and four tributaries of Oatka Creek. Such an approach allows a priority ranking of the main stem and tributary sites of Evans, Warsaw, Ellicott, and Garbutt with the Buck, Wyoming, Roanoke, and Parmalee 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 main stem (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 OCSWAT 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 field approach 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 OCSWAT model.

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

The main stem 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 main stem 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 (116 g/ha/yr), TP (455 g/ha/yr), and TSS (169 kg/ha/yr) areal load of the four main stem locations, indicating 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.

In the Evans Road subwatershed of Oatka Creek, one CAFO 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 2010), 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 (OC Evans Rd), 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 OCSWAT model to identify management recommendations. As noted, two major nutrient sources were identified with the Evans Road segment (agriculture and the Double B Farms CAFO operation) along with one nutrient sink (wetland). According to the allocated loads from the OCSWAT 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 OCSWAT determined remediation by buffer strips to be an appropriate approach. A simulation adding buffer strips to the entire watershed results in an 8.4% reduction in TP loading, reducing the P load from 13,477 kg P/yr to 12,348 kg P/yr (Table 19) and 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. However, based on field observations and source locations, buffer strips would be the most appropriate strategy because of 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 4 m of buffer strips.

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

The Warsaw Segment is located downstream from the main stem 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 main stem 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 main stem site Evans Road to downstream main stem 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 main stem of Oatka Creek just upstream of Warsaw, contributed a fraction of the TP (16.1%), nitrate (20.9%), TN (20.8%), and TSS (6.4%) to the total annual load (kg/yr) of the Warsaw site, indicating main stem 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 and sediment to the downstream system including lakes (Makarewicz et al. 2009a, 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 (292,147 to 5,791,046 kg/yr, + 1,882%). To determine the severity of erosion along the main stem 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 main stem was determined to be highly erodible and represents the likely cause of elevated TSS variables observed (Fig. 29, Table 15). 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 unstable stream banks upstream from site OC Warsaw are the likely reason for erosion (Table 15).

One objective of this study was to determine the cause of elevated nitrogen concentrations observed in the Oatka Creek watershed. 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 advertised as the #1 county in New York State for agriculture production, has twice as many nitrogen-producing cows as people (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 observed 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 land uses (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 OCSWAT model allowed evaluation of remediation strategies of the main stem source areas upstream from Warsaw (stream bank erosion and Warsaw WWTP). Since much of the sediment is lost upstream of Warsaw in Oatka Creek, a stream bank stabilization simulation was conducted on this portion of the watershed to identify the overall effect. When implemented, sediment losses were reduced by 96.0% from the Warsaw segment, suggesting that armoring the stream bank would significantly reduce TSS loads. When implemented to the entire watershed, relative sediment losses were reduced by 87.0% (Table 19), but no concomitant change in P load or concentration (Table 19). Phosphorus is physically bound to sediment so indicating a large soil loss and increased phosphorus loading is unrealistic. For example, P concentration was simulated at 55.9  $\mu\text{g P/L}$  after stream bank stabilization, which was actually higher than the current concentration without any management (51.6  $\mu\text{g P/L}$  (Table 19). Both Rea et al. (2013) and Tuppada et al. (2010) report similar results with the stream bank stabilization scenario. Tuppada et al (2010) concluded that this unexpected result was a product of the equations used in SWAT; that is, a flaw in the SWAT model is the poor link between the sediment and phosphorus routing modules for stream bank erosion. Only peak flow rates influence the transport of nutrients in the QUAL2E model (Brown and Barnwell (1987). However, regressions of TP versus TSS at Garbutt, NY indicate a strong relationship between discharge and TP ( $r^2=0.73$ , Fig. 56) and TSS and TP concentration ( $r^2=0.78$ , Fig. 55). Using the TP/TSS regression equation (Fig. 55) to calculate the expected TP concentration from the modeled TSS concentration yielded a TP concentration of 3.1  $\mu\text{g P/L}$ , a 94% reduction of TP concentrations when compared to the base model concentration of 55.9  $\mu\text{g P/L}$ .

In fact, this management strategy has already been implemented in some problem areas upstream of Warsaw, NY, to limit erosion, and beneficial results have already been noted (personal communication: Greg McKurth, Wyoming County Soil and Water District manager). Stream bank stabilization techniques such as channelization or rock armoring techniques (stone riprap, concrete pavement, and asphalt mixes) may be 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 is a management practice suggested to reduce erosion in this source area of Oatka Creek.

One wastewater 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 (Wilcoxon:  $p$ -value  $< 0.05$ ) higher concentrations of soluble reactive phosphorus, TP, nitrate and TN were observed downstream of the Warsaw Wastewater 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 wastewater 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 (26.2% of the total P load, Table 12) in this segment. Simulation of upgrading all Oatka WWTPs to a tertiary treatment system resulted in a 24.9% reduction in total phosphorus loading (13,477 kg P/yr to 10,117 kg P/yr; Table 19). Upgrading WWTPs also reduced the average phosphorus concentration from 51.6  $\mu\text{g P/L}$  to 38.8  $\mu\text{g P/L}$  (24.8% reduction) at the main outlet point at Garbutt. From the OCSWAT analysis, upgrading the Warsaw WWTP 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. In summary, the most effective simulated BMPs in the Warsaw segment were stream bank stabilization to combat stream bank erosion and the upgrade of the secondary WWTP at Warsaw to tertiary treatment.

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

The Ellicott Road main stem segment represented the middle main stem reach of Oatka Creek (Fig. 2). Total annual and areal TSS load decreased from the upstream main stem site at Warsaw to the downstream middle main stem site at Ellicott [Total annual load –TSS: -51.4% from Warsaw to Ellicott; Total areal load – TSS: Warsaw (658.6) to Ellicott (167.2 kg/ha/yr)] (Table 14), suggesting sequestering of suspended solids as sediment: that is, settling of sediment and nutrients in this segment. One tributary (Wyoming Road) (Fig. 2) enters the main stem segment just upstream from the Pavilion WWTP. The largest tributary areal loads for SRP, TP, nitrate, TN, and TSS were observed for the Wyoming Road tributary (Table 14), indicating major source areas upstream in this subwatershed. 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 (Figs. 33 and 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. There were significant increases in nutrients (nitrate: +201 %; TN: +110%) (Fig. 42) from a site upstream of Logwell Acres to a site below the CAFO. 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 macroinvertebrate communities (Burkholder *et al.* 2007). Similarly, Bowhill Farms (285 head of cattle) (Fig. 42) had large increases in nitrate (+ 646%) and TN (Bowhill Farms: + 75%) 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: 311 g/ha/yr; TP: 1,098 g/ha/yr; nitrate: 27.7 kg/ha/yr; TN: 34.5 kg/ha/yr; TSS: 692.4 kg/ha/yr; Table 14), management efforts should be focused on nonpoint source areas.

Two WWTPs are downstream from the Warsaw WWTP but upstream from the Garbutt USGS station (Pavilion WWTP and Leroy WWTP) (Fig. 2). Significantly (Wilcoxon: 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 also very high (Table 18). Being the smallest of all four waste treatment plants, Pavilion only contributes roughly 168 kg P/yr; Leroy is the largest of the treatment plants in Oatka Creek contributing 2,146 kg P/yr. Similar to the Warsaw WWTP, the Leroy and Pavilion WWTPs are point sources for SRP, TP, nitrate, and TN. The Warsaw WWTP is an activated sludge system. 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), was accomplished with the OCSWAT model. Of the four WWTPs in the Oatka Creek watershed, the Pavilion WWTP has the lowest discharge into the Oatka Creek. 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 CAFOs. 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 (18.1% reduction)](Table 19). When application is limited to 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 implementation will have a significant impact on the Wyoming Road watershed. 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 implementing grassed waterways 290 m long by 37 m wide reduced runoff and sediment transport by 87 to 93%, respectively. The Bracmort (2006) study also indicated that high runoff periods existed from February through April, as with most watersheds. Over 70% of the total outflow was due to storm events (Bracmort *et al.* 2006), which suggests management efforts should 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 kg P/yr to 13,043 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 main stem segment at Garbutt (Fig. 2) is also the second USGS gauging station location on the creek (Fig. 2). Two weekly sampling tributary segments are located upstream from Garbutt (Roanoke Road and Parmalee Road) (Fig. 2) but downstream from the middle main stem segment at Ellicott. When compared to other sites, total annual loads were lowest (Table 14a) at the Parmalee Road tributary, suggesting that a minimal contribution of nutrients and sediment was discharged from the tributary. The Roanoke Road tributary had high areal SRP (306 g/ha/yr), TP (1098 g/ha/yr), nitrate (11.3 kg/ha/yr), TN (13.7 kg/ha/yr), and TSS (261.7 kg/ha/yr) loads, indicating areas of concern upstream from the sampling site on Roanoke Road (Table 14b). The Garbutt segment, excluding the Parmalee Road and Roanoke Road tributaries (Fig. 2), accounted for 28% of the SRP and 36% of the TP load, suggesting other sources of nutrients and soil.

In the Roanoke Road subwatershed of Oatka Creek, a medium-sized (1830 ha) CAFO site with 1175 cattle (Barniak Farms) exists (Fig. 44). The Barniak Farm CAFO appears to be a source for nutrients as concentrations are very high just below the farm (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 for coliform bacteria (64,000 CFU/100 mL) (Figs. 44 and 45). When compared to subwatershed 2b, Site D (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).

Barniak Farms CAFO site is a cause for nutrient runoff in the Roanoke subwatershed whose remediation was simulated with the OCSWAT 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 may be 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%) were 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.

A secondary WWTP 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 (Wilcoxon, p-value < 0.05) below the Scottsville WWTP during baseline conditions (Table 18). 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 OCSWAT model to remove all WWTPs in Oatka Creek solved this issue by reducing TP loads by 25.0% (Table 19).

Excluding the four WWTPs, 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 (NYSDEC 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 410% increase in SRP concentrations and a 193% 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 pipes 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 communication: Alan Mack, manager of the Caledonia Fish Hatchery).

In the OCSWAT model, the Caledonia Fish Hatchery was indicated as a source 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 WWTPs, 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- $\mu\text{g P/L}$  level, and the 20  $\mu\text{g P/L}$  is not feasibly attainable unless all human presence is removed. A 45- $\mu\text{g P/L}$  target in the OCSWAT model was attained in nine different management strategies. For example, upgrading all four secondary WWTPs to tertiary plants resulted in a 24.9% reduction in total annual TP load, lowering the average TP concentration from 51.6 to 38.8  $\mu\text{g P/L}$  (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 kg P/yr (18.1% reduction) and lowered the TP concentration to 42.3  $\mu\text{g P/L}$  (18.0% reduction)(Table 19).

Combined management, a utilization of several BMPs, also attained the 45- $\mu\text{g P/L}$  concentration target goal. The most vigorous implementation included upgrading all four WWTPs and implementing 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  $\mu\text{g P/L}$ ). 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- $\mu\text{g P/L}$  concentration target for Garbutt and the entire watershed was reached with [45 Target Scenario (2)] adequately reducing TP load (13,477 to 11,068 kg P/yr: 17.9% reduction) and concentration (51.6  $\mu\text{g P/L}$  to 44.3  $\mu\text{g P/L}$ : 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  $\mu\text{g P/L}$  [14.0% reduction (Table 19)].

### ***Conclusions and Recommendations***

Oatka Creek is the second largest tributary of the Genesee River and is a highly prized trout fishery. 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), all anthropogenic sources, accounts for ~70% of the phosphorus load of Oatka Creek (Figs. 58 and 59), suggesting improvements in stream water quality are possible. The Oatka Creek portion of the Genesee River Project Study focused on identifying nonpoint and point sources, locating and quantifying the nutrient and sediment losses from Oatka Creek watershed, and through simulation identifying possible remediation or management practices. A water quality target of 45- $\mu\text{g P/L}$  for phosphorus stream concentration is the most logical target for Oatka Creek as the stream is below the 65- $\mu\text{g P/L}$  proposed target (modeled concentration: 51.6  $\mu\text{g P/L}$ ) and would allow for attainable management practices. The most effective management recommendation to reduce the overall TP loading in Oatka Creek is to upgrade all four wastewater treatment plants (Warsaw, Pavilion, Leroy and Scottsville) to tertiary treatment systems. Other effective management recommendations focused on nonpoint sources 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. Either or both practices together would significantly improve the water quality in the Oatka Creek watershed by reducing the average annual P concentration to below the 45- $\mu\text{g P/L}$  target. Portions of the creek are experiencing stream bank soil erosion. Stream bank stabilization techniques, some already implemented, would have a beneficial impact on reducing the TP and TSS loading in this segment of Oatka Creek. By making remediation recommendations, not only will the water quality of Oatka Creek improve significantly, but it will also 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.

### *Literature Cited*

- 3M. 2010. Petrifilm coliform count plate: interpretation guide. St. Paul, MN. USA. Available at: [http://multimedia.3m.com/mws/mediawebserver?mwsld=66666UuZjcFSLXt4XMa4XM\\_EVuQEcuZgVs6EVs6E666666--&fn=70-2008-4573-6.pdf](http://multimedia.3m.com/mws/mediawebserver?mwsld=66666UuZjcFSLXt4XMa4XM_EVuQEcuZgVs6EVs6E666666--&fn=70-2008-4573-6.pdf). Accessed 17 April 2011.
- Al-Kaisi, M. 2008. Soil Erosion, Crop Productivity and Cultural Practices. Iowa State University Extension. Available at: <http://www.extension.iastate.edu/Publications/PM1870.pdf>. Accessed 18 June 2011.
- American Society of Agricultural Engineers (ASAE). 1988. D384.1: Manure production and characteristics. St. Joseph, Mich:ASAE.
- APHA. 2005. Standard Methods for the Examination of Water and Wastewater. Twenty-First Edition. Washington D.C., USA.
- Arabi, M., J.R. Frankenberger, B.A. Engel and J.G. Arnold. 2007. Representation of agricultural conservation practices with SWAT. Hydrological Processes 2007.
- Arnold, J.G., J.R. Kiniry, R. Srinivasan, E.B. Haney and S.L. Neitsch. 2010. Soil and water assessment tool input/output file documentation. Texas Water Resources Institute Technical Report No. 365. Texas A&M University System. College Station, Texas 77843.
- Blanco-Canqui, H., C. J. Gantzer., S.H. Anderson., E.E. Alberts and A.L. Thompson. 2003. Grass barrier and vegetative filter strip effectiveness in reducing runoff, sediment, nitrogen, and phosphorus loss. Soil Science Society of America 68(5): 1670-1678.
- Bond, P.L., R. Erhart, M. Wagner, J. Keller and L. L. Blackall. 1999. Identification of some of the major groups of bacteria in efficient and nonefficient biological phosphorus removal activated sludge systems. Appl. Environ. Microbiol. 65(9): 4077-4084.
- Bracmort, K. S., M. Arabi, J.R. Frankenberger, B. A. Engel and J.G. Arnold. 2006. Modeling long-term water quality impact of structural BMPs. American Society of Agricultural and Biological Engineers 49 (2): 367-374.
- Braskerud, B.C. 2002. Factors affecting phosphorus retention in small constructed wetlands treating agricultural non-point source pollution. Ecological Engineering (19): 41-61.
- Burkholder, J., B. Libra, P. Weyer, S. Heathcote, D. Kolpin, P.S. Thorne and M. Wichman. 2007. Impacts of waste from concentrated animal feeding operations on water quality. Environmental Health Perspectives (115): 308-312.
- Cain, K.D., and D. L. Garling. 1995. Pretreatment of soybean meal with phytase for salmonid diets to reduce phosphorus concentrations in hatchery effluents. 57(2):114-119.
- Chern, J.A., S.R. Chou and C.H. Shang. 2001. Effects of impurities on oxygen transfer rates in diffused aeration systems. Water Research. 35(13): 3041-3048.
- Cornell Cooperative Extension. 2010. 2010 Cornell Guide for Integrated Field Crop Management: downloaded 6/2011 from <http://ipmguidelines.org/FieldCrops/default.asp>.
- Dorioz, J.M., D. Wang., J. Poulénard and D. Trevisan. 2006. The effect of grass buffer strips on phosphorus dynamics - A critical review and synthesis as a basis for application in agricultural landscapes in France. Agriculture, Ecosystems and Environment 117: 4-21.
- Eghball, B., B. J. Wienhold., J. E. Gilley and R. A. Eigenberg. 2002. Mineralization of manure nutrients. Journal of Soil and Water Conservation 57(6): 470-473.

- Ellis, K.V. 1987. Slow sand filtration as a technique for the tertiary treatment of municipal sewages. *Water Research* 21(4): 403-410.
- Fiener, P. and K. Auerswald. 2006. Seasonal variation of grassed waterway effectiveness in reducing runoff and sediment delivery from agricultural watersheds in temperate Europe. *Soil and Tillage Research* 87(1): 48-58.
- Frankenberger, J.R., E.S. Brooks., M.T. Walter., M.F. Walter and T.S. Steenhuis. 1999. A GIS-based variable source area hydrology model. *Hydrological Process* 13:805-822.
- Genesee/Finger Lakes Regional Planning Council. 2010. Genesee - Finger Lakes regional blueway analysis: An inventory and description of blueway opportunity areas in the Genesee - Finger Lakes region. New York State Department of State Division of Coastal Resources, Town of Wheatland, USA. Available at: <http://www.gflrpc.org/Publications/Blueways/Report/CoverTOC.pdf>. Accessed 13 July 2011.
- Haith, D.A. 1975. Land use and nutrient export in rural watersheds tributary to Cayuga Lake. In: *Influence of land development and land use patterns on water quality*. (G.D. Gates and D.A. Haith, eds.) PB 248071. NTIS.
- Julien, P. Y. 2010. *Erosion and Sedimentation*. Second Edition. Cambridge University Press. The Edinburgh Building, Cambridge, United Kingdom.
- Li, M.H. and K.E. Eddleman. 2002. Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach. *Landscape and Urban Planning* 60: 225-242.
- Limnotech Inc. 2006. Upper River Rouge subwatershed in Farmington Hills: stream bank erosion inventory report. [Online]. Limnotech. Ann Arbor, MI. Available at: [http://www.rougeriver.com/pdfs/stream bank/RVIB22%20OCDC%20Stream bank%20Erosion%20Inventory%20Final%20Report.pdf](http://www.rougeriver.com/pdfs/stream%20bank/RVIB22%20OCDC%20Stream%20bank%20Erosion%20Inventory%20Final%20Report.pdf).
- Makarewicz, J.C. and T.W. Lewis. 1994. Stress stream analysis of a sub-watershed of Conesus Lake: South McMillian Creek. Report # 97, Livingston County Planning Department, New York, USA.
- Makarewicz, J.C. and T.W. Lewis. 2004a. Segment analysis of Oatka Creek. Report #192, Soil and Water Conservation Districts of Genesee and Wyoming Counties, New York, USA.
- Makarewicz, J.C. and T.W. Lewis. 2004b. Segment analysis of Oneida Creek the location of sources of pollution. Report # 193, Central New York Regional Planning and Development Board, New York, USA.
- Makarewicz, J.C. and T. Howell. 2007. Lake Ontario intensive year – 2008: The Lake Ontario coastal zone - status and assessment. LOLA Workshop, International Joint Commission. Kingston, Ontario.
- Makarewicz, J.C., T.W. Lewis, I. Bosch, M.R. Noll, N. Herendeen, R.D. Simon, J. Zollweg and A. Vodacek. 2009. The impact of agricultural best management practices on downstream systems: soil loss and nutrient chemistry and flux to Conesus Lake, New York, USA. *J. Great Lakes Res.* 35: 23-36.
- Makarewicz, J.C., T.W. Lewis and D. Pettenski. 2009a. Stream water quality assessment of Long Point Gully, Graywood Gully, and Sand Point Gully: Conesus Lake Tributaries Spring 2012. Livingston County Planning Department, New York, USA.
- Makarewicz, J.C., W.G. Booty and G. Bowen. 2012. Tributary loading of phosphorus to Lake Ontario. *J. Great Lakes Res.* 38(supplement): 14–20.

- Makarewicz, J. C., T.W. Lewis, B. Snyder, M.J. Winslow, D. Pettenski, E. Rea, L. Dressel and W.B. Smith. 2013a. Genesee River Watershed Project. Volume 1. Water Quality Analysis of the Genesee River Watershed: Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model. A report to the USDA. Technical Reports. Paper 124. [http://digitalcommons.brockport.edu/tech\\_rep/124](http://digitalcommons.brockport.edu/tech_rep/124)
- Makarewicz, J. C., T.W. Lewis, B. Snyder and W.B. Smith. 2013b. Genesee River Watershed Project. Volume 2. Water Quality Analysis of the Upper Genesee River Watershed: Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model. A report to the USDA. Technical Reports. Paper 125. [http://digitalcommons.brockport.edu/tech\\_rep/125](http://digitalcommons.brockport.edu/tech_rep/125)
- Makarewicz, J.C., T.W. Lewis and B. Snyder. 2013c. "Genesee River Watershed Project. Volume 3. Water Quality Analysis of the Honeoye Creek Watershed: Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model. A report to the USDA. Technical Reports. Paper 126. [http://digitalcommons.brockport.edu/tech\\_rep/126](http://digitalcommons.brockport.edu/tech_rep/126)
- Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands. Third Edition. John Wiley & Sons, Inc. Canada.
- Morgan, R.P.C. 2005. Soil Erosion & Conservation. Third Edition. Blackwell Publishing. Malden, Massachusetts, USA.
- Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L. Binger, R.D. Harmel and T.L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. ASABE 50: 885-900.
- Narasimhan, B., P.M. Allen, R. Srinivasan, S.T. Bednarz, J.G. Arnold and J.A. Dunbar. 2007. Stream bank erosion and best management practice simulation using SWAT. In: Proceedings of 4th conference on Watershed management to meet water quality standards and TMDLs, San Antonio. ASABE publication # 701P0207.
- Neitsch, S.L., J.G. Arnold, J.R. Kinery, R. Srinivasan and J.R. Williams. 2002. Soil and water assessment tool – user’s manual – version 2000. Grassland, Soil and Water Research Laboratory, Agricultural Research Service and Blackland Research Center, Texas Agricultural Experiment Station, Temple, Texas.
- Nichols, D. 1983. Capacity of natural wetlands to remove nutrients from wastewater. Water Pollution Control Federation 55 (5): 495-505.
- NOAA-NWS (National Oceanic and Atmospheric Administration: National Weather Service). 2011. Climate Data. [Online]. Available at: <http://lwf.ncdc.noaa.gov/oa/climate/stationlocator.html>
- NYDEC (New York State Department of Environmental Conservation). 2006. SPDES multisector general permit for stormwater discharges associated with industrial activity. NYS Department of Environmental Conservation, New York, USA. Available at: [http://www.dec.ny.gov/docs/water\\_pdf/gp0601.pdf](http://www.dec.ny.gov/docs/water_pdf/gp0601.pdf). Accessed 18 June 2011.



- Ontario: Ministry of Agriculture, Food, and Rural Affairs. 1987. Soil Erosion - Causes and Effects: Factsheet. Queens printer for Ontario. Ontario, Canada. Available at: <http://www.omafra.gov.on.ca/english/engineer/facts/87-040.html>. Accessed 13 July 2011.
- Pettenski, D., J.C. Makarewicz and T. W. Lewis. 2013. Genesee River Watershed Project. Water Quality Analysis of the Oatka Creek Watershed. Volume 6. Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model. A report to the USDA. Technical Reports. Paper 129. [http://digitalcommons.brockport.edu/tech\\_rep/129](http://digitalcommons.brockport.edu/tech_rep/129)
- Rea, E., J.C. Makarewicz and T. W. Lewis. 2013. Genesee River Watershed Project. Volume 5. Water Quality Analysis of the Canaseraga Creek Watershed Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model. A report to the USDA. Technical Reports. Paper 128. [http://digitalcommons.brockport.edu/tech\\_rep/128](http://digitalcommons.brockport.edu/tech_rep/128)
- Richards, P., T.W. Lewis, J.C. Makarewicz and J. Zollweg. 2010a. The Oak Orchard Soil Water Assessment Tool: A decision support system for watershed management, FINAL REPORT, Departments of Earth Science and Environmental Science & Biology at the College at Brockport, Brockport NY.
- Richards, P., J.L. Libby, A. Kuhl, T. Daniluk and M. Lyzwa. 2010b. Prediction of areas sensitive to fertilizer in thinly soiled Karst, FINAL REPORT, New York State Water Resources Institute. <http://wri.eas.cornell.edu/grants.html>
- Ruiz, R. G. and G. H. Hall. 1996. Phosphorus fractionation and mobility in the food and faeces of hatchery reared rainbow trout (*Onchorhynchus mykiss*). *Aquaculture* 145(1-4): 183-193.
- Santhi, C., J.G. Arnold., J.R. Williams, W.A. Dugus, R. Srinivasan and L.M. Hauck. 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. *Journal of the American Water Resources Association* 37(5): 1169-1188.
- Sims, J.T., R.R. Simard and B.C. Joern. 1998. Phosphorus loss in agricultural drainage: Historical perspective and current research. *Journal of Environmental Quality* 27:277-293.
- Steeves, M. 2002. The EPA's proposed CAFO regulations fall short of ensuring the integrity of our nations waters. *J. Land Resources & Environ. L.* 22:367-397.
- Takakis, T.A. 2002. State of the Basin Report: The Oatka Creek Watershed. Rochester Area Community Foundation, Rochester, New York, USA. Available at: <http://www.oatka.org/Reports/StateofBasin.pdf>. Accessed 4 June 2010.
- The Oatka Creek Watershed Committee. 2001. Improving Water Quality in Monroe County. USGS, Monroe County, New York, USA. Available at: <http://ny.water.USGS.gov/pubs/jrn/ny3022/jrn01-r00155n.pdf>. Accessed 4 June 2010.
- Tuppad, P., N. Kannan, R. Srinivasan, C. Rossi and J. Arnold. 2010. Simulation of agricultural management alternatives for watershed protection. *Water Resour. Manage.*; Online. USDA-NASS (United States Department of Agriculture-National Agricultural Statistics Service). 2010. 2010 Cropland Data Layer (CDL). [Online]. Available at: <http://www.nass.usda.gov/research/Cropland/SARS1a.html>.

- USDA-NRCS (United States Department of Agriculture-National Resources Conservation Service). 2006. United States General Soil Map: State Soil Geographic Database (STATSGO). [Online]. Available at: <http://soildatamart.nrcs.usda.gov/USDGSM.aspx>
- USEPA (United States Environmental Protection Agency). 2007. Advanced wastewater treatment to achieve low concentration of phosphorus. EPA Report; 910-R-07-002. Seattle, Washington, USA.
- USEPA (United States Environmental Protection Agency). 2011. Water Discharge Permits (WDPS). Washington D.C., Maryland, USA.
- USGS-MRLC: Multi-Resolution Land Characteristics Consortium . 2006. National Land Cover Database 2006. [Online]. Available at:[http://www.mrlc.gov/nlcd06\\_data.php](http://www.mrlc.gov/nlcd06_data.php).
- USGS. 2010a. National Water Information System: Web Interface. Available at: <http://waterdata.USGS.gov/ny/nwis/rt>. Accessed 18 November 2010.
- USGS (USGS). 2010b. Seamless Data Warehouse: Digital Elevation Model (DEM). [Online]. Available at: <http://seamless.USGS.gov/ned13.php>.
- USGS. 2011. Multi-Resolution Land Characteristics Consortium (MRLC): NLCD 2006 Provisional Products and Supplementary Layers. Available at: [http://www.mrlc.gov/nlcd2006\\_downloads.php](http://www.mrlc.gov/nlcd2006_downloads.php). Accessed 11 August 2011.
- USGS (United States Geological Survey). 2012. Groundwater quality in the Genesee River Basin, New York, 2010. Open-File Report 2012-1135.
- Wing, S., S. Freedman and L. Band. 2002. The potential impact of flooding on confined animal feeding operations in Eastern North Carolina. *Environmental Health Perspectives* 110: 387-391.
- Winslow, M. J., J.C. Makarewicz and T. W. Lewis. 2013. Genesee River Watershed Project. Water Quality Analysis of the Black Creek Watershed. Volume 4. Nutrient Concentration and Loading, Identification of Point and Nonpoint Sources of Pollution, Total Maximum Daily Load, and an Assessment of Management Practices using the Soil Water Assessment Tool (SWAT) Model. A report to the USDA. Technical Reports. Paper 127. [http://digitalcommons.brockport.edu/tech\\_rep/127](http://digitalcommons.brockport.edu/tech_rep/127)
- Zhu, J.C., C.J. Gantzer, S.H. Anderson, E.E. Alberts and P.R. Beuselinck. 1988. Runoff, soil, and dissolved nutrient losses from no-till soybean with winter cover crop. *Soil Science Society of America* 53(4): 1210-1214.

Table 1. Wastewater Treatment Plants (WWTP) located in the Oatka Creek watershed (Fig. 2).

WWTP Site	Location	Contact #	SPDES #	Daily Maximum Discharge (m <sup>3</sup> /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. Location of weekly field sampling locations in the Oak Orchard Creek watershed (Fig. 2).

Site	Latitude	Longitude
Garbutt USGS (Union Street)	43.01025 <sup>o</sup>	-77.79169 <sup>o</sup>
Parmalee Road	43.01498 <sup>o</sup>	-77.97026 <sup>o</sup>
Roanoke Road	42.94206 <sup>o</sup>	-78.05186 <sup>o</sup>
Ellicott Road	42.88100 <sup>o</sup>	-78.02925 <sup>o</sup>
Wyoming Road	42.84858 <sup>o</sup>	-78.04319 <sup>o</sup>
Warsaw USGS (Court Street)	42.733493 <sup>o</sup>	-78.133399 <sup>o</sup>
Evans Road	42.68447 <sup>o</sup>	-78.10132 <sup>o</sup>
Buck Road	42.72795 <sup>o</sup>	-78.16161 <sup>o</sup>

Table 3. Analytical methods employed in this study.

<b>Analyte</b>	<b>Standard Method</b>
Total Phosphorus (TP)	(APHA 2005) 4500-P B.#5 Persulfate Digestion Method
Soluble Reactive Phosphorus (SRP)	(APHA 2005) 4500-P F. Automated Ascorbic Acid Reduction Method
Total Suspended Solids (TSS)	(APHA 2005) 2540 D. Dried TSS 103 to 105°C
Total Nitrogen (TN)	(APHA 2005) 4500-N C. Persulfate Method
Nitrate-Nitrite (NO <sub>3</sub> + NO <sub>2</sub> )	(APHA 2005) 4500-NO <sub>3</sub> <sup>-</sup> F. Automated Cadmium Reduction Method
Total Coliform	(3M 2010). 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. SRP = Soluble reactive phosphorous, TP = Total phosphorus, TN = Total nitrogen and TSS = Total suspended solids.

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	Manure applied (kg)	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. Monthly regression equations determining the amount of water added from the Karst topography in the Oatka Creek watershed. The (x) represents the average flow measured at the USGS monitoring station at Garbutt, NY while the (y) represents karst water input. See text for details.

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. Comparison of OCSWAT generated total suspended solid (TSS) loads to the observed (measured) TSS loads at eight monitoring locations in the Oatka watershed (1 June 2010 through 31 May 2011). M= main stem, T = Tributary, MT = Metric tons, PBIAS = percent bias.

Site	Watershed Area (ha)	Observed TSS (MT/yr)	Simulated TSS (MT/yr)	PBIAS (%)
Evans Road (M)	1,731	292.1	284.2	-2.7
Warsaw (M)	8,793	5,791.0	6,531.8	12.8
Ellicott Road(M)	13,366	2,811.8	1,962.7	-30.2
Garbutt (M)	19,074	4,969.6	5,094.1	2.5
Buck Road (T)	2,121	370.9	457.2	23.3
Wyoming Road (T)	3,456	2,393.1	2,335.8	-2.4
Roanoke Road (T)	2,293	600.0	780.6	30.1
Parmalee Road (T)	4,016	73.9	70.7	-4.3

Table 10. Comparison of OCSWAT generated P loads to the observed (measured) P loads at eight monitoring locations in the Oatka watershed (1 June 2010 through 30 May 2011). M= main stem, T = Tributary, MT = Metric tons. PBIAS = percent bias. TP = Total phosphorus.

Site	Watershed Area (ha)	Observed TP (kg/yr)	Simulated TP (kg/yr)	PBIAS (%)
Evans Road (M)	1,731	787.2	657.9	-16.4
Warsaw (M)	8,793	5,230.9	5,079.9	-2.9
Ellicott Road(M)	13,366	9,210.8	6,923.1	-24.8
Garbutt (M)	19,074	15,017.6	13,477.4	-10.3
Buck Road (T)	2,121	840.9	815.0	-3.0
Wyoming Road (T)	3,456	3,792.5	4,115.0	8.5
Roanoke Road (T)	2,293	2,012.0	2,347.0	16.7
Parmalee Road (T)	4,016	215.2	270.5	25.7



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

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

Table 12. Annual allocation of total phosphorus (TP) per source based on Oatka Creek SWAT model simulation (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	<0.1	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
<b>Sum of Allocated Loads</b>	12,861		
<b>Total Predicted Load (From SWAT)</b>	13,477		
<b>Allocation Error</b>	-616		

Table 13. Event versus nonevent SRP, TP, nitrate, TN, and TSS concentrations and total coliform abundance at all weekly sampling locations in the Oatka watershed (June 2010 through May 2011) (Fig. 2). SRP = Soluble reactive phosphorus, TP = Total phosphorus, TN = Total nitrogen and TSS = Total suspended solids.

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

Table 14. A. Total annual load (kg/yr) (1 June 2010 to 7 June 2011) of nutrients and sediments at four main stem segments (M) and four tributary (T) watersheds of the Oatka Creek watershed. B. Total annual areal load for nutrients and sediments (kg/ha/yr or g/ha/yr) at four main stem (M) and four tributary (T) segments/subwatersheds of the Oatka Creek watershed. See Figure 2 for a map showing the segments. SRP = Soluble reactive phosphorus, TP = Total phosphorus, TN = Total nitrogen and TSS = Total suspended solids. In parentheses is the percent (%) contribution of the given reach to the total watershed load at Garbutt, NY. Areas represent the area of the entire reach or segment. For example, the Ellicott reach is the combined area of the Ellicott Road reach plus the Wyoming Road tributary and extends from.

<b>A. Total Annual Load (kg/yr)</b>						
Site	Area (ha)	SRP	TP	Nitrate	TN	TSS
Parmalee Road (T)	4,016	47 (0.83%)	215 (1.43%)	11,878 (2.13%)	16,263 (2.40%)	73,900 (1.48%)
Roanoke Road (T)	2,293	702 (12.46)	2,012 (13.40)	19,511 (3.50)	31,366 (4.63)	600,035 (11.98)
Wyoming Road(T)	3,456	1,075 (19.08)	3,793 (25.26)	95,864 (17.22)	119,139 (17.58)	2,393,098 (47.80)
Buck Road (T)	2,121	169 (3.00)	841 (5.60)	23,917 (4.30)	29,137 (4.30)	370,903 (7.41)
Evans Road Reach (M)	1,731	201 (3.57)	787 (5.24)	17,538 (3.15)	22,658 (3.34)	292,147 (5.83)
Warsaw Reach (M)	8,793	592 (10.51)	5,231 (34.83)	114,164 (20.51)	139,828 (20.64)	5,791,046 (155.66)
Ellicott Road Reach (M)	16,822	3,314 (58.81)	9,211 (61.33)	268,733 (48.27)	316,487 (46.71)	2,811,827 (56.16)
Garbutt Reach (M)	26,013	5,635	15,018	556,686	677,504	5,006,876
Entire Watershed	55,590					
<b>B. Areal Load</b>						
Site	Area (ha)	SRP (g/ha/yr)	TP (g/ha/yr)	Nitrate (kg/ha/yr)	TN (kg/ha/ yr)	TSS (kg/ha/yr)
Parmalee Road (T)	4,016	12	54	3.0	4.0	18.4
Roanoke Road (T)	2,293	306	877	8.5	13.7	261.7
Wyoming Road(T)	3,456	311	1098	27.7	34.5	692.4
Buck Road (T)	2,121	80	397	11.3	13.7	174.9
Evans Road Reach (M)	1,731	116	455	10.1	13.1	168.8
Warsaw Reach (M)	8,793	67	595	13.0	15.9	658.6
Ellicott Road Reach (M)	16,822	197	548	16.0	18.8	167.2
Garbutt Reach(M)	26,013	217	577	21.4	26.0	192.5
Entire Watershed	55,590					

Table 15. Results from the erosion inventory of a portion of the Oak Orchard Creek watershed 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	27.3%
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, kg/season), total phosphorus (TP, kg P/season), nitrate (kg N/season), total nitrogen (TN, kg N/season) and total suspended solid (TSS, kg/season) 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. Chemistry results from two locations (George Street) on Spring Creek between Mumford, NY near the Genesee Country Village (site 1) on 12 July 2010. SRP = Soluble reactive phosphorous, TP = Total phosphorus, TN = Total nitrogen and TSS = Total suspended solids.

	SRP ( $\mu\text{g P/L}$ )	TP ( $\mu\text{g P/L}$ )	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	2.10	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 Wastewater Treatment Plants (WWTP). Distances samples were taken above and below the WWTP are listed. Asterisk represents a Wilcoxon statistical test was conducted. SRP = Soluble reactive phosphorous, TP = Total phosphorus, TN = Total nitrogen and TSS = Total suspended solids.

Wastewater Treatment Plant (WWTP)		SRP ( $\mu\text{g P/L}$ )	TP ( $\mu\text{g P/L}$ )	Nitrate (mg N/L)	TN (mg N/L)	TSS (mg/L)	Total Coliform (CFU/100mL)
Above Warsaw WWTP	820m	1.1 $\pm$ 0.24*	7.9 $\pm$ 0.39*	0.82 $\pm$ 0.01*	1.02 $\pm$ 0.02	3.10 $\pm$ 0.52	7875 $\pm$ 550
Below Warsaw WWTP	1,200m	138.4 $\pm$ 1.55*	148.7 $\pm$ 3.68*	1.58 $\pm$ 0.01*	1.95 $\pm$ 0.04	2.25 $\pm$ 0.59	13050 $\pm$ 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 $\pm$ 0.41*	40.6 $\pm$ 0.46	1.14 $\pm$ 0.01*	1.62 $\pm$ 0.03	2.72 $\pm$ 0.37	725 $\pm$ 111
Below Leroy WWTP	1,600m	64.9 $\pm$ 0.42*	84.3 $\pm$ 0.52	1.23 $\pm$ 0.00*	1.79 $\pm$ 0.02	1.66 $\pm$ 0.24	850 $\pm$ 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 $\pm$ 0.19	40.2 $\pm$ 0.52	1.30 $\pm$ 0.01*	1.60 $\pm$ 0.01	4.30 $\pm$ 0.49	250 $\pm$ 96
Below Pavilion WWTP	190m	21.0 $\pm$ 0.71	45.2 $\pm$ 0.83	1.40 $\pm$ 0.00*	1.70 $\pm$ 0.01	2.60 $\pm$ 0.33	1725 $\pm$ 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 $\pm$ 0.27	55.0 $\pm$ 1.87	2.10 $\pm$ 0.02	2.53 $\pm$ 0.02	11.88 $\pm$ 0.28	4875 $\pm$ 225
Below Scottsville WWTP	200m	28.7 $\pm$ 0.32	62.4 $\pm$ 5.01	2.13 $\pm$ 0.04	2.27 $\pm$ 0.01	11.22 $\pm$ 0.63	6600 $\pm$ 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. Results of simulated 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 total phosphorus (TP) and total suspended solids (TSS) loading in the stream channel. Kg = kilograms, µg = micrograms, MT = metric tons. Target Scenario 45 #1 = Upgrading all four WWTPs, grassed waterways and buffer strips to the entire watershed. Target Scenario 45 #2 = Cover crops to entire watershed and grassed waterways/buffer strips to Wyoming Road and Roanoke tributaries. Target Scenario 45 #3 = cover crops and buffer strips to the entire watershed. Target Scenario 45 #4 = grassed waterways to entire watershed. Target Scenario 45 #5 = Remove all SPDES sources.

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
Target Scenario 45 #1	6,028	55.3	29.6	42.6	5114	-0.4
Target Scenario 45 #2	11,068	17.9	44.3	14.1	5191	-1.9
Target Scenario 45 #3	11,493	14.7	44.4	14.0	5165	-1.4
Target Scenario 45 #4	9,847	26.9	37.7	26.9	5,094	0.0
Target Scenario 45 #5	11,043	18.1	42.3	18.0	5,315	-4.3

Table 20. Agricultural management scenarios simulated with OCSWAT on the Evans Road and Wyoming Road subwatersheds. Percentage values represent TP load reductions 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. Annual and areal tributary total phosphorus (TP) loading to Lake Ontario from New York watersheds of differing dominant land uses. Adapted from Makarewicz *et al.* (2013), Winslow *et al.* (2013), Rea *et al.* (2013).

Tributary	Dominant Landuse	TP Load (Mton/yr)	Area (ha)	Areal Load (kg P/ha/yr)
Oak Orchard	Agriculture	38.29	36,989	1.04
Golden Hill Creek	Agriculture	5.28	5,973	0.88
Wolcott Creek	Agriculture	6.04	4,416	1.37
Johnson Creek	Agriculture/Suburban	13.87	25,530	0.54
Salmon River	Agriculture/Forested	14.0	61,642	0.23
Irondequoit Creek	Sewage Treatment	23.0	43,771	0.53
Northrup Creek	Urban	4.50	1,863	2.42
Buttonwood Creek	Suburban	1.31	2,308	0.57
Larkin Creek	Suburban	0.80	3,132	0.26
First Creek	Forested	0.08	800	0.10
Clark Creek	Forested	0.03	155	0.21
Bobolink Creek	Forested	0.00	278	0.01
Black Creek Watershed				
Bigelow Creek	Agriculture (82%)	2.93	2,616	1.12
Upper Black Creek	Agriculture (82%)	6.93	11,784	0.59
Spring Creek	Agriculture (96%)	4.3	5,542	0.78
Middle Black Creek	Agriculture (76%)	13.8	22,262	0.30
Lower Black Creek	Agriculture (63%)	16.5	15,021	0.18
Honeoye Creek	Agriculture (43%)/Forest(39%)	14.7	69,478	0.21
Upper Genesee River	Agriculture (37%)/Forest(57%)	230.0	254,842	0.90
Canaseraga Creek	Agriculture (49.8%)/Forest (44.4%)	58.9	89,240	0.66
Oatka Creek	Agriculture (69.5%)/Forest (20.4%)	14.6	55,590	0.26



Table 22. Main stem total phosphorus (TP) and total suspended solid (TSS) concentrations based on measured (observed) values, OCSWAT generated “base” model simulation, and OCSWAT generated natural forested simulation.

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

Sample	TP ( $\mu\text{g P/L}$ )	Address	Depth of Well (ft)
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 ( $\mu\text{g P/L}$ )	22.1		

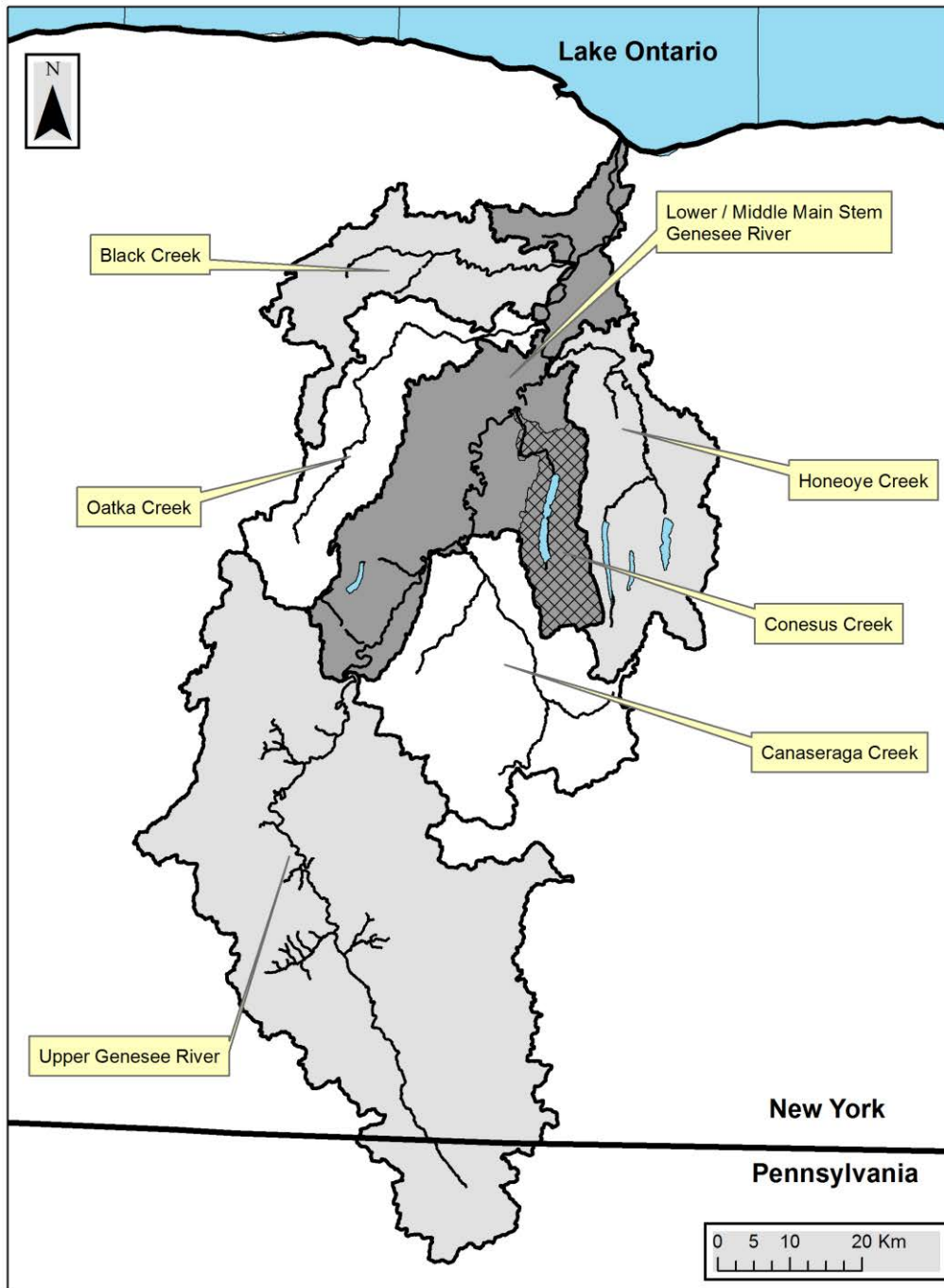


Figure 1. Genesee River watershed along with the major tributaries (Black Creek, Oatka Creek, Canaseraga Creek, Honeoye Creek)

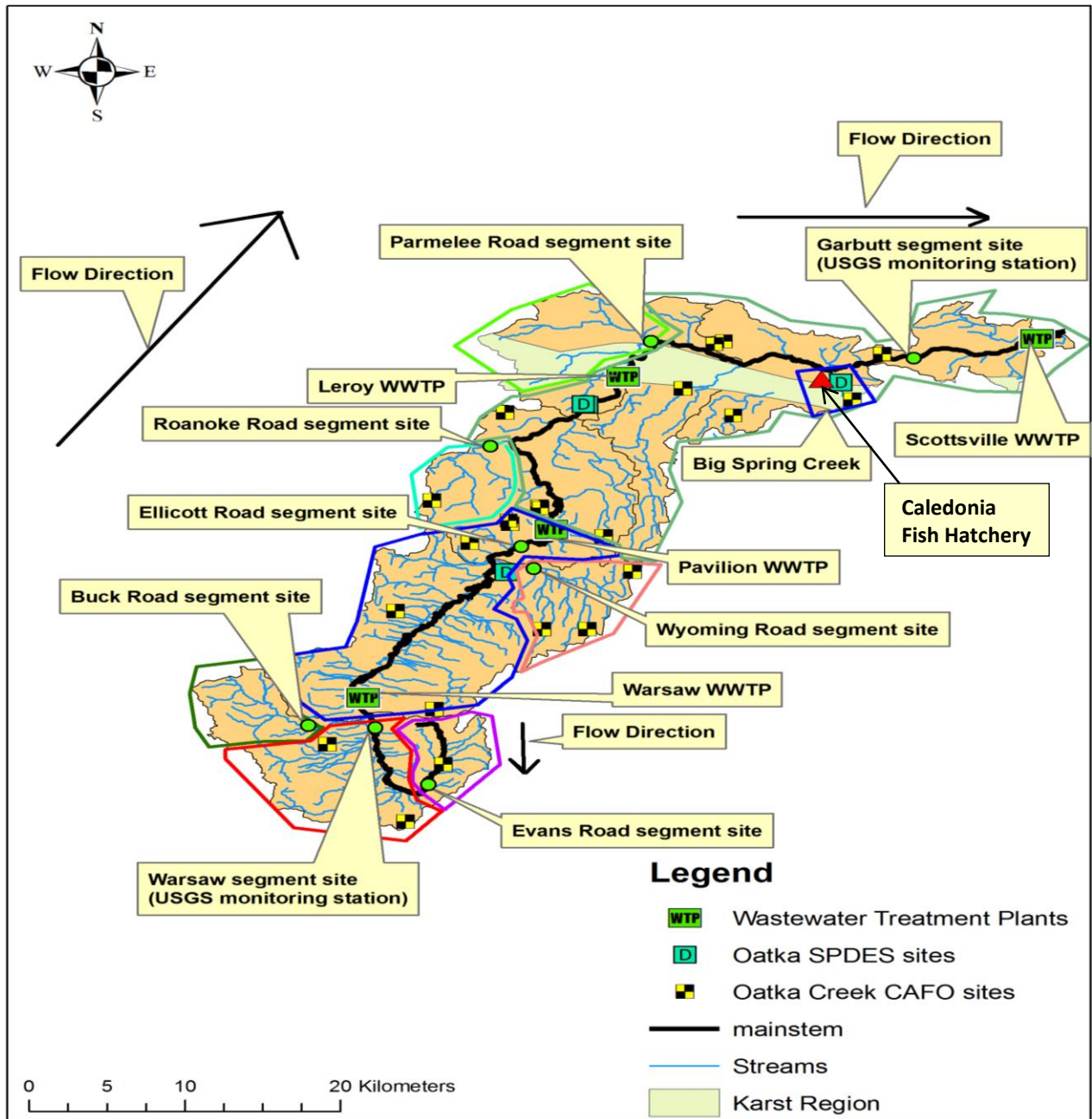


Figure 2. Map of the four major study segments [Evans Road Segment, Warsaw Segment= Warsaw +Buck Road, Ellicott Road Segment = Ellicot+ Wyoming, Garbutt Segment= Garbutt+Roanoke Road +Parmelee Road ) in the Oatka Creek watershed. Arrows signify flow direction and outlined polygons show minor tributaries. Green dots are sampling locations within the polygon The red triangle is the NYDEC fish hatchery at Caledonia, NY.

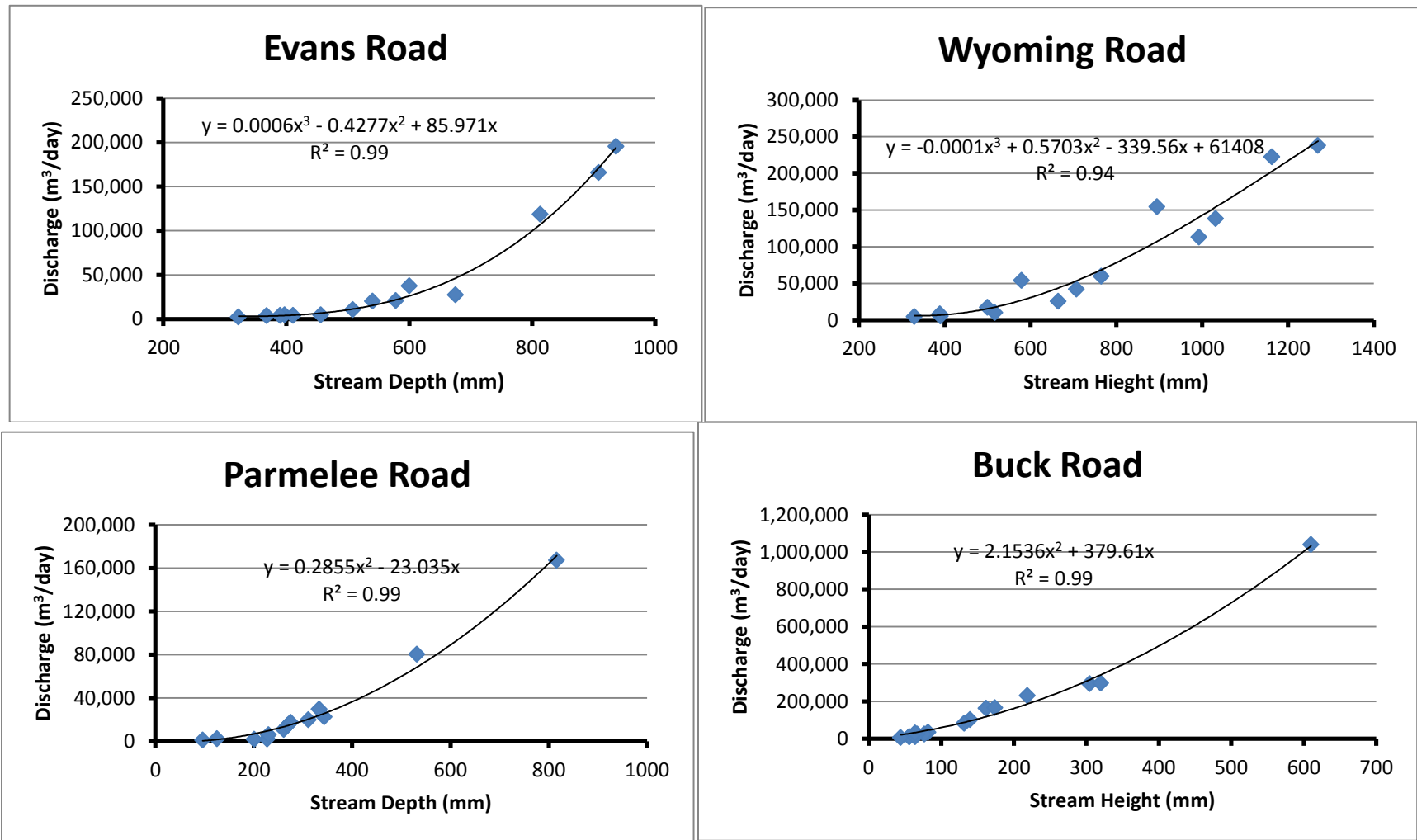


Figure 3. Rating Curves for discharge locations at Evans Road, Wyoming Road, Parmelee Road and Buck Road, Oatka Creek.

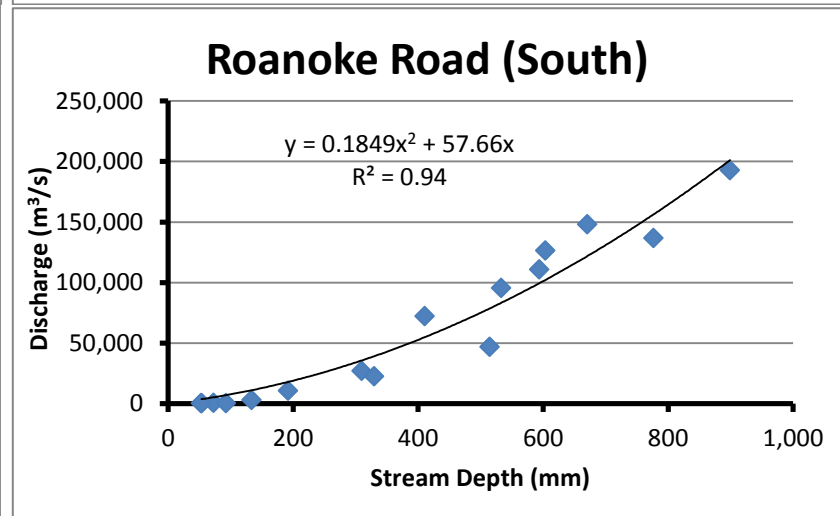
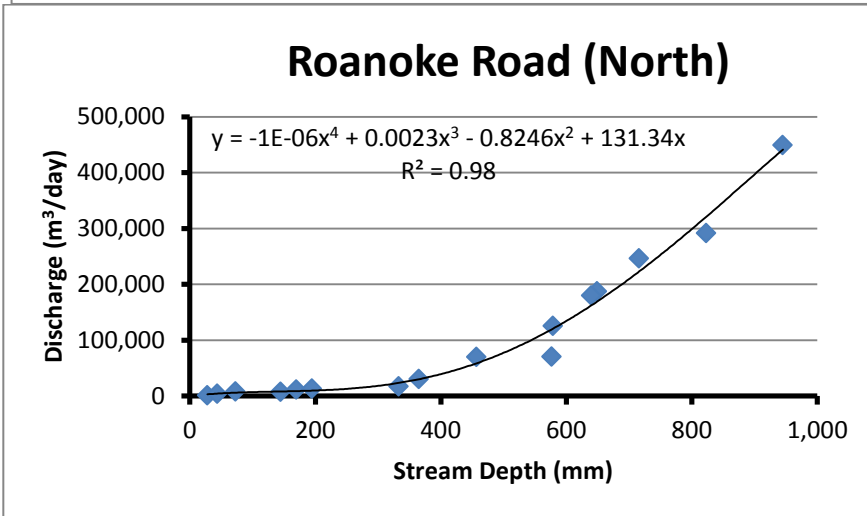
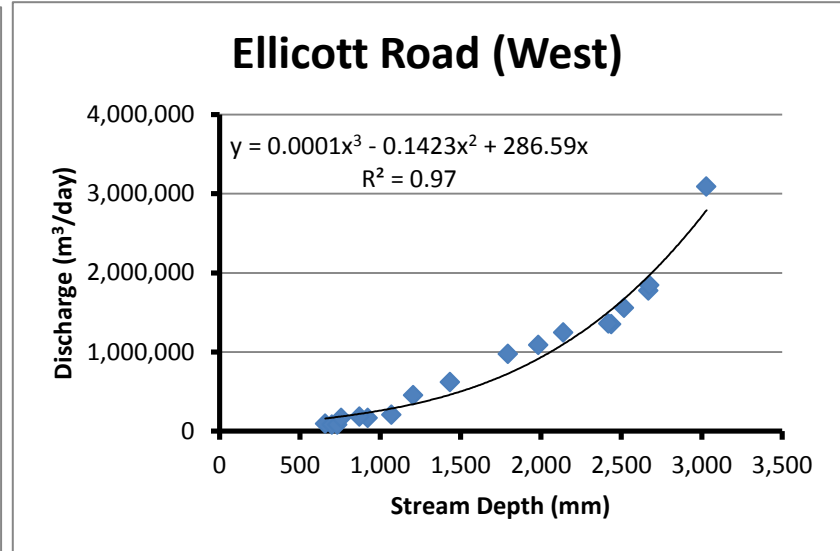
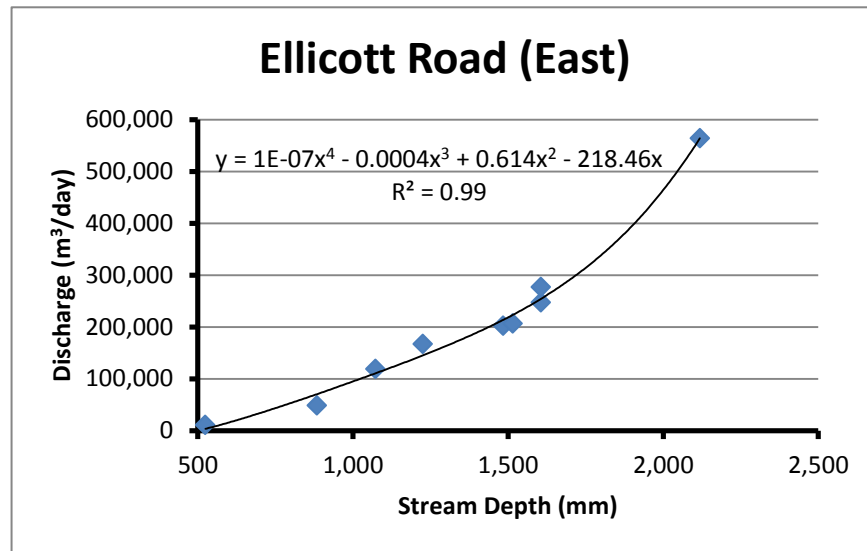


Figure 4. Rating Curves at Roanoke Road (North and South culverts) and Ellicott Road (East and West culverts), Oatka Creek.

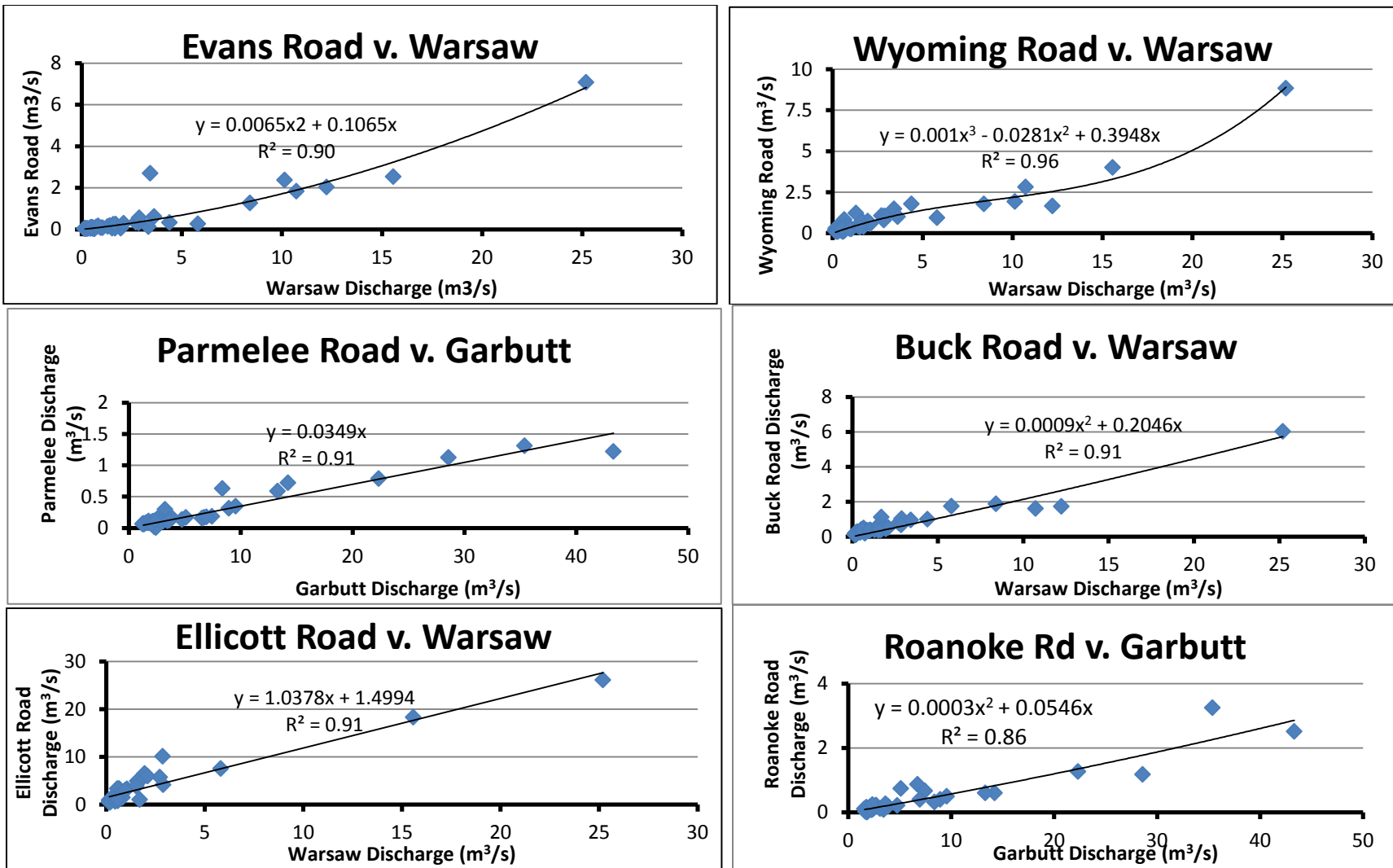


Figure 5. Regression of daily discharge (no lagtime for all monitoring locations) of Evans, Wyoming, Ellicott and Buck Roads with the USGS monitoring site at Warsaw. Roanoke and Parmelee Roads are with the USGS monitoring site at Garbutt, NY.

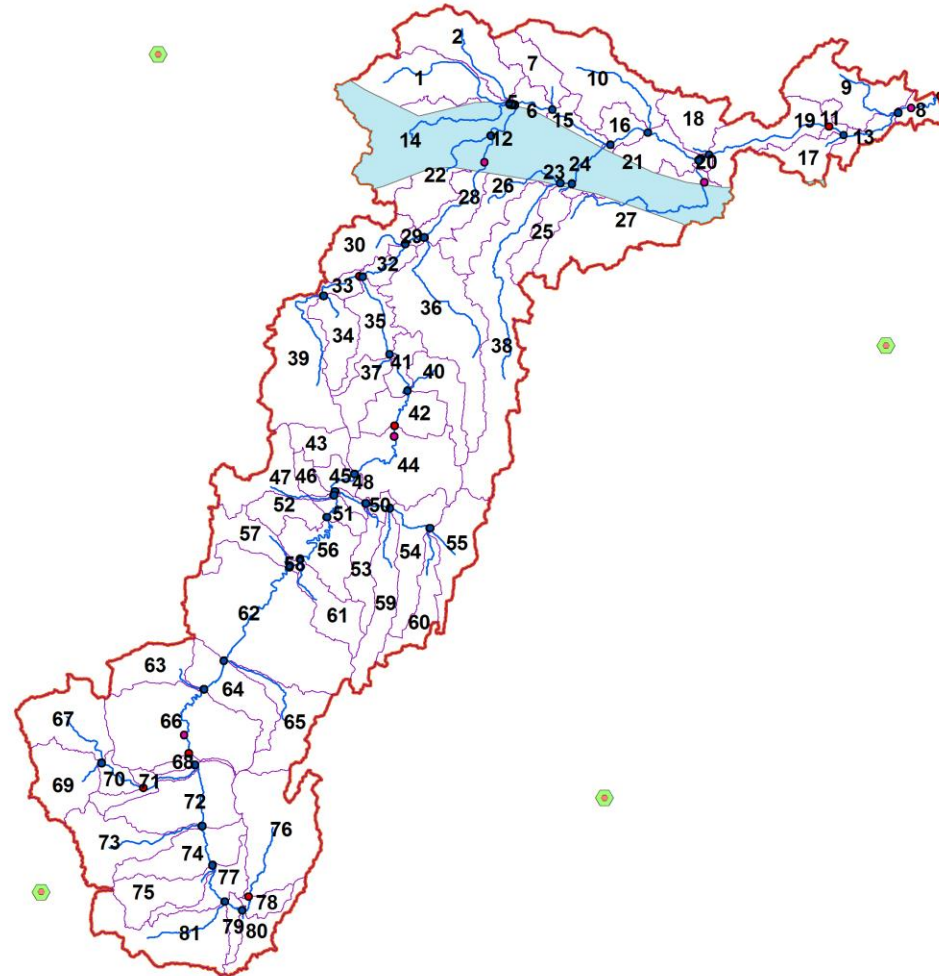


Figure 6. Oatka Creek showing the 81 subbasins used in the OCSWAT model. Shaded blue region symbolizes the carbonate rock aquifer.



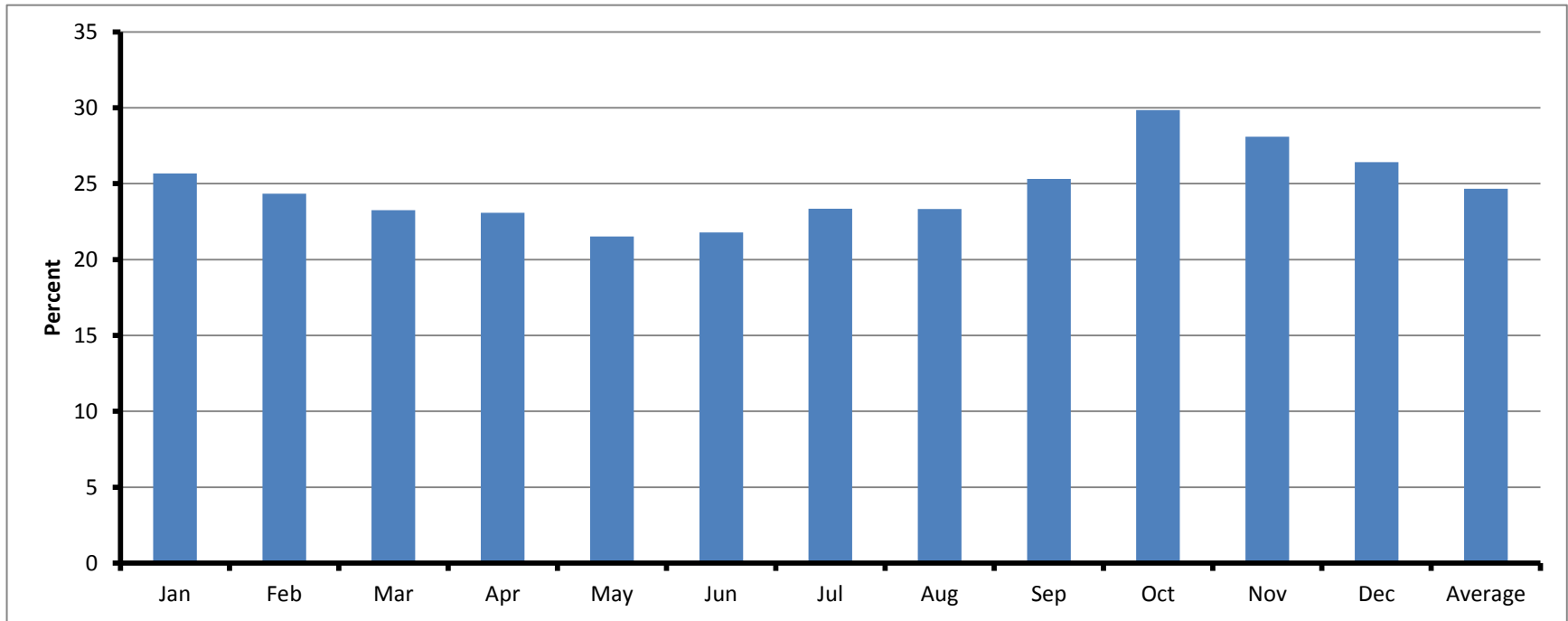


Figure 7. The ratio of average monthly discharge (1970 to 2009) from Warsaw, NY, to average monthly discharge at Garbutt, NY expressed as a percentage, Oatka Creek.

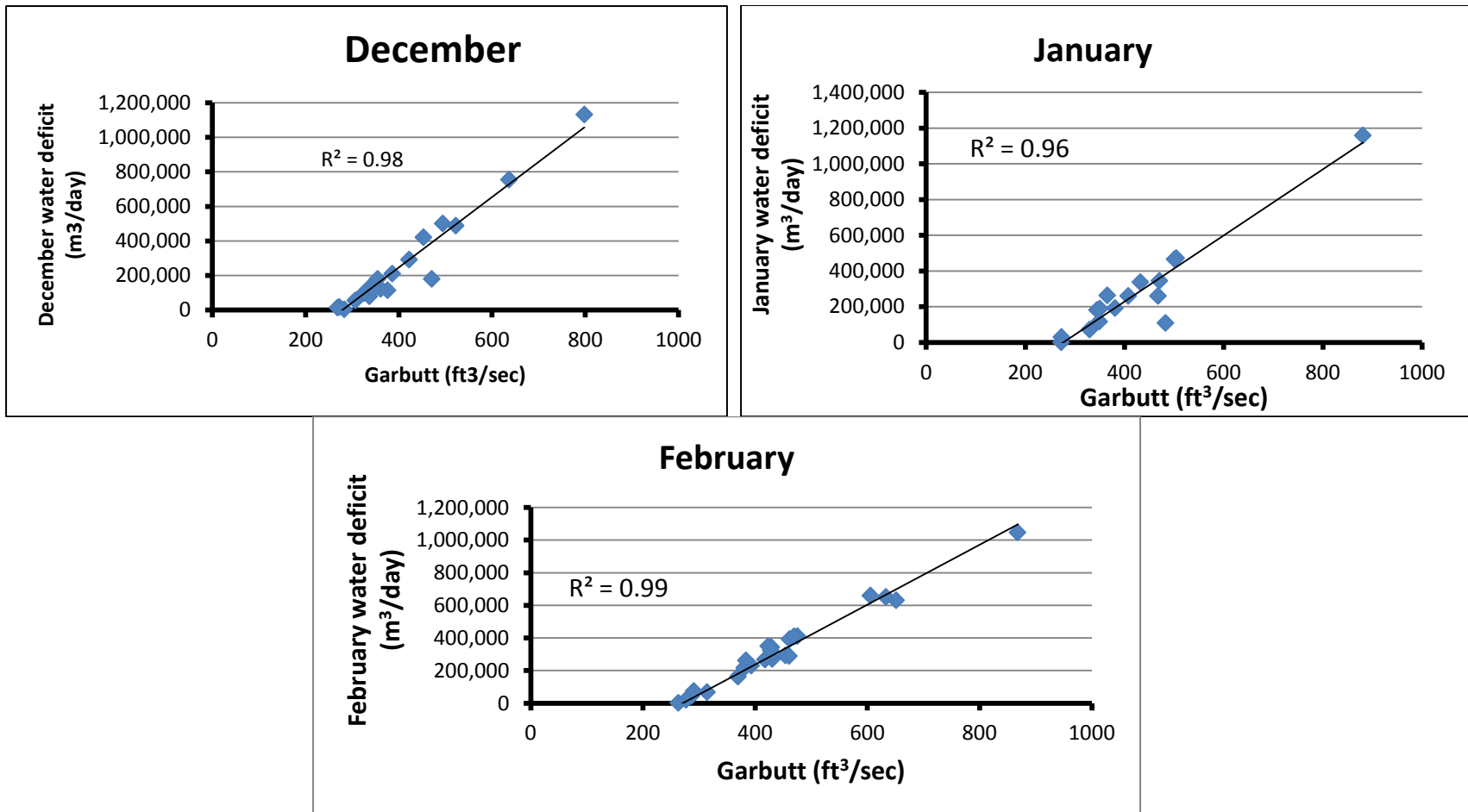


Figure 8. Regression of flow deficit (outside groundwater source) on discharge measured at Garbutt, NY, in December through February over a 40-year period (1970 – 2009), Oatka Creek. Flow deficits equations are presented in Table 7.

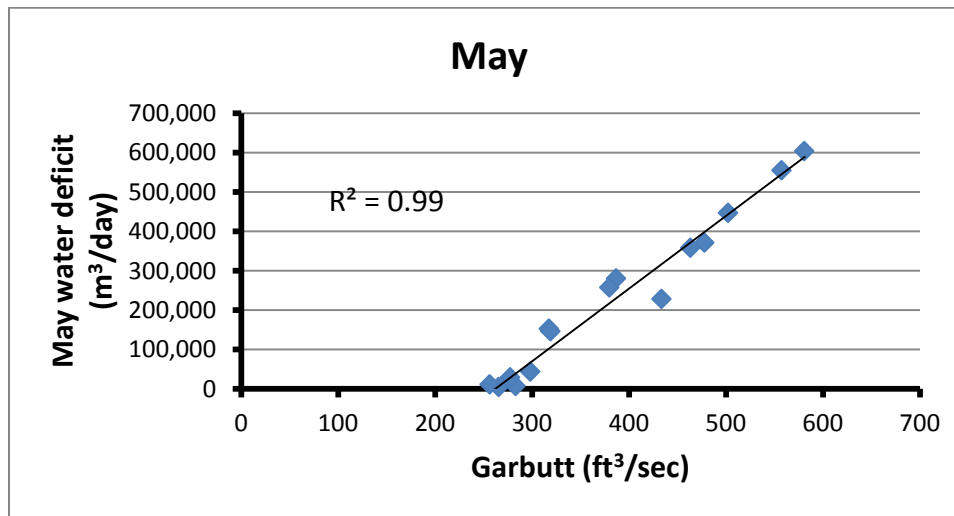
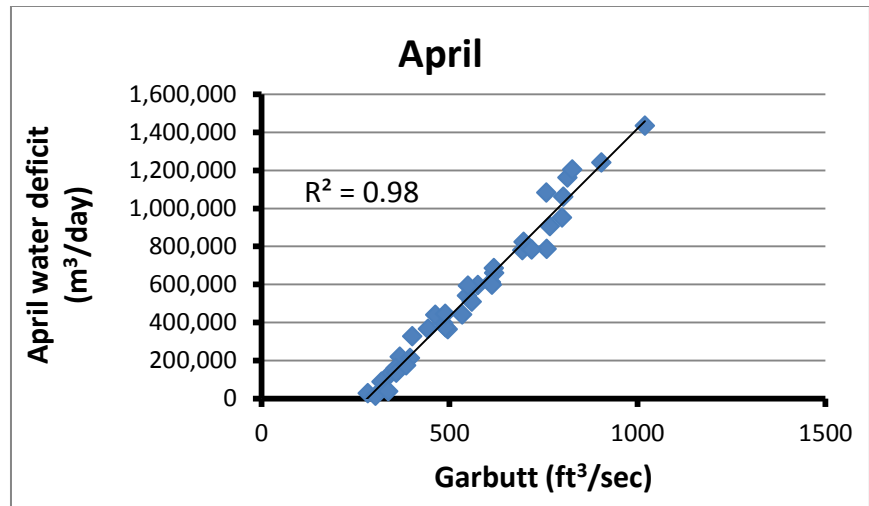
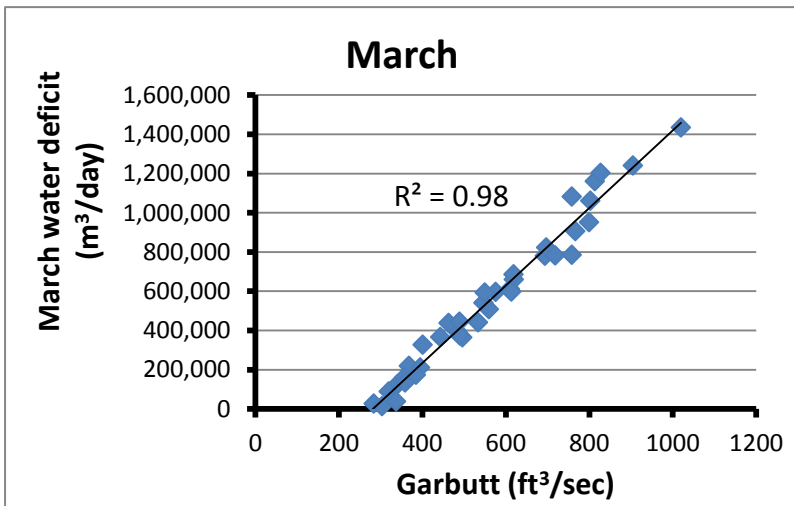


Figure 9. Regression of flow deficit (outside groundwater source) on flow measured at Garbutt, NY in March through May over a 40 year period (1970 – 2009), Oatka Creek. Flow deficit equations are presented in Table 7.

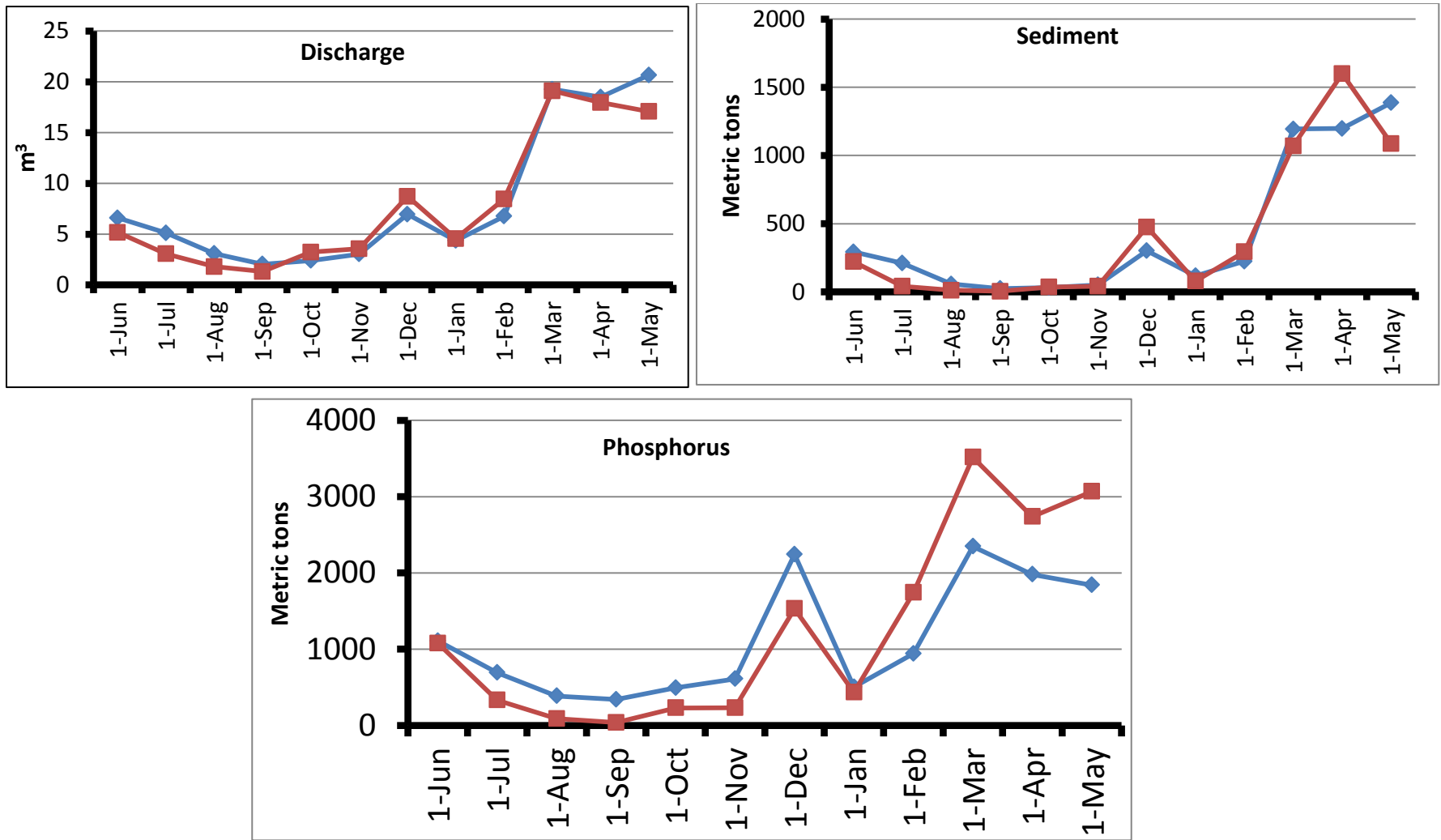


Figure 10. A comparison of OCSWAT model flow, sediment and phosphorus of observed (square points) to simulated (diamond points) resulting from the model run year (1 June 2010 through 30 May 2011), Oatka Creek.

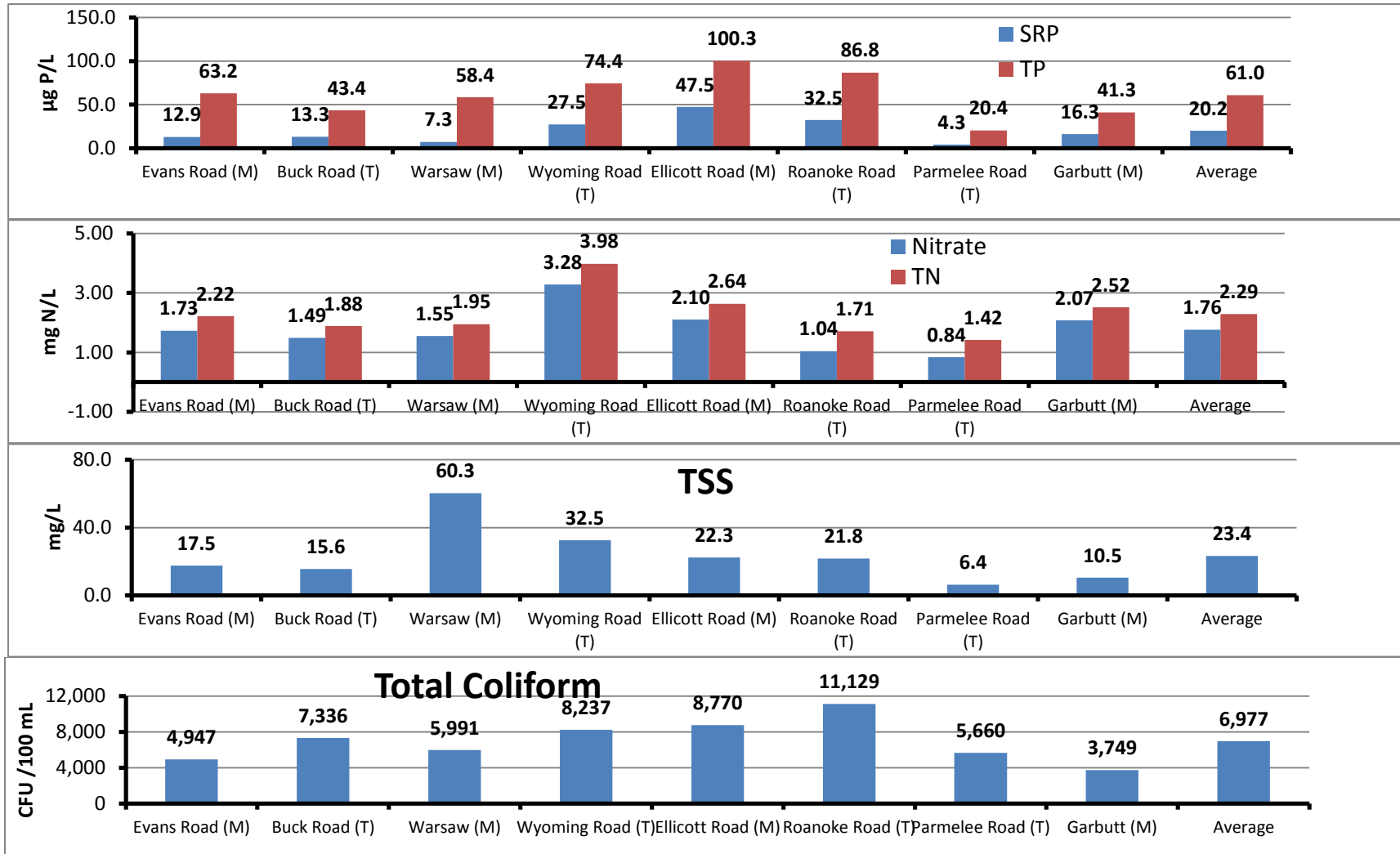


Figure 11. Average annual concentrations of soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate, total nitrogen (TN), total suspended solids (TSS) and total coliform abundances at all eight weekly monitoring locations from June 2010 to May 2011, Oatka Creek. M = main stem. T = tributary.

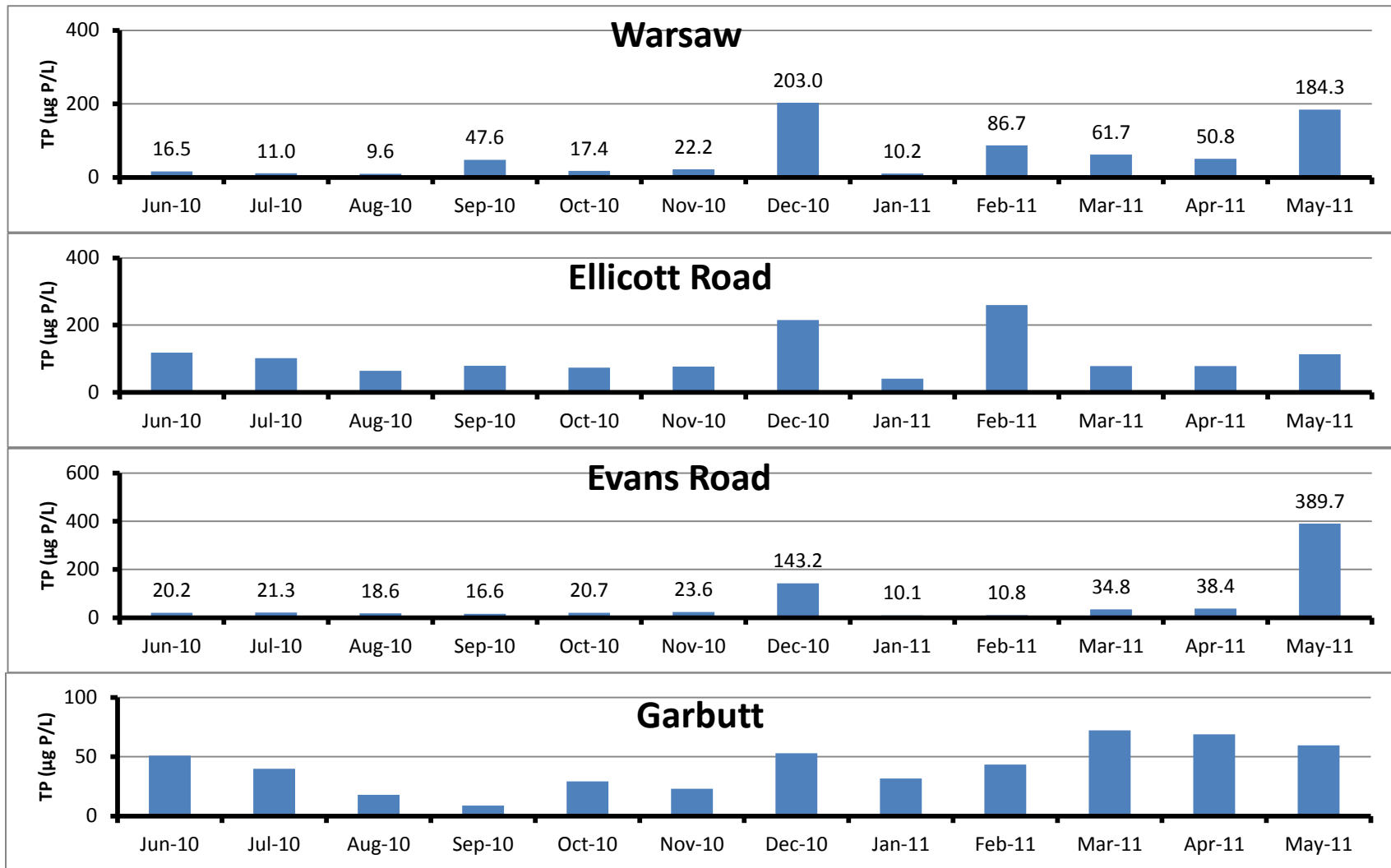


Figure 12. Average monthly total phosphorus concentrations at all eight (Fig. 2) weekly sampling sites, Oatka Creek.

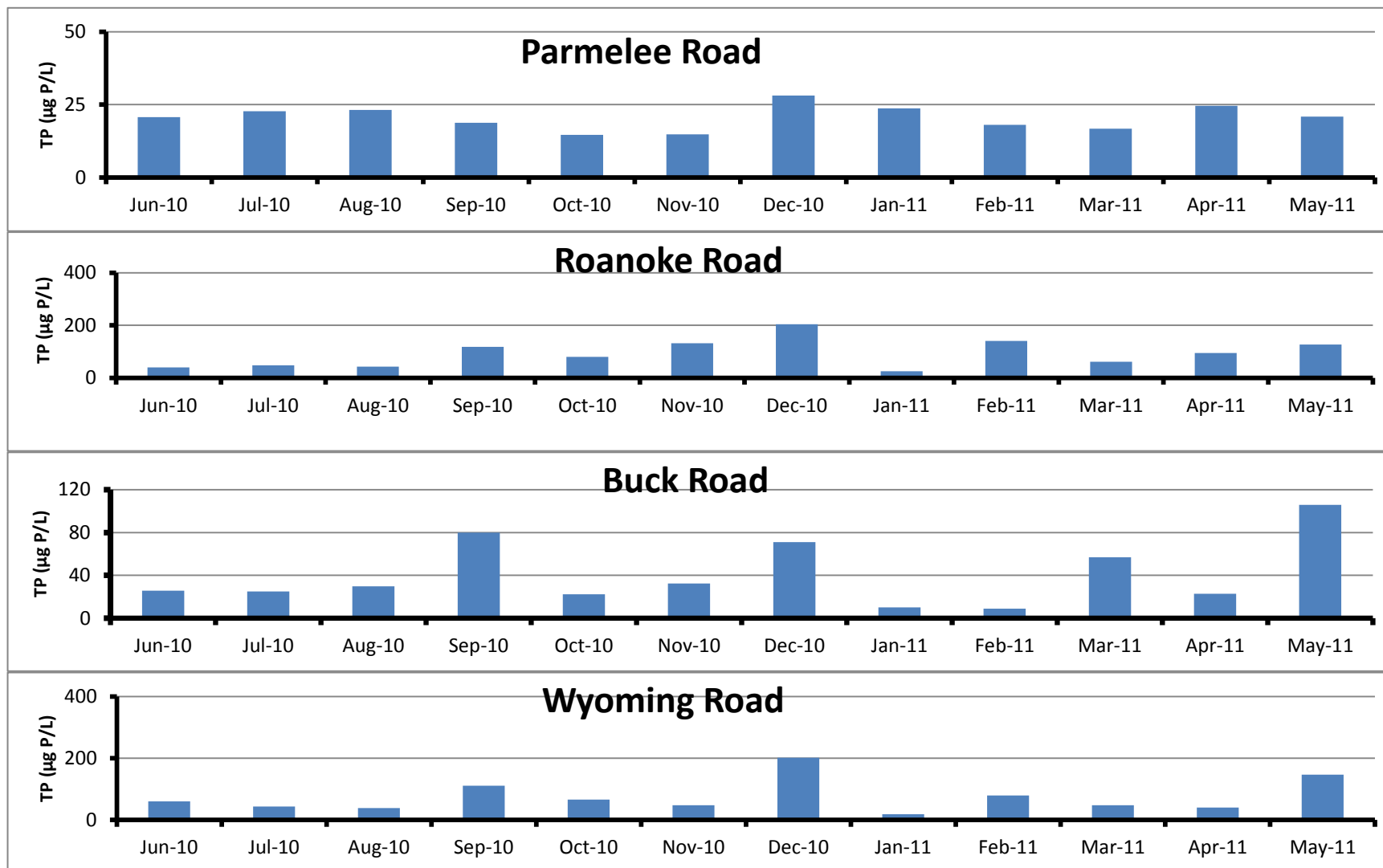


Figure 12. (Continued). Average monthly total phosphorus concentrations at all eight (Fig. 2) weekly sampling sites, Oatka Creek.

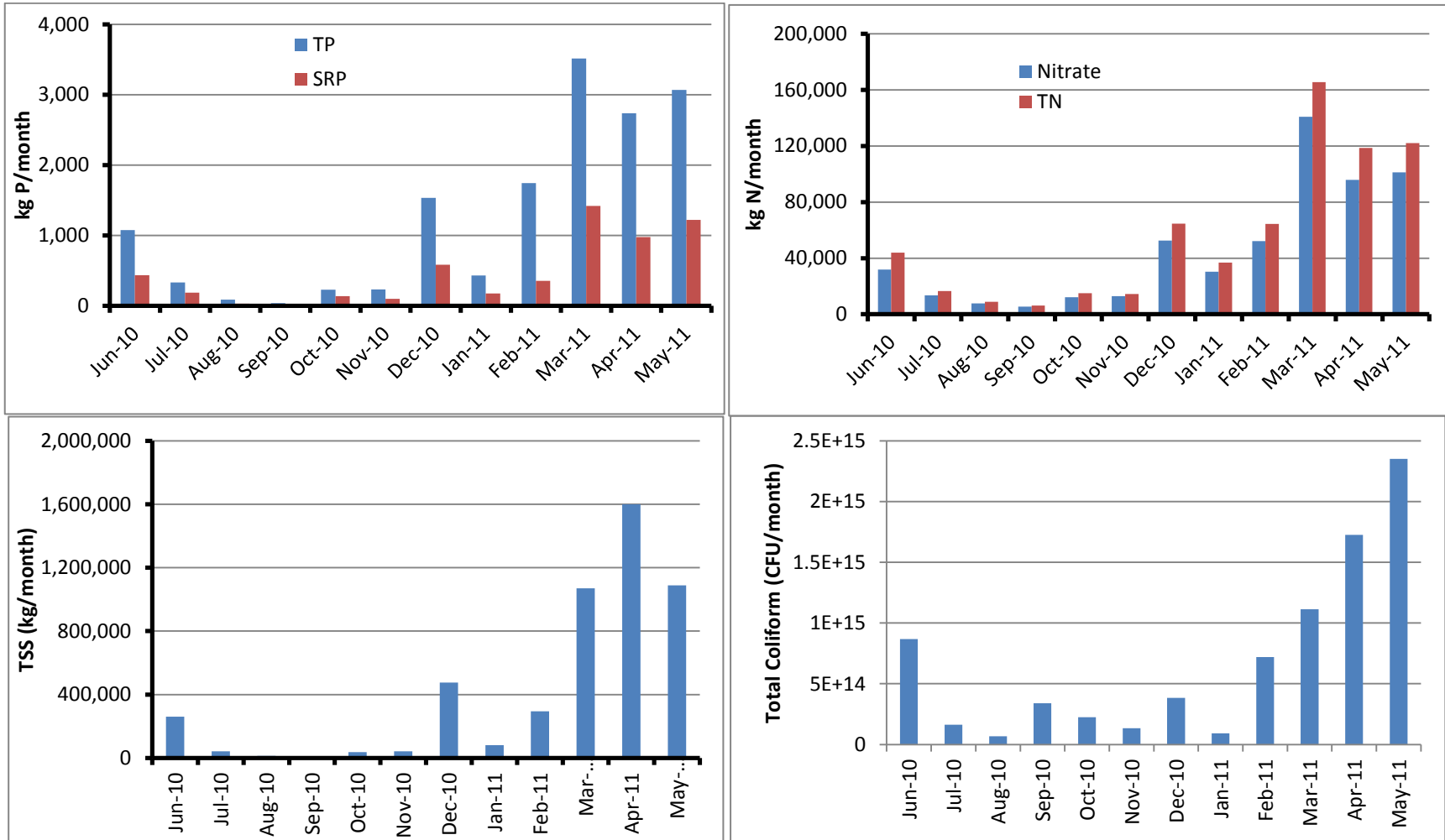


Figure 13. Measured monthly loads of soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate, total nitrogen (TN), total suspended solid (TSS), and total coliform at the USGS monitoring location at Garbutt, NY, Oatka Creek.





Figure 14. Initial stress stream sites (1-15, green dots) and the eight weekly sampling sites Evans Road, Buck Road, Warsaw, Wyoming Road, Ellicott Road, Roanoke Road, Parmalee Road and Garbutt on 12 July 2010. The arrows signify flow directions, and the Oatka Creek subwatershed is broken up into three sections (Headwater, Middle, and Downstream). The red triangle is the Caledonia Fish Hatchery.

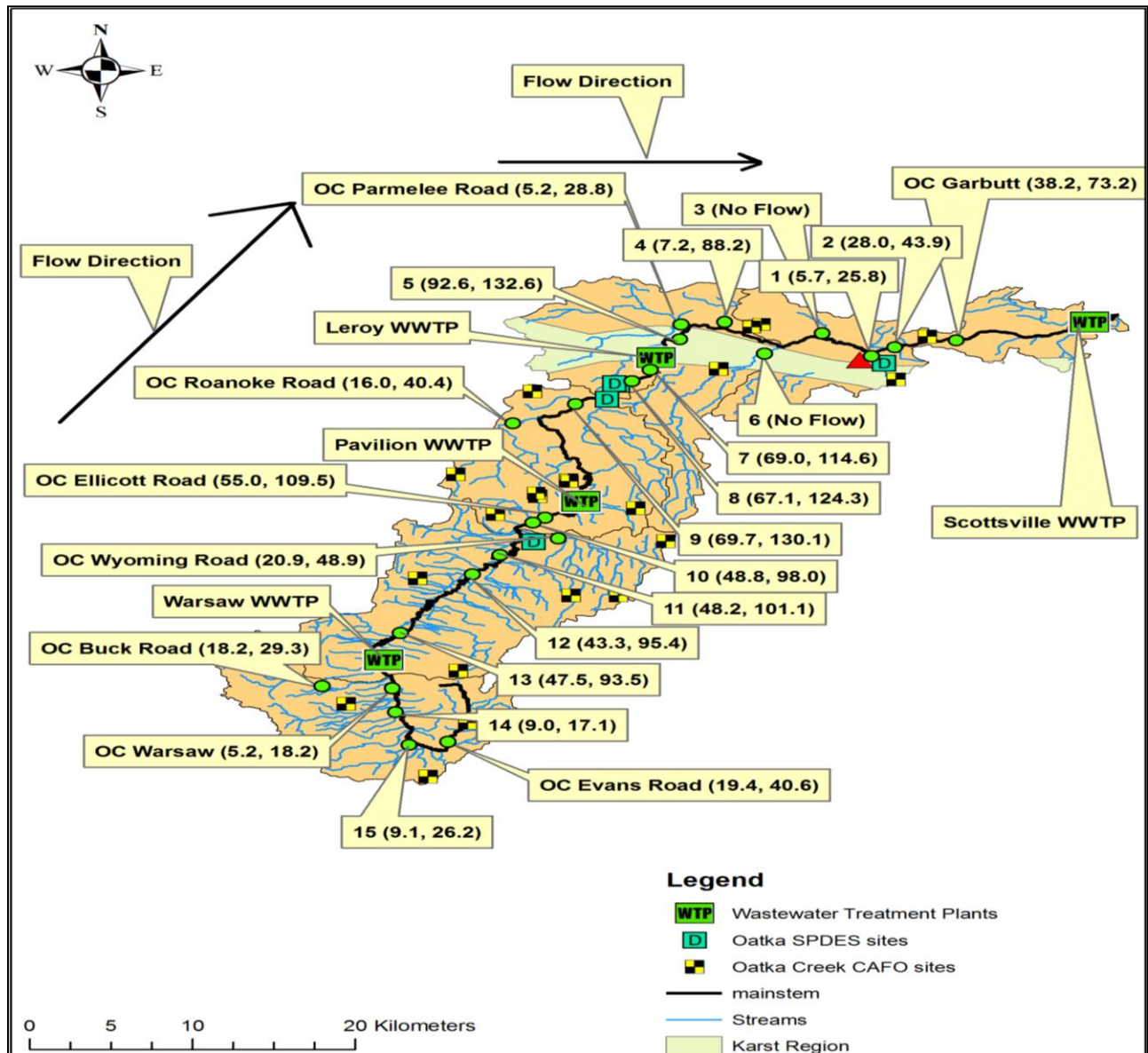


Figure 15. Soluble reactive phosphorus (SRP) and total phosphorus (TP) concentrations ( $\mu\text{g P/L}$ ) at the Oatka Creek subwatershed on 12 July 2010. Green dots represent sample sites.

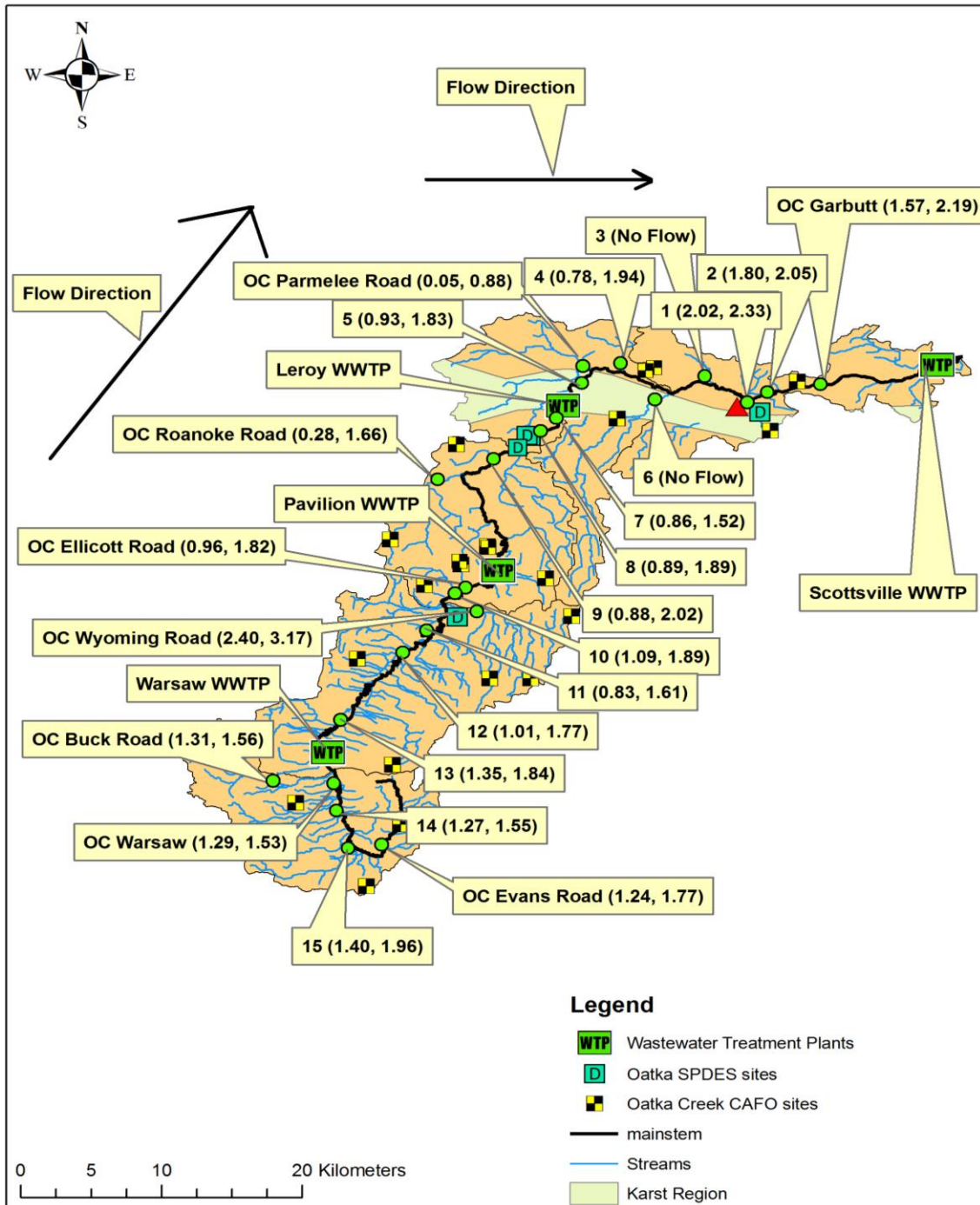


Figure 16. Nitrate and total nitrogen (TN) concentrations (mg N/L) in the Oatka Creek subwatershed on 12 July 2010. Green dots represent sample sites.

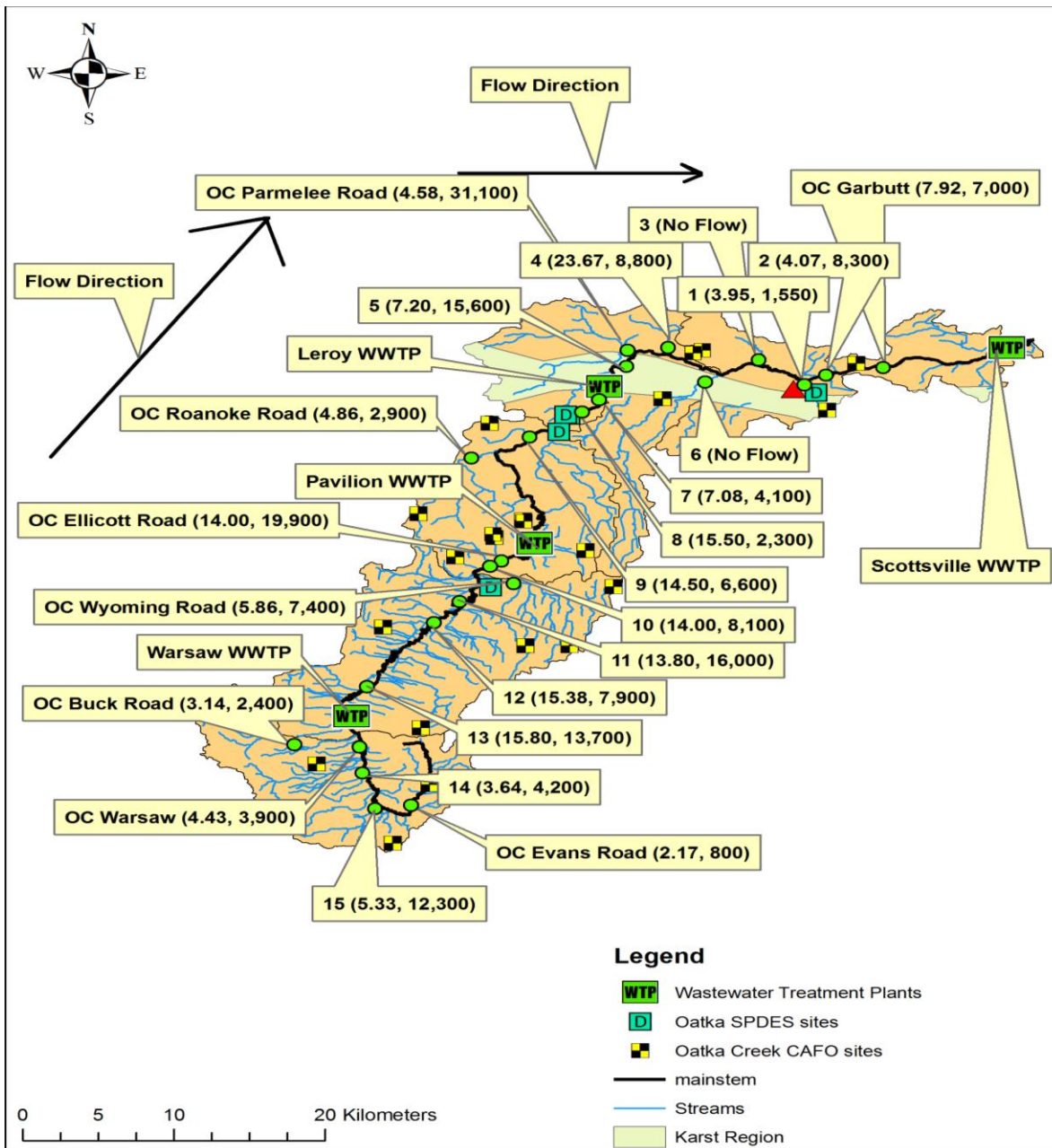


Figure 17. Total suspended solid (mg/L) and total coliform (CFU/100 mL) abundances at the Oatka Creek subwatershed on 12 July 2010. Green dots represent sample sites.

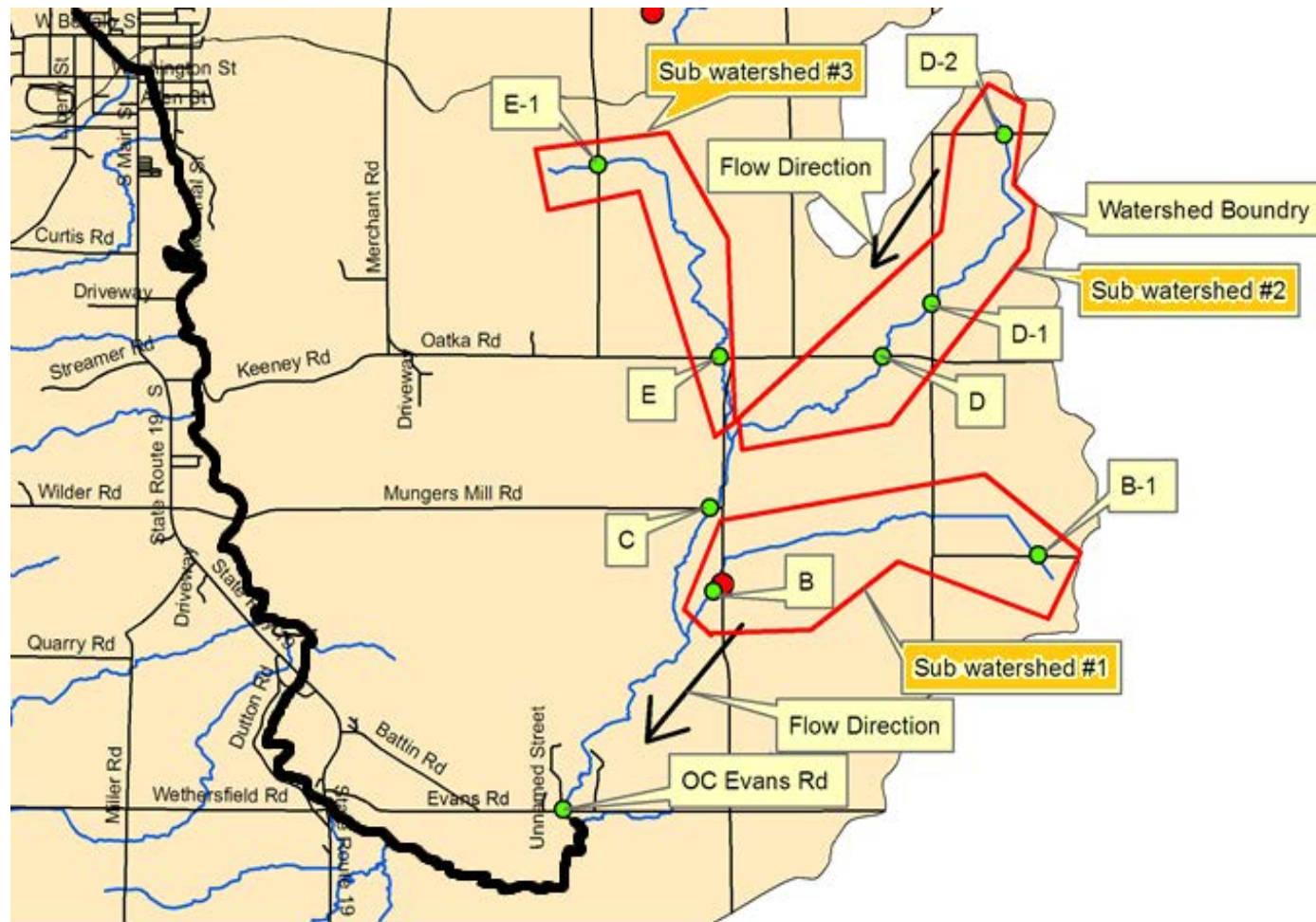


Figure 18. Segment analysis sites (B to E) of the Evans Road subwatershed (Fig. 2) on 5 October 2010 (Event) and 19 October 2010 (Nonevent), Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red outlines show each individual subwatershed (1-3).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

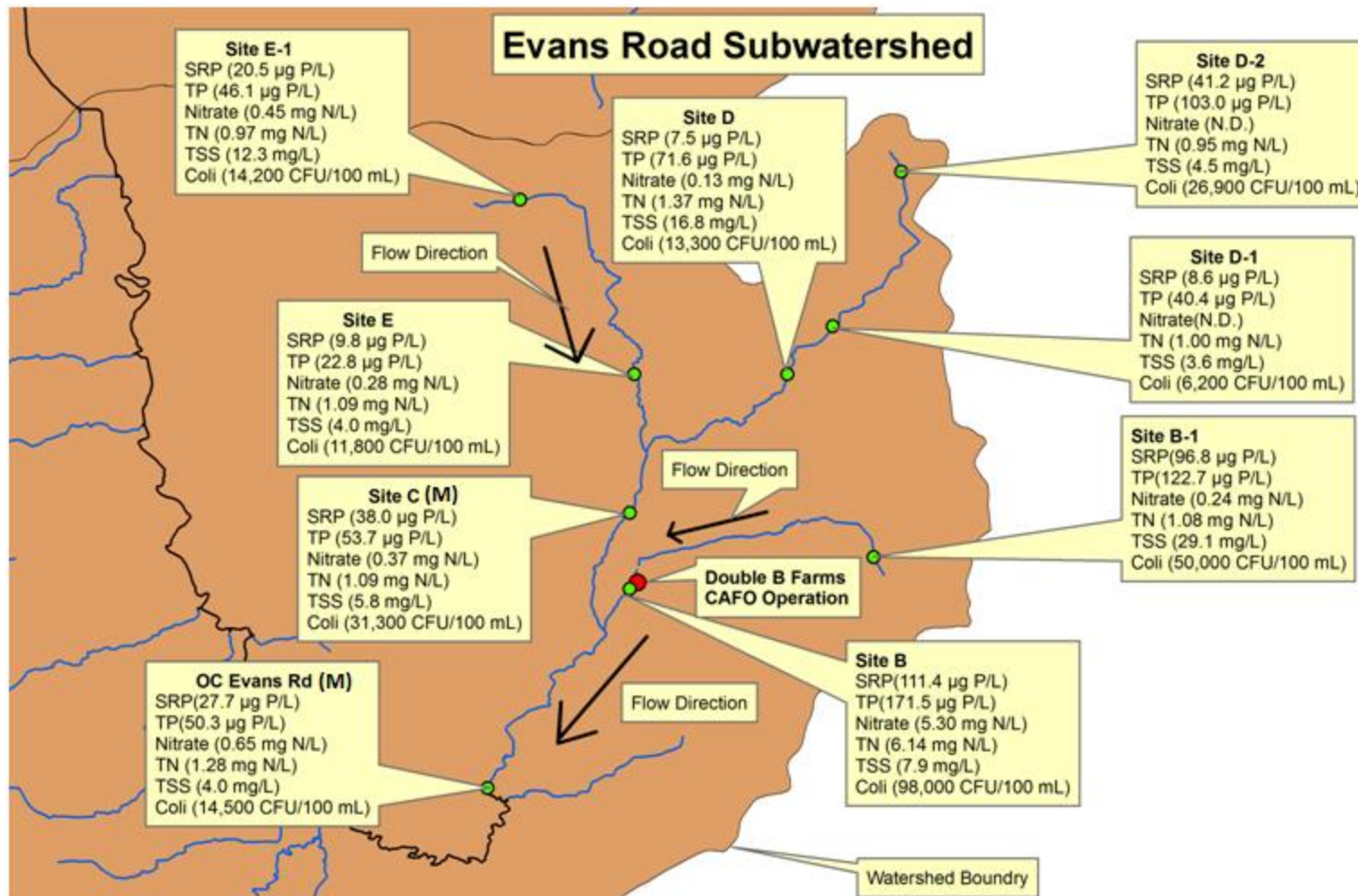


Figure 19. Soluble reactive phosphorus (SRP), total phosphorus (TP), total suspended solid (TSS), nitrate, and total nitrogen (TN) concentrations, and total coliform abundances in the Evans Road subwatershed (Fig. 2) on 5 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample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

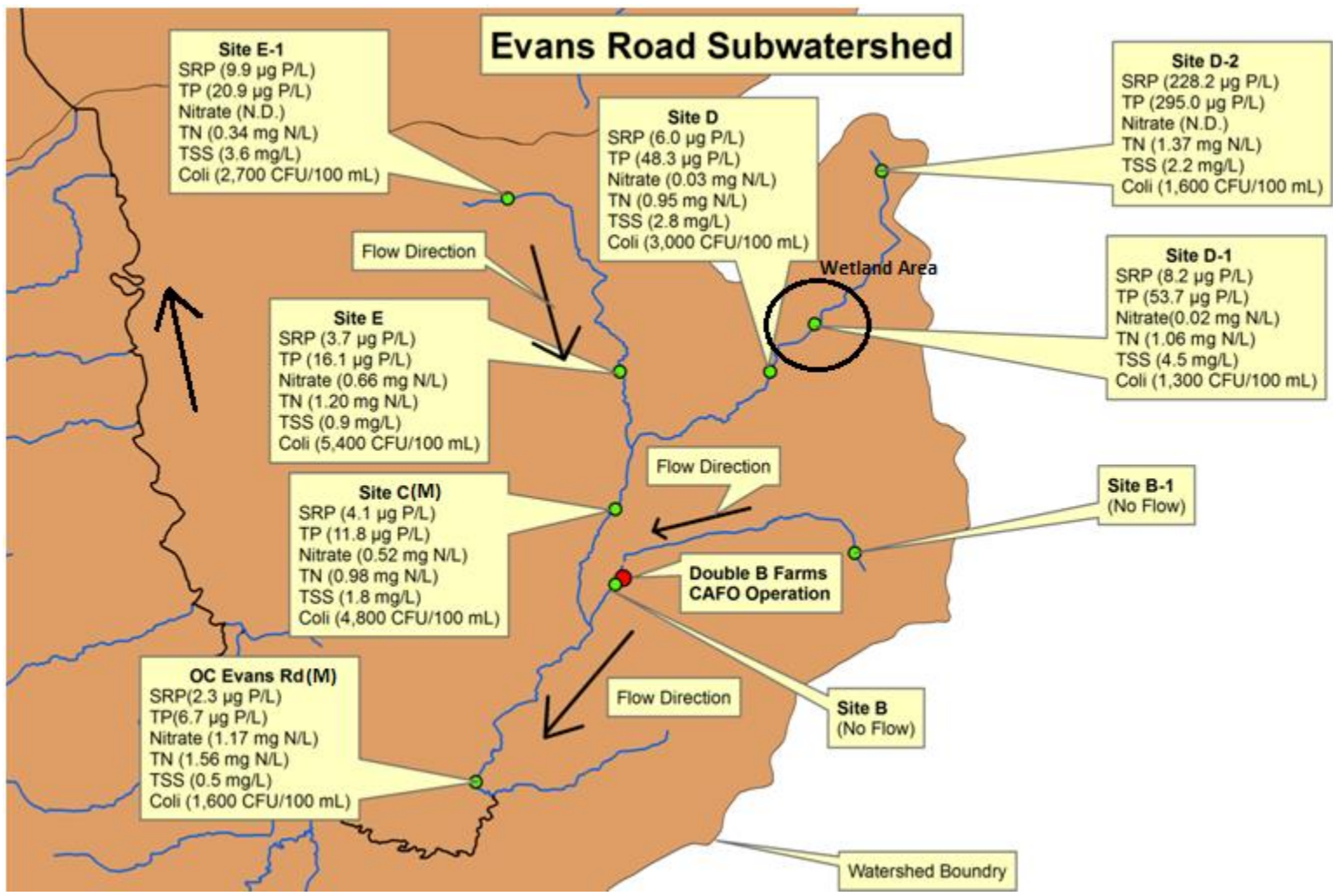


Figure 21. Soluble reactive phosphorus (SRP), total phosphorus (TP), total suspended solid (TSS), nitrate, and total nitrogen (TN) concentration, and total coliform abundances for Evans Road subwatershed (Fig. 2) on 19 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites.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



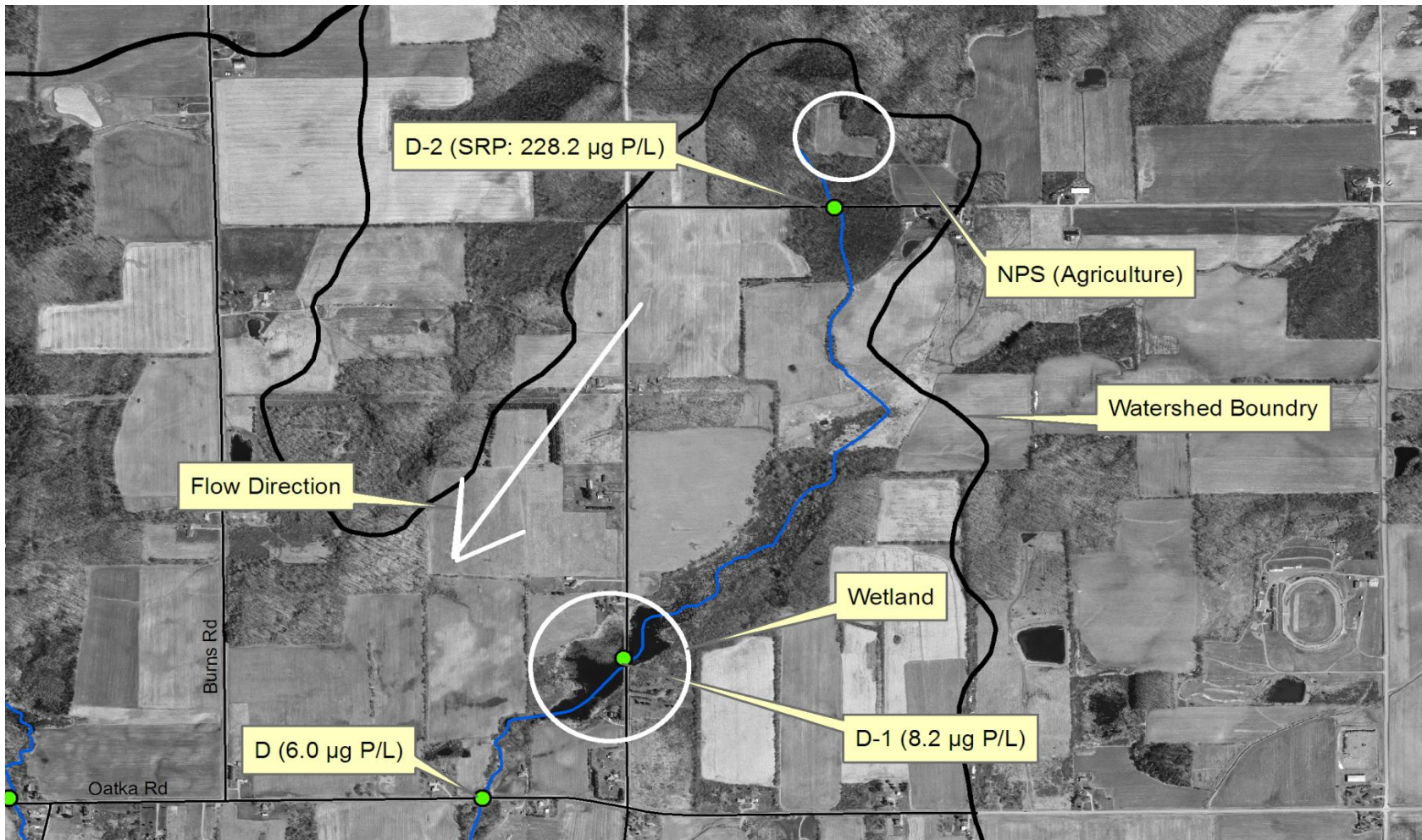


Figure 22. Soluble reactive phosphorus ( $\mu\text{g P/L}$ ) concentrations at sites D, D-1, and D-2 (Fig. 21) in the Evans Road subwatershed on 19 October 2010, Oatka Creek. The wetland and agriculture sites are circled in white. Black line is the watershed boundary.

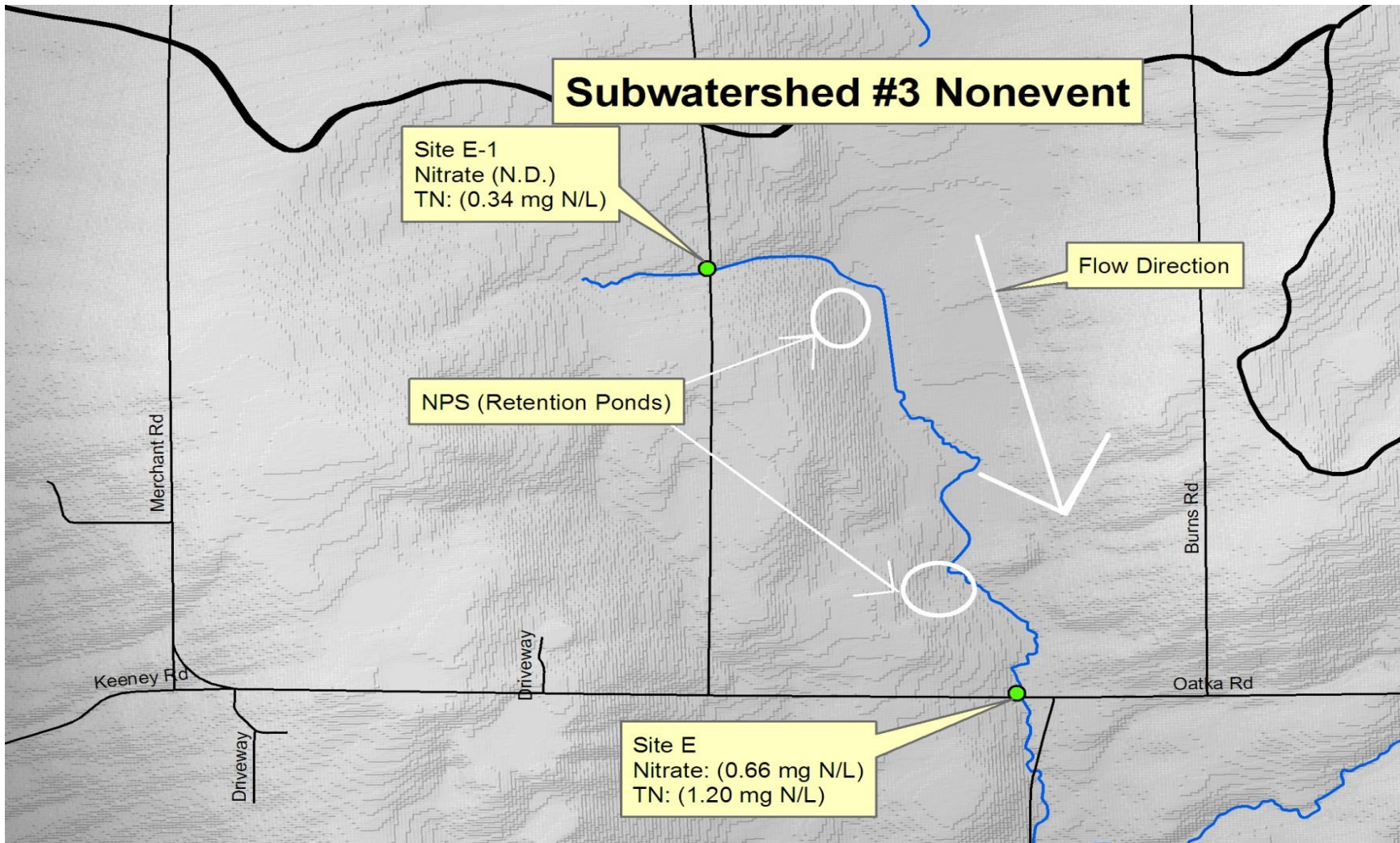


Figure 23. Digital Elevation Map (DEM) of sites E and E-1 (Fig. 21) in the Evans Road subwatershed on 19 October 2010, Oatka Creek. Both retention ponds are located on a downward slope towards the stream. Green dots signify sampling locations. White arrow illustrates flow direction.

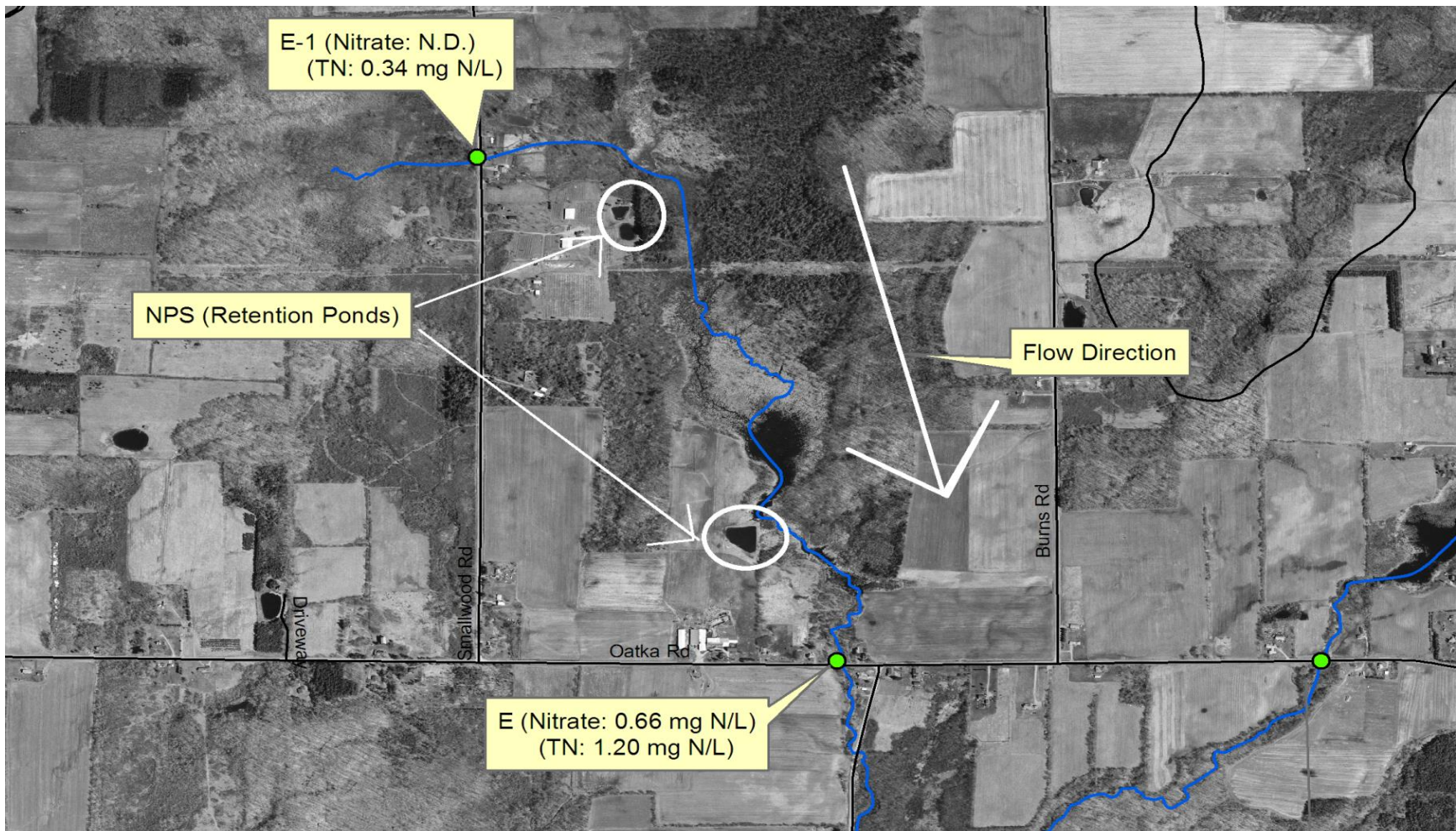


Figure 24. Nitrate and total nitrogen (mg N/L) concentrations at Sites E, E-1 (Fig. 21) in the Evans Road subwatershed on 19 October 2010, Oatka Creek. The retention ponds are circled in white. Black line is the watershed boundary.

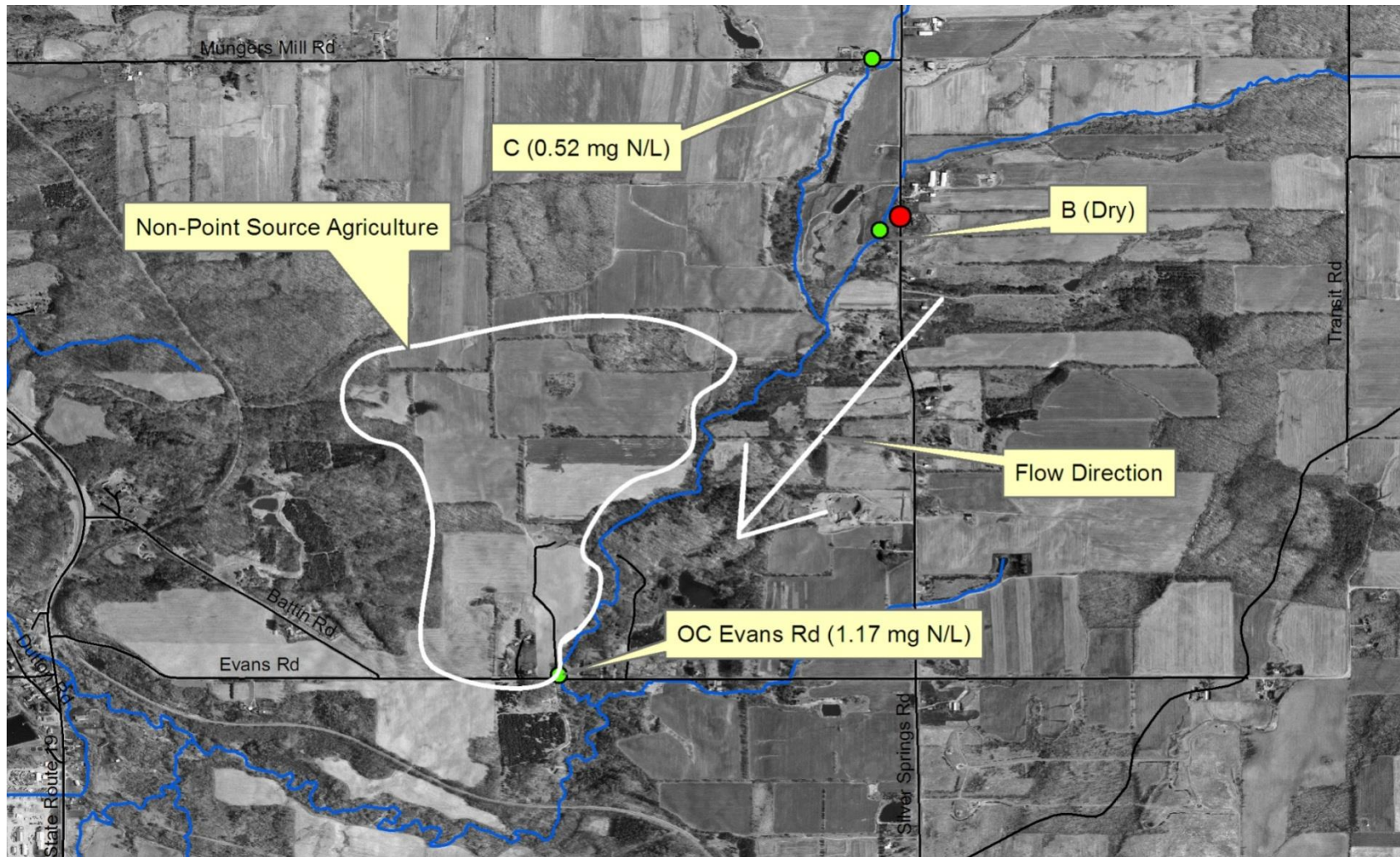


Figure 25. Nitrate (mg N/L) concentrations at Sites C, OC Evans Road (Fig. 21) in the Evans Road subwatershed on 19 October 2010, Oatka Creek. The agriculture area is circled in white. The red dot is a CAFO site. Black line is the watershed boundary.

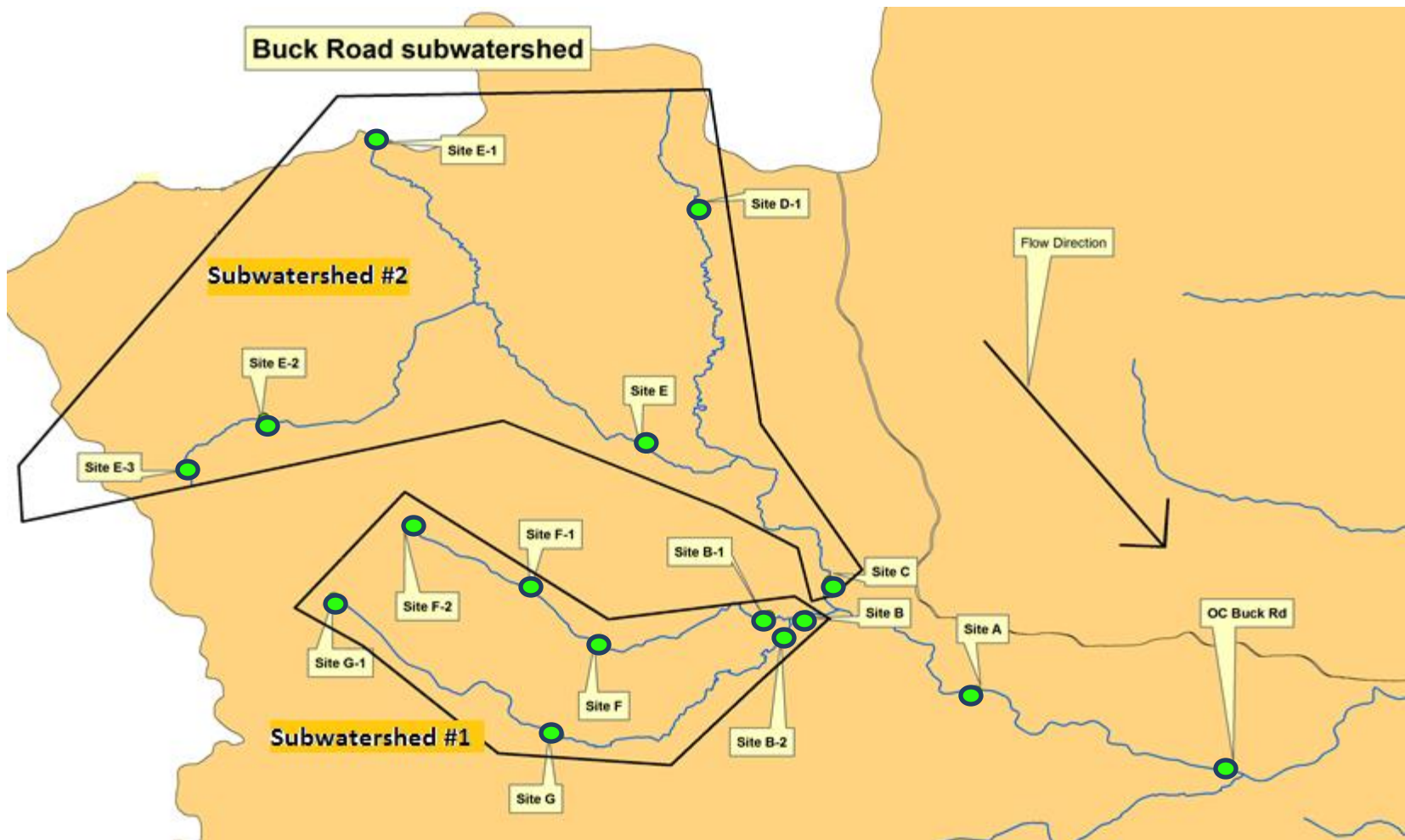


Figure 26. Segment analysis sites (OC Buck Road, A, B to B-2, C, D-1, E to E-3, F to F-2, G and G-1) in the Buck Road subwatershed (Fig. 2) on 15 March 2011, Oatka Creek. Light green dots are sample sites. Arrows signify flow direction. Black outlines are watershed boundaries.

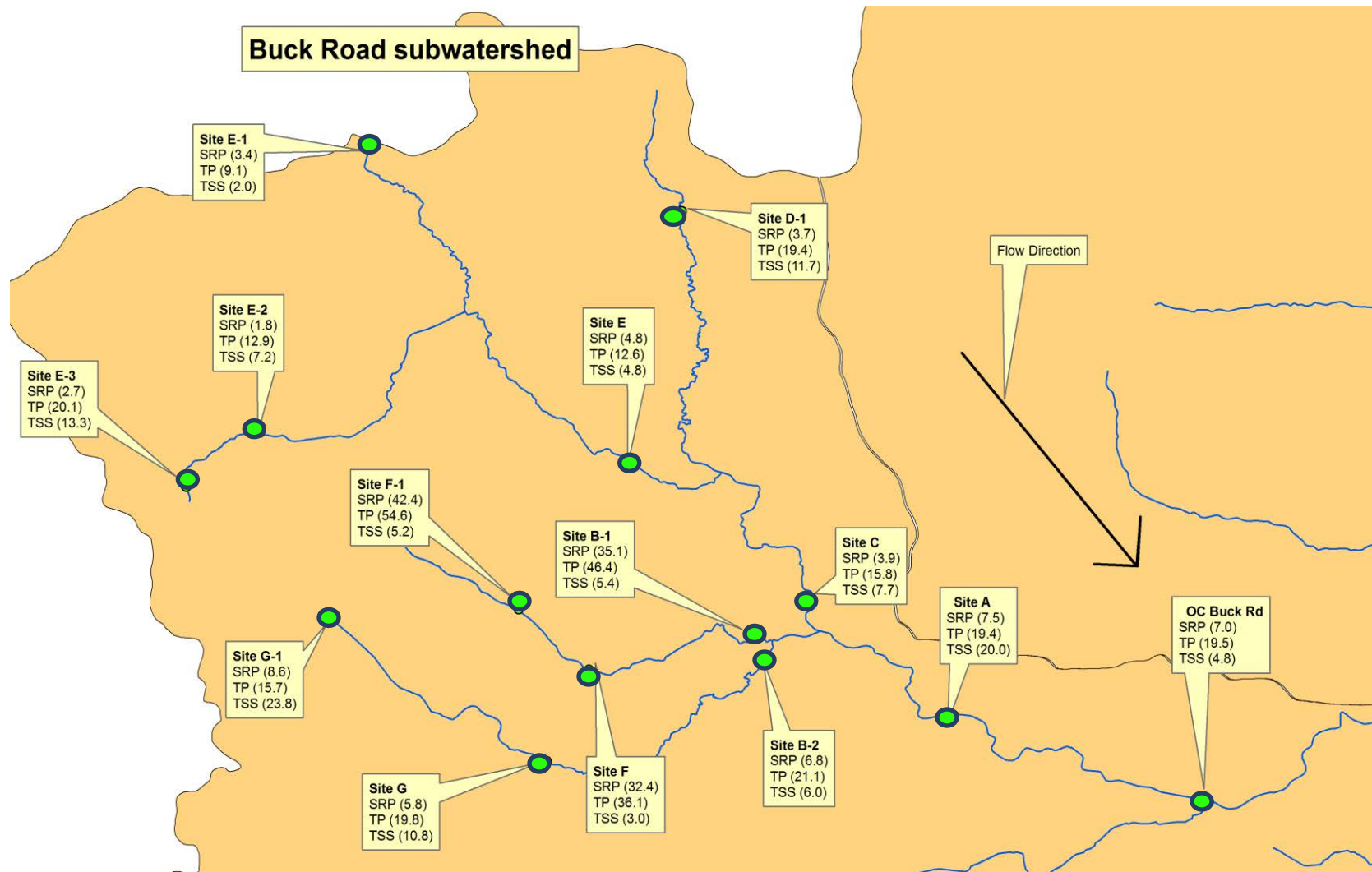


Figure 27. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), and total suspended solid (TSS: mg/L) concentrations in the Buck Road subwatershed (Fig. 2) on 15 March 2011, Oatka Creek. Light green dots are sample sites. Black arrow signifies flow direction.

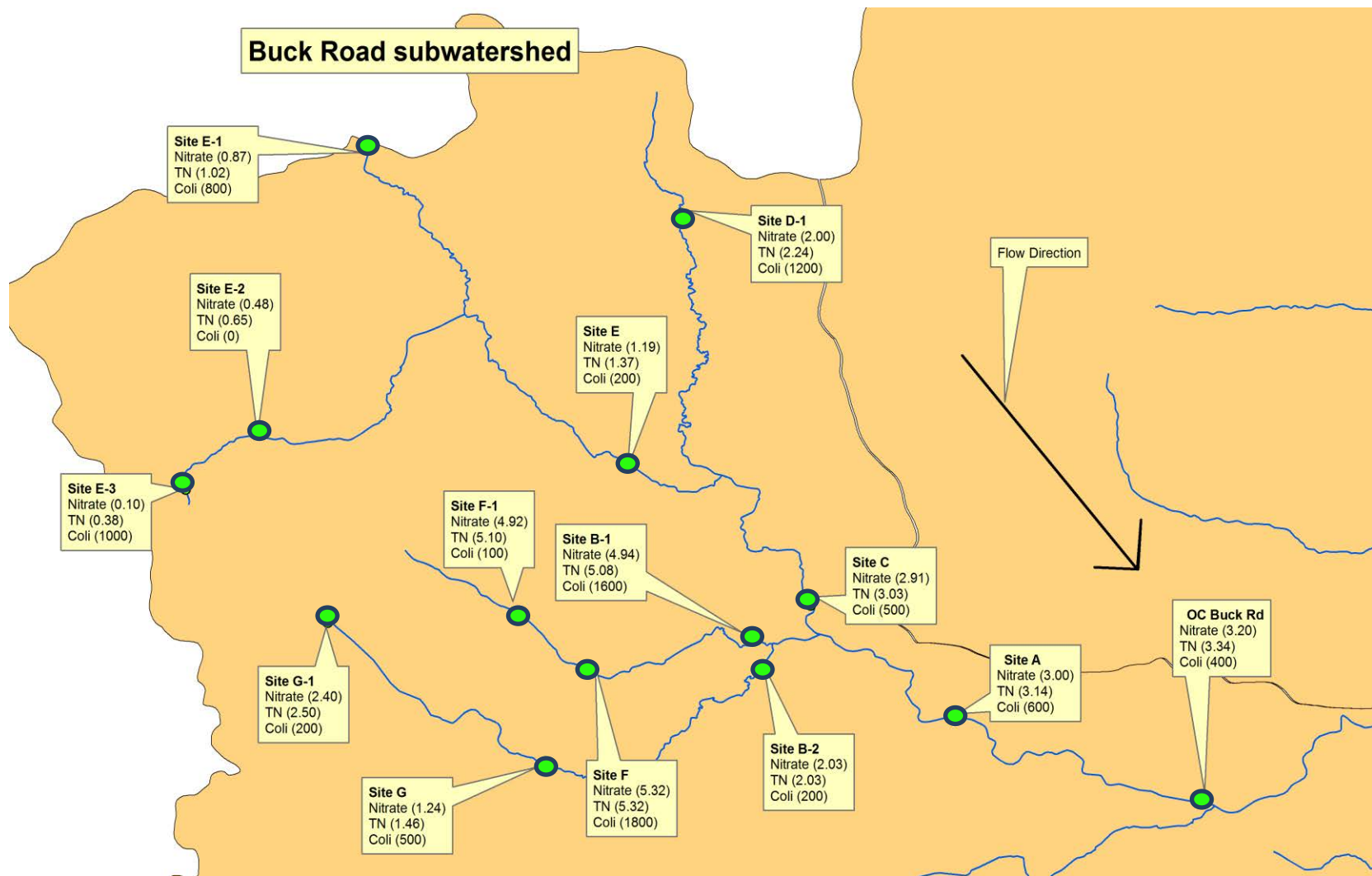


Figure 28. Nitrate (mg N/L) and total nitrogen (TN: mg N/L) concentrations and total coliform abundances (CFU/100 mL) in the Buck Road subwatershed (Fig. 2) on 15 March 2011, Oatka Creek. Light green dots are sample sites. Black arrow signifies flow direction.

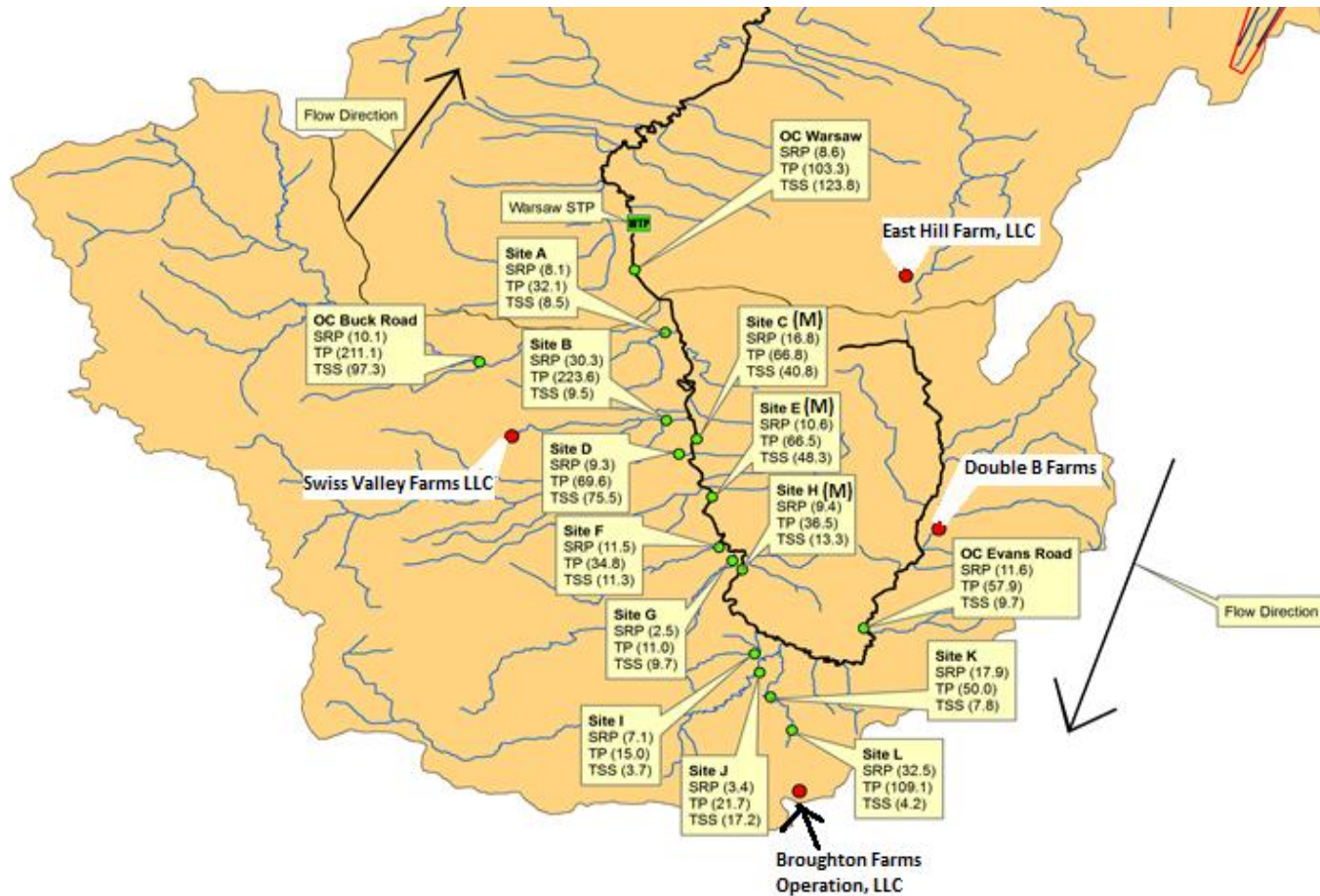


Figure 29. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), and total suspended solid (TSS: mg/L) concentrations upstream from OC Warsaw on 8 March 2011, Oatka Creek (Fig. 2). Red dots are CAFO operations. Light green dots are sample sites. Black arrow signifies flow direction.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



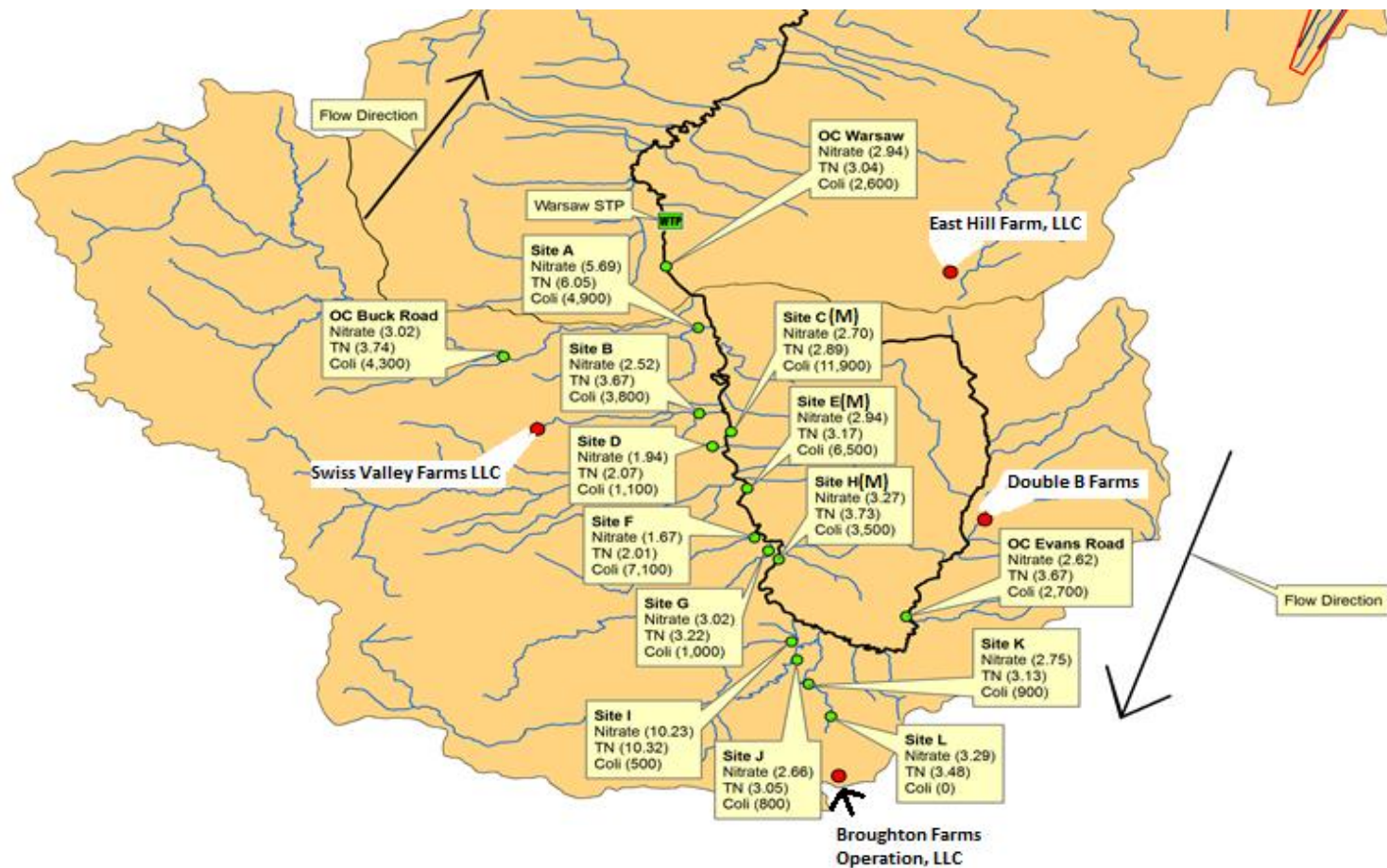


Figure 30. Nitrate (mg N/L) and total nitrogen (TN: mg N/L) concentrations and total coliform abundances (CFU/100 mL) upstream from OC Warsaw on 8 March 2011, Oatka Creek (Fig. 2). Red dots are CAFOs. Light green dots are sample sites. Black arrow signifies flow direction. Oatka Creek main stem is bolded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

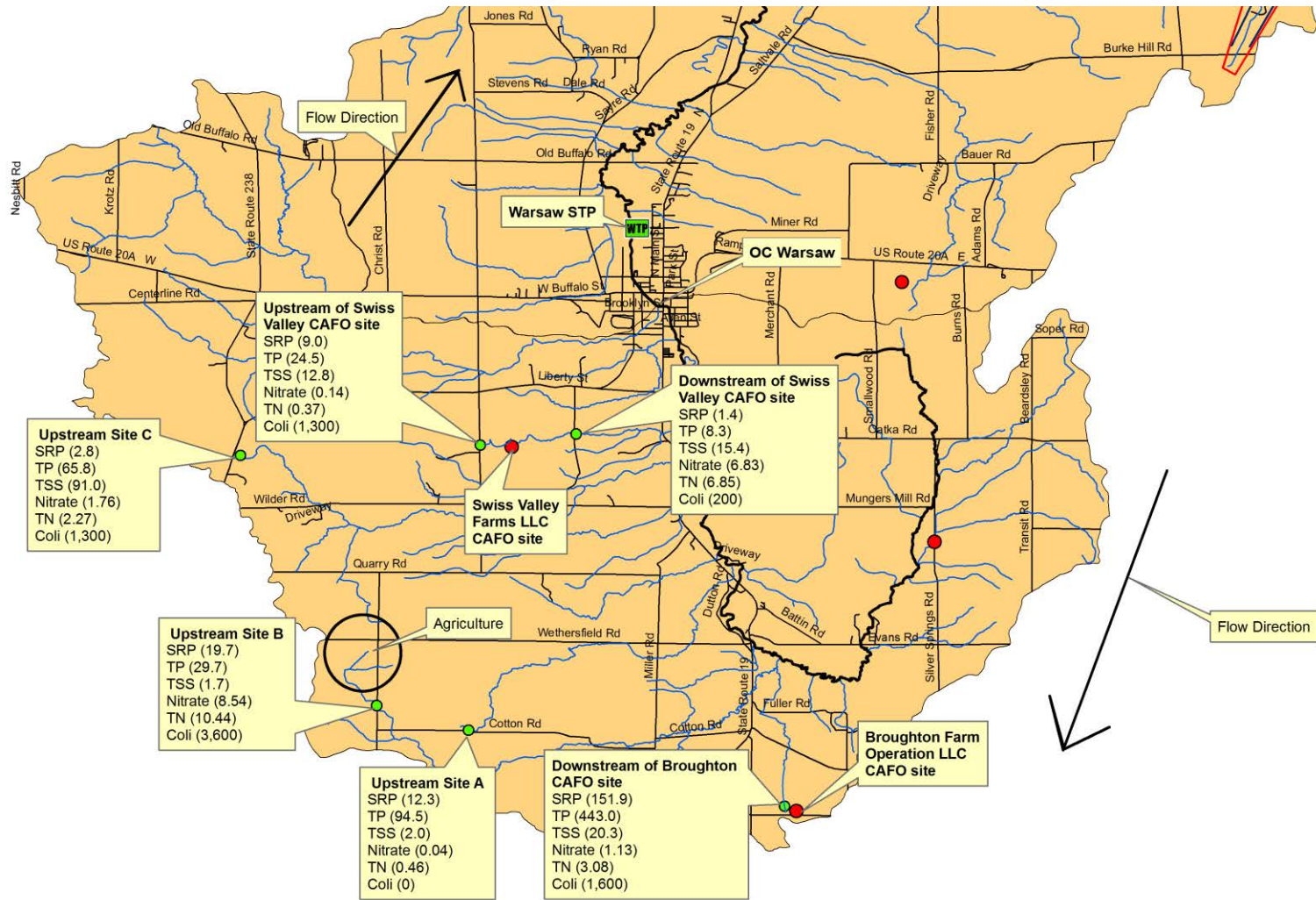


Figure 31. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), total suspended solid (TSS: mg/L), nitrate (mg N/L), and total nitrogen (TN: mg N/L) concentrations and total coliform abundances (CFU/100 mL) upstream from OC Warsaw CAFO operation and headwater sites on 15 March 2011,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

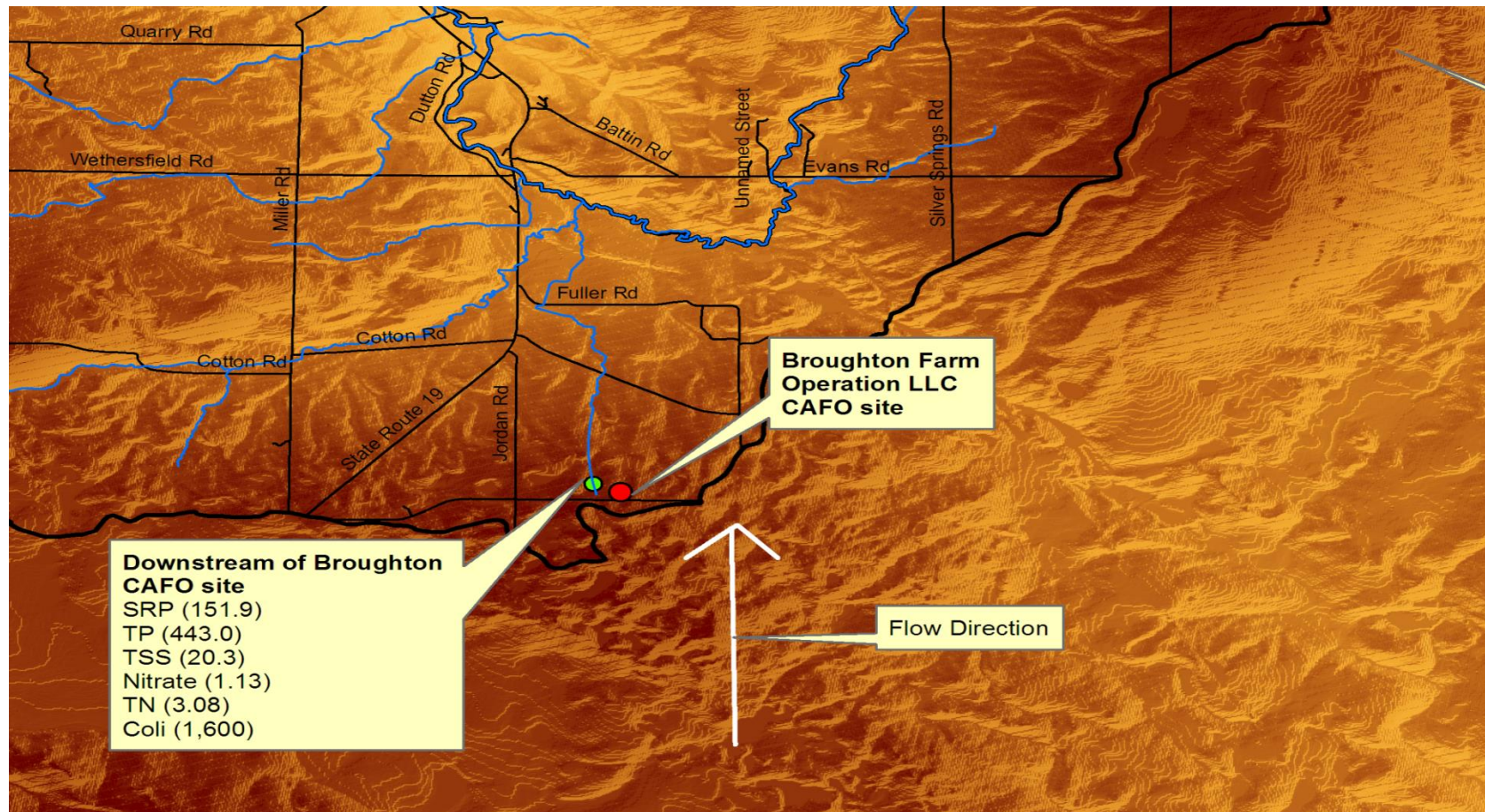


Figure 32. Digital Elevation Map (DEM) of the furthest upstream reach of Oatka Creek and nutrient concentrations on 15 March 2011 (Fig. 31). Higher elevation is illustrated by the darker background. Green dot is a sampling location. White arrow illustrates stream flow direction.

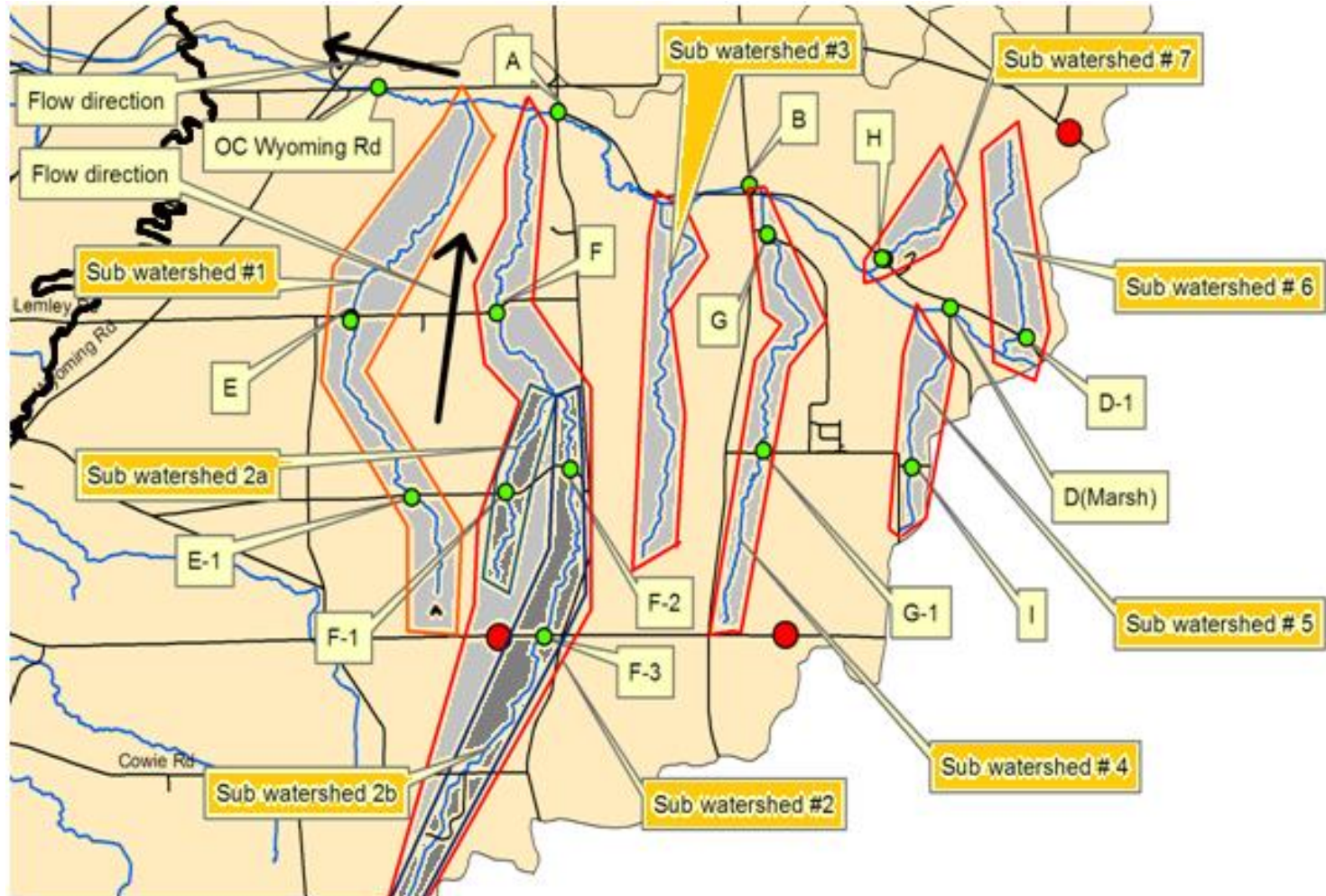


Figure 33. Segment analysis sites (A to H) in the Wyoming Road subwatershed (Fig. 2), 3 August 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red and blue outlines show each individual subwatershed (1-7). Oatka Creek main stem is bolded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

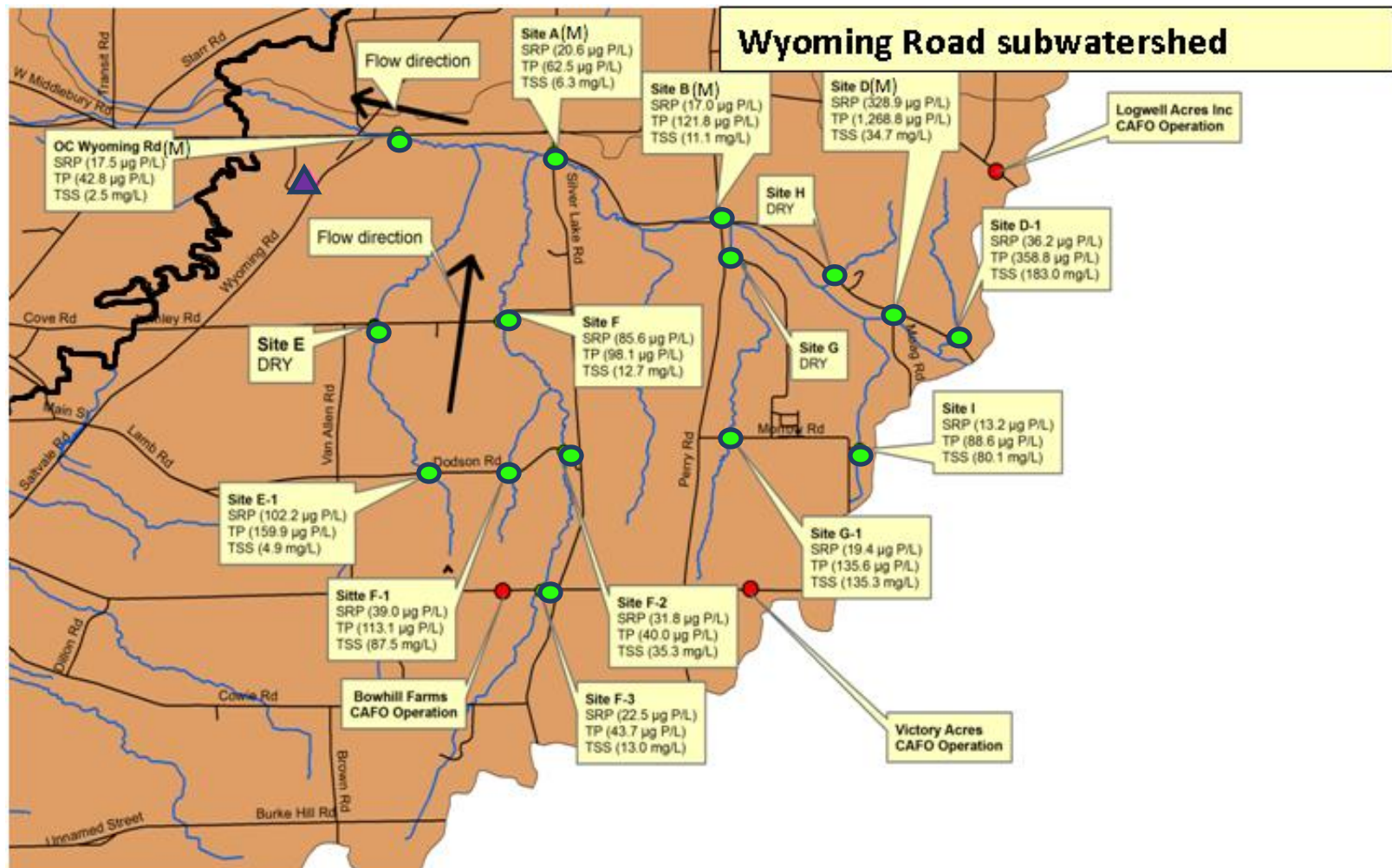


Figure 34. Soluble reactive phosphorus (SRP), total phosphorus (TP), and total suspended solid (TSS) concentrations in the Wyoming Road subwatershed on 3 August 2010. Light green dots are sample sites. Purple triangle is a SPDES site. Arrows signify flow direction. Oatka Creek mains tem is bolded in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

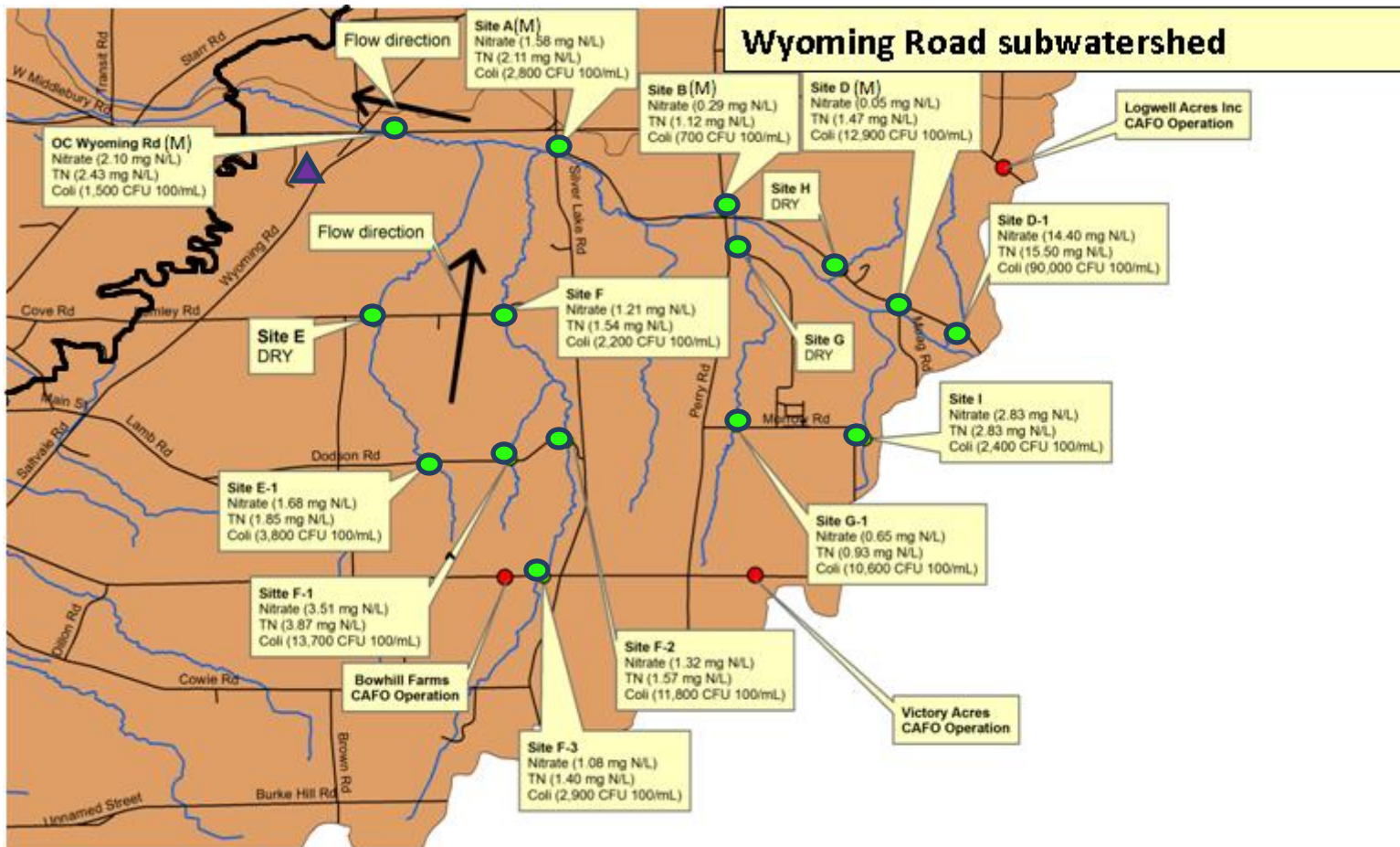


Figure 35. Nitrate and total nitrogen (TN) concentrations and total coliform abundances in the Wyoming Road subwatershed on 3 August 2010. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction. Oatka Creek main stem is bolded in black on left side of figure.

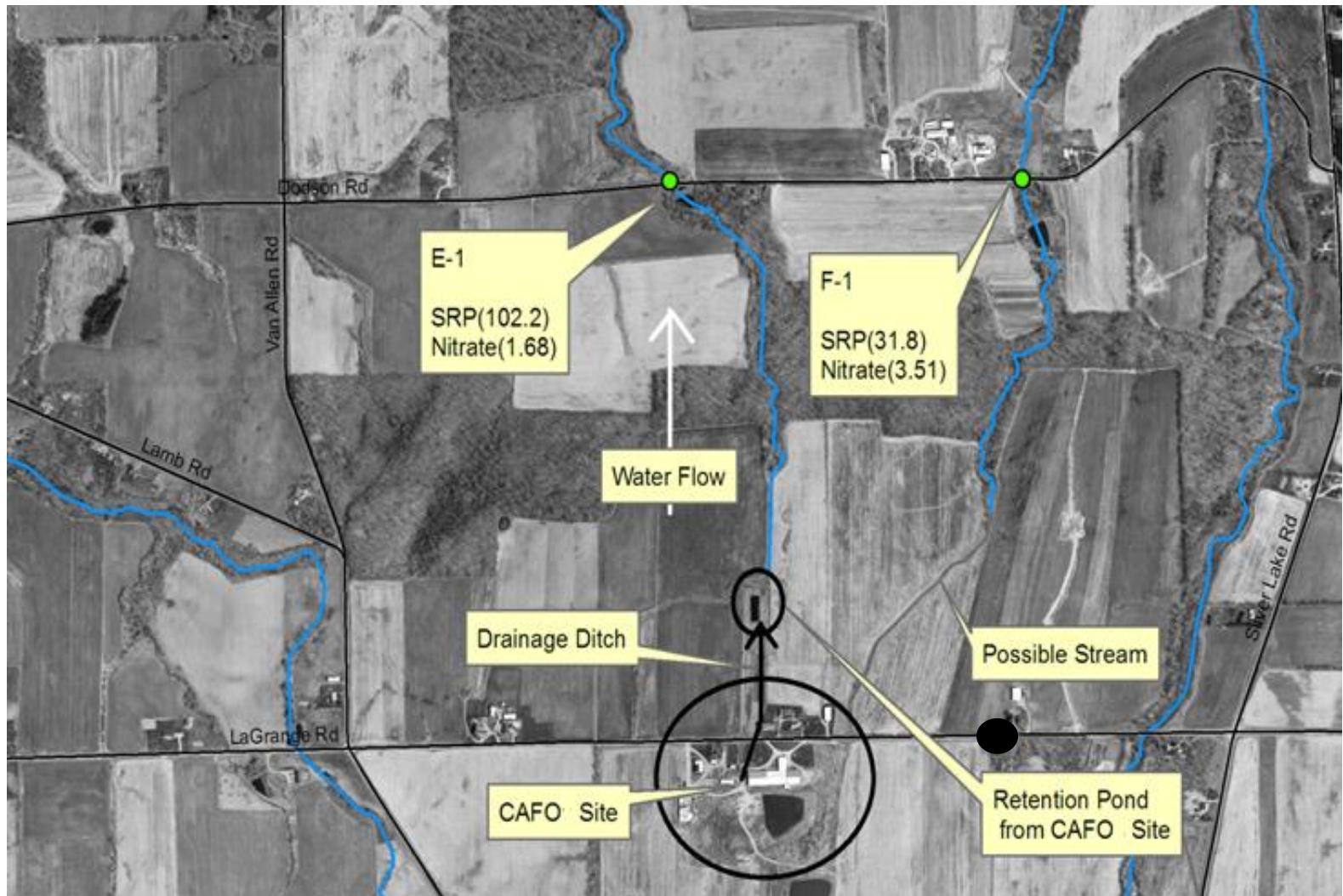


Figure 36. Soluble reactive phosphorus ( $\mu\text{g P/L}$ ) and nitrate ( $\text{mg N/L}$ ) concentrations in in the Wyoming Road subwatershed at Sites E-1 and F-1 on 3 August 2010, Oatka Creek. CAFO site (Bowhill Farms) is circled and there is a retention pond that drains from Bowhill Farms to the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

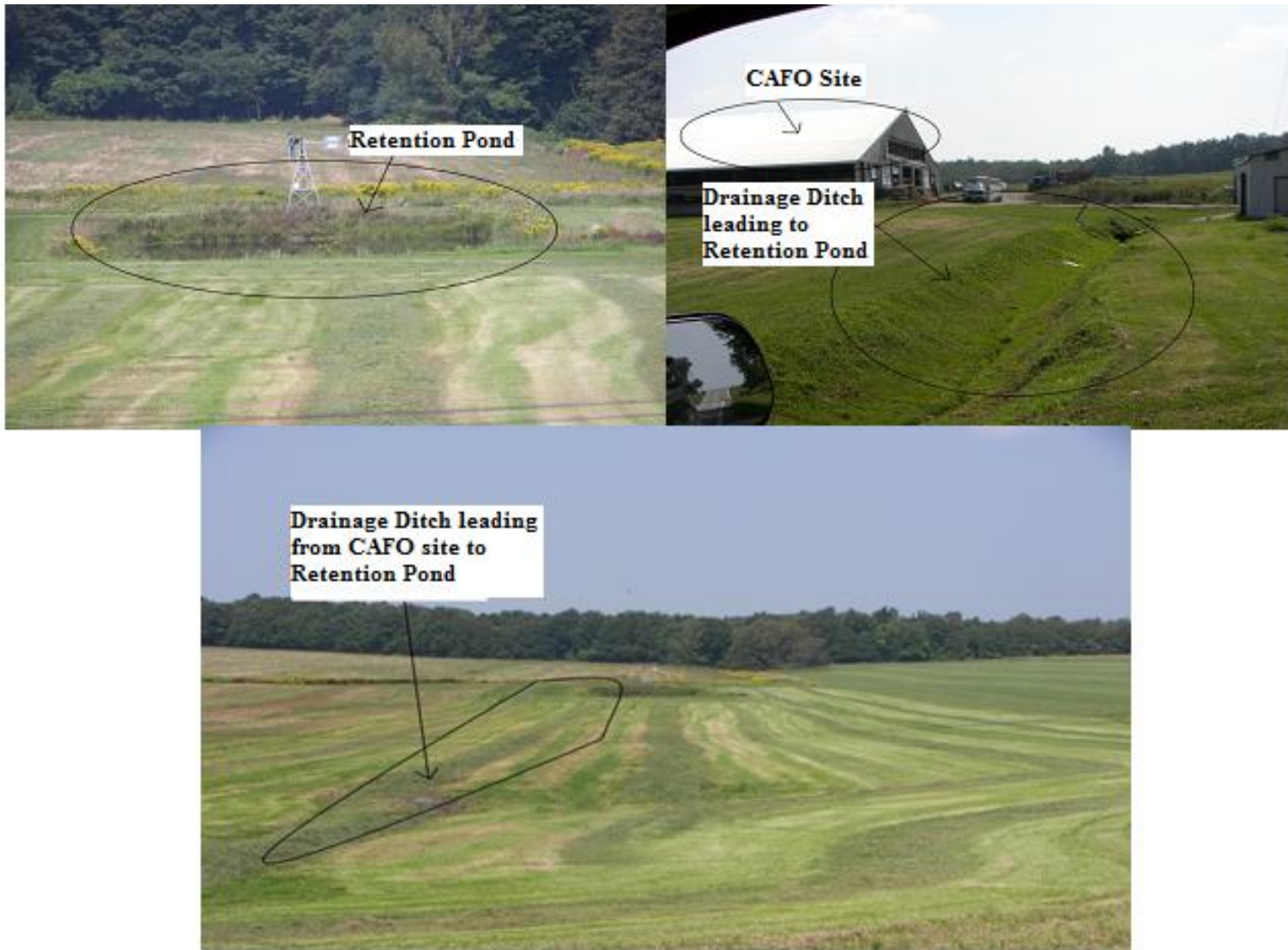


Figure 37. Pictures of the CAFO site (Bowhill Farms), drainage ditch, and retention pond located upstream of subwatershed #2 (Figs. 33-36 ) on (Date of picture: 7 September 2010).



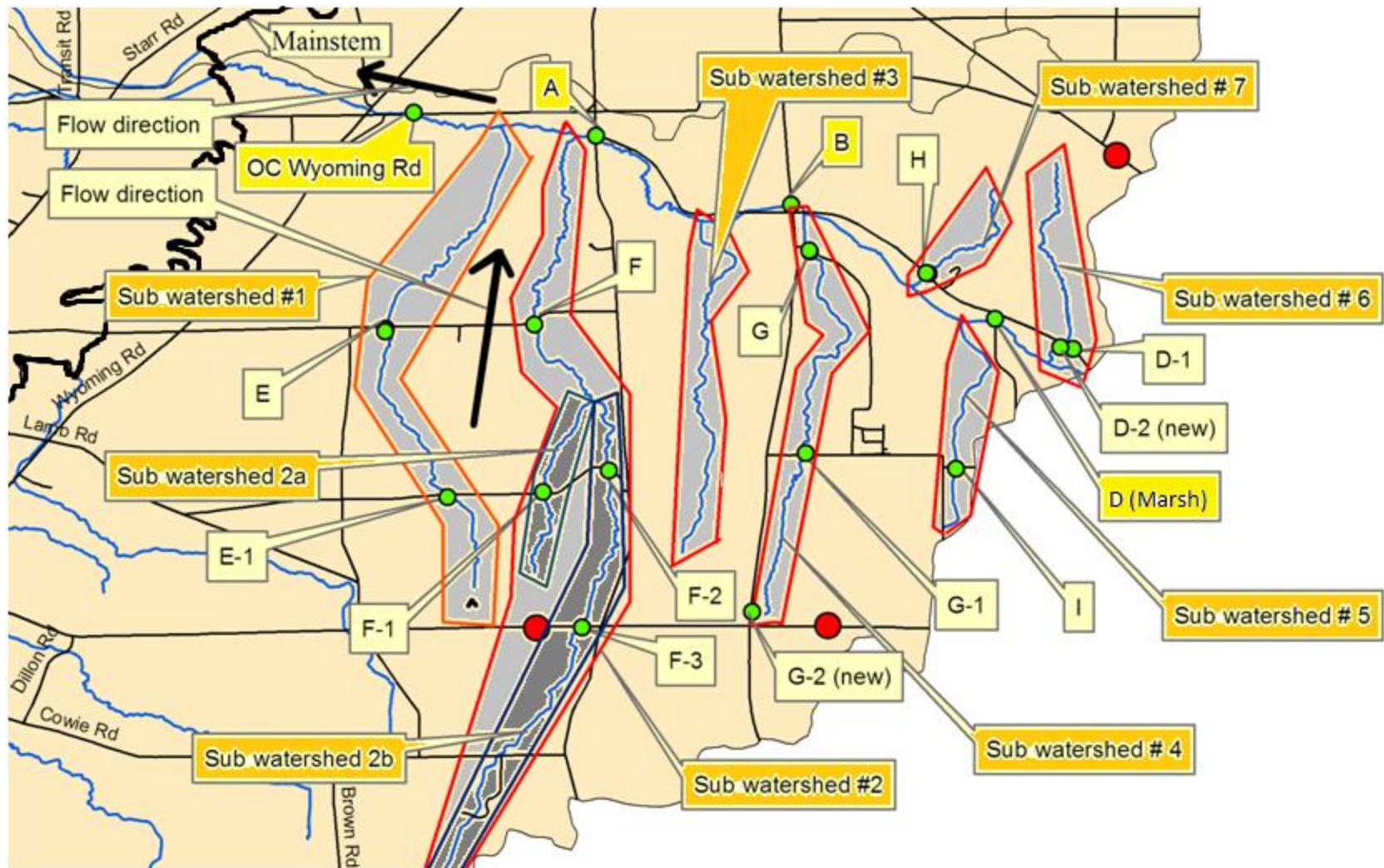


Figure 38. Segment analysis sites (A to H) in the Wyoming Road subwatershed (Fig. 2), 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red and blue outlines show each individual subwatershed (1-7). Sites bolded in yellow (OC Wyoming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

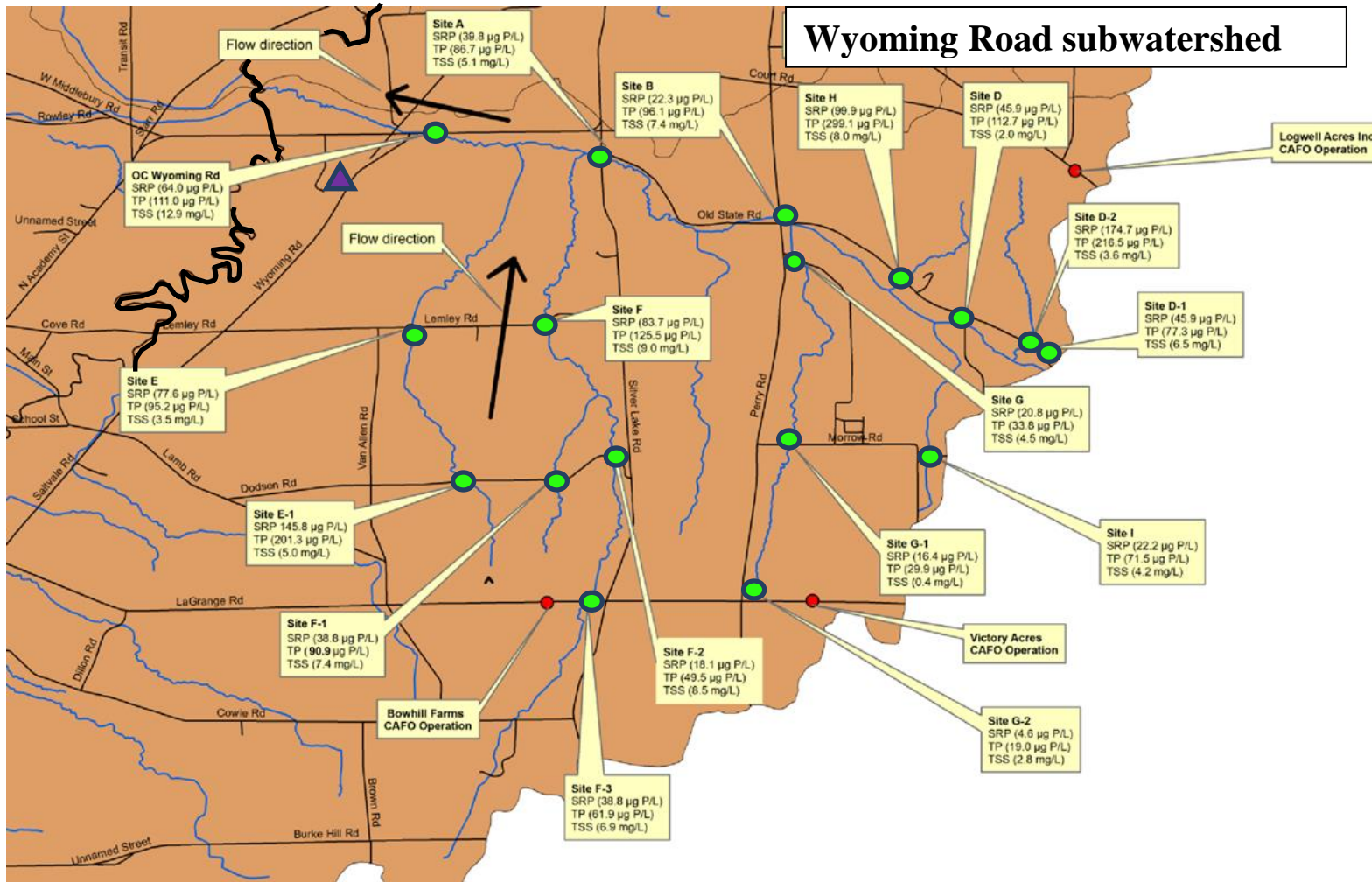


Figure 39. Soluble reactive phosphorus (SRP), total phosphorus (TP), and total suspended solid (TSS) concentrations in the Wyoming Road subwatershed on 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Purple triangle is a SPDES site. Oatka Creek main stem is bolded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

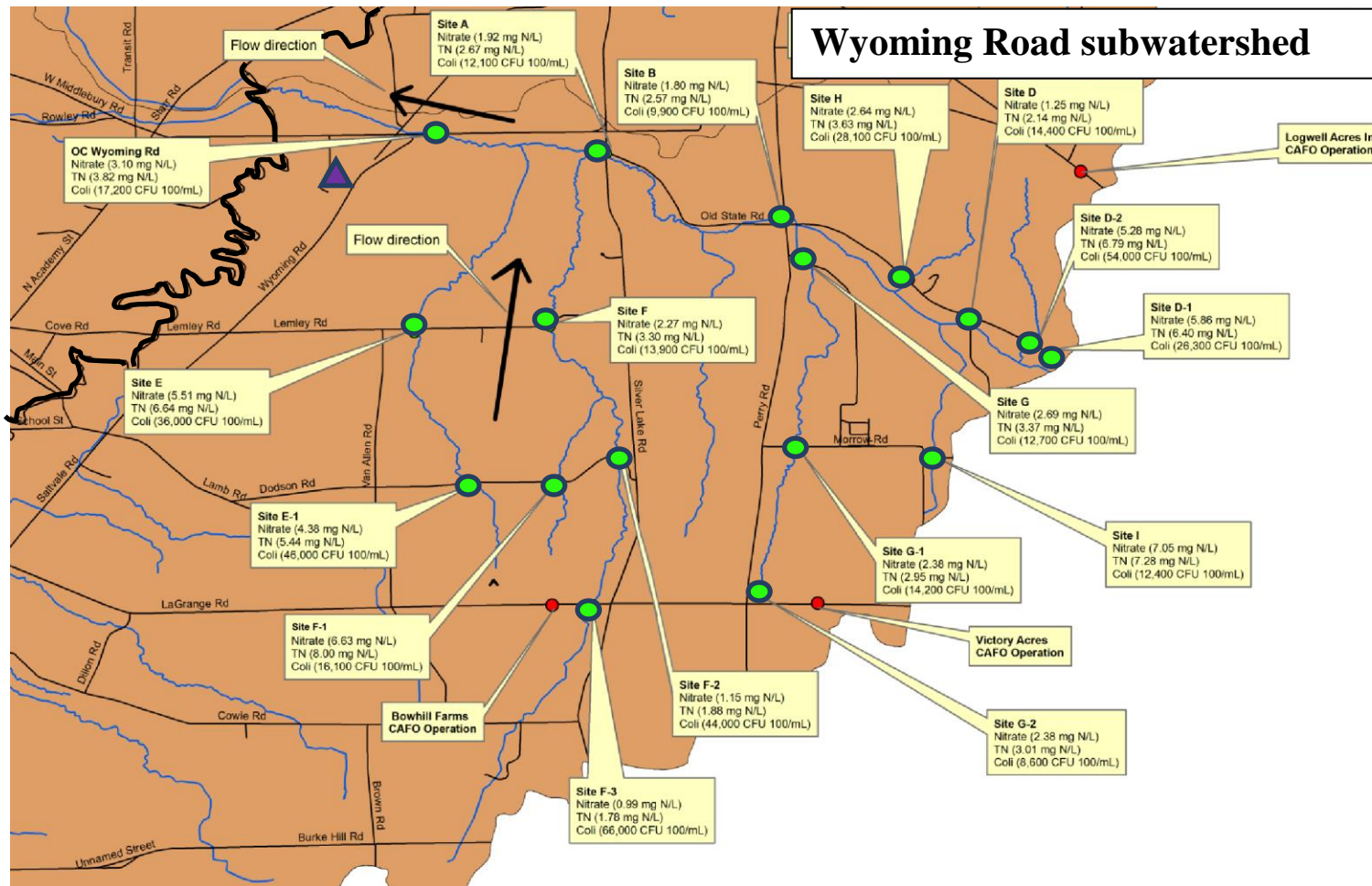


Figure 40. Nitrate and total nitrogen (TN) concentration and total coliform abundances in the Wyoming Road subwatershed, 6 October 2010. Red dots are CAFO sites. Light green dots are sample sites. Purple triangle is a SPDES site. Oatka Creek main stem is bolded black on left side of figure. Arrows signify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



Figure 41. Picture of Site D-1 in the Wyoming Road subwatershed (Fig. 38). Black drainage pipe feeding from a residence.

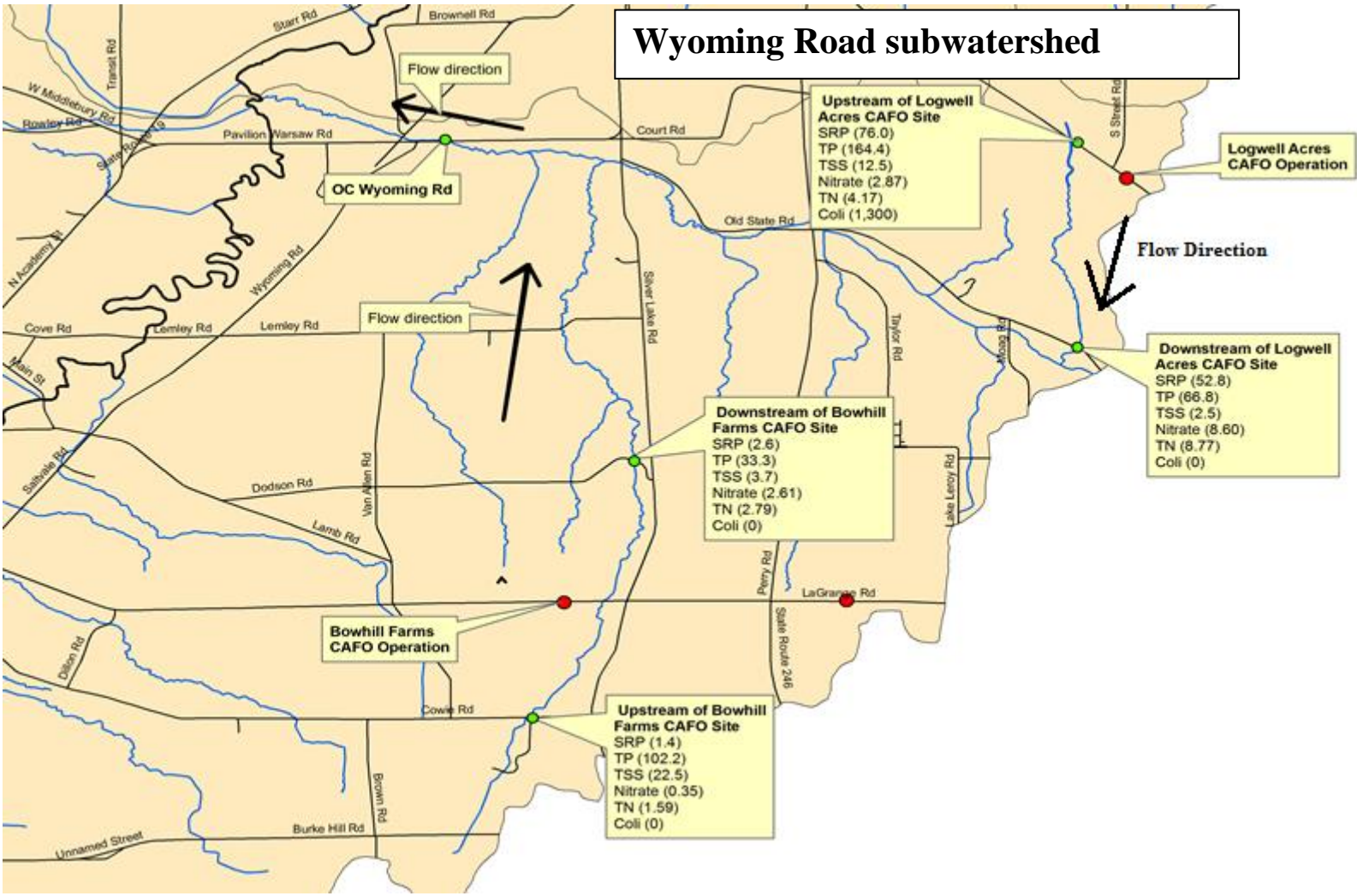


Figure 42. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), total suspended solid (TSS: mg/L), nitrate (mg N/L), and total nitrogen (TN: mg N/L) concentrations and total coliform abundances (CFU/100 mL) in the Wyoming Road (Fig. 2) CAFOs, 29 March 2011, Oatka Creek. Red dots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

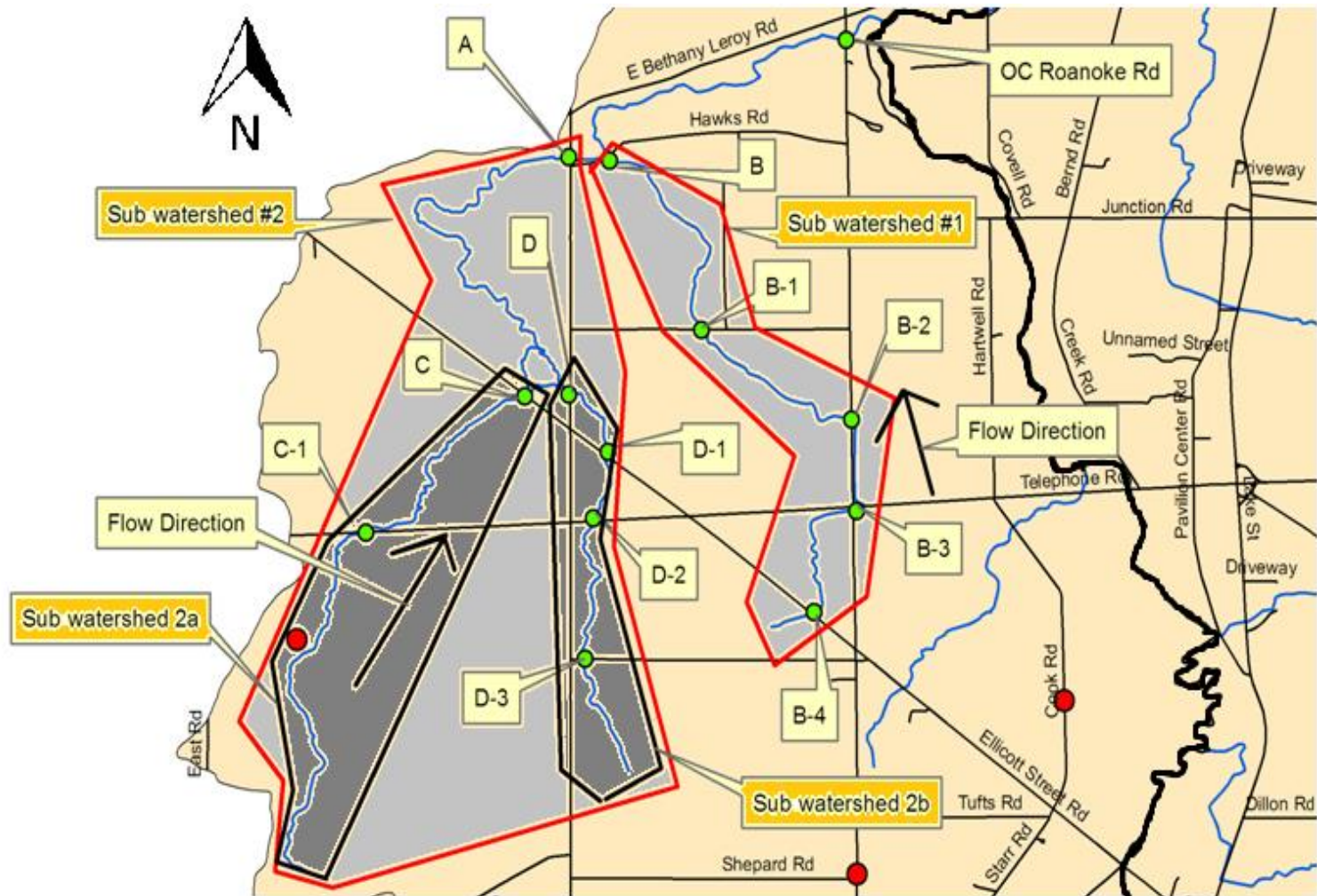


Figure 43. Segment analysis sites (A to D-3) of the Roanoke Road subwatershed (Fig. 2), 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Arrows signify flow direction and red and black outlines show each individual subwatershed (1-2b). Oatka Creek main stem is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

# Roanoke Road subwatershed

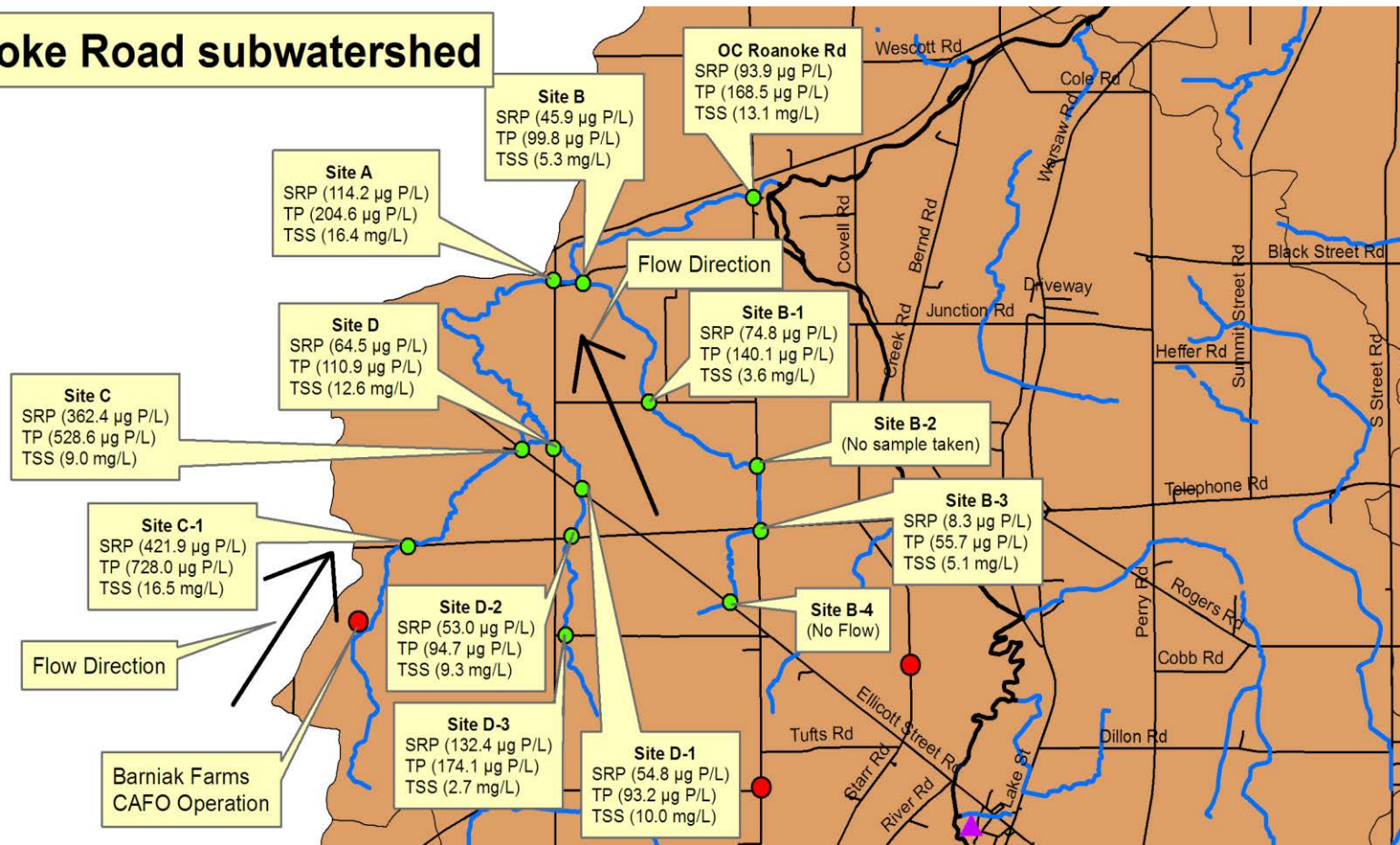


Figure 44. Soluble reactive phosphorus (SRP), total phosphorus (TP), and total suspended solid (TSS) concentrations in the Roanoke Road subwatershed on 6 October 2010, Oatka Creek. Red dots are CAFO sites. Light green dots are sample sites. Purple triangle is a SPDES site. Arrows signify flow direction.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

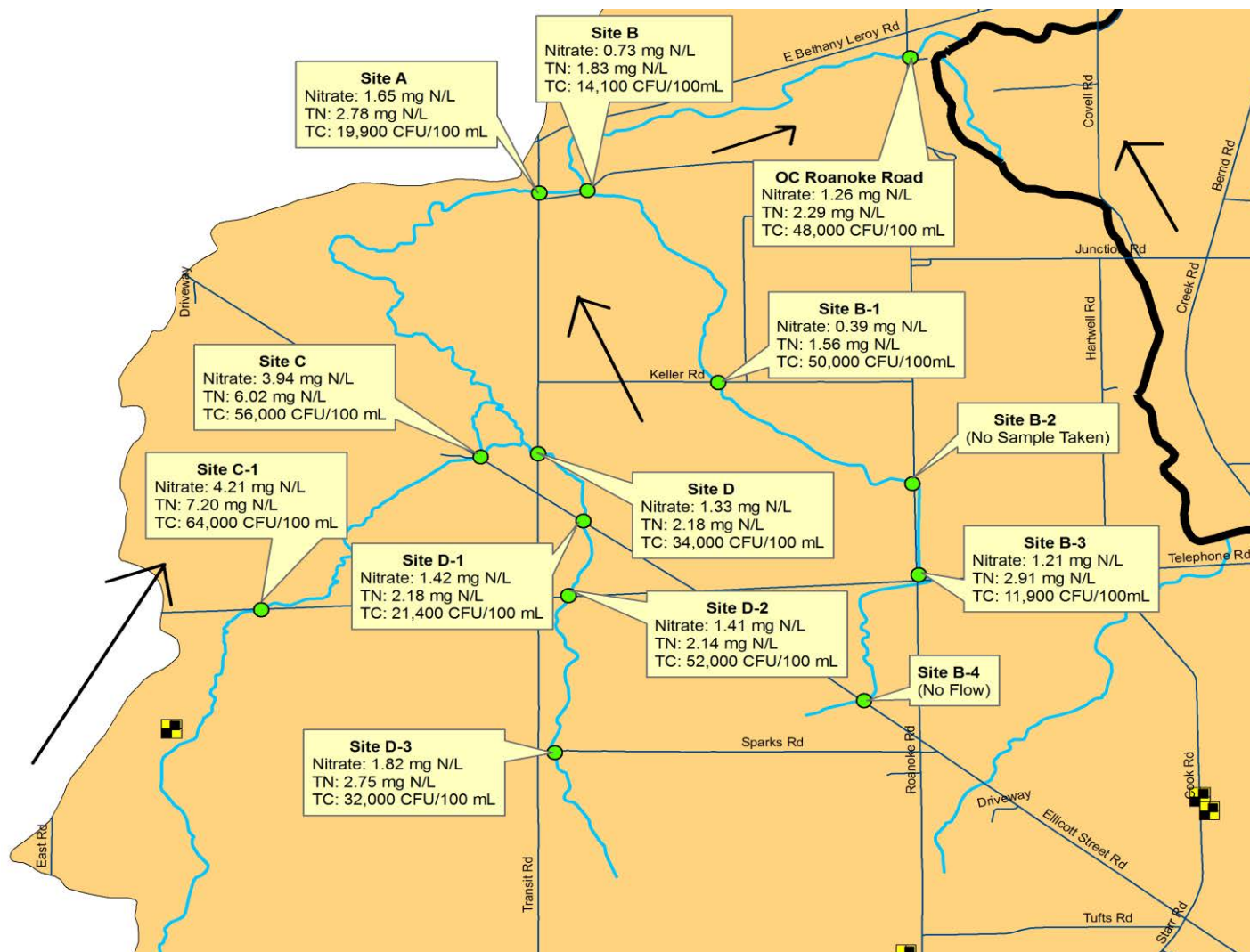


Figure 45. Nitrate and total nitrogen (TN) concentrations and total coliform abundances in the Roanoke Road subwatershed (Fig. 2) on 6 October 2010, Oatka Creek. Black/yellow squares are CAFO sites. Light green dots are sample sites. Arrows signify flow direction. Oatka Creek main stem is bolded in black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



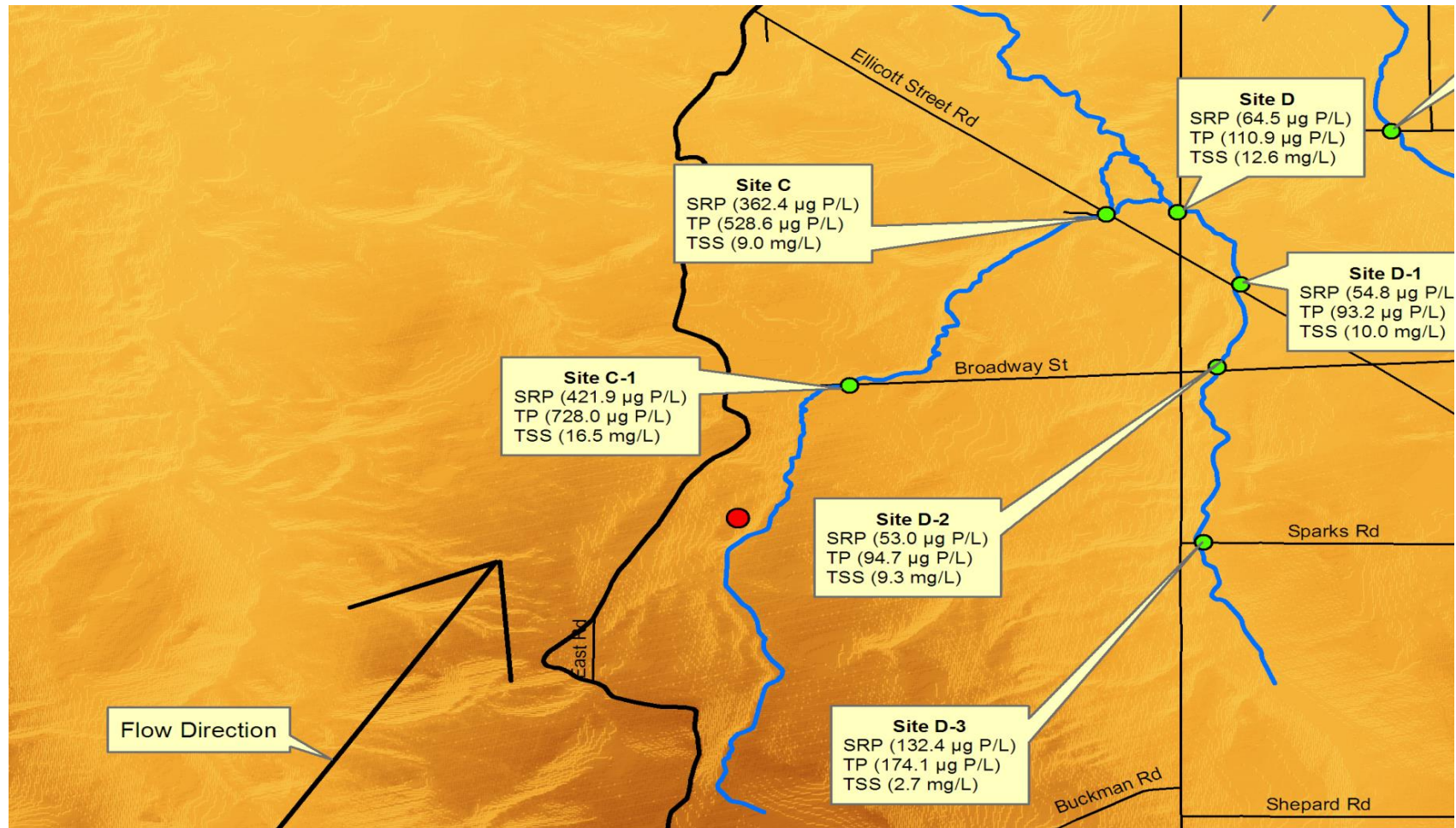


Figure 46. Digital Elevation Map (DEM) of the Roanoke Road subwatershed (Fig. 2) and nutrient concentrations on 6 October 2010, Oatka Creek. Darker orange signifies higher elevation while lighter orange illustrates lower elevations. Light green dots are sampling locations. Red dot is Barniak Farms CAFO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

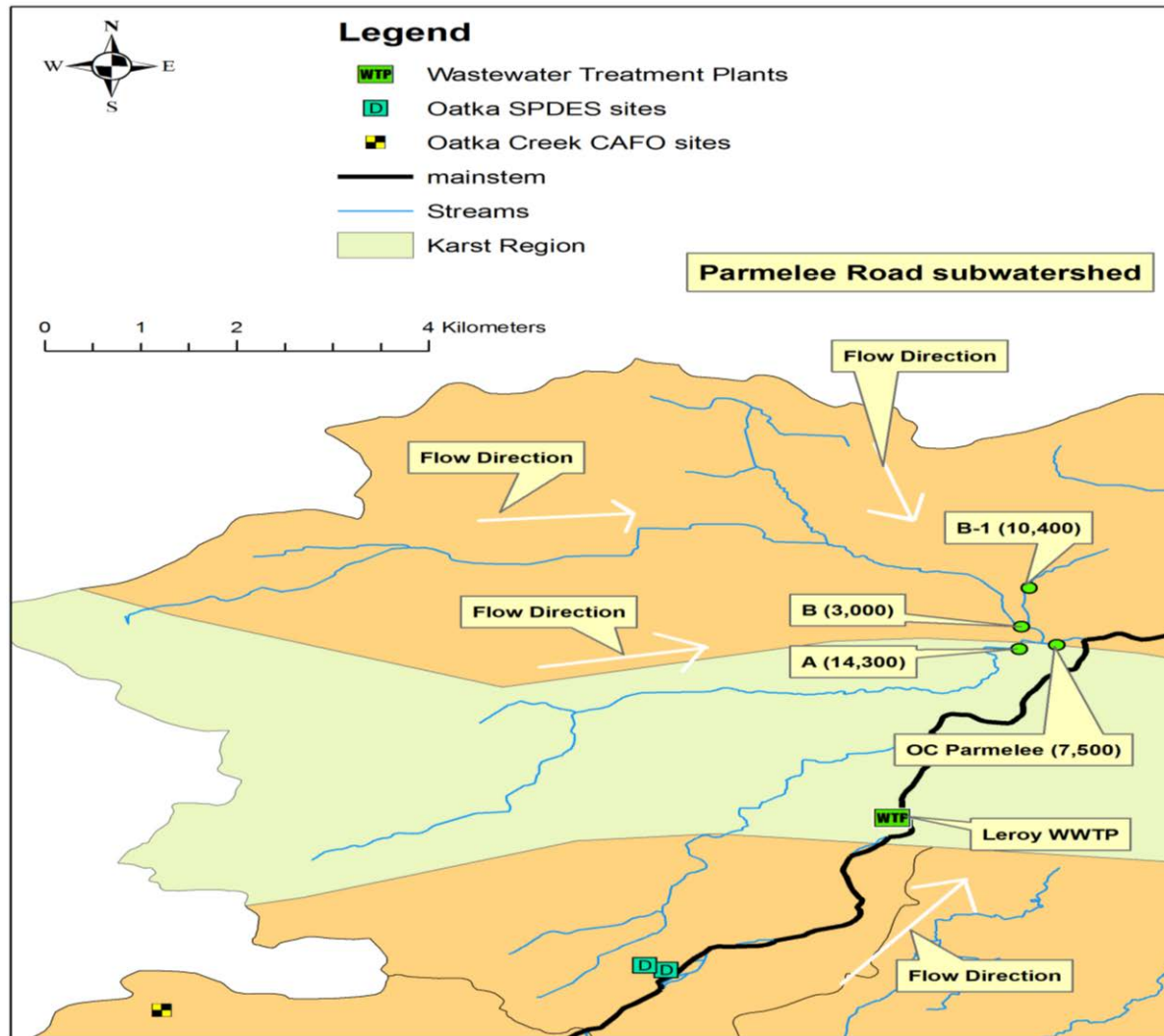


Figure 47. Total coliform abundance (CFU/100mL) at the Parmelee Road subwatershed (Fig. 2), 27 July 2010, Oatka Creek. Green dots represent sample sites.

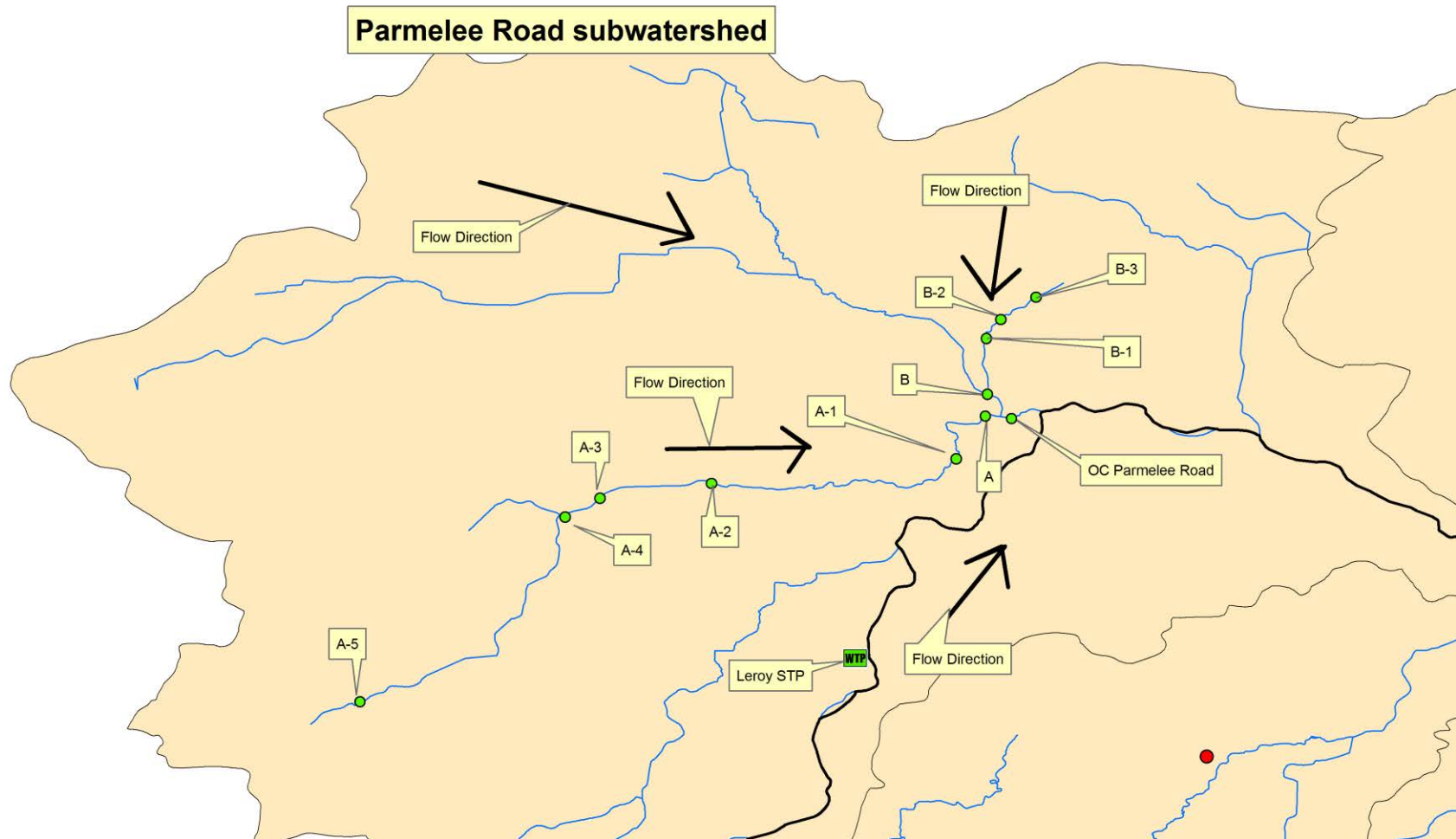


Figure 48. Segment analysis sites (OC Parmalee Road, A to A-5, B, B-1, B-3 to B-5) in the Parmalee Road subwatershed (Fig. 2), 7 June 2011, Oatka Creek. Light green dots are sample sites. Arrows signify flow direction. Red dot signifies a CAFO site. The Oatka Creek main stem is bolded in black.

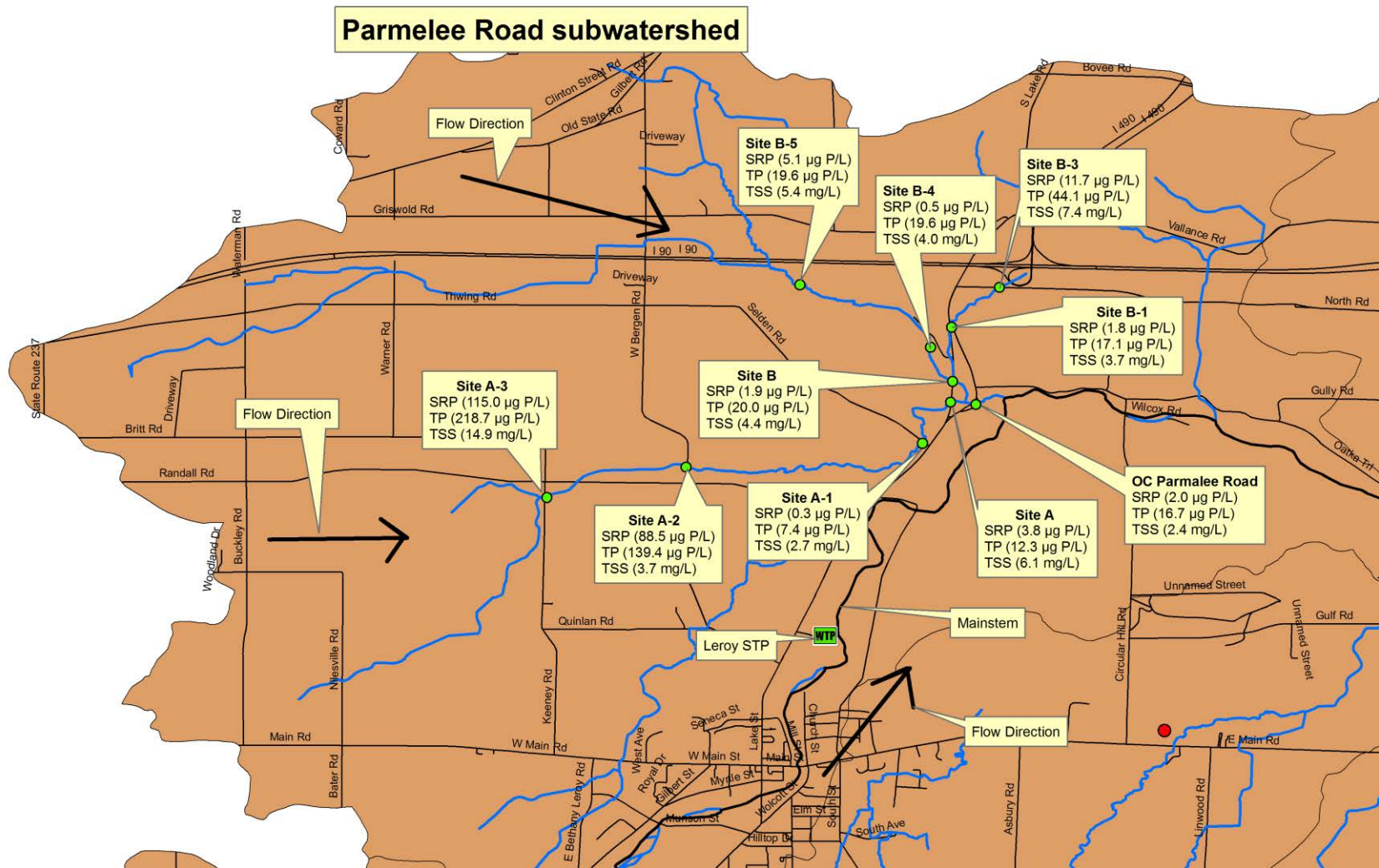


Figure 49. Soluble reactive phosphorus (SRP: µg P/L), total phosphorus (TP: µg P/L), and total suspended solid (TSS: mg/L) concentrations in the Parmelee Road subwatershed (Fig. 2) on 7 June 2010, Oatka Creek. Light green dots are sample sites. Red dot is a CAFO site. Black arrow signifies flow direction. The Oatka Creek main stem is bolded in black.

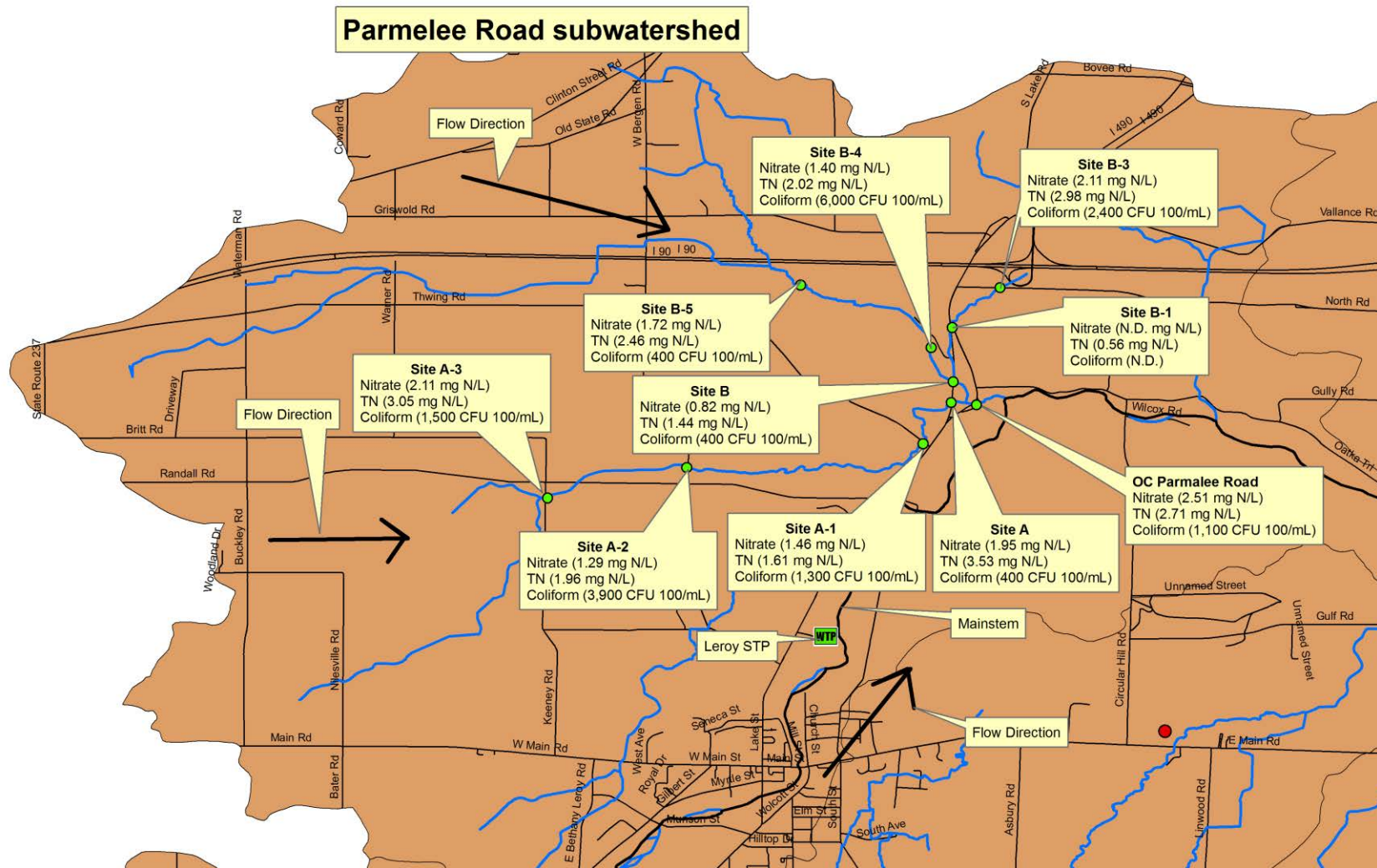


Figure 50. Nitrate (mg N/L) and total nitrogen (TN: mg N/L) concentrations and total coliform abundances (CFU/100 mL) in the Parmelee Road subwatershed (Fig. 2) on 7 June 2010, Oatka Creek. Light green dots are sample sites. Red dot is a CAFO site. Black arrow signifies flow direction. The Oatka Creek main stem is bolded in black.

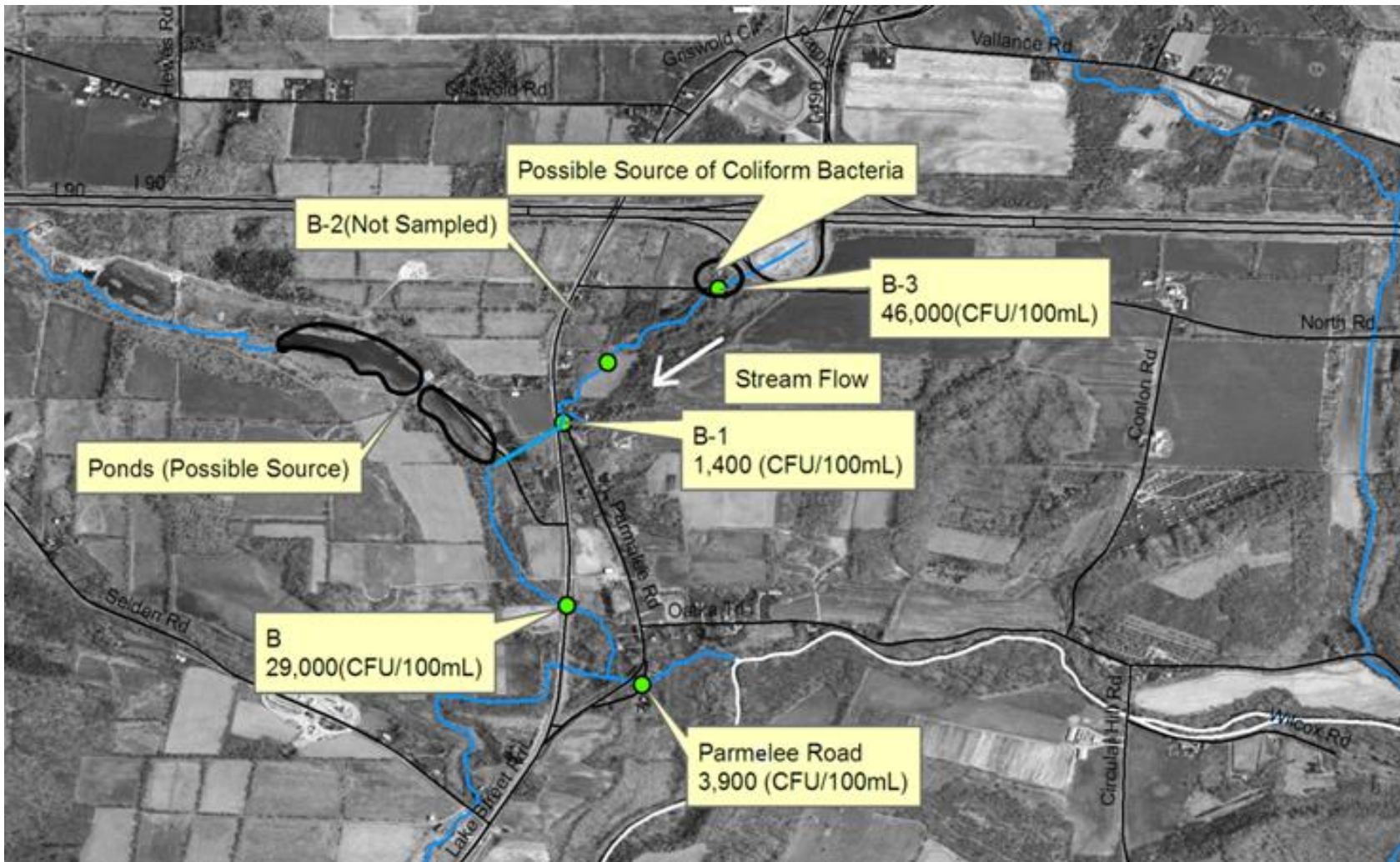


Figure 51. Total coliform abundances (CFU/100 mL) at the Parmelee Road subwatershed (Fig. 2) on 3 August 2010, Oatka Creek. Oatka Creek main stem is bolded in white.

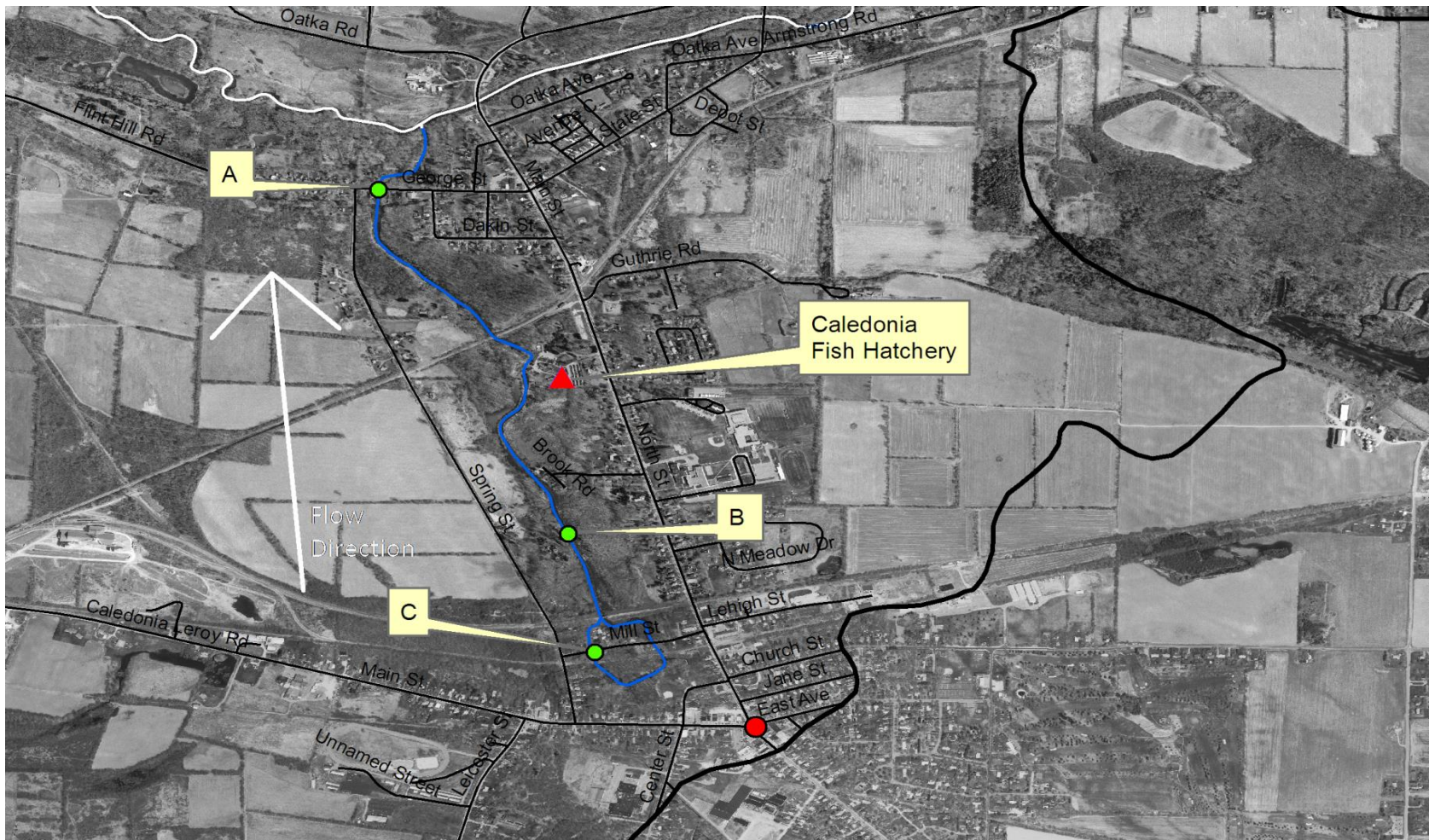


Figure 52. Segment analysis sites (A to C) in the Big Spring Creek subwatershed (Fig. 2), 4 January 2011, Oatka Creek. Red dot is a CAFO site. Light green dots are sample sites. Red triangle is the Caledonia Fish Hatchery. Arrows signify flow direction. Black line is the watershed boundary. Oatka Creek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

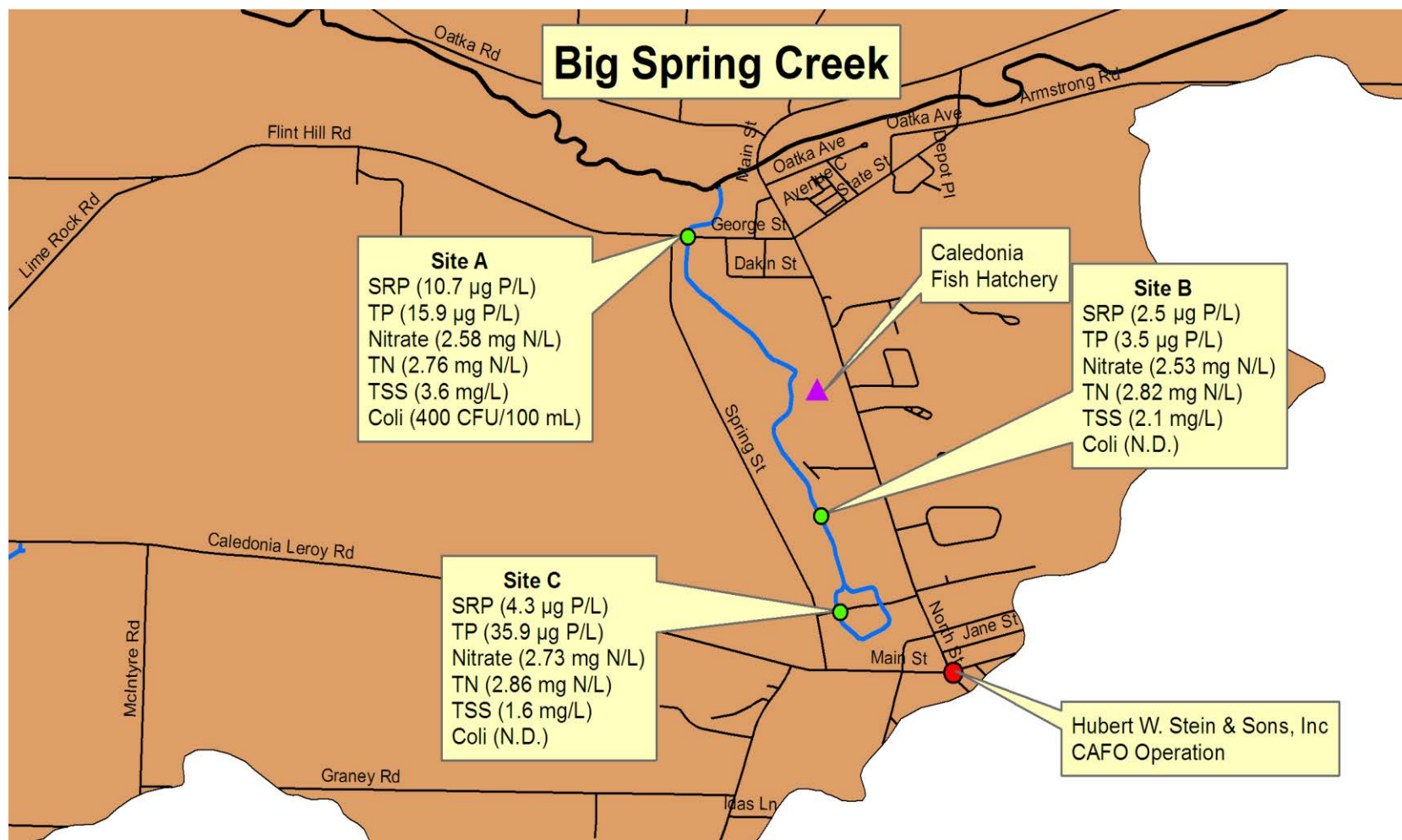


Figure 53. Soluble reactive phosphorus (SRP), total phosphorus (TP), total suspended solid (TSS), nitrate, and total nitrogen (TN) and total coliform abundances in the Big Spring Creek subwatershed (Fig. 2), 4 January 2011, Oatka Creek. Red dot is a CAFO operation. Light green dots are sample sites. Purple triangle is a SPDES site. White arrow signifies flow direction. Oatka Creek main stem is bolded black on top of figure.



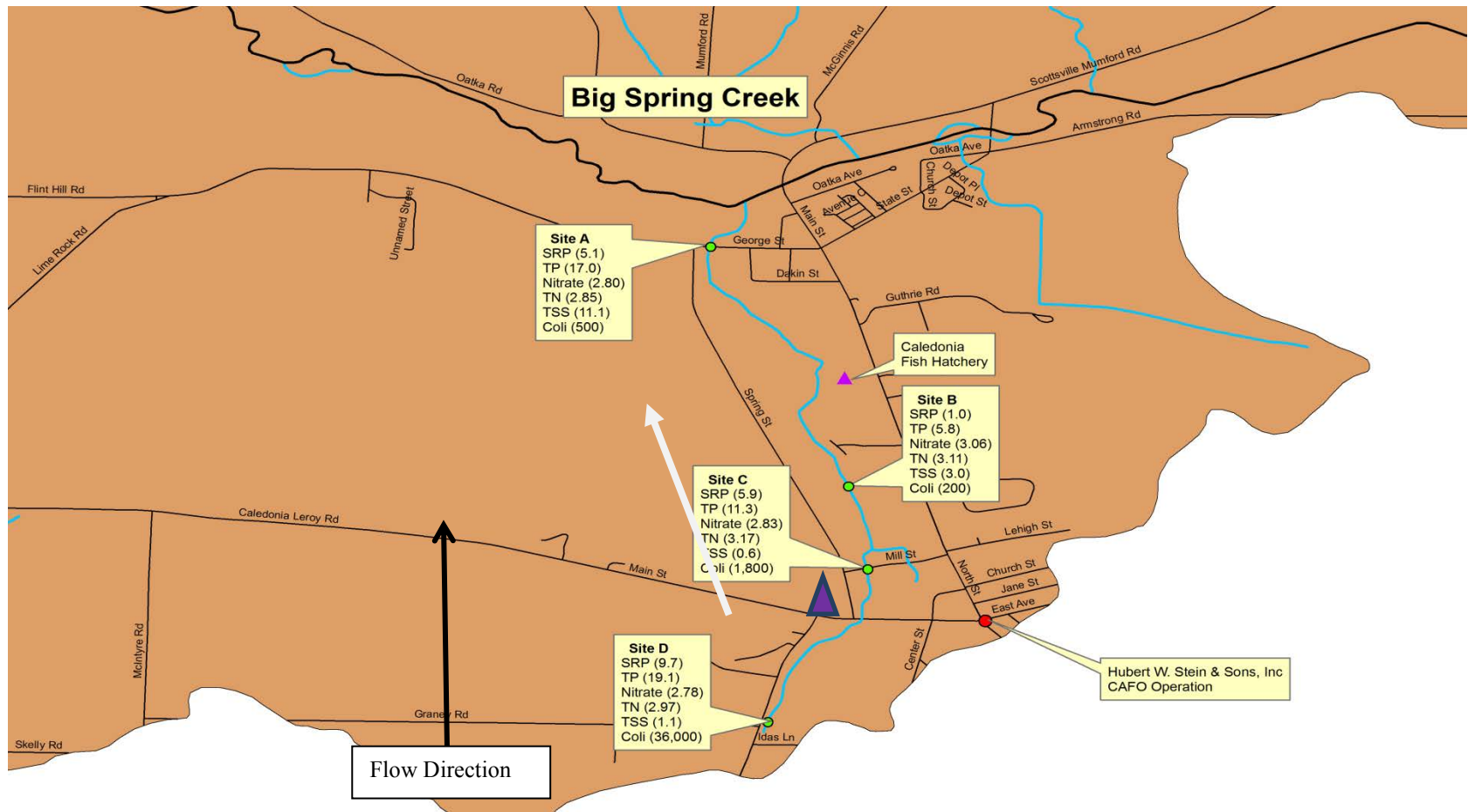


Figure 54. Soluble reactive phosphorus (SRP:  $\mu\text{g P/L}$ ), total phosphorus (TP:  $\mu\text{g P/L}$ ), total suspended solid (TSS:  $\text{mg/L}$ ), nitrate ( $\text{mg N/L}$ ), and total nitrogen (TN:  $\text{mg N/L}$ ) concentrations and total coliform abundances (CFU/100 mL) in the Big Spring Creek subwatershed (Fig. 2), 3 May 2011, Oatka Creek. Red dots are CAFOs. Light green dots are sample sites. Black arrow signifies flow direction. Oatka Creek main stem is bolded black.

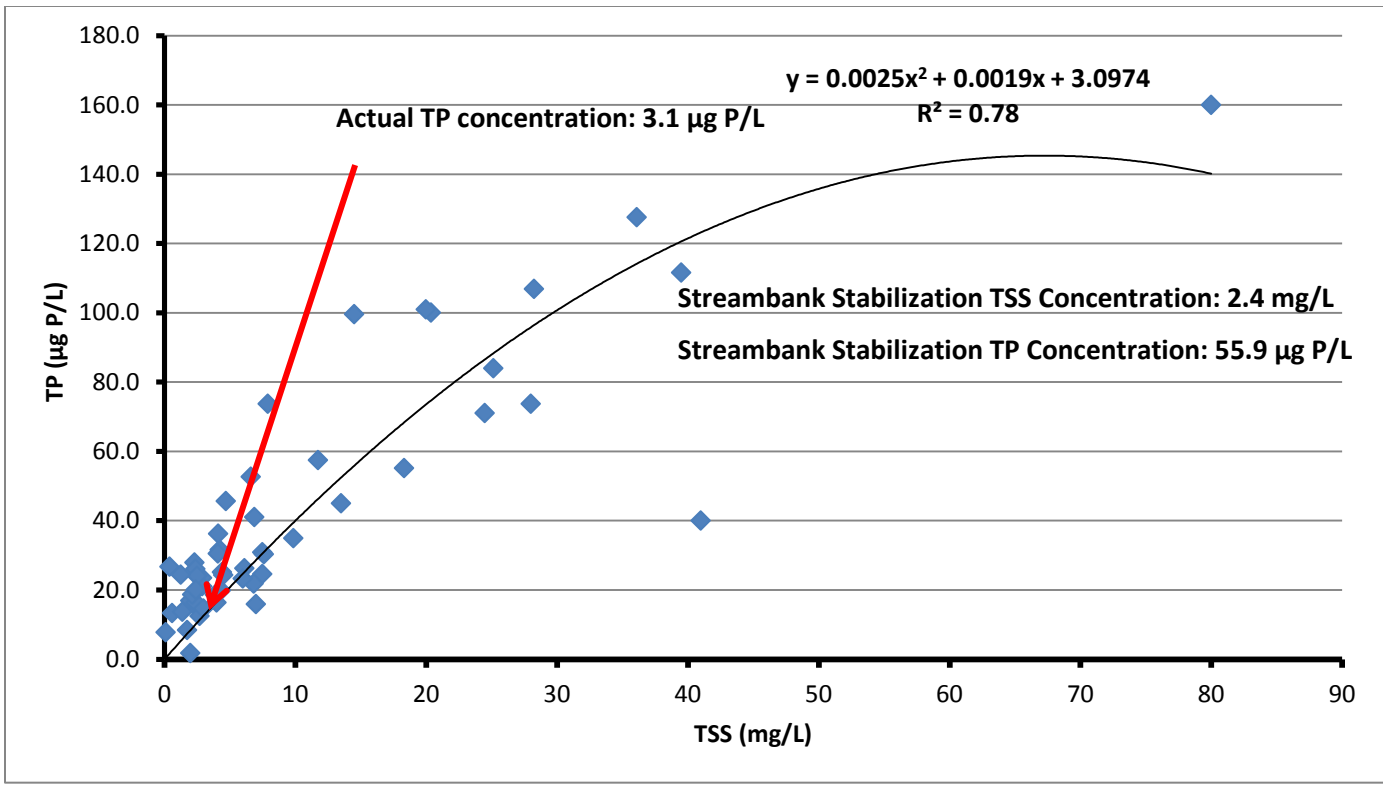


Figure 55. Regression of measured TP and TSS concentrations at Garbutt, NY.

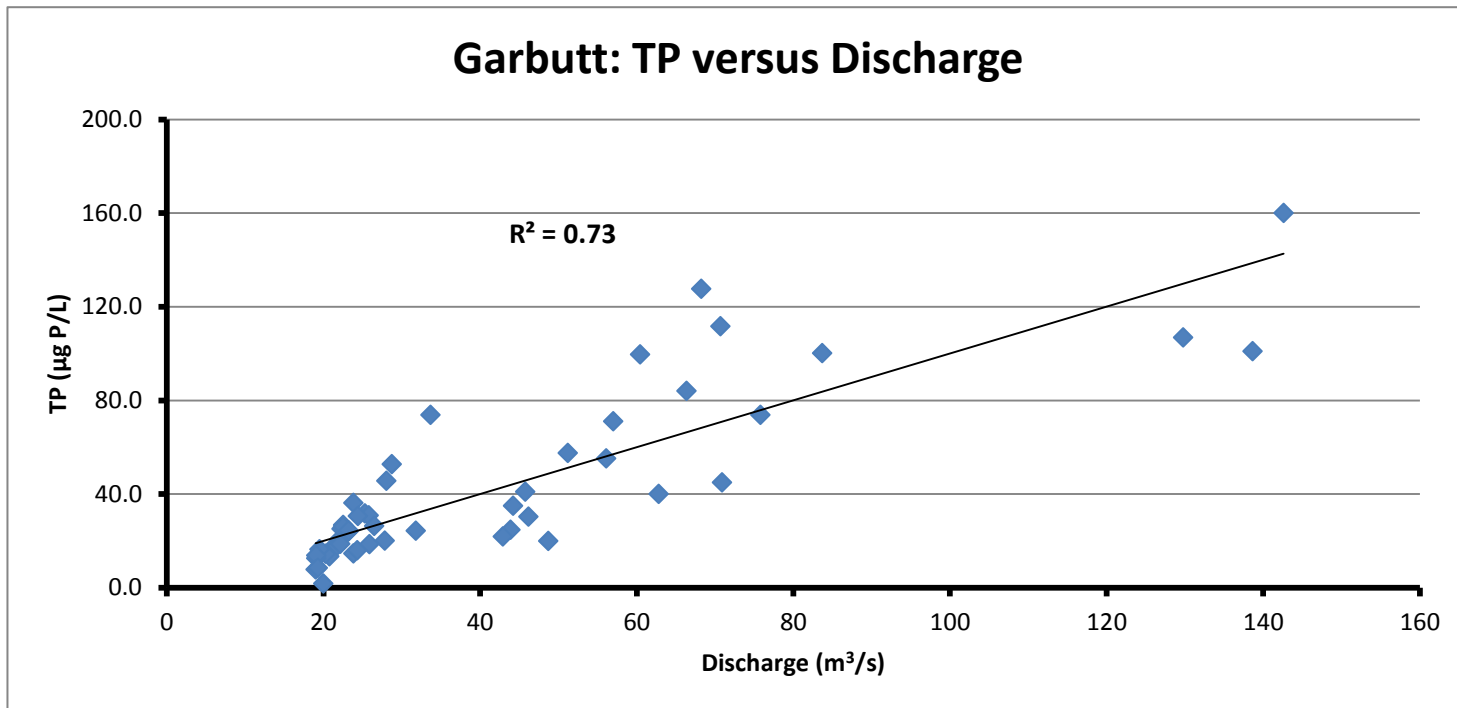


Figure 56. Total phosphorous (TP) concentration versus discharge (m³/s) at the USGS monitoring station located in Garbutt, NY.

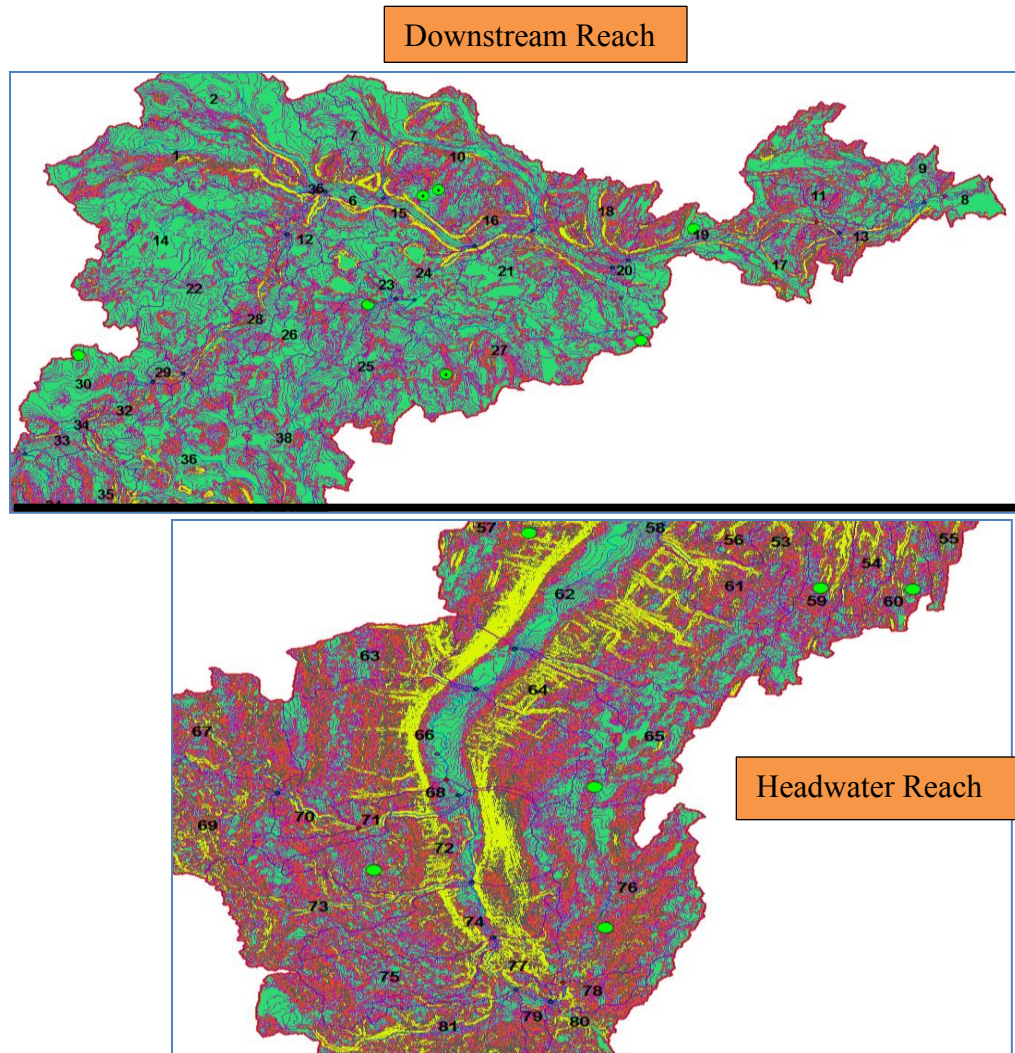


Figure 57. Percent slope of landscape in the Downstream Reach (top) and Headwater Reach (bottom) of the Oatka Creek watershed (Fig. 14). Green = 0-2% land slope, Maroon = 2-5% land slope, Orange = 5-8 % land slope, Gray = 8-15% land slope and Yellow = 15-100% land slope.

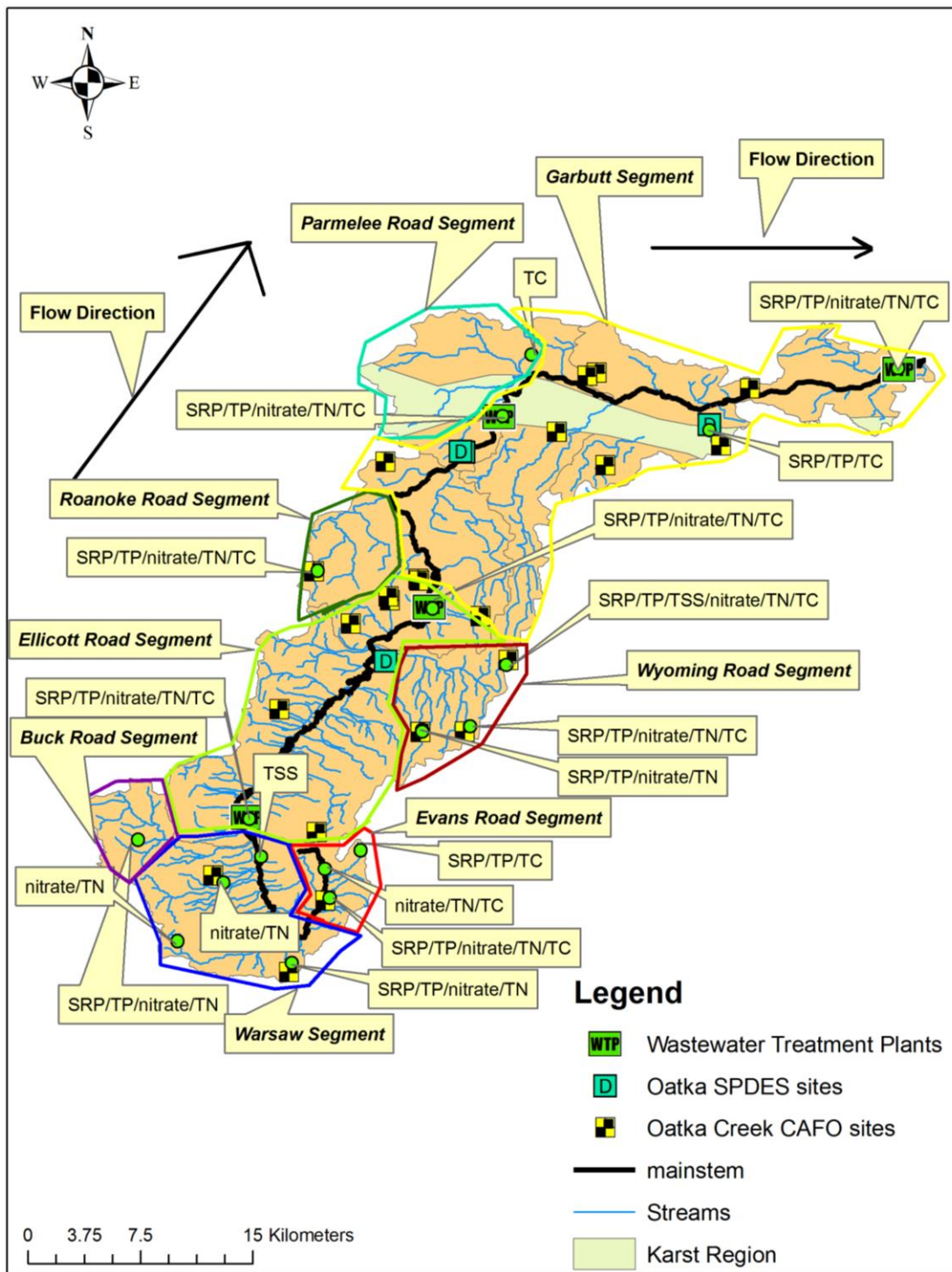


Figure 58. Summary map of all critical source areas within the Oatka Creek Watershed found using segment analysis. Subbasin boundaries for Evans Road, Warsaw, Wyoming Road, Buck Road, Roanoke Road, Parmelee Road, and Garbutt segments are shown. , TP= Total Phosphorus, SRP= Soluble Reactive Phosphorus, TN= Total Nitrogen, TSS=Total Suspended Solids, and TC=Total Coliform Bacteria. CAFO=Concentrated Animal Feeding Operations. STP =Wastewater Treatment Plant.

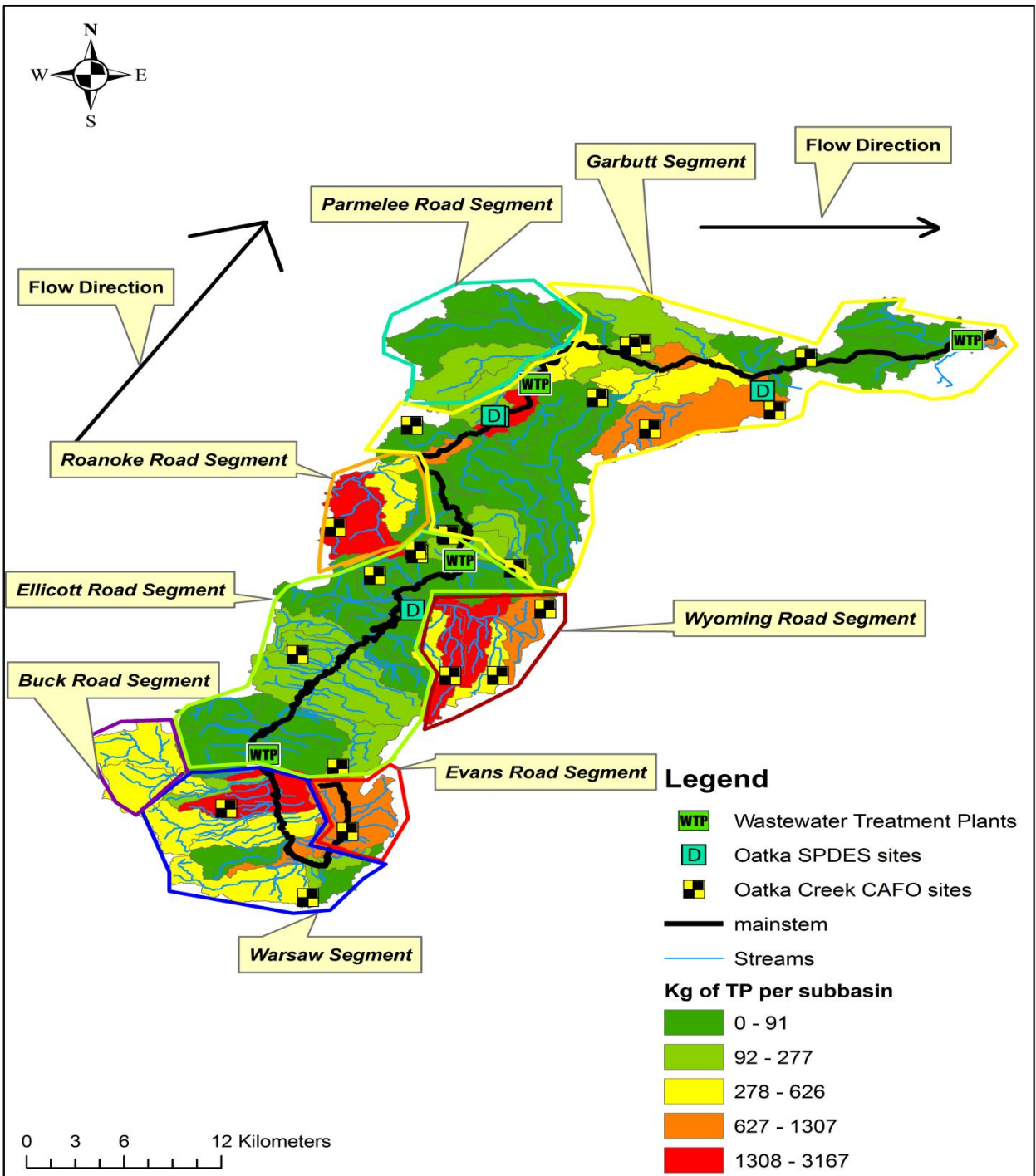


Figure 59. Map of annual total phosphorus (TP) loads from subbasins in the Oatka Creek watershed obtained from the Oatka Creek SWAT model. Subbasins with the lowest individual load are green and those with the highest individual load are red. WWTP=Wastewater Treatment Plant. CAFO=Concentrated Animal Feeding Operations.

## Appendix A

Extended table of SWAT calibration parameters. The parameter name, description of parameter, and value 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 = Parmalee Road; H = Garbutt), all values are given.

<b>Oatka Creek SWAT Calibration Parameters by Input Table</b>									
		<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>	<b>F</b>	<b>G</b>	<b>H</b>
<b>Soils (.sol)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
CN2	SCS Curve Number	-23%							
All Parameters	Soil Type Specific Parameters	Default							
SOL_AWC	Soil Antecedent Water Content	Default							
<b>Subbasin (.sub)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
All Parameters	Subbasin Specific Parameters	Default							
<b>HRU (.hru)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
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							
<b>Groundwater (.gw)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							

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	Half-life of Nitrogen in Water	0							
LAT_ORGN	Organic Nitrogen in Lateral Flow	0.055							
GWLATP	Organic P in Baseflow	0.8							
<b>Routing (.rte)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
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							
<b>Management (.mgf)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
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							
<b>Soil Chemical (chm.)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
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							
<b>Pond/Wetland (pnd.)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
All	Pond/Wetland Specific Parameters	Default							
<b>Stream Water Quality (swq.)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
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
<b>Basin (.bsn)</b>									
<i>Parameter</i>	<i>Description</i>	<i>Value</i>							
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
<b>Watershed Water Quality Parameters (.wwq)</b>		
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 Parmalee 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		Promoesia	<i>elegans</i>	3	10	10	0.33	0.33
J2	Coleoptera		Elmidae		Optioservus		7	9	4	0.70	0.31
I2	Coleoptera		Elmidae		Optioservus (Adult)	<i>ovalis</i>	6	9	4	0.60	0.27
J5	Crustacea	Amphipoda	Gammaridae		Gammarus		1	8	9	0.09	0.10
J1	Diptera		Empididae (pupae)				1	No Score	No Score	0.00	0.00
H7	Diptera	Nematocera	Simuliidae		Simulium Latreille	<i>tuberosum</i>	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	<i>trifascia gr.</i>	1	9	9	0.10	0.10
H6#2	Diptera	Nematocera	Chironomidae	Orthocladiinae	Eukiefferiella	<i>devonica gr.</i>	1	9	9	0.10	0.10
H6#3	Diptera	Nematocera	Chironomidae	Orthocladiinae	Parametrioconemus	<i>sp.</i>	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	<i>pygmaea</i>	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	<i>auriculuria</i>	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	<i>sp.</i>	1	1	6	0.01	0.07	
J8	Plecoptera		Perlidae		Agnetina		3	No Score	No Score	0.00	0.00	
J4	Trichoptera		Brachycentridae		Brachycentrus	<i>appalachia</i>	2	3	4	0.07	0.09	
G7	Trichoptera		Hydropsychidae		Hydropsyche	<i>sparna</i>	5	6	7	0.33	0.39	
G5	Trichoptera		Hydropsychidae		Cheumatopsyche	<i>sp.</i>	21	6	6	1.40	1.40	
G4	Trichoptera		Hydropsychidae		Hydropsyche	<i>sp.</i>	9	5	4	0.50	0.40	
							Total	100		NBI Scores	5.89	5.24

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

Total	100
Total with NBI score	90

## Appendix C

Average annual event and nonevent soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate, total nitrogen (TN), total suspended solids (TSS), and total coliform concentrations. Red bars = event (E), blue bars = nonevent (NE).

