THE 2016 WATER QUALITY REPORT FOR OWASCO LAKE, NY.

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INTRODUCTION

Since the initial Finger Lake Institute (FLI) water quality survey of the eastern Finger Lakes in 2005, Owasco Lake and its watershed has been the focus of additional research due to the lake's poor water quality in comparison to neighboring Finger Lakes. This focus established a monitoring program of Owasco Lake and its watershed to: (1) document spatial and temporal trends in pertinent water quality / water clarity / limnological parameters; (2) investigate the source and magnitude of nutrients in the watershed, as their inputs to the lake promote algal growth and thus degrade water quality; (3) investigate associations between the water quality data and the recent rise in blue-green algae and their associated toxins; and, (4) promote the development of comprehensive and effective watershed management policies to improve water quality in Owasco Lake. This multi-year effort was supported, in part, by the Fred L. Emerson Foundation, Auburn, NY, New York State funds secured by New York State Senator Michael Nozzolio, the Owasco Lake Watershed Association (OWLA), the Town of Fleming, Cayuga County Soil and Water Conservation District, Finger Lakes – Lake Ontario Watershed Protection Alliance and the Cayuga County Legislature. Thank you all for your support.

The ongoing monitoring effort has highlighted the following results to date:

- The trophic status (productivity level) of Owasco Lake fluctuates above and below the oligotrophic (good water quality) – mesotrophic (intermediate water quality) boundary.
- Phosphorus is the limiting nutrient in Owasco Lake. Additional inputs of phosphorus would stimulate additional algal growth and degrade water quality.
- The lake has experienced late-summer blooms of blue-green algae. Blue-green algae are a concern due to their affiliation with impaired / eutrophic (poor water quality) water bodies, their ability to form unsightly, surface water, algal scums, and some species of blue-greens may produce toxins that have health implications for humans and other warm blooded organisms.
- Nutrient and sediment sources include point sources like wastewater treatment facilities and onsite wastewater (septic) systems, and nonpoint sources like animal and crop farms, lawn fertilizers, soil erosion, stream bank erosion, roadside ditches, and construction activities.
- A DEC mandated reduction of phosphorus by the Groton Wastewater Treatment Facility effluent has reduced nutrient loading to the Owasco Inlet and thus to Owasco Lake. The adoption of some agricultural best management practices in the watershed and establishment and follow through on recommendations made by the Watershed

Inspector's Office and the Owasco Lake Watershed Management Council should also have reduced nutrient loads to the lake as well.

- Streams and tributaries are the primary source of nutrients and sediments to the lake, even during "dry" years.
- Event *vs*. base flow analyses indicated that over 90% of the nutrient and sediment loads are delivered during precipitation/runoff events, especially in the spring season.
- Annual nutrient load estimates positively correlated to precipitation totals, especially precipitation in the spring season.
- Since 2011, annual phosphorus budgets for Owasco Lake estimated larger inputs than outputs in all but 2012, a very dry year. The continued net addition of phosphorus to the lake will degrade water clarity and water quality.
- Phosphorus loading must be curtailed to move Owasco Lake into a recovery phase, and better water quality. If the loads were curtailed today, it would take a minimum of five water retention times, i.e., decades, before the lake would naturally cleanse itself of phosphorus and display improvements in water quality.

The water quality research is also passing into an exciting phase. NY State funds to Cayuga County Soil and Water Conservation District and Owasco Lake Watershed Association should establish preliminary BMPs in the Owasco Lake watershed. Support has also been secured by Cayuga County Planning to expand on the recent Owasco Lake Watershed Management & Waterfront Revitalization Plan and develop an EPA Nine Key Elements Plan. Let's keep this momentum going.

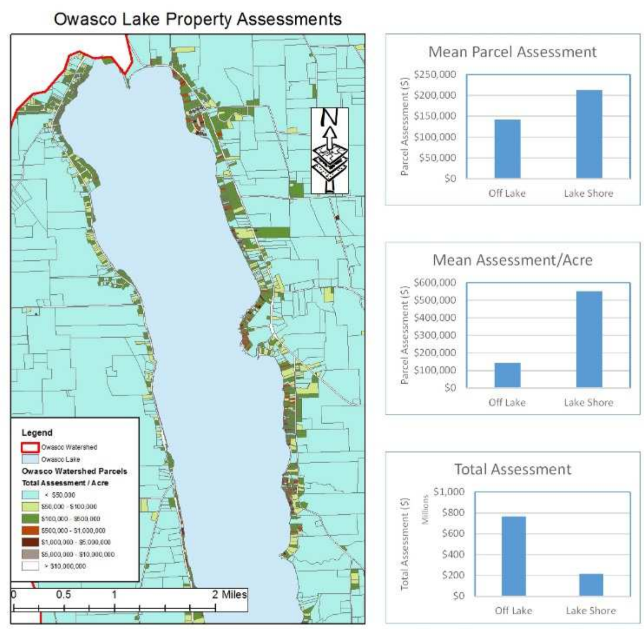

Fig. 1. Owasco Lake property assessments per acre of land. Lakeshore property assessments are significantly larger than properties away from the lake.

Numerous economic reasons mandate remediation efforts in the watershed. First and foremost, the lake supplies drinking water to Auburn, Owasco and neighboring communities, and numerous private systems for lakeshore residents. Second, the lake is the focus for recreational, sports fisheries, and other tourism industries in the region. In both cases, poor water quality would yield economic challenges. Declining water quality will also negatively impact local property values and tax revenues. Recent[1] property assessments in the watershed, like other Finger Lake watersheds, reveal significantly larger property assessments per acre for parcels adjacent to the lakeshore than parcels away from the lake (Fig. 1). Municipal budgets are therefore reliant on the revenue from the lakeshore acreage. This revenue should decline as property values decline in the wake of deteriorating water quality. A survey of selected real estate venues indicated that lakeshore properties have recently declined in value, and have taken

[1] Assessment data and parcel's map acquired from Cayuga County in the summer 2016.

longer to sell once put on the market in the watershed. Therefore, municipal officials should do everything in their power to maintain water quality in the lake. More importantly, we owe it to future generations to leave this lake in better shape than when we got it.

METHODS

The sample sites and field/laboratory methods used in 2016 were similar to the 2005 – 2015 programs.

Owasco Lake: The 2016 lake survey sampled Sites 1 and 2 on a monthly basis from late May through late September (Table 1, Fig. 2). These are the same sites utilized since the 2005 survey, and are representative of the open water limnology in Owasco Lake. The specific 2016 survey dates were: 5/24, 6/14, 7/19, 8/19 & 10/1.

The lake-monitoring field methods were identical to the earlier research. A CTD water quality profile, Secchi disk depth, vertical plankton tow (80-μm mesh), and surface and bottom water samples were collected at each site. A fluoroprobe collected algal profiles on 8/19 and 20/1. The CTD electronically gathers water column profiles of temperature (°C), conductivity (reported as specific conductance, μS/cm, a measurement proportional to salinity), dissolved oxygen (mg/L), pH, turbidity (NTUs), photosynthetic active radiation intensities (PAR, $\mu E/cm^2$-s), and fluorescence (a measure of chlorophyll-a, μg/L) using a SeaBird SBE-25 CTD. The CTD was lowered from the surface to ~1m above the lake floor, collecting data every 0.5 seconds (~0.2 meters) along the downcast. The bbe fluoroprobe measures four different algal groups based on their accessory pigments and distinguishes among: 'green' algae (Chlorophyta and Euglenophyta), 'brown' algae (diatoms: Baccillariophyta, Chyrsophyta, and Dinophyta), 'blue-green' algae (Cyanophyta), and 'red' algae (Cryptophyta). The plankton collected by each tow were preserved in an alcohol-formalin solution and typically identified and enumerated to species level back in the laboratory under a microscope. Water samples were analyzed onsite for temperature (°C), conductivity (specific conductance, μS/cm), pH, dissolved oxygen (mg/L), and alkalinity (mg/L, $CaCO_3$) using hand-held probes and field titration kits, and analyzed back in the laboratory for total phosphate (μg/L, P), dissolved phosphate (SRP, μg/L, P), nitrate (mg/L, N), chlorophyll-a, and total suspended solid (mg/L) concentrations. Lab samples were stored at 4°C until analysis.

Table 1. Owasco Lake monitoring site locations and water depths.

Site Name	Latitude	Longitude	Water Depth
Site 1	42° 52.4' N	76° 31.35' W	34 m
Site 2	42° 49.15' N	76° 30.45' W	52 m
Buoy Site	42° 50.35' N	76° 30.85' W	49 m

Drone Flights: Drones were flown at 100 m above nearshore and open water locations to investigate their suitability to measure various water quality parameters in 2016 (Fig. 3). Two drones were used, DJI's Matrice 100 with a gimbaled Zenmuse Z3 camera and DJI's Phantom 3 Advanced with a Sony EXMOR gimbaled camera. Both drones captured 12 megapixel digital photographs. Each image spanned an area of ~200 by 300 meters at a flight altitude of 100 m. Photographs were collected along the lakeshore at and just offshore of Emerson Park (east side) and Martin Point (south side) to investigate nearshore attached algae and macrophyte distributions, and open water algal concentrations. The nearshore photographs were spatially georeferenced in ArcGIS to 2015 satellite digital orthoimagery (NYS Clearinghouse data). Flights dates were: 8/7, 8/9, 8/10, 8/11, 8/19, 8/22, & 10/1.

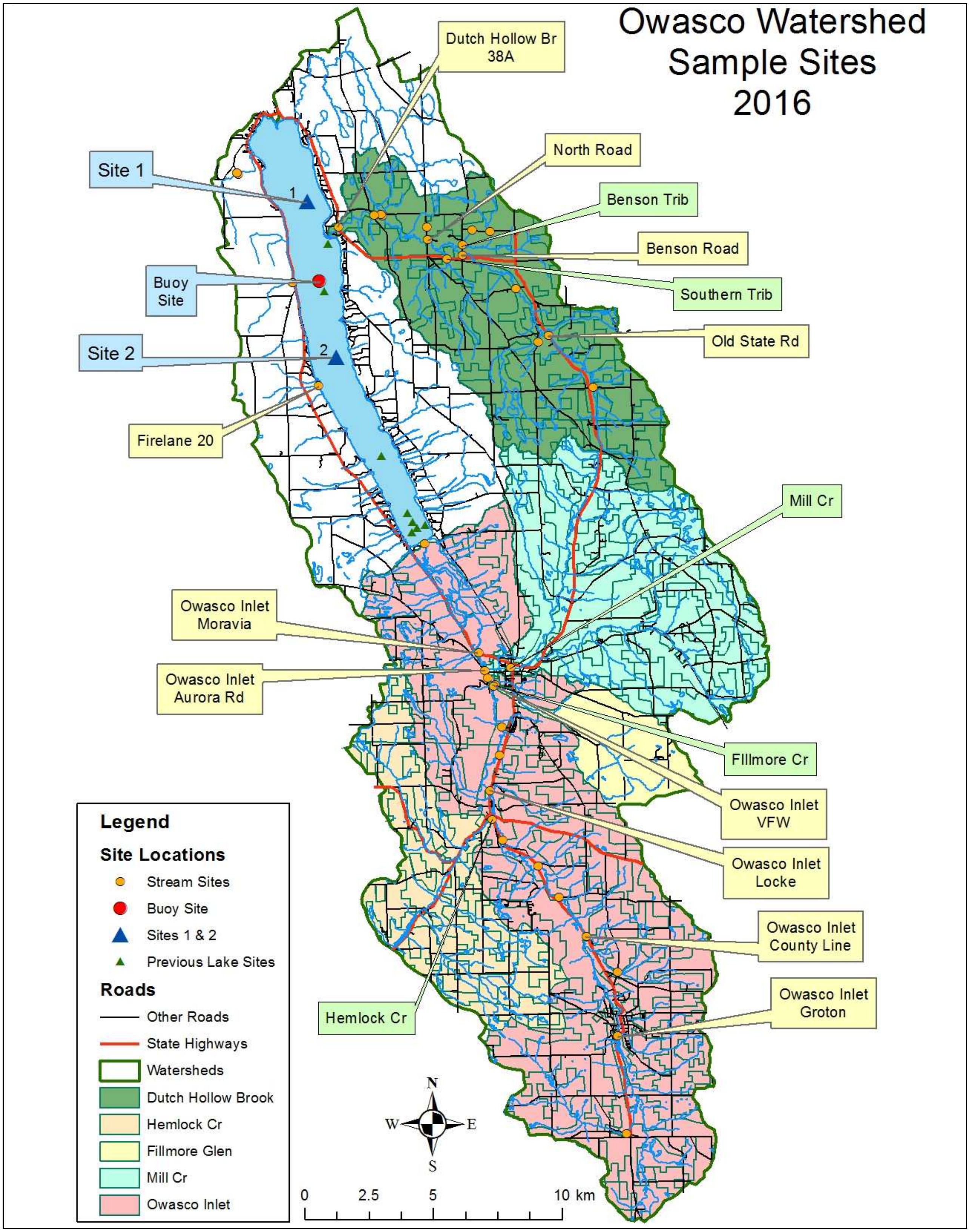

Fig. 2. The 2016 lake and stream sites. The 2016 stream sites focused on previously sampled sites within Dutch Hollow Brook and the Owasco Inlet. The small tributary near the terminus of Fire Lane 20 was also sampled.

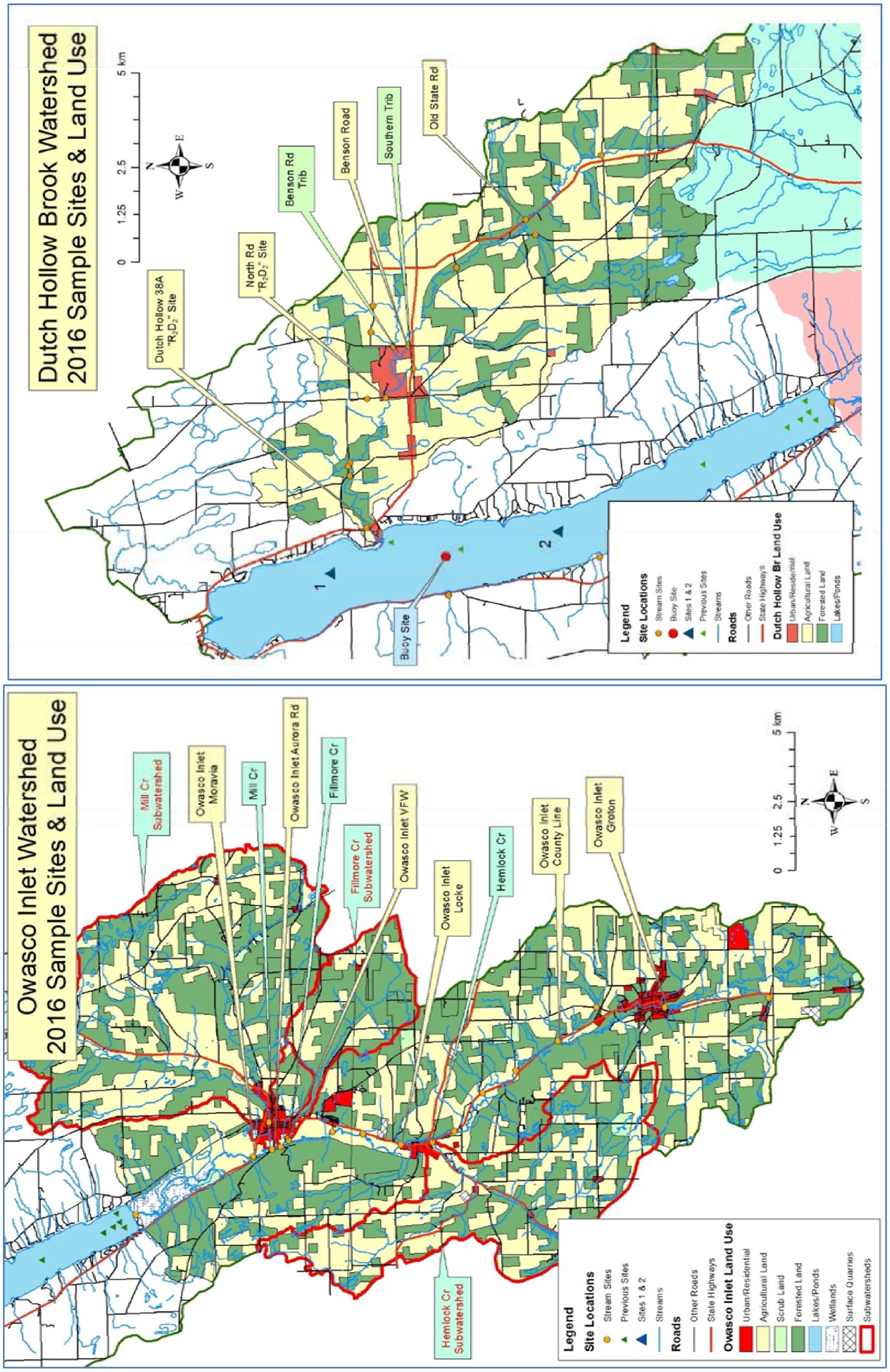

Fig. 2 continued. 2016 site locations (yellow boxes) and land use within Dutch Hollow Brook and Owasco Inlet watersheds. Subwatersheds are identified by green boxes.

Fig. 3. The two drones used in this study, Matrice 100 (left) and Phantom 3 Advanced (right).

Owasco Buoy: The FLI meteorological and water quality monitoring buoy manufactured by YSI/Xylem was redeployed at its mid-lake site from 4/23 through 10/25 (Fig. 2, & Table 1). The buoy was programmed to collect water column profiles every 12 hours (noon and midnight) of temperature (°C), conductivity (µS/cm, reported as specific conductance), dissolved oxygen (mg/L & % saturation, by optical sensor), turbidity (NTUs by backscattering), and fluorescence measuring both total chlorophyll and blue-green algae phycocyanin (µg/L, after specific pigment excitation by different wavelengths of light). Data was collected every 1.5 meters down the water column starting at 1 m using a YSI/Xylem EXO2 water quality sonde. The buoy also contained a standard suite of meteorological sensors that recorded five-minute mean air temperature, barometric pressure, relative humidity, light intensity and wind speed and direction data every 30 minutes. All of the data were periodically transferred to HWS by cellular phone ~1 hour after collection. Buoy hardware and software issues prevented collection of water quality data from 4/28 to 5/11, 5/13 to 5/16, 5/18, and 9/29 to 10/5, and meteorological data from 4/23 to 4/25 in 2016.

Owasco Streams: The 2016 stream monitoring focused on Dutch Hollow Brook, Owasco Inlet, and a small tributary at the end of Fire Lane 20 West. The stream sites were visited six times, specifically 4/13, 6/1, 6/6, 6/28, 7/11 and 10/24, for onsite analyses and collection of water samples for nutrient and sediment analyses back in the laboratory. The 4/13 and 10/24 dates were sampled by the Owasco Watershed Inspection Office team (thanks guys). Halfman's Environmental Hydrology class also sampled three sites along Dutch Hollow Brook, 38A, North Rd and Old State Rd sites, on 3/31 at no cost to this project.

Dutch Hollow Brook was sampled at six sites in 2016 (Fig. 2). Progressing upstream, four sites were sequentially located along 38A, including the terminus at Rt 38A, and sequentially upstream at North Rd, Benson Rd, and near Old State Rd. Two unnamed tributaries in the watershed were also sampled. The South tributary was sampled along Rt 38A just east of the Owasco town center. The Benson tributary was sampled along Benson Rd just north of the Benson Rd site. These sites were also used in the past.

Owasco Inlet was sampled at nine sites in 2016 (Fig. 2). Proceeding upstream, five sites were sequentially located along the main stream starting at Moravia on Rt 38, Aurora St in Moravia, VFW just upstream of Fillmore Cr, north of Locke, the County Line, and just upstream of Groton (near Spring St). Three tributaries, Mill, Fillmore, and Hemlock Creeks, were also sampled just upstream from where they join the Inlet. These sites were also used in the past.

Samples were not collected at VFW on 4/13 and 10/24, the high flow dates, due to a communication error.

The small tributary at the end of Fire Lane 20 was also sampled.

Stream discharge, water temperature, conductivity, dissolved oxygen, pH and alkalinity were measured onsite using hand-held probes or field titration kits. Only discharge was measured onsite during the 10/24 survey. Water samples were also collected and analyzed in the laboratory for total phosphate (TP), dissolved phosphate (SRP), nitrate and total suspended sediment (TSS) concentrations. Laboratory samples were stored at 4°C until analysis. Stream discharge (the volume of water per unit time flowing past a site) was calculated from measured stream width, depth and velocity data (using a 30 m tape, wading rod and HACH FH950 portable velocity flow meter with electromagnetic sensor). Both velocity and stream depth were measured at ten (or five) equally distributed segments aligned perpendicular to stream flow. The velocity was measured at ~60% of the stream depth to acquire an average velocity for each segment. Ten segments were utilized when the stream was wide or more accuracy was necessary, e.g., some of the Inlet sites and the Dutch Hollow Brook at 38A and North Rd. Stream discharge (water volume per unit time, e.g., m^3/s) is required for the flux (loading) calculations of nutrients and suspended sediments, because flux of a substance (its mass/time, e.g., kg/day) is stream discharge (volume water/time, e.g., m^3/s) times its concentration (mass/volume water, e.g., mg/L).

Runoff/Event Flow versus Base Flow Variability: A Teledyne ISCO automated water sampler, one *In Situ* Aqua Troll 200 data logger and a pair of *ONSET* HOBO U290L-04 loggers were deployed at the Rt 38A site in Dutch Hollow Brook from 4/13 to 10/25 to investigate the impact of event *versus* base flow variability on the delivery of nutrients and sediments to the lake (Figs. 4a & 4b). Another automated sampler and two pairs of HOBO data loggers were deployed upstream from Rt 38A at North Rd to investigate event *versus* base flow variability along Dutch Hollow Brook. A pair of Hobo loggers were required at each deployment, one deployed in air and the other underwater to subtract changes in atmospheric pressure from changes in water level detected by HOBO's unvented pressure transducers. The *In Situ* pressure transducer is vented, thus automatically compensates for changes in atmospheric pressure, and does not require paired deployment. Deploying multiple loggers at each site hedged against logger malfunctions.

At both sites, the autosamplers were programmed to collect 1-L of water every day (4 am). This frequency collected both event and base flow samples in previous years. At each site, stream discharge was measured and autosamplers were serviced bi-monthly. Each sample was analyzed for suspended sediment and nutrients. The daily sample frequency in 2016 was reduced from 8-hours to daily samples in response to funding issues. Over the 182 day deployment at 38A and North Rd, a few water samples (9/7 to 9/20) were lost at 38A due to a pinched water hose.

The data loggers were programmed to record hourly stream stage (height), temperature and specific conductance (only by the *In Situ* logger). The stage data and bi-monthly stream discharge measurements established a rating curve, a relationship between stream height and stream discharge to estimate a stream discharge for every ISCO water sample at each site. Data logger data were missing from the end of the survey at 38A because the large precipitation event and resulting flood on 10/21 uprooted the data loggers from their poles.

Fig. 4a. Servicing "R_2D_2" the *Teledyne* ISCO automated water sampler located at the Rt 38A site. It collected 1-liter of water daily (4 am) and was serviced bi-monthly.

Fig. 4b. *In Situ* Aqua Troll 200 and *ONSET* HOBO U20L-04 data loggers. Both logged hourly stream height (to estimate hourly stream discharge) and temperature. The Aqua Troll also measured hourly specific conductance of the stream.

Laboratory Analyses: Laboratory analyses for nutrient, chlorophyll-a (only lake samples), and total suspended sediment concentrations followed standard limnological techniques. An aliquot of each sample was processed for total phosphate colorimetric analysis by spectrophotometer after digestion of any organic-rich particles in hot (100ºC) persulfate for 1 hour. Additional sample water was filtered through pre-weighed, 0.45 μm glass-fiber filters. The filter and residue were dried at 80°C for at least 24 hours. The weight gain and filtered volume determined the total suspended sediment concentration. Lake water was also filtered through a Gelman HA 0.45 μm membrane filter, and the filtered residue was kept frozen until chlorophyll-a analysis by spectrophotometer after acetone extraction. The filtrate was saved and stored at 4°C until dissolved phosphate (SRP), nitrate and dissolved silica colorimetric analyses by spectrophotometer. Laboratory precision was determined by periodic replicate analyses resulting in the following mean standard deviations: total suspended sediments ±0.2 mg/L, phosphate ±0.1 μg/L (both TP and SRP), silica ±5 μg/L, and nitrate ±0.1 mg/L. For the plankton enumerations, over 100 individuals were identified to genus (and typically species) level and reported as date averaged relative percentages.

LAKE MONITORING RESULTS & DISCUSSION

Lake CTD & Fluoroprobe Profiles: The 2016 water temperature profiles were typical for any late spring through early fall transition (Fig. 5). The 5/24 cast revealed the initial establishment of seasonal stratification, the initiation of less dense and warmer epilimnion (surface water) overlying the denser and uniformly cold hypolimnion (bottom water). Epilimnetic temperatures ranged from 11ºC (~50ºF) in late-May to 24ºC (~75ºF) in June, and cooled to 18ºC (~65ºF) by the last cruise of the survey (10/1). Hypolimnetic temperatures remained a uniform 5ºC (~39ºF) through the survey.

Epilimnetic salinity (specific conductance) ranged from ~295 to 335 μS/cm in 2016 (~150 ppm TDS). Like previous years, epilimnetic salinity in 2016 decreased by ~25 μS/cm (~10 ppm TDS, a small amount) from the largest values detected in the late spring into the early fall as the epilimnion was progressively diluted by less saline precipitation and stream runoff. The 2016 early spring specific conductance was similar to those detected in 2015, and both years were slightly larger previous years. The annual change in salinity is interpreted to reflect the extent of road salt application during the preceding winter, e.g., the larger salinity in 2015 was due to more snowfall and road salt the previous winter, concentrations which carried over into the spring of 2016.

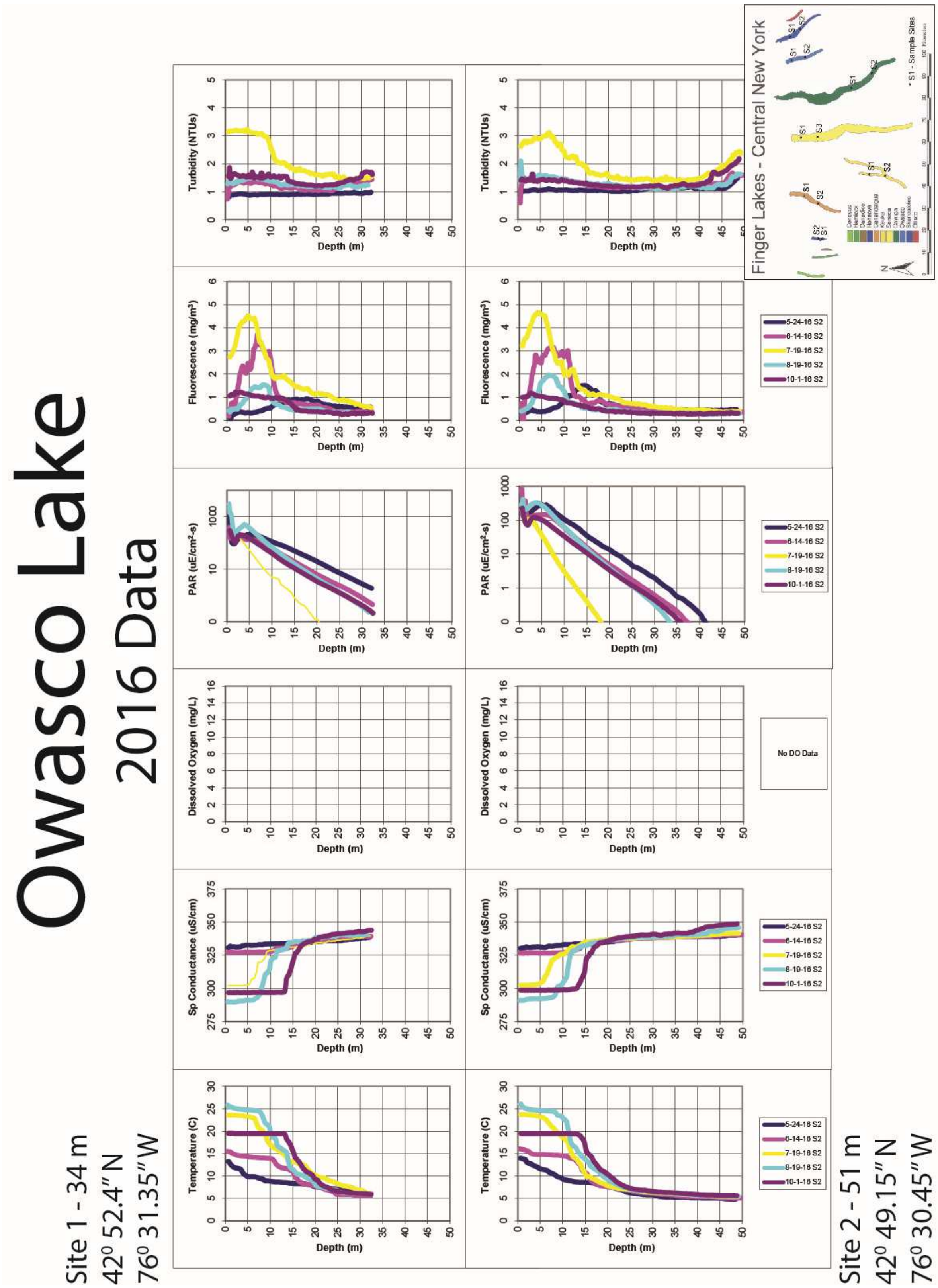

Fig. 5. 2016 CTD profiles from Sites 1 & 2. The PAR (light) data are plotted on an exponential scale, so that exponential changes with water depth appear as straight lines. The dissolved oxygen sensor malfunctioned this year.

The 2015 hypolimnetic specific conductance data were just above 340 μS/cm and remained relatively uniform over time and depth (Fig. 5). These values were similar to those in 2015 and both years were 10 to 20 μS/cm larger than previous years. Again, the use of an estimated 10,000 tons of additional road de-icing salt from the larger and more frequent snowfall in 2014 & 2015 probably maintained the slightly larger hypolimnetic salinity in 2014 &5 than earlier years, and the concentrations carried over into 2016.

The dissolved oxygen sensor malfunctioned in 2016, and resources were not available to fix it.

Profiles of photosynthetic available radiation (PAR), i.e., light intensity, in 2016 were similar to earlier results (Fig. 5). Available light decreased exponentially with water depth from a maximum intensity of a few 100 to a few 1,000 μE/cm^2-s at the surface to 1% of surface light intensities within the epilimnion at water depths of 10 to 15 m. The observed decrease in light reflects the normal exponential absorption and conversion of longer wavelengths of light (infrared, red, orange, yellow) to heat, and scattering of shorter wavelengths of light (ultraviolet, violet, blue) back to the atmosphere. The range in surface intensities reflected the season, the extent of cloud cover, and the turbidity of the water (suspended sediment and/or algal density) on the survey date. The 1% of surface light threshold represents the minimum amount of light required for algae to photosynthesize enough biomass to survive. Thus, algal photosynthesis and growth was restricted by light to the epilimnion in Owasco Lake. Many of the profiles revealed a marked decrease in light at 2 or 3 meters. It corresponded to the sensor passing through the shadow of the boat.

Fluorescence, a measure of algal concentrations, revealed peaks in chlorophyll abundance within the epilimnion at approximately 5 to 15 m below the lake's surface (Fig. 5). Peak concentrations exceeded 4 μg/L (mg/m^3) on 7/19, above 3 μg/L (mg/m^3) on 6/14 but were lower, between 1 and 2 μg/L on the other survey dates. The 2016 epilimnetic data were similar to previous years. Hypolimnetic concentrations were consistently below 1 μg/L, i.e., algae are typically absent in the dark bottom waters.

The turbidity profiles revealed uniform or nearly uniform turbidities from 1 to just above 2 NTUs down to the lake floor at Site 1 and down to just above (5 to 10 m) the lake floor at Site 2 (Fig. 5). At Site 2, turbidity then increased by ~one NTU by the lake floor. The exception to these generalizations was on 7/19 when epilimnetic turbidities rose above 3 NTUs due to an intense but brief algal bloom. The lake floor increase in turbidity at Site 2 was much less pronounced in 2016 than those observed in 2014 and especially 2015. The change from year to year parallels the change in rainfall and wind velocities as the primary source of suspended sediments (turbidity) is runoff events from precipitation and snowmelt and resuspension events by waves. Algae and algal blooms provide another source of turbidity.

The fluoroprobe data revealed the dominance of diatoms/dinoflagellates (up to 2 μg/L), cryptophytes (up to 3.2 μg/L) and green algae (up to 1 μg/L) in the epilimnion (Fig. 6). Site 1 also revealed small concentrations of blue-green algae (below 0.5 μg/L) in the epilimnion. More persistent concentrations of BGA (up to 0.4 μg/L) were detected in the hypolimnion but these results were an artifact of the colder water temperature, as the BGA sensor is temperature sensitive. Algae should not be alive in the dark hypolimnion.

Limnology & Trophic Status: The 2016 chlorophyll and nutrient data indicated that the lake was not a health threat or significantly impaired (Table 2 in appendix, Fig. 7). Annual mean chlorophyll concentrations in the epilimnion ranged from 0.9 to 3 μg/L on all survey dates except for 7/19 where concentrations spiked to 9 μg/L. The annual mean of 3.5 remained below the 4 to 6 μg/L not to exceed DEC threshold for potable water bodies[2], except for the 7/19 date-averaged concentration. Nitrate concentrations ranged from 0.5 to 0.8 mg/L and an order of magnitude (10 times) below the 10 mg/L maximum contaminant level (MCL) established by the EPA. The lake was not impaired due to phosphorus, as the annual mean total phosphate concentration was 14.9 μg/L, below the 20 μg/L total phosphate (TP) threshold established for impaired water bodies by the DEC. The 10/1 date was an exception, with a date-averaged TP concentration of 21 μg/L. This date was just after a recent rainfall and the last of the detected blue-green algae blooms. Secchi disk depths ranged from 1.8 to 8.1 meters, and averaged 5.6 meters (Fig. 7). This was the deepest annual average measured by the FLI monitoring effort. Total suspended sediments date averaged concentrations ranged from 0.6 to 4.9 mg/L and averaged 1.8 mg/L. The large value resulted from the large bloom on 7/19.

From one year to the next, annual average Secchi disk data suggest improving water clarity from 2009 through 2013 but declining water clarity in 2014 and 2015. The 2016 data revealed a return to improving conditions. It suggests that the major trigger for the decline in water quality during 2014 and 2015 was the larger rains in those years, and associated nutrient loads. It was very dry in 2016, allowing the lake to recover. The influence of precipitation, stream runoff and water quality in the lake will be discussed future in a later section of this report.

Since 2005, annual mean total phosphate concentrations have increased from ~8 to over 17 μg/L in 2015 with a slight dip in 2013, and another dip in 2016 (Fig. 7). Dissolved phosphate concentrations were larger in 2006, 2011, 2013 and 2015 than other years, but never as large as those in 2014 (Fig. 7). The large 2014 mean value was biased by a sample collected immediately after the intense May rains. The 2015 and 2016 mean SRP concentrations returned to the pre-2014 concentrations. Chlorophyll-a concentrations were larger in 2009, 2010, and again in 2014 and 2015 (3.9, 3.7, 3.2 & 3.8 μg/L, respectively) than other years (1.9 to 2.3 μg/L; Fig. 7). The 2016 concentration decreased to 3.5 μg/L. Total suspended sediment (TSS) annual mean concentrations continued their decline since 2014 from a peak of 3.5 in 2014, down to 2.1 in 2015, and 1.8 mg/L in 2016 (Fig. 7). In summary, 2014 and 2015 revealed the worst water quality for the lake. These two years also experienced the largest spring rainfall totals. It indicates that the intense spring rain impact water quality. The following dry year, 2016 allowed the lake return to pre-2014 conditions. The nutrient loading information presented below support this conclusion.

The 2016 annual mean Secchi disk, nitrate and chlorophyll-a data place Owasco Lake below the oligotrophic-mesotrophic trophic boundary (Table 3, Fig. 7). The 2016 annual mean TP concentration and hypolimnetic dissolved oxygen concentration placed Owasco Lake in the mesotrophic range. Thus, the trophic status of Owasco Lake remains borderline oligotrophic-mesotrophic, and slightly improved since 2015. The fluctuations above and below the boundary indicate that the lake is in a delicate balance. Any increase or decrease in nutrient loads from one year to the next influence the lake's water quality.

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[2]Callinan, C.W., J.P Hassett, J.B. Hyde, R.A. Entringer & R.K. Klake. 2013. Proposed nutrient criteria for water supply lakes and reservoirs. American Water Works Association Journal, E157-E172.

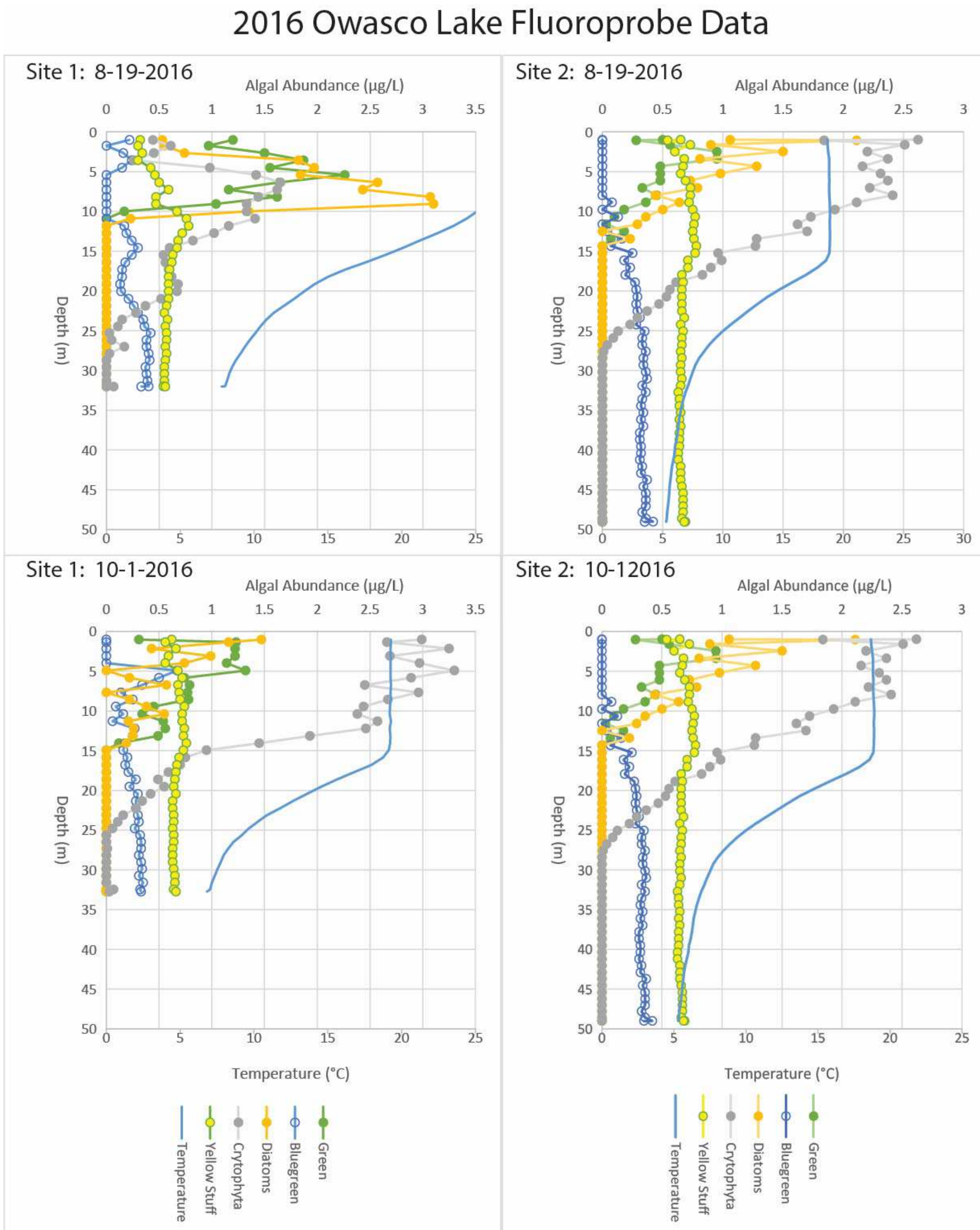


Fig. 6. Fluoroprobe data from Sites 1 & 2 that reveal concentration profiles of four major algal groups.

A few additional observations about the limnological data are noteworthy. First, the mean, surface water, dissolved phosphate to nitrate ratio in the lake, the two nutrients that typically limit algal growth, averaged 1:710 in 2016. The P:N ratio required by algae is 1:7 (Redfield Ratio). The measured ratios indicate that phosphate was still, by far, the limiting nutrient in Owasco Lake. The limiting nature of phosphorus is unlikely to change because fluvial sources yield 30 times more nitrogen than phosphorus, and fluvial sources of nitrates are augmented by additional sources of nitrogen to the lake (e.g., acid rain nitrates) not available to phosphorus.

Second, variability was observed in every parameter from one survey date to the next. The variability is best observed in the box and whiskers plots (Fig. 8). It reflects, for example, algal blooms that do not last the entire summer but are instead episodic and last for a week or two at a time. Third, the dissolved nutrient concentrations revealed nearly uniform or slightly larger concentrations between the epilimnion to the hypolimnion, rather than noticeably depleted epilimnion and enriched hypolimnion concentrations detected in earlier years. The annual mean surface and bottom water concentrations were 0.9 and 0.7 μg/L for SRP, 0.7 to 0.9 mg/L for nitrate, and 1,020 to 1,280 μg/L for dissolved silica. The difference in SRP is unclear at this time, but might be related to the dry year in 2016. Chlorophyll-a concentrations revealed a small decrease from 3.5 and 1.0 μg/L from the epilimnion to the hypolimnion, a similar trend as earlier years.

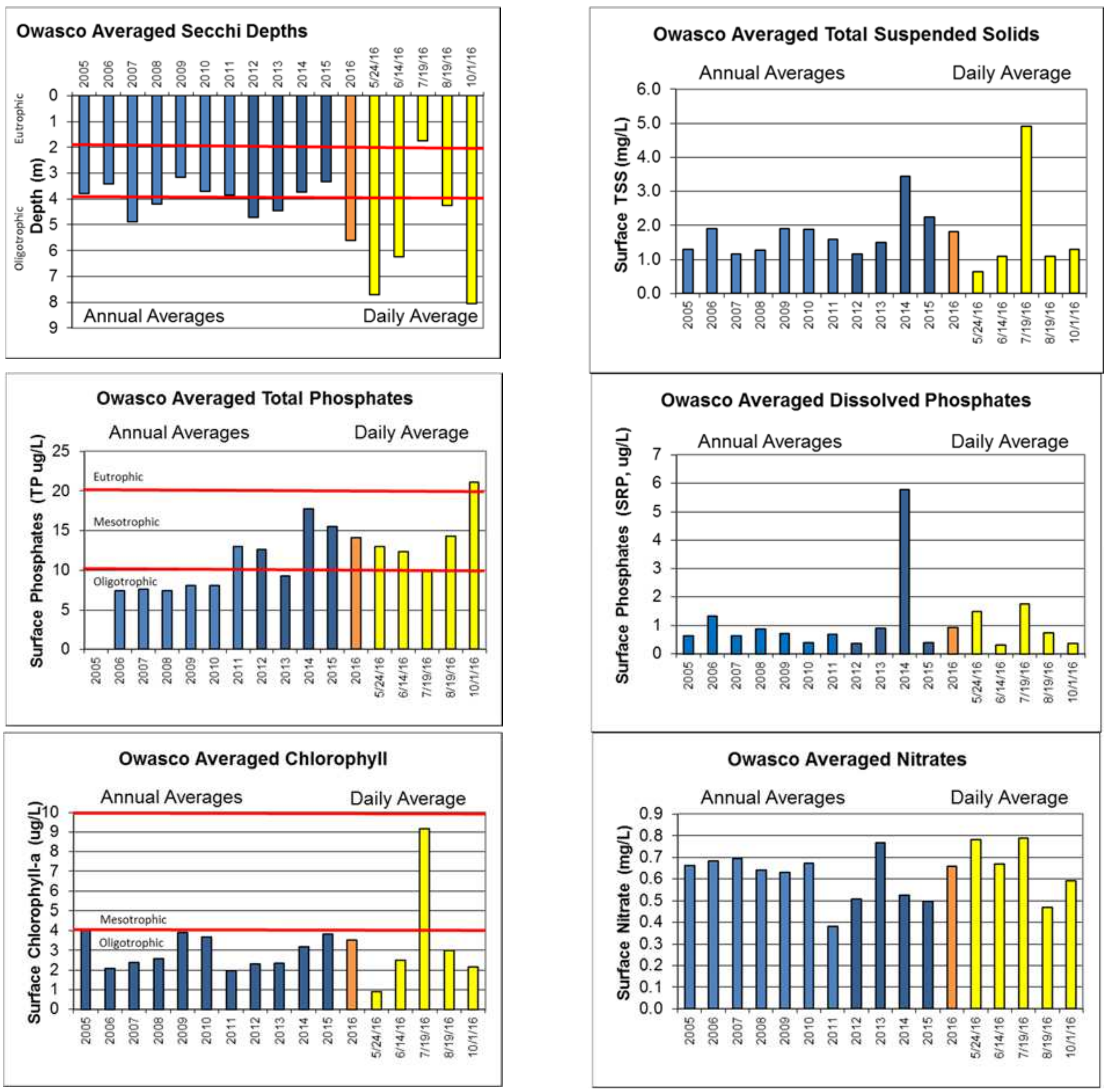


Fig. 7. Annual average surface water concentrations since 2005 (blue), for 2016 (orange), and date averaged surface water data from 2016 (yellow). When appropriate, boundaries for oligotrophic, mesotrophic and eutrophic concentrations are marked.

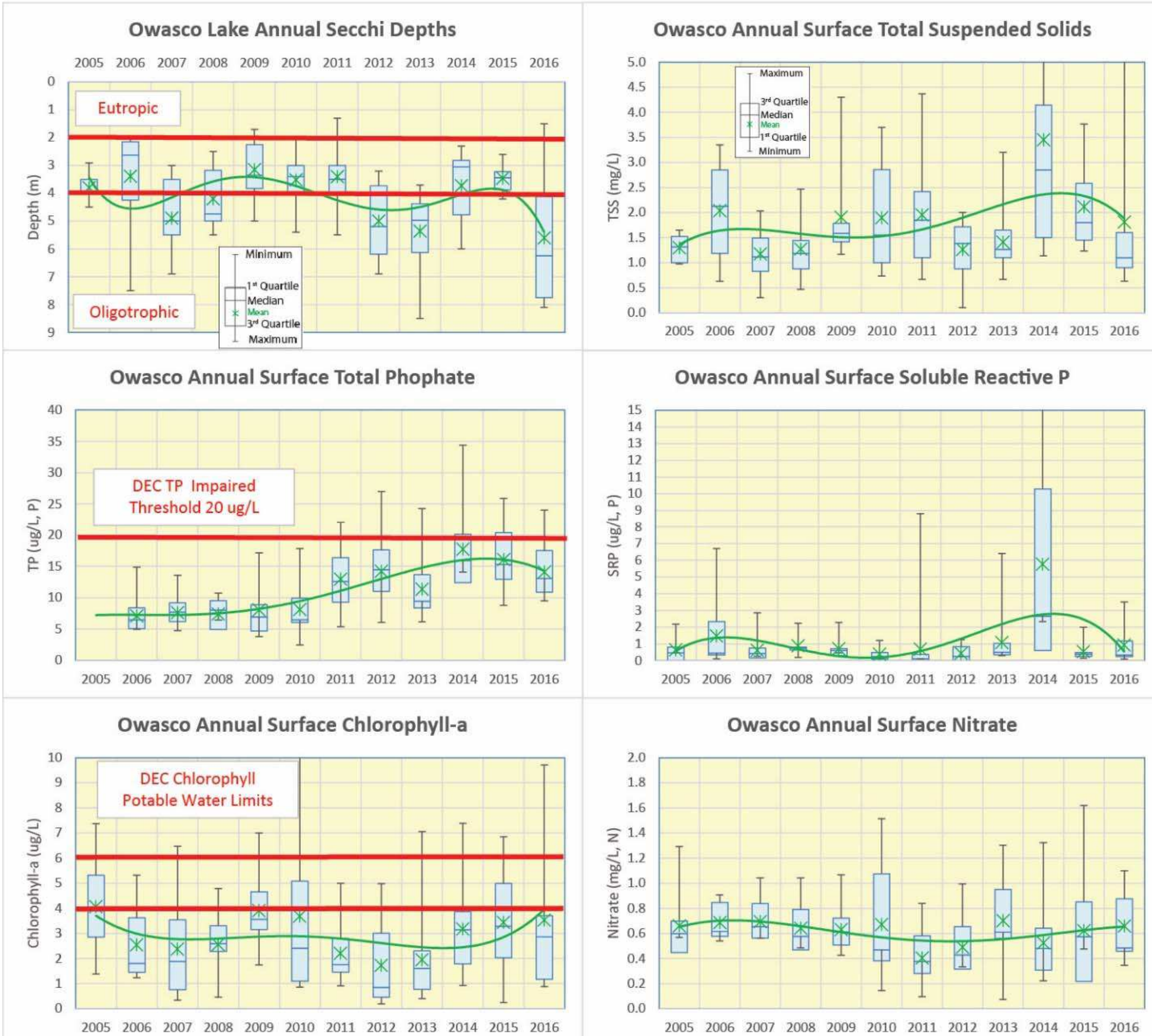


Fig. 8. Box and whisker plots of the lake data.

Table 3. Concentration ranges for Oligotrophic (low productivity), Mesotrophic (mid-range productivity), and Eutrophic (high productivity) lakes. The bold entries in the table reflect Owasco's 2016 mean values.

Trophic Status	Secchi Depth (m)	Total Nitrogen (N, mg/L, ppm)	Total Phosphate (P, µg/L, ppb)	Chlorophyll a (µg/L, ppb)	Oxygen (% saturation)
Oligotrophic	**> 4**	**< 2**	< 10	**< 4**	> 80
Mesotrophic	2 to 4	2 to 5	**10 to 20**	4 to 10	**10 to 80**
Eutrophic	< 2	> 5	> 20 (> 30)	> 10	< 10

Plankton Data: The phytoplankton (algal) species in Owasco Lake during 2016 were dominated by diatoms, primarily *Flagillaria* and *Asterionella*, with smaller numbers of *Diatoma, Melosira*, *Tabellaria, Rhizoselenia,* and *Synedra* (Table 4 in appendix, Fig. 9). Like previous years, *Asterionella* and *Fragillaria* dominated in the spring and early summer, *Tabellaria* and *Diatoma* replaced *Asterionelia*. *Dinobryon* (a dinoflagellate) dominated in the late summer. Two blue-greens, *Anabaena* and *Microcystis* dominated in the fall. In the past, *Tabellaria* instead of *Asterionella* occasionally dominated the algae population (e.g., 2011, 2012). Other phytoplankton species included a few *Ceratium* and *Coalcium*. Zooplankton species were dominated by rotifers, namely *Polyarthra* and *Vorticella* with some cladocerans, like *Copepods*, *Nauplius*, and *Cercopagis*, the fishhook water flea. Zebra and quagga mussel larvae were also detected in the plankton tows.

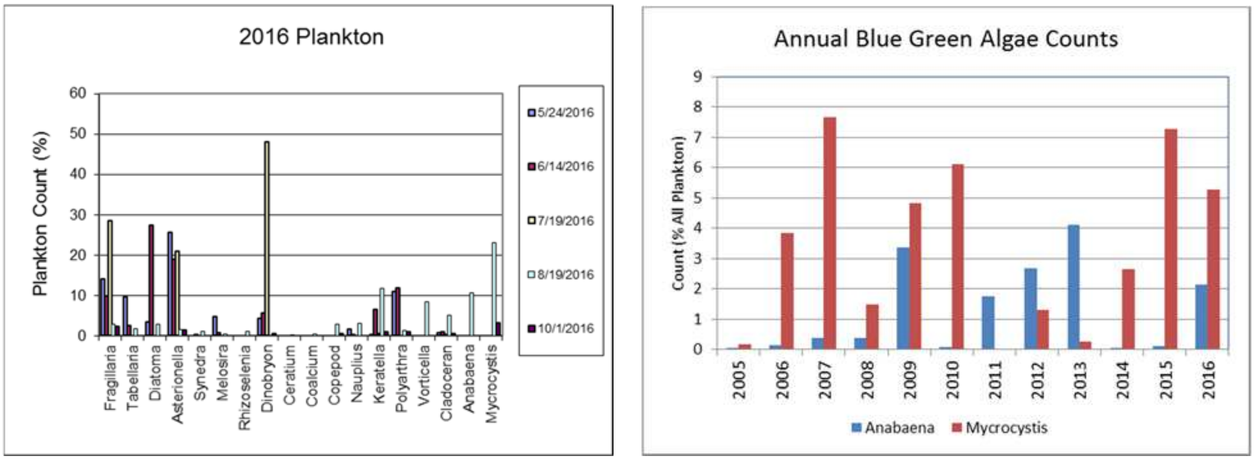


Fig. 9. Date averaged plankton data for 2016 (left) and the mean annual abundance of blue-green algae species since 2005 (right).

Mycrocystis and *Anabaena* were detected in the late summer and early fall surveys in 2016 (Fig. 9). This is not new. Blue-green algae (BGA) were always detected in the open water of Owasco Lake since the initial FLI surveys in 2005. However, the annual means never exceeded 10% for any BGA species at these open water sites (Fig. 9). Typically the largest proportions were restricted to the late summer and/or early fall, with *Mycrocystis* representing up to 40% of the plankton counts during a survey in 2007, 2010, 2014 and 2015, and *Anabaena* making up 30% of the late-summer counts in 2013. In fact, blue-green species were detected in a neighboring Finger Lake as long ago as 1914[3]. It is disturbing that very large BGA blooms were recently detected in the oligotrophic and mesotrophic Finger Lakes, as BGA were thought to only impact eutrophic systems. Owasco Lake is among the impacted systems, as major blooms of BGA have been increasingly detected along the shoreline in Owasco Lake since 2012[4]. The BGA section below has more details.

Finger Lake Water Quality Ranks: The 2016 Finger Lakes water quality ranks still place Owasco Lake as one of the worst lakes among the eight easternmost Finger Lakes (Table 5 in appendix, Figs. 10 & 11). The ranks were based on annual average Secchi disk depths, and surface water concentrations of chlorophyll-a, total and dissolved phosphate, nitrate and total suspended sediments collected by the monthly, May through October, FLI survey. The in-house ranks revealed similar trends as other comparative water quality / trophic state methods like the oligotrophic-eutrophic trophic states, and Carlson's Trophic Indices (combines chlorophyll-a, total phosphorus and Secchi depth data). In 2016, water quality in Owasco ranked poorer than Canandaigua, Keuka, and Skaneateles, similar or slightly better than Cayuga and Seneca Lakes and better than Honeoye and Otisco Lakes. Interestingly, all of the lakes revealed better water quality in 2016 than in 2014 and 2015, and 2016 rankings were more similar to the mean rank of the earlier years. It indicates that the 2014 & 2015 rains and the associated nutrient and sediment loading have degraded water quality in all the Finger Lakes, and 2016 was a year of recovery.

[3] Bloomfield, J.A. (ed.), 1978. Lakes of New York State. Vol.1: The Ecology of the Finger Lakes. Academic Press.
[4] http://www.dec.ny.gov/chemical/83332.html

The change in water quality among lakes is influenced by a number of competing and intertwined factors. First and foremost, the degree of water quality protection legislation and its implementation. They are important to protect the lakes from nutrient and sediment loading issues. So does ecological, "top-down" pressures by zebra and quagga mussels, Asian clams and *Cercopagis*, the fishhook water flea.

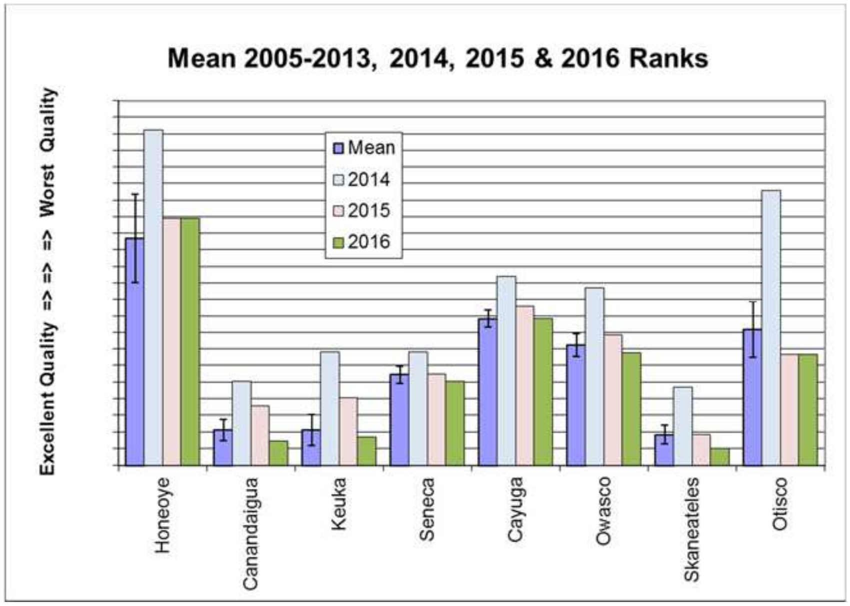
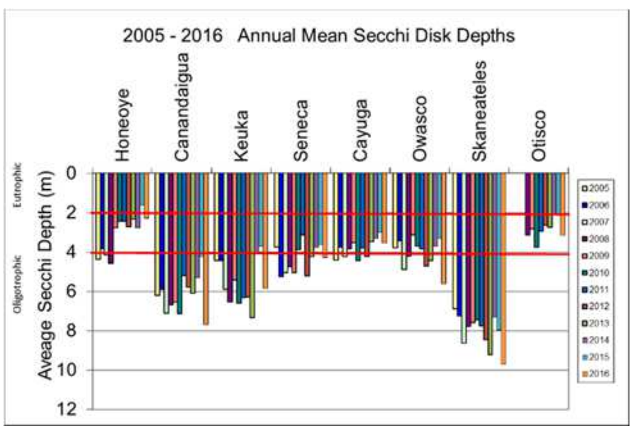
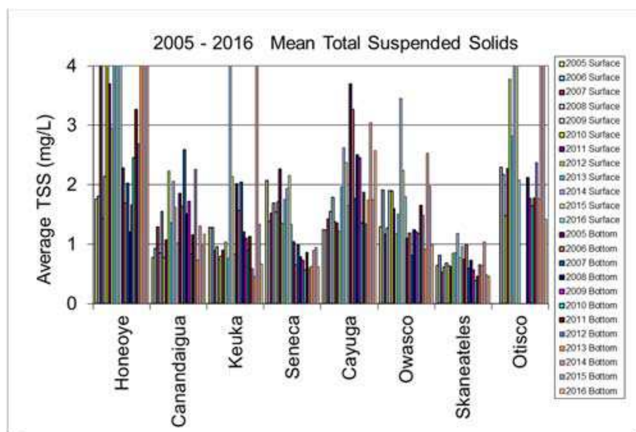
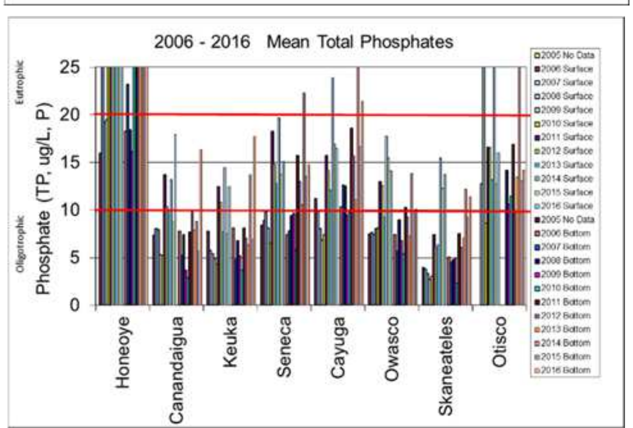
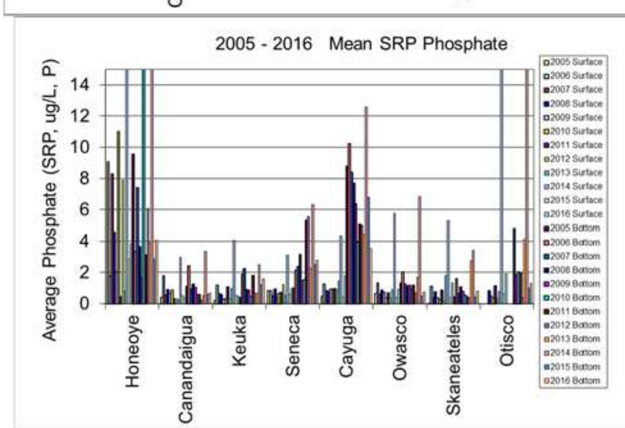


Fig. 10. Annual Water Quality Ranks from 2005 – 2016 for the eight easternmost Finger Lakes. The "mean" dark blue bar averaged the 2005 - 2013 ranks for each lake with a 1σ standard deviation error bar.









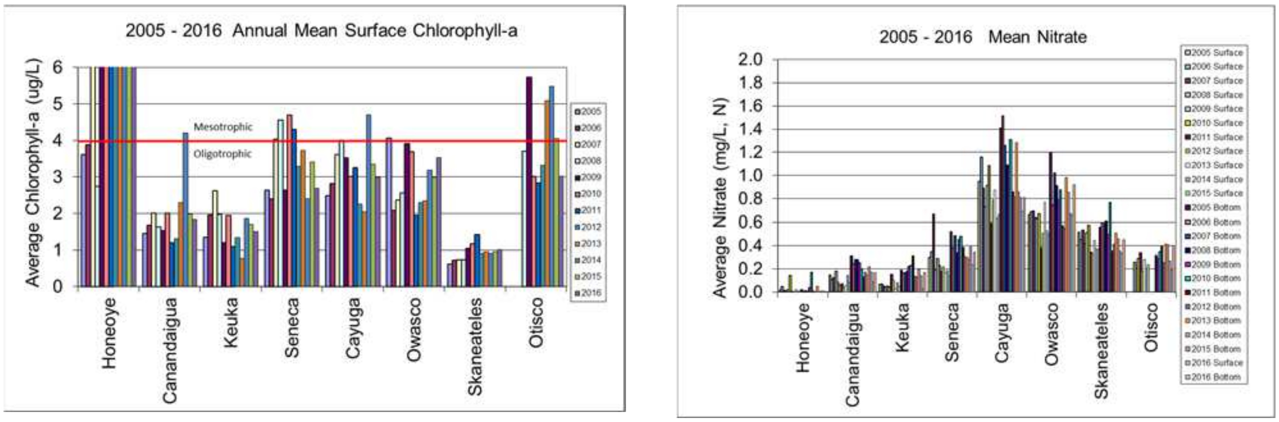


Fig. 11. Annual mean limnological data from selected Finger Lakes. When appropriate, boundaries for oligotrophic, mesotrophic and eutrophic conditions are shown.

DRONE FLIGHTS

Drone photographs appeared to map the distribution and aerial extent of encrusting algae and other macrophytes along the shoreline (Fig. 12)[5]. Mapping algal distributions and concentrations in the open water was promising as well. The digital cameras recorded the red, green and blue bands of the color spectrum that enabled further computer analysis back in the laboratory. The results suggest that green (algae) to blue (clear water) intensity ratios were proportional to chlorophyll-a abundance and inversely proportional to Secchi disk depths. The impact of numerous variables, e.g., glare from the sun, camera tilt angle, cloudiness, and extent and size of wind driven waves, however still needs further investigation. The promising results indicate that drone photography can map aquatic organisms in the Finger Lakes. Future monitoring should include drones flights to assess water quality in Owasco and neighboring lakes and, e.g., map the distribution and concentration of nearshore blue-green algae blooms in the years ahead.

Fig. 12. Georeferenced drone photos from 8-19-16 superimposed on a 2015 satellite image of the eastern side of Emerson Park (left) and southern side of Martin Pt (right). Each figure has five overlapping photographs

[5] Swete, B., Bradt, S., Halfman, J.D., I. Dumitriu, 2016. Exploratory drone research on water quality of the Finger Lakes. Rochester Academy of Science 43rd Annual Fall Conference.

THREE YEARS OF BUOY DATA

The FLI meteorological and water quality monitoring buoy was redeployed in Owasco Lake during the 2016 field season. It revealed higher resolution but otherwise consistent changes in the water column as described above (Fig. 13). Epilimnetic (surface water) temperatures increased from mid-May through early August to 26ºC (77ºF), then fluctuated between 22.5 and 25ºC to 9/21 until cooling down to 14ºC (55ºF) by the end of the deployment (Fig. 13). These changes are expected and related to the daily, weekly and seasonal changes in climate. Hypolimnetic temperatures slowly increased from 4 to 6.6ºC (40ºF) during the deployment. In comparison to 2014 & 2015, both the epilimnion and hypolimnion were slightly warmer in 2016. The timing of the epilimnetic peak temperatures were similar to 2015, warming to 25ºC by Late July whereas it warmed to 25ºC by early July in 2014. The seasonal cooling in the fall started earlier in 2014 as well, i.e., the surface waters cooled below 20ºC by mid-September in 2014 but was two weeks later in 2015 & 2016. The change probably reflected the earlier onset and longer duration of the very cold 2014/2015 winter season.

The depth of the thermocline, the boundary between the epilimnion and hypolimnion, gradually increased through the field season from < 10 m to > 20 m. The thermocline depth deepened faster during September and October reflecting the vertical mixing of surface water to deeper depths as the epilimnion cooled into the fall, i.e., the gradual decay of summer stratification. It also revealed daily oscillations of 1 to 2 meters in response to internal seiche and/or wave activity. Similar oscillations were detected in 2014 and 2015.

The epilimnetic specific conductance decreased from just over 330 μS/cm in early June to 300 μS/cm by early October, and then increased by ~15 μS/cm by the end of October (Fig. 13). These changes are small and the decrease reflects the dilution of the epilimnion by stream inputs and rainfall. The subsequent increase reflects the mixing of slightly more saline hypolimnetic water into the epilimnion as the surface waters cool and vertically mixed with deeper water in the fall. The hypolimnetic salinity increased from ~340 μS/cm by just over 10 μS/cm from late April to early October, then decreased by a few μS/cm until recovery in late October. Similar hypolimnetic trends were observed in 2014 and 2015, although salinities were slightly larger in 2015 than both 2014 and 2016.

The turbidity in the epilimnion remained relatively constant in 2016 until late September when it increased by ~1 NTU perhaps reflecting the rainfall in the fall season (Fig. 13). A turbidity spike was observed in mid-July, and corresponded to an intense algal bloom. The values were similar in 2014 and significantly less than 2015. The larger 2015 turbidities most likely reflect the runoff from spring rains and subsequent resuspension events, and the late summer algal populations. Lake-floor turbidities were much larger in 2015 than 2014 and 2016. The change is interpreted to reflect the early spring rains and wind/wave resuspension events in 2015 supplying suspended sediment to the nepheloid layer.

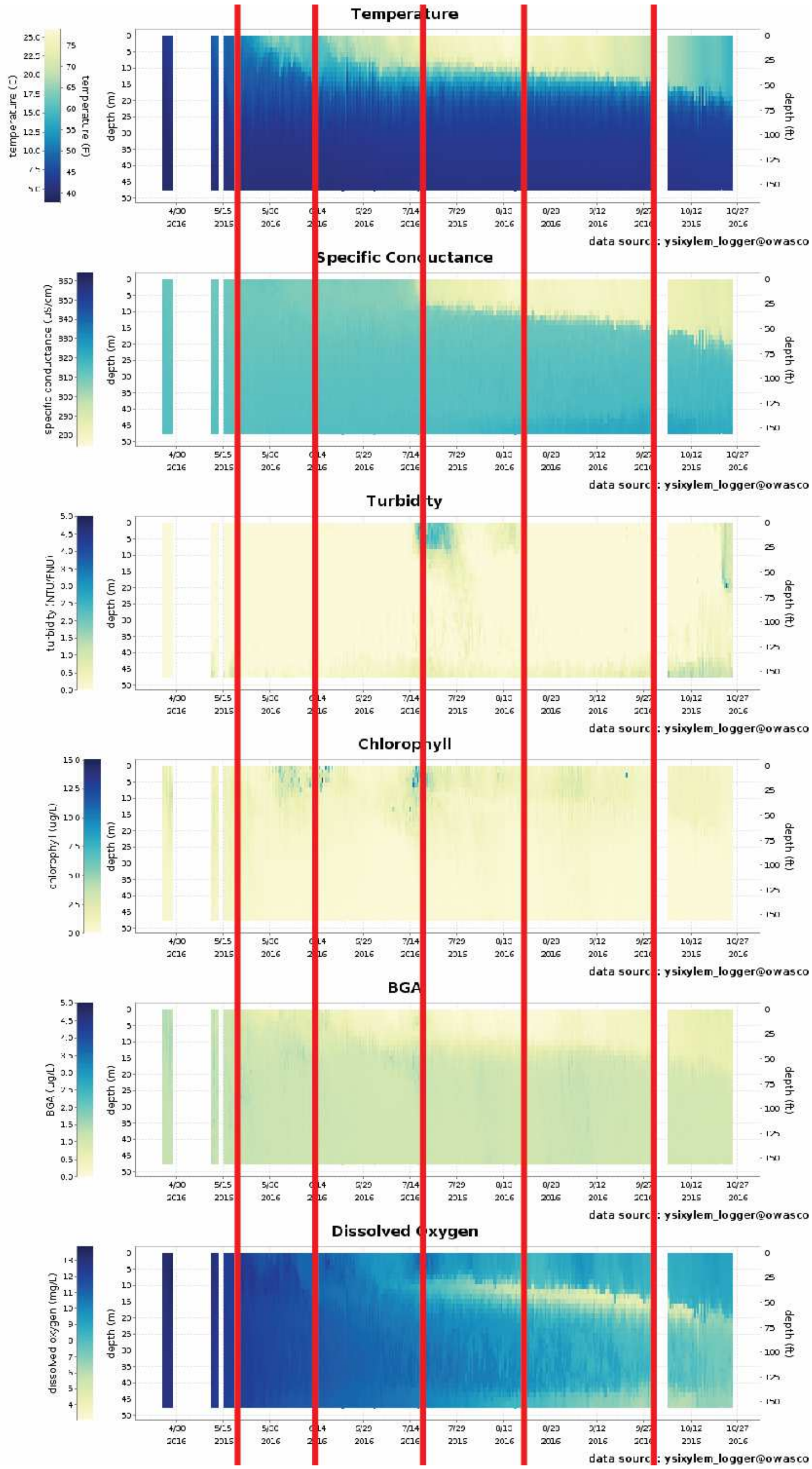


Fig. 13. Buoy water quality data for 2016. Note, algal concentrations shown above are under-estimates. The buoy website will have corrected values shortly but the correction did not influence the relative changes. The red lines depict the monthly monitoring cruise dates.

The chlorophyll-a concentrations changed significantly from ~2 to over 18 μg/L on different temporal scales (Fig. 13). One to two week long blooms with concentrations exceeding 10 μg/L were detected in May, early to mid-June, late July/early August and early September. The algae were typically concentrated within the upper epilimnion (10 m), however the late July bloom extended down to 15 meters. The September and October algal bloom probably responded to nutrients from rain events and the thermal decay of the season stratification, and mixing of nutrient-rich hypolimnetic waters into the epilimnion.

The blue-green algae sensor detected an increase in epilimnetic BGA concentrations in September (Fig. 13). However, BGA concentrations at the buoy never exceeded 1.5 μg/L, compared to the nearshore concentrations up to 16,700 μg/L in 2016 (DEC and Watershed Inspector data, by permission). The low open-water BGA concentrations were confirmed by fluoroprobe water column profiles collected during 8/16 and 10/1 surveys (Fig. 6). The discrepancy therefore reflects the surface and nearshore hugging distribution of BGA blooms, as the buoy BGA sensor and fluoroprobe started measuring concentrations at a water depth of 1 meter and both were deployed at a central, open-lake location. It confirms that the minimal response of the BGA sensor on the buoy in 2014 and 2015 was also due to the mid-lake deployment of the buoy. The increase in BGA concentrations below the thermocline by the buoy and fluoroprobe is an artifact of the instrumentation, i.e., a sensor response to a change in temperature and not an actual change in the BGA concentrations. BGA are also unlikely to survive in the dark hypolimnion. The nearshore/offshore separation should be investigated in the years ahead by deploying of a number of BGA sensors along the shoreline.

Finally, epilimnetic dissolved oxygen (DO) concentrations in 2016 were at or just above saturation throughout the deployment (Fig. 13). Hypolimnetic DO concentrations decreased from nearly saturated concentrations in early June to nearly 40% below saturation just below the thermocline and down to 50% saturation along the lake floor by the end of September. The depletion reflects the respiration of algae by bacteria, zooplankton and other animals at these oxygen depleted depths. A similar pattern in DO was observed in 2014 and 2015 but the depletion was more severe, i.e., to 30% in 2015, and extended later into the fall, i.e., into September in 2015 than 2014 and 2016.

BLUE-GREEN ALGAE AND HARMFUL ALGAL BLOOMS

Owasco Lake experienced significant surface-water, blue-green algal blooms in 2016 (Fig. 14). Blue-green algae (BGA) contain gas vacuoles that enable them to float at or near the surface of a lake as surface water, smelly scums, whereas, other algae live at deeper depths within the epilimnion, and typically out of sight of humans in boats or onshore. BGA do this to outcompete other algal species for light. Unlike other algae, BGA can vertically migrate during a 24-hour day. During the daytime, their photosynthesis of dense carbohydrates forces BGA to sink by mid-day or late afternoon. After sinking to low light levels, BGA respire and consume their carbohydrates, create carbon dioxide gas, which accumulates in their tissues, and thus enables them to buoyantly rise to the surface by early to late morning during calm days. Mixing by wind-driven waves can retard the upward migration.

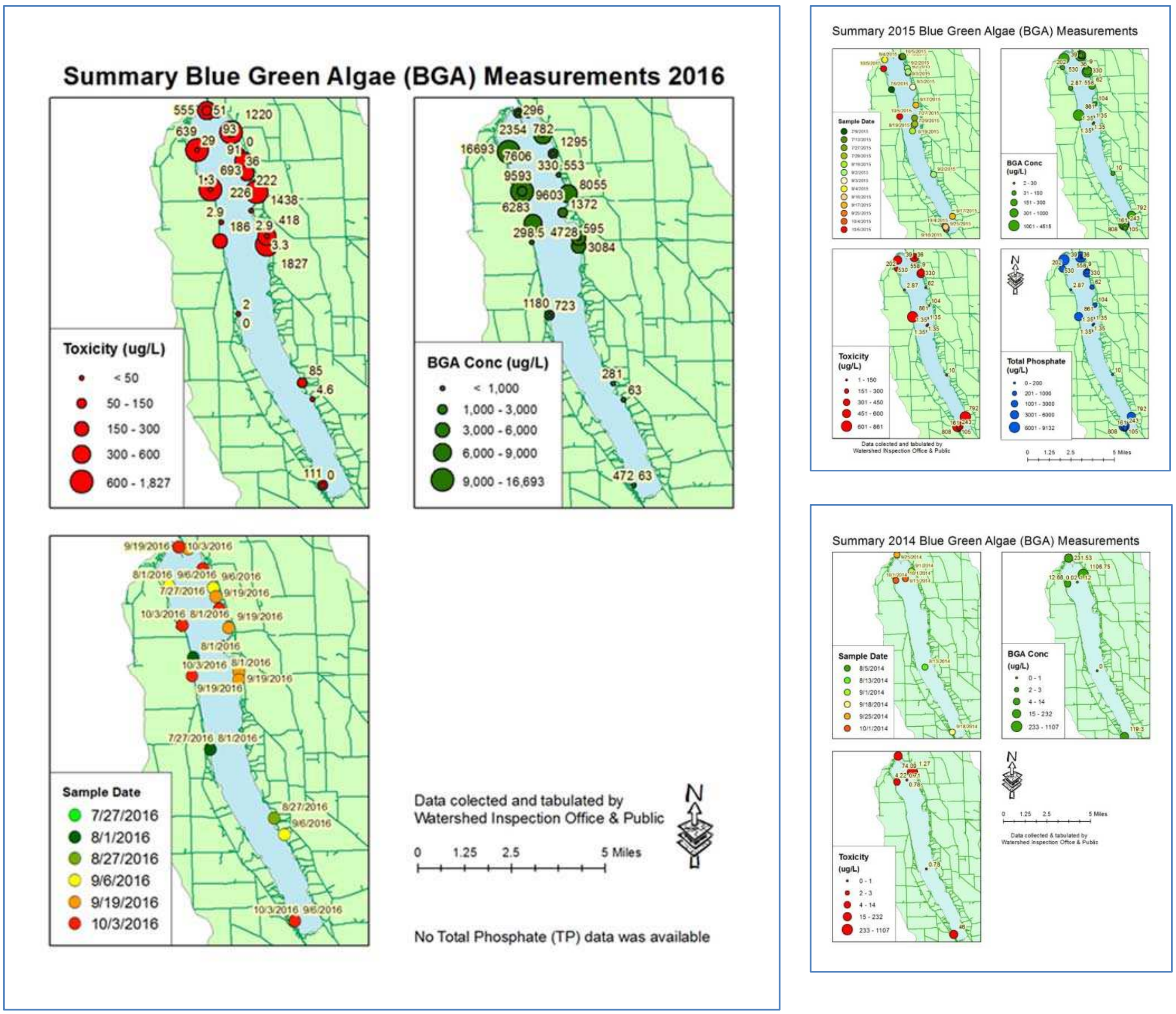


Fig. 14. Maps of the 2016, 2015 & 2014 BGA bloom dates, BGA concentrations and BGA toxin concentrations (data from the Owasco Lake Watershed Inspector & DEC). Total phosphate data for these samples were only available in 2015.

Some BGA species like those in the *Anabaena* genus can “fix” atmosphere nitrogen (N_2) for their source of nitrogen, whereas most other forms of algae including some forms of BGA like *Mycrocystis* cannot “fix” N_2 and are instead dependent on the dissolved forms of nitrogen like nitrate (NO_3^-) or ammonium (NH_4^+) to photosynthesize organic matter. Nitrogen fixing BGA have an ecological edge in nitrogen-starved lakes like Honeoye. Nitrogen starvation is not a concern in Owasco and the other phosphorus-limited Finger Lakes. BGA may also disrupt food chain dynamics, because they are avoided, i.e., preferentially not eaten, by zooplankton and fish.

More importantly, some species of BGA produce a variety of toxins that in turn generate various health threats to humans and other warm blooded animals (e.g., dogs). BGA taxa that can produce toxins do not synthesize toxins all the time. When toxins are produced the blooms are called harmful algal blooms (HABs). Different toxins are synthesized by different BGA taxa that impact different parts of the body, most notably, the liver, the nervous system, and/or gastrointestinal system. Liver cyanotoxins like mycrocystins are most commonly found in HAB blooms, and at high doses can cause organ damage, heart failure and death in lab animals. Mycrocystins can be synthesized by various species of *Mycrocystis* and *Anabaena* genera. Both genera of BGA have been detected in all the Finger Lakes including Owasco Lake. Anatoxins impact the nervous system and can be synthesized by *Anabaena* and other BGA genera. Their impact on humans at low concentrations still remains elusive. The World Health Organization (WHO) has issued a provisional finished drinking water guideline of 1 μg/L for chronic exposure to mycrocystin, and recreational exposure limit of 20 μg/L[6]. The EPA’s drinking water limit for mycrocystin is 0.3 μg/L for infants and 1.6 μg/L for school-age children and adults; their recreational contact limit is 4 μg/L. No thresholds are set for anatoxins yet, although 4 μg/L may be used. The half-life of anatoxins are very short, thus difficult to monitor.

The blooms are not unique to Owasco Lake. In 2016, major BGA blooms were also confirmed in Conesus (4 weeks), Honeoye (9 weeks), Canandaigua (3 weeks), Seneca (2 weeks), Cayuga (7 weeks) and Owasco (9 weeks)[7]. Over 140 lakes in New York State had confirmed BGA blooms in 2016 out of the tens of thousands of lakes in the state (Rebeca Gorney, DEC, person. comm.). The DEC defines a BGA bloom when BGA chlorophyll-a concentrations exceed 25 μg/L. Even more disturbing is that that many blooms contained toxins above the World Health Organization advisory threshold of 1 μg/L and DEC’s MCL of 0.3 μg/L for safe drinking water.

In Owasco Lake, BGA occurrences as conformed by the DEC has increased from one week in 2012 (9/6 – 9/27), to two weeks in 2013 (8/25 – 10/3), to six weeks in 2014 (8/22 – 10//12), and to nine weeks in both 2015 (7/10 – 10/16) and 2016 (7/29 – 10/14). The length of time detected in each lake might only reflect the intensity and number of people looking for blooms. Notwithstanding, the past three years have detected the largest concentrations of BGAs and HABs. Measured concentrations ranged from 0 to 1,100 μg/L and averaged 165 μg/L in 2014, from 2 to 4,500 μg/L and averaged 820 μg/L in 2015, and, 60 to 16,800 μg/L and averaged 3,150 μg/L in 2016 (Fig. 14). The nearshore blooms were more common along the northern margins of the lake although this may be an artifact of the detected occurrences. Toxin concentrations ranged from 0 to 75 μg/L in 2014, 0 to 860 μg/L in 2015 and up to 1,800 μg/L in 2016. The DEC lists Owasco Lake as impaired by excessive BGA concentrations, using their BGA chlorophyll-a concentration threshold of 25 μg/L, and a mycrocystin recreational concentration

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[6] WHO, 2011. Guidelines for Drinking Water Quality. 4th Edition. World Health Organization. Switzerland.
[7] www.dec.ny.gov/docs/water_pdf/habsarchive2016.pdf

threshold of 20 μg/L. Toxin concentrations up to 0.22 μg/L were detected in the Auburn and/or Town of Owasco municipal water supplies for ~45,000 residents and drawn from Owasco Lake eleven (11) times between 9/22 through 10/10. All detections were just below the EPA's drinking water threshold of 0.30 μg/L for the most vulnerable populations, the elderly and under 3-years of age. Strategies to eliminate BGA from the municipal drinking water supplies are under development for the coming year. Lakeshore residents with private water systems should make sure they can remove BGAs from the drinking water without busting the organism apart and releasing toxins into their drinking water. It is not easy[8].

The magnitude of the largest BGA and TP concentrations are, at first glance, staggering. In the open water, algal and TP concentrations rarely exceed 10 to 20 μg/L. However, some of the measured BGA concentrations exceeded these "typical" concentrations by nearly 1,000 times. It is a limnological challenge to increase a localized algal population with nutrients or other growth stimulants by 1,000 times using normal ecological scenarios. Existing BGA can be concentrated into smaller volumes of water, however.

Two mechanisms concentrate algae into a smaller volume of water. First, as they buoyantly rise from deeper depths to the surface of the lake, they concentrate in smaller volumes of water. Second, when light winds push and accumulate the algae against the shoreline, they again concentrate in smaller volumes of water. Once against the shoreline, the lake floor would also restrict the bloom's depth and thus restrict/reduce the bloom's water volume some more. Accurate wind speed and direction data and depth profiles of BGA concentrations during the formation of a bloom are required to confirm this hypothesis. The buoy collects hourly wind information but the exact time of the bloom formation is lacking, and nearly calm winds are rarely constant in speed or direction across the lake. Multiple BGA sensors along with meteorological wind speed and direction sensors distributed around the shoreline should be deployed to confirm this hypothesis.

Scientists have generalized that BGA blooms prefer the following conditions:

- warm water, temperatures between 60 and 80^{o} F (15 to 30^{o}C);
- elevated (eutrophic) concentrations of nutrients, especially waters rich in phosphorus, the limiting nutrient for many BGAs;
- lake stratification, as BGA buoyancy regulation provides a competitive edge in a stratified, warm, water column;
- calm or near-calm conditions as turbulence disrupts buoyancy and light limits their growth;
- rainfall events, as events deliver nutrients to the lake; and,
- other potential factors may include pH.

However, predicting their occurrence remains a challenge due to the large number of BGA species and the diversity of their habitats. BGA blooms in the Finger Lakes are a larger challenge because most of these lakes are oligotrophic or mesotrophic systems, and not the eutrophic lakes that BGA blooms were commonly found in earlier.

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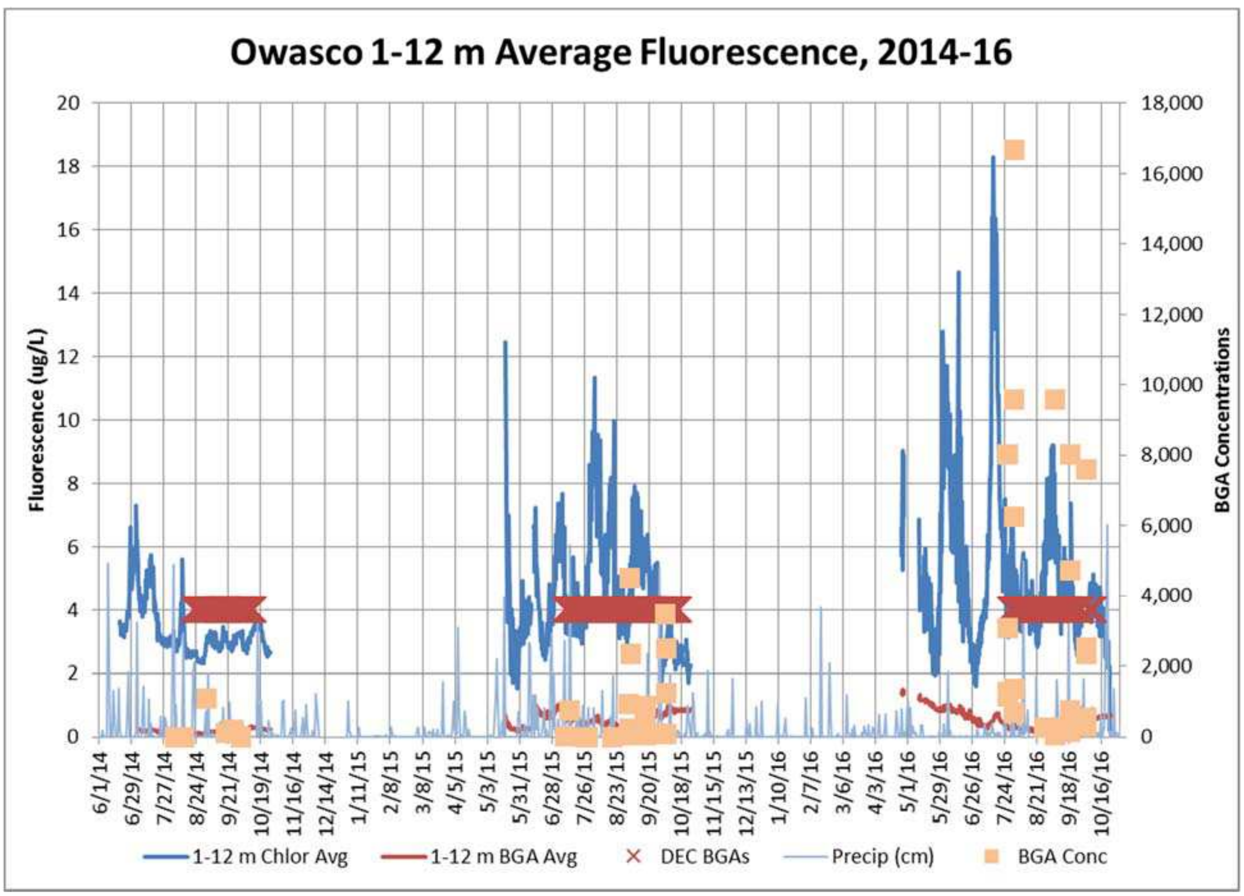
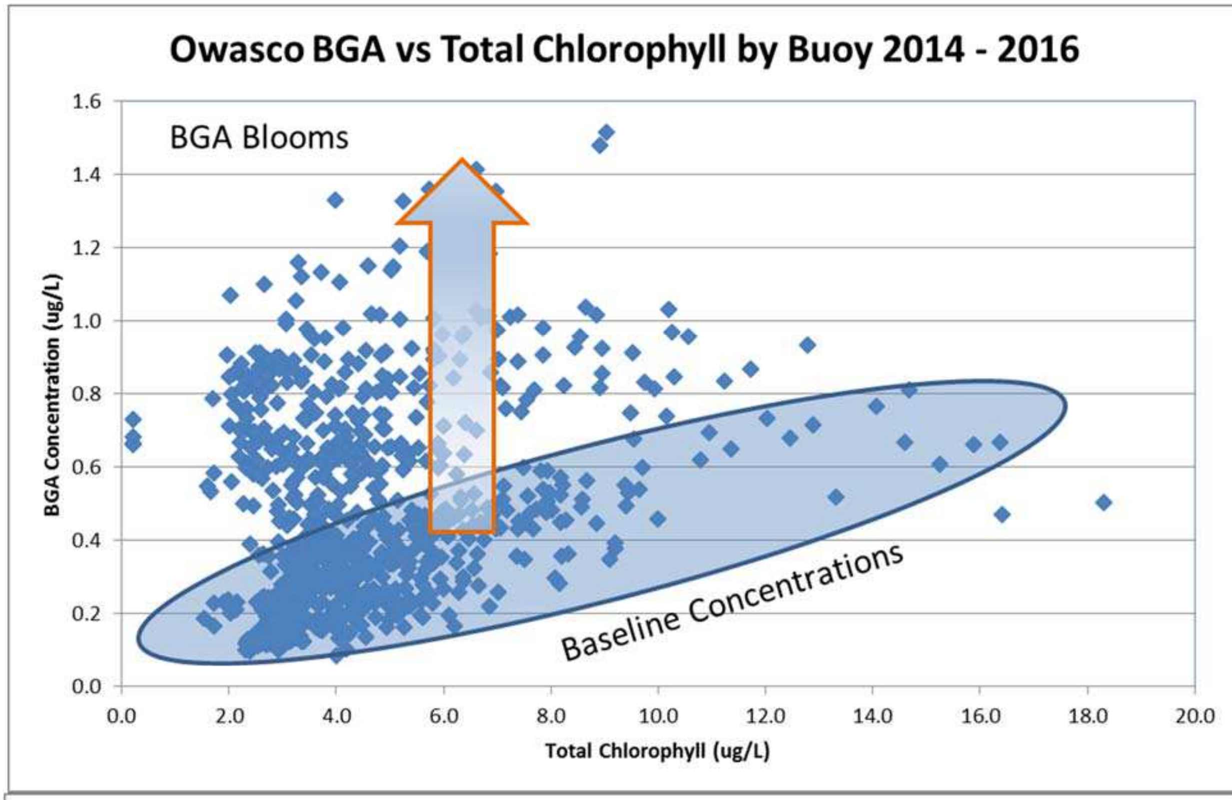
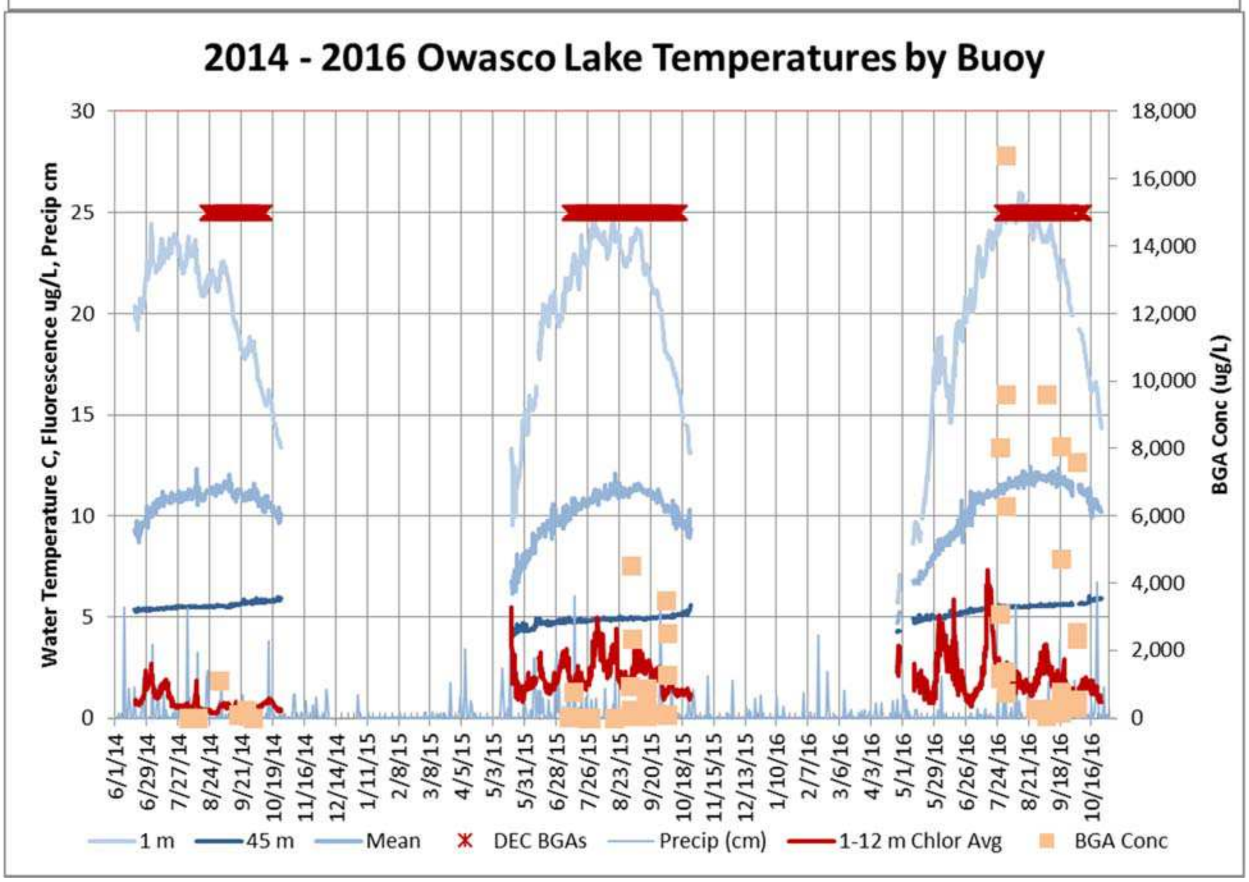
[8] A Water Utility Manger's Guide to Cyanotoxins. 2015. Water Research Foundation, American Water Works Association, 18 pgs. www.waterrf.org

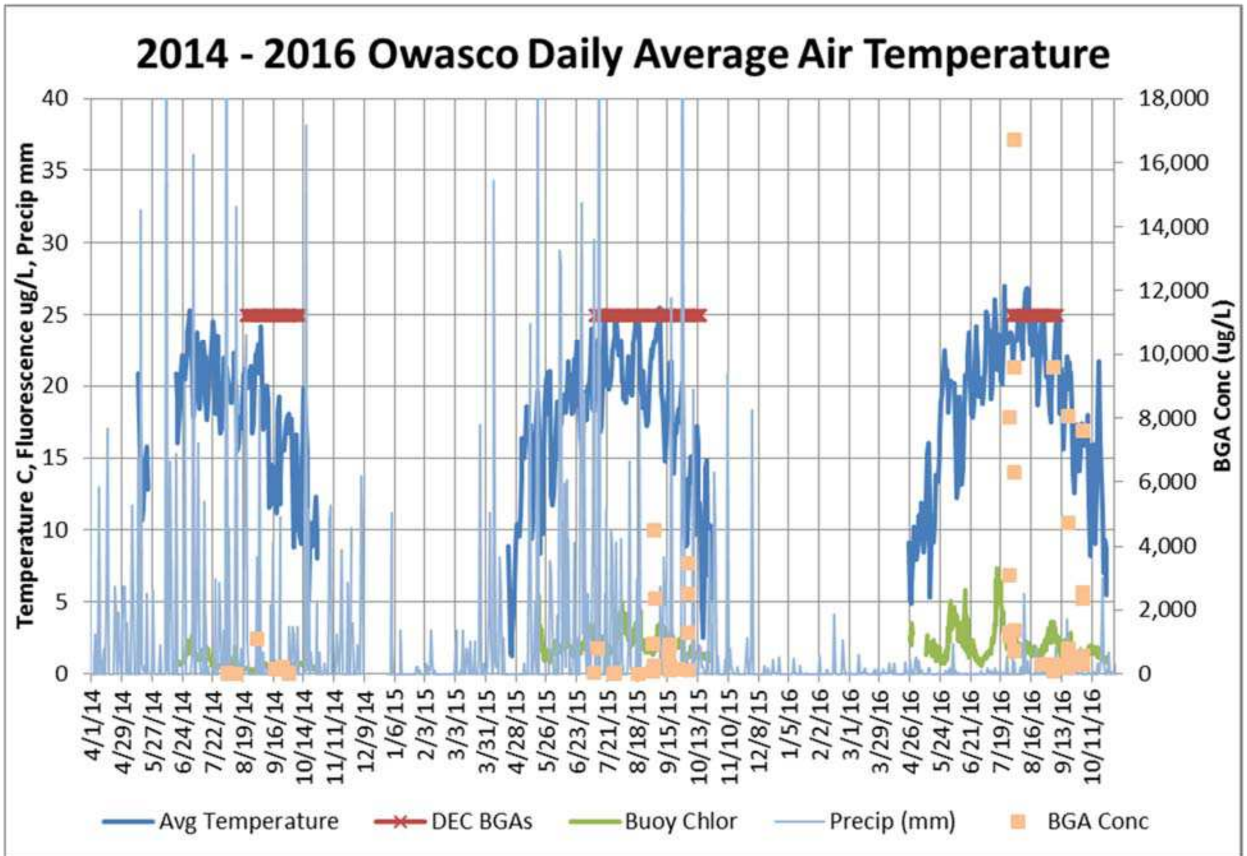
The last three years of buoy data shed some light on the occurrence and development of BGA blooms in Owasco Lake (Fig. 15). These figures plot the buoy's mean epilimnetic total algal and BGA fluorescence, average surface and bottom water temperatures, mean daily air temperatures, mean daily available sunlight, and mean daily wind speeds from 2014 through 2016. Each plot also includes the weeks with BGA blooms confirmed by the DEC, the mean epilimnetic total algae concentration detected at the FLI buoy, the BGA concentration detected in water samples collected by the Watershed Inspector, FLI or the public, and daily rainfall totals to look for any obvious correlations (or lack thereof).

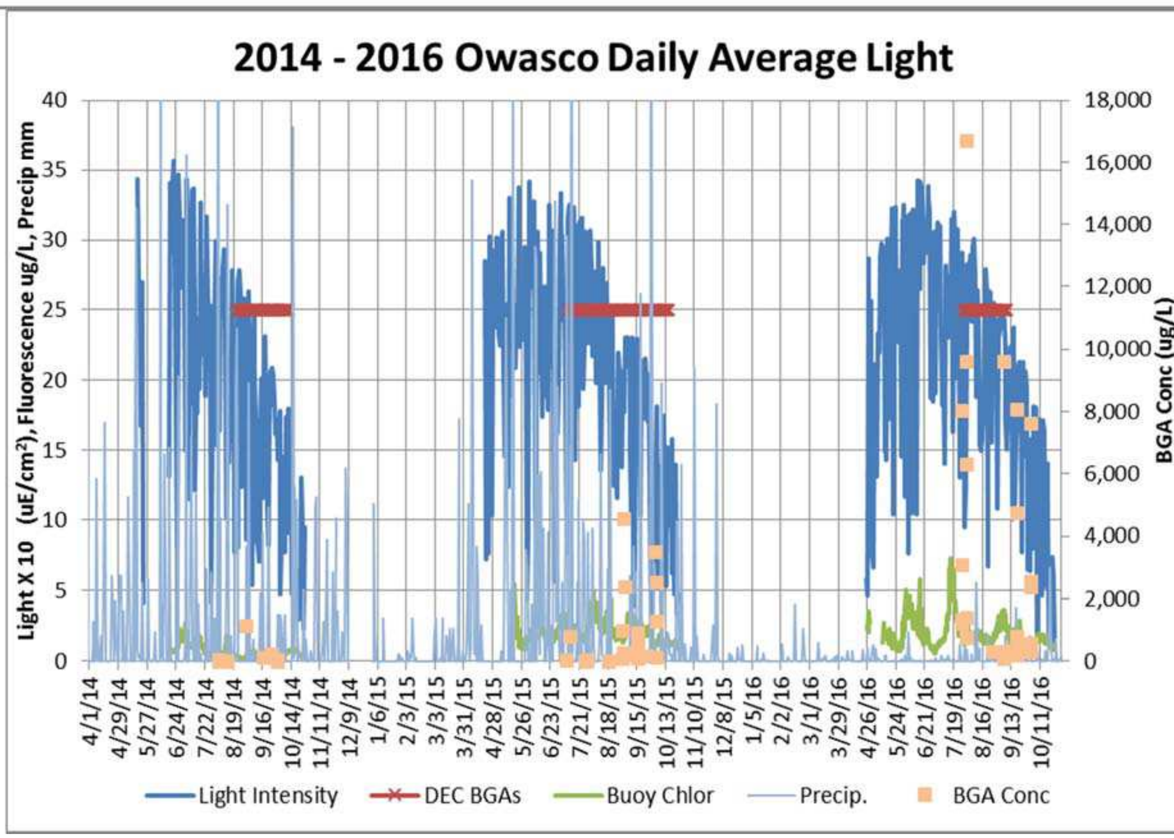
Buoy Total Algae and BGA Fluorescence: Minimal correlations were observed between the buoy fluorescence data and the BGA occurrence and concentration data (Fig. 15). The lack of a correlation is not disturbing because the buoy measures open water parameters, and the bulk of the BGA bloom data was from nearshore locations. Two observations were noteworthy. The buoy detected larger algal concentrations and more frequent blooms in 2016 than 2015 and 2014. Thus, lake conditions in 2016 were more favorable for algal growth. In all three years, baseline BGA concentrations were proportional to total chlorophyll (Fig. 15). It suggests that BGA species were always in the plankton population in low (~10% of total plankton) percentages waiting for the "ideal" stimulus (or stimuli) to bloom.




Owasco BGA vs Total Chlorophyll by Buoy 2014 - 2016
BGA Blooms
Baseline Concentrations
BGA Concentration (ug/L)
Total Chlorophyll (ug/L)


2014 - 2016 Owasco Lake Temperatures by Buoy
Water Temperature C, Fluorescence ug/L, Precip cm
BGA Conc (ug/L)
1 m
45 m
Mean
DEC BGAs
Precip (cm)
1-12 m Chlor Avg
BGA Conc


2014 - 2016 Owasco Daily Average Air Temperature
Temperature C, Fluorescence ug/L, Precip mm
BGA Conc (ug/L)
Avg Temperature
DEC BGAs
Buoy Chlor
Precip (mm)
BGA Conc


2014 - 2016 Owasco Daily Average Light
Light X 10 (uE/cm²), Fluorescence ug/L, Precip mm
BGA Conc (ug/L)
Light Intensity
DEC BGAs
Buoy Chlor
Precip.
BGA Conc

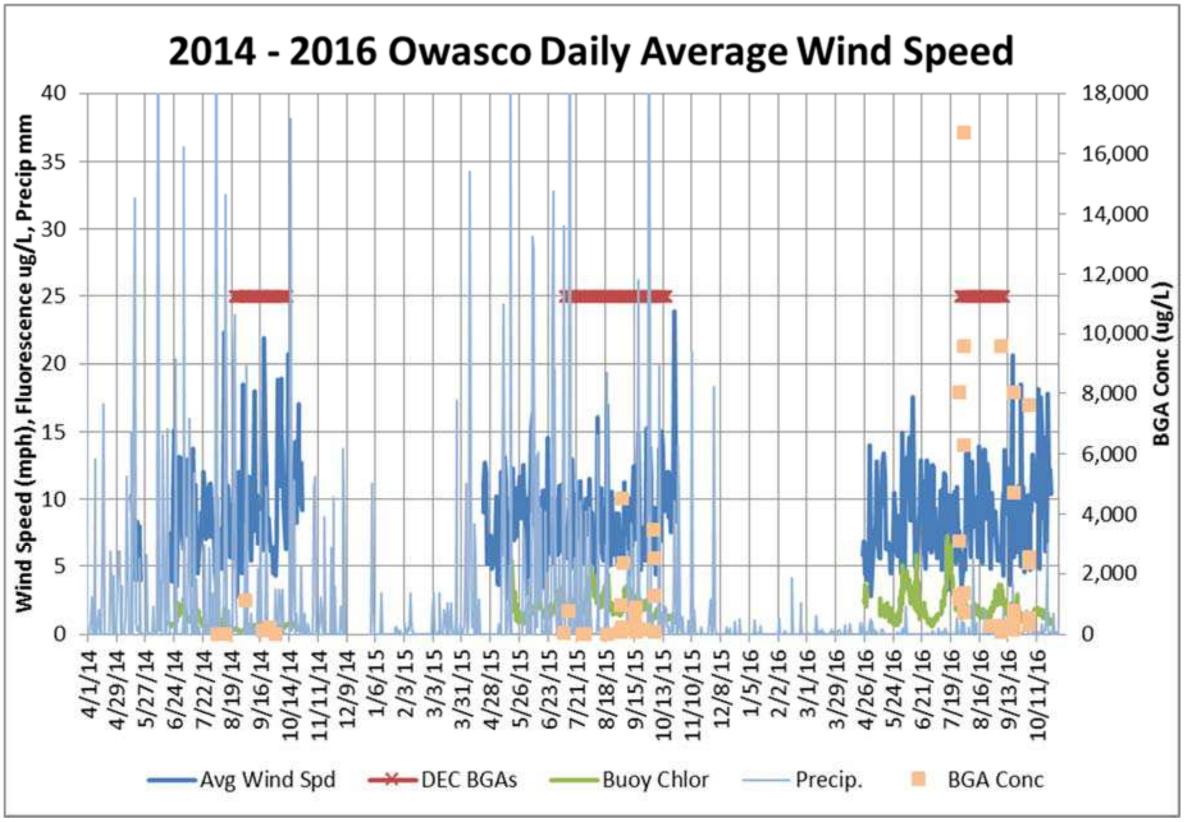


Fig. 15. Average daily total fluorescence, blue-green algae fluorescence, water temperature, air temperature, light intensity (sunlight) and wind speed data from the Owasco Lake monitoring buoy. Also plotted are nearshore BGA concentrations and precipitation data for comparison.

Buoy Lake Temperature: In all three years, BGA blooms waited until water temperatures rose to 22 or 23°C (70 – 75°F, Fig. 15). However, the 2014 and 2016 blooms did not appear until a week or two after the warm water threshold, indicating that warm water by itself does not trigger bloom activity. Blooms did not continue to appear after the surface water cooled below 15°C (60°F). A mean water column temperature, revealing the strength of thermal stratification, appeared to peak during the majority of BGA blooms as well. It indicates that blooms required warm water. Cold water, below 15°C, appears to terminate BGA blooms.

Buoy Air Temperature: Like water temperatures, the BGA blooms appear to start at or a few weeks after peak (23 to 24°C, 70-75°F) air temperatures (Fig. 15). Blooms end when the air temperature cooled below 10°C (50°F). Thus, blooms prefer warm air temperatures as well, and are terminated by cold air temperatures. The parallel nature for air and water temperatures is not surprising because both air and water temperatures are linked to solar insolation.

Buoy Sunlight Intensity: The first BGA blooms for the season happened until after summer solstice, and BGA blooms were no longer detected when daily average insolation (sunlight) decreased below 150 $\mu E/cm^2$ (Fig. 15). Perhaps BGA outcompete other algae in periods of lower light, i.e., post peak light intensities, because BGA can float closer to the lake's surface, water depths with more light. However, blooms were not pervasive throughout the late summer and early fall. Thus, solar intensity, and air and water temperatures were associated with but not the sole trigger for blooms.

Rainfall: In all three years, BGA blooms appeared after a storm (Fig. 15). It suggests that the rainfall and associated storm induced runoff brought in sufficient nutrients to stimulate a bloom. Interestingly, the algae appeared to "wait" for the subsequent calm, sunny day after the rain to bloom. In support, the bloom activity in 2016 was absent until mid-August, and only detected after the first rain events, late in the summer season. The decreased spring and summer rainfall 2016 compared to 2014 and 2015 suggests that high annual rainfall totals, "wet" years, are not important for individual bloom genesis. However, the significant spring rains of 2014 and 2015 and their associated nutrient/sediment loads may have provided enough nutrients to the lake to trigger the intermittent BGA blooms along the shoreline in Owasco and the neighboring Finger Lakes during the past three years.

Buoy Wind Speed & Direction: Both 2016 and 2015 were not as windy as 2014, especially when BGA blooms were detected (Fig. 15). The wind speed in 2015 and 2016 was at or below 10 mph (small waves) with only a few days with wind speeds above 15 mph (large waves with white caps). 2014 had fewer calm to light-breeze days and multiple days with wind speeds above 15 mph. It suggests that BGA bloom development was more likely during calm or light-breeze days. However, BGA blooms were not detected on every available calm or nearly calm day in August and September, so calm days are not the sole trigger but windy days prevent nearshore blooms. Winds above 20 mph (very large waves with white caps) coincide with the end of the bloom activity in 2015 and 2016 but not 2014. Thus larger wind speeds probably retarded BGA blooms by mixing BGA throughout the epilimnion and towards open water thus mixing the blue-green algae into a larger volume of water and decreased its concentration.

The average wind direction blew from the south and did not appreciably change over the three years (Fig. 16). The direction was consistent with the majority of the BGA concentrations along the northern margins of Owasco Lake (Fig. 14). A similar BGA lakeshore bloom distribution and wind direction connection was observed in Seneca Lake.

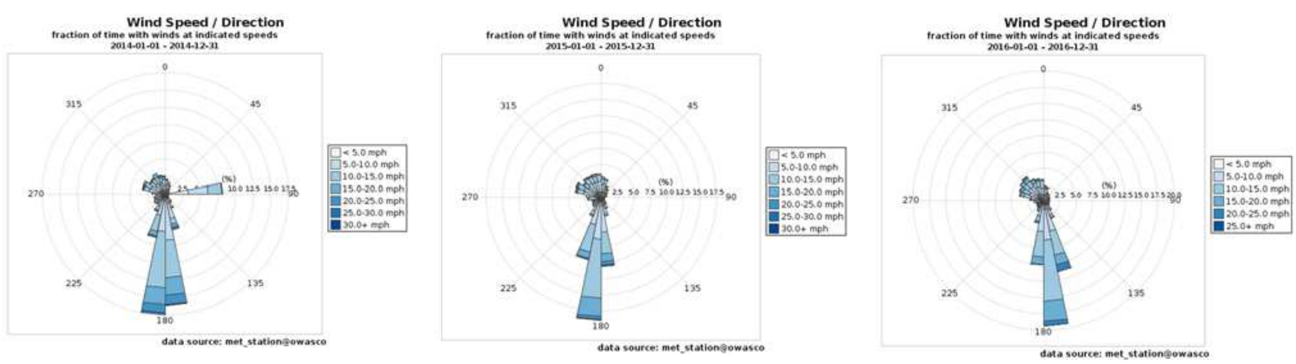


Fig. 16. Wind rose diagrams showing frequency of wind direction and speed for 2014 (left), 2015 (center) and 2016 (right) from the Owasco Lake buoy.

Summary: The buoy water quality and meteorological data indicate that BGA blooms occurred between the summer solstice and a few weeks after the fall equinox, coincident with the warmest and subsequent decline in air and water temperatures. They favor periods of calm or nearly calm weather, but were not detected during every calm day. Sunny, calm days after a recent runoff event typically coincides with each bloom but did not consistently initiate a bloom. The southerly wind direction was consistent with the northerly location of the majority of the nearshore blooms. The decay of the epilimnetic thermal stratification in the fall season, due to cooler temperatures and wind events, can also mix more nutrients into the epilimnion and stimulate additional bloom growth. Strong winds were also coincident with the last bloom in any given year. It again suggests the importance to investigate the spatial and temporal characteristics of BGA blooms along the shoreline in relation to local metrological conditions by deploying numerous BGA, wind and temperature sensors at different locations around the shoreline.

Please note: all of these observations/correlations are tentative at this time. They were coincident with BGA blooms but coincidence does not mean causation. These associations also lacked a consistent and unique event to trigger the large blooms detected since 2014, as previous summers also experienced calm sunny days after some rain near the end of the summer but lacked intense BGA blooms. It indicates the importance of the significant rain events and the associated nutrient delivery during 2014 and 2015 were important.

Do not lose sight of the bigger picture! The focus should not only be predicting blooms and understanding their ecology but more importantly eliminating blooms from the lake. The ultimate means to limit any algae bloom is to limit nutrients in the watershed.

STREAM MONITORING RESULTS & DISCUSSION

Stream Discharge: Stream discharge data from the six survey dates in 2016 ranged from dry (0.00) conditions at Fillmore Creek and South Tributary to 13.2 m^3/s in Owasco Inlet at Moravia (Table 6 in appendix, Fig. 17). These flows revealed typical seasonal variability but significantly smaller discharges than previous years.

Spatial patterns in discharge were consistent over time. The 2016 mean and individual discharge measurements were larger at those sites with a larger drainage basin upstream from the site on any given sample day as in previous years (Fig. 18, $r^2 = 0.97$). The annual mean measured discharge of Owasco Inlet (299 km^2), Dutch Hollow Brook (77 km^2), Mill (78 km^2), Hemlock (47 km^2) and Fillmore Creek (16.5 km^2) were 3.9, 0.65, 1.26, 0.34 and 0.26 m^3/s, respectively. Discharge was always larger at successively downstream sites along Owasco Inlet but this trend was occasionally not true for Dutch Hollow Brook.

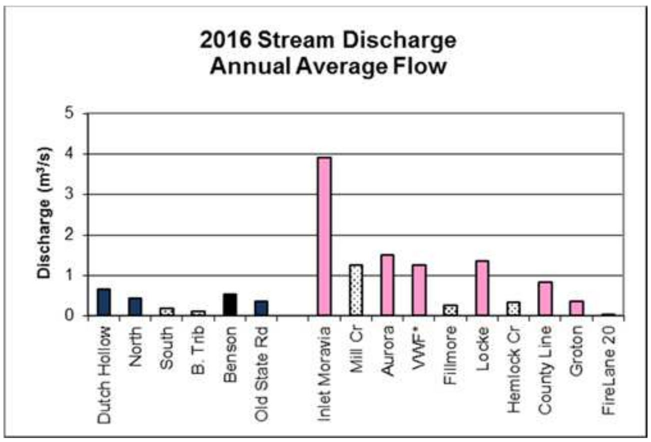


Fig. 17. Annual average stream discharge at each stream site in the Dutch Hollow Brook (purple), Owasco Inlet (pink) and Fire Lane 20 watersheds based on the 6 grab sample survey dates. Tributary sites are stippled. Sites are arranged, left to right, from downstream to upstream.

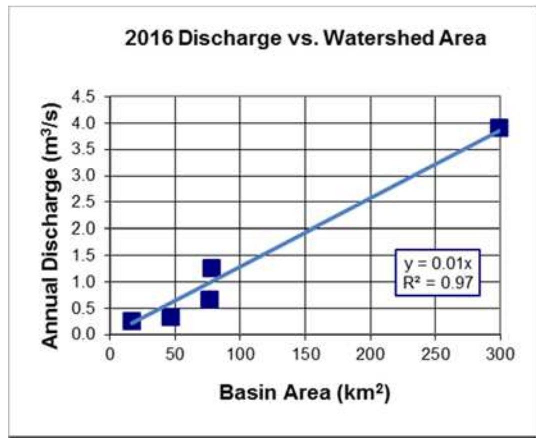


Fig. 18. Discharge vs. Basin Size.

Within Dutch Hollow Brook, mean annual discharge at each site typically equaled or was slightly larger than the sum of the discharges at the next upstream site and any measured tributaries entering along the segment between sites. For example, the sum of the mean annual discharge at North Rd was similar to the sum of the discharges at South, Benson tributary, and Benson Rd sites. Discharge decreased slightly from North Rd to 38A on all but one sample date which had the largest measured discharge. It suggests that surface runoff persistently contributed to and increased stream discharge during events from North down to Rt 38A. In contrast, the stream probably lost water to instream plants along this stretch of stream, and into the permeable sand of gravel groundwater system of the Dutch Hollow Brook delta, during base flow.

Within Owasco Inlet, tributary inputs typically accounted for the majority of the observed downstream increases in discharge. For example, the mean discharge at the Locke site was slightly smaller than the sum of the mean discharge upstream of Locke and Hemlock Creek. The discharge at Moravia (at Rt 38) was slightly smaller than the combined discharge at Mill Creek, a tributary to Owasco Inlet, and at Aurora St, the next upstream site. Groundwater inputs probably provided the difference, and were especially important this year, a very dry year. The exception was VFW which revealed smaller mean annual discharge than Locke and other upstream sites. The smaller annual discharge at VFW was most likely due to not collecting samples at the VFW site on the two "high flow" survey dates, 4/13 and 10/1.

Seasonal Variability: The largest discharges of 2016 were detected in the spring and smallest in the summer using the bi-monthly discharge data for Dutch Hollow at the Rt 38A site and the USGS gauge data for Owasco Inlet (Fig. 19). The spring dominance in flow was also detected in previous years. The seasonal pattern between the summer and fall discharges varies from year to year but always paralleled the seasonal change in precipitation and evapotranspiration (Fig. 20).

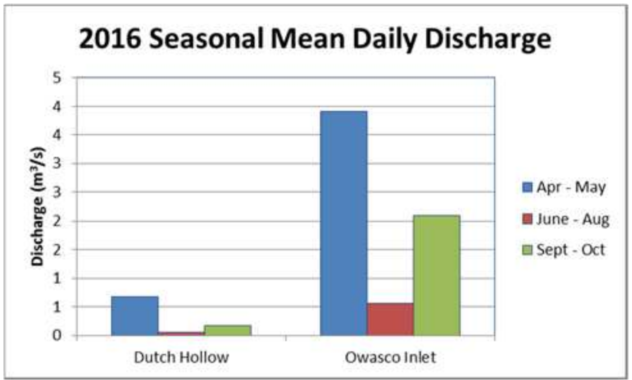


Fig. 19. Seasonal averaged stream discharge for the Rts. 38A and 38 sites, the terminal sites on Dutch Hollow Brook and Owasco Inlet, respectively.

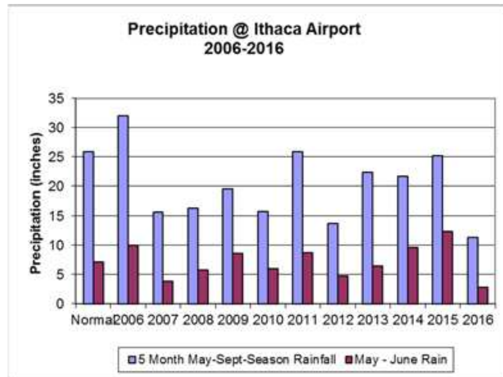


Fig 20. Monthly and "normal" precipitation totals for the Ithaca Airport.

Differences to Earlier Years: The 2016 annual mean discharge was the smallest detected at Dutch Hollow Brook and 2nd smallest at Owasco Inlet over the past six years (Fig. 21). These differences are explained by parallel changes in precipitation. The 2016, May through June, and the 5-month field season precipitation totals were small, 43% and 41% of normal as measured at the Ithaca Airport, and the driest year since 2006 (Fig. 22). It designates 2016 and 2012 as "dry" years, 2013 and 2014 as "in-between" years, and 2011 and 2015 as "wet" years. As noted before, differences in discharge parallel changes in precipitation.

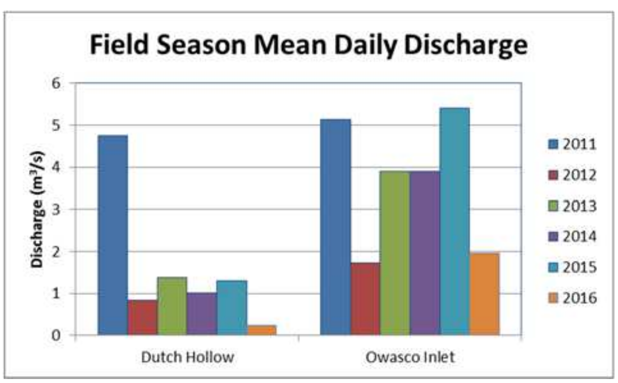


Fig. 21. Field season annual average stream discharge for the Rts. 38A and 38 sites. This plot used the estimated Dutch Hollow Brook data logger and USGS daily Owasco Inlet discharge data.

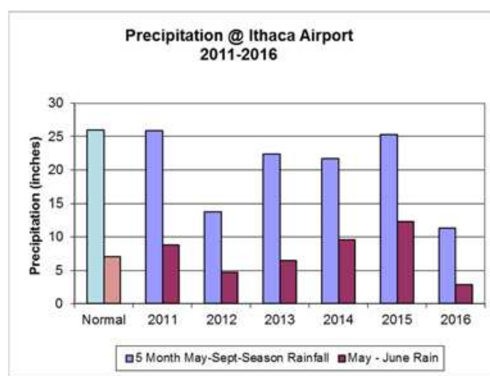


Fig. 22. Annual precipitation totals during the 8-month, March – October, field season, and during May & June at the Ithaca Airport.

The Owasco Inlet (USGS Gauge, 4235299) eight month, field season, annual discharge of 2.0 m^3/s revealed a "dry" year for 2016 compared to 5.1, 1.7, 3.9, 3.0 and 5.4 m^3/s in 2011 through 2015, respectively (Fig. 23). Similar variability was observed for the Owasco Outlet (USGS

Gauge, 4235440). Annual mean daily outflows were 11.4, 8.4, 8.3, 8.7, 8.4, 9.2 and 6.1 m^3/s for 2011 through 2016, respectively. Clearly, 2013 and 2014 were "in between" and perhaps more typical for Owasco Lake compared to the 2011 and 2015 "wet", and 2012 and 2016 "dry" years.

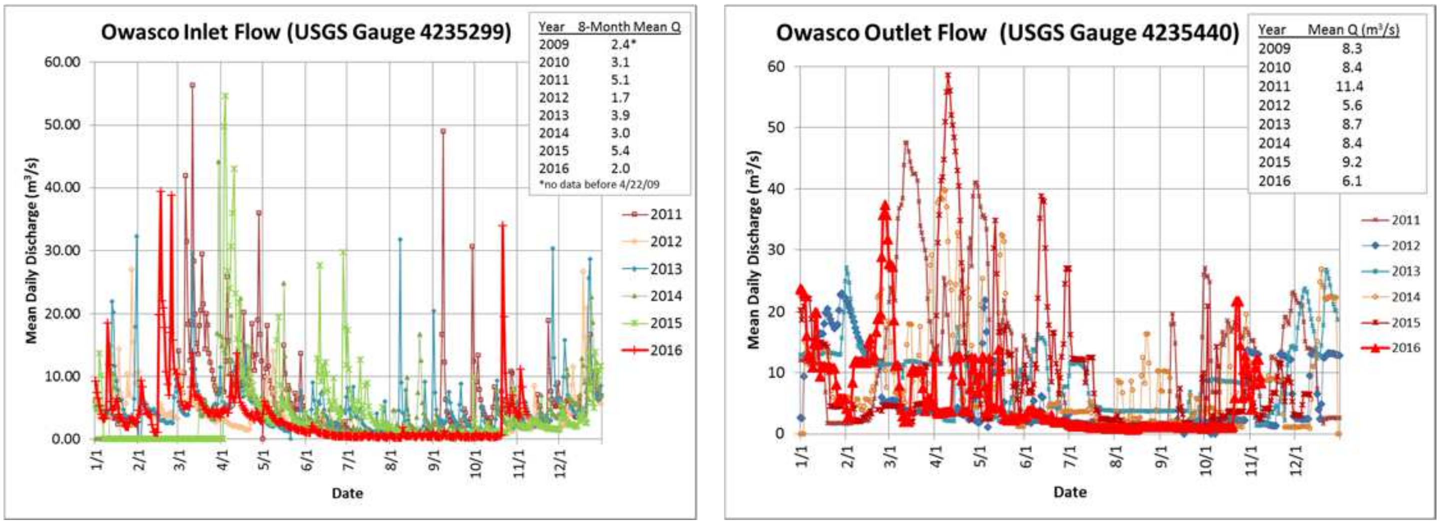
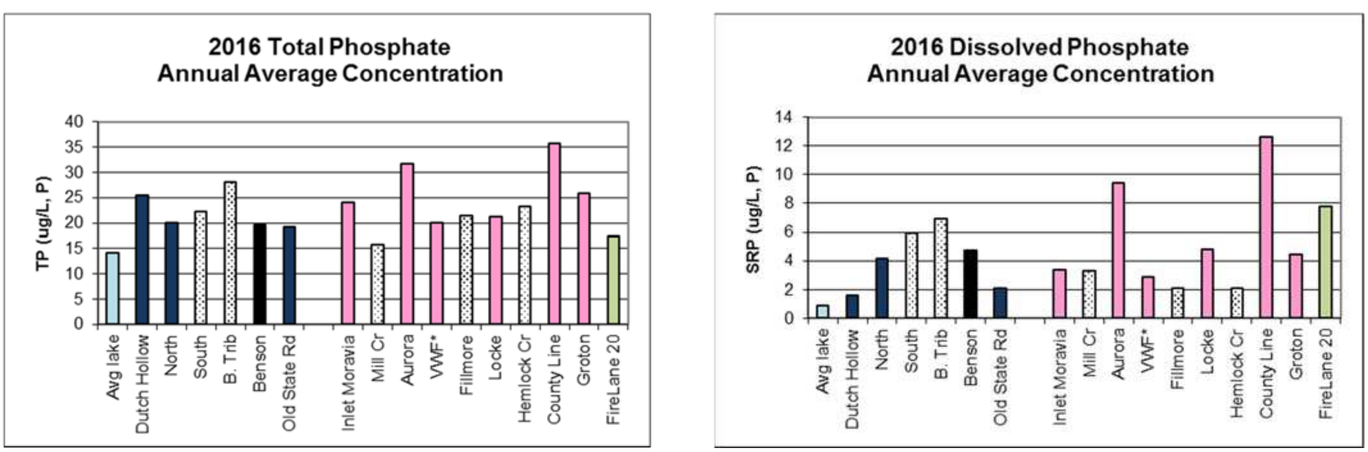
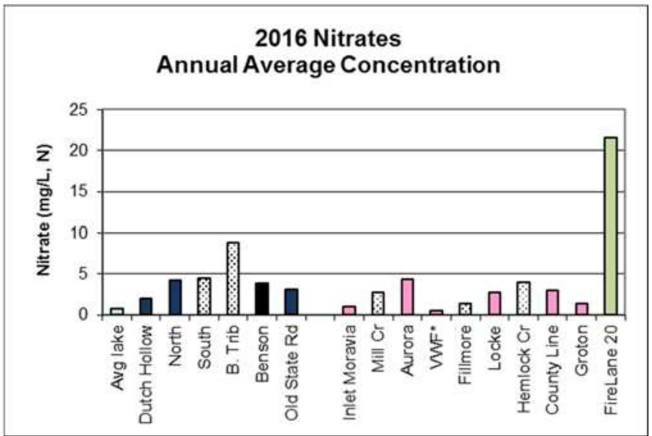
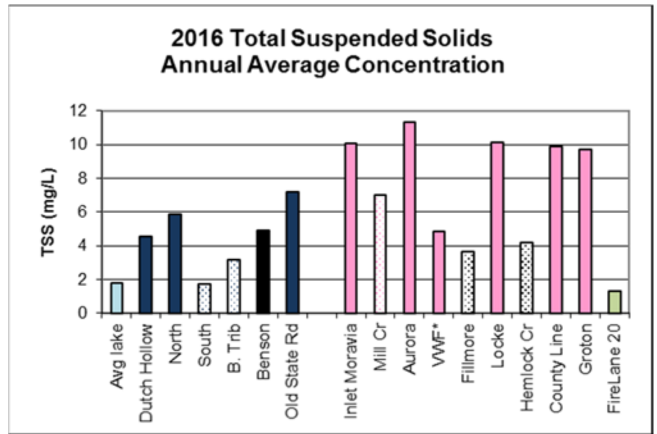


Fig. 23. Annual average stream discharge for the Owasco Inlet near Moravia – USGS Stream Gauge 4235299 and the Owasco Outlet – USGS Stream Gauge 4235440.

Stream Concentration Data: Total phosphate (TP) concentrations in 2016 ranged from 1.5 to nearly 59 μg/L, and averaged 22 μg/L in Dutch Hollow Brook; and it ranged from 0 (dry) to 68 μg/L, and averaged 24.6 μg/L in Owasco Inlet (Table 6 in appendix, Fig. 24). Along Dutch Hollow Brook, the 38A, South, and Benton Rd tributary sites revealed the largest annual mean TP concentrations of ~22 to 28 μg/L, whereas the North Rd, Benson Rd and Old State Rd sites revealed slightly smaller mean TP concentrations (just under 20 μg/L). Of note, the Benson tributary did not have significantly larger TP concentrations as detected in earlier years. Thus, it suggests that recent remediation efforts within the Benson Tributary watershed, i.e., at Young's Farm, and on other agriculturally-rich sub-basins in this watershed decreased nutrient loading from the watershed.







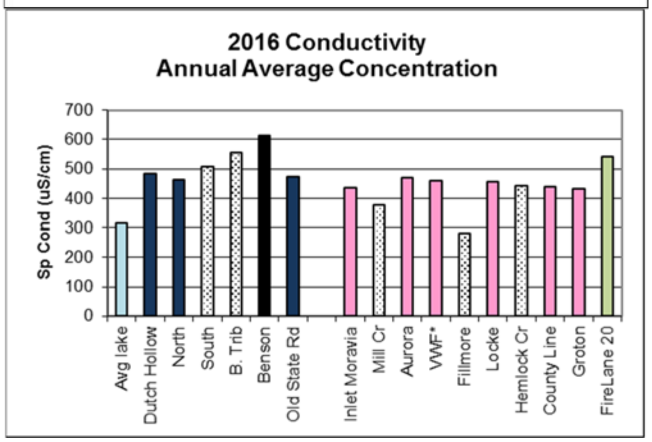


Fig. 24. Site averaged lake (light blue) and stream nutrient and suspended sediment concentrations for Dutch Hollow Brook (blue), Owasco Inlet (pink), and Fire Lane 20 (green). Tributary sites are stippled. Sites are arranged from downstream (left) to upstream (right).

Total suspended sediment (TSS) concentrations were largest at the 38A, North, Benson Rd and Old State Rd sites (4.5 to 7.2 mg/L). The agriculturally-rich tributaries, South and Benson Rd tributaries, were lowest (1.7 & 3.2 mg/L). A notable increase in TSS from North Rd to Rt 38A, was not observed in 2016 as in previous years. It suggests that recent agricultural BMPs are decreasing suspended sediment in the runoff and/or lower rainfalls in 2016 decreased the erosion of soils from these watersheds compared to previous years. Alternatively, the high flows of 2014 and 2015 washed out all of the easily erodible materials from the agriculturally-rich watershed.

Dissolved phosphate (SRP), nitrate and specific conductance (salinity) concentrations were larger at the South and Benson tributary sites compared to the other sites but the difference was much less in 2016 and the concentrations were smaller in 2016 than earlier years.

Along the Owasco Inlet, nutrient and sediment concentrations were similar to those at Dutch Hollow Brook. Mean annual TP and SRP concentrations increased slightly from Groton to County Line, and from Locke to Aurora, as in past years. The increase between these sites was not as dramatic as in past years, especially the notable increase in phosphorus between Groton and County Line before 2007 attributed to the Groton WWTF effluent. The TP and SRP concentrations were typically smaller at Mill, Fillmore, and Hemlock Creeks than the neighboring main stream sites but these differences were small. Mean annual total TSS concentrations did not reveal consistent patterns, except that Fillmore Creek had the smallest concentrations.

Fire Lane 20 was routinely sampled every year since 2012. It revealed the largest salinities and nitrate concentrations but similar TSS, TP and SRP concentrations as the other sites. It appears that the agricultural impact on this watershed has decreased in 2016 compared to earlier years and/or the easily eroded materials were already flushed during the 2014 and 2015 high flows.

Stream Fluxes: Owasco Inlet revealed larger fluxes of nutrients and sediments than Dutch Hollow Brook (TP 8.1 vs. 1.4 kg/day; SRP 1.1 vs. 0.1 kg/day; TSS 3,400 vs. 254 kg/day; N 1,160 vs. 110 kg/day, respectively, Fig. 25). Similar concentrations of nutrients and sediments between these two streams, but significantly larger discharges down the larger Owasco Inlet resulted in its larger fluxes to the lake. As before, fluxes in the Owasco Lake watershed were sensitive to discharge and basin size. The fluxes measured in 2016 were smaller than those in previous years, highlighting the 2016 "dry" year (Fig. 26).

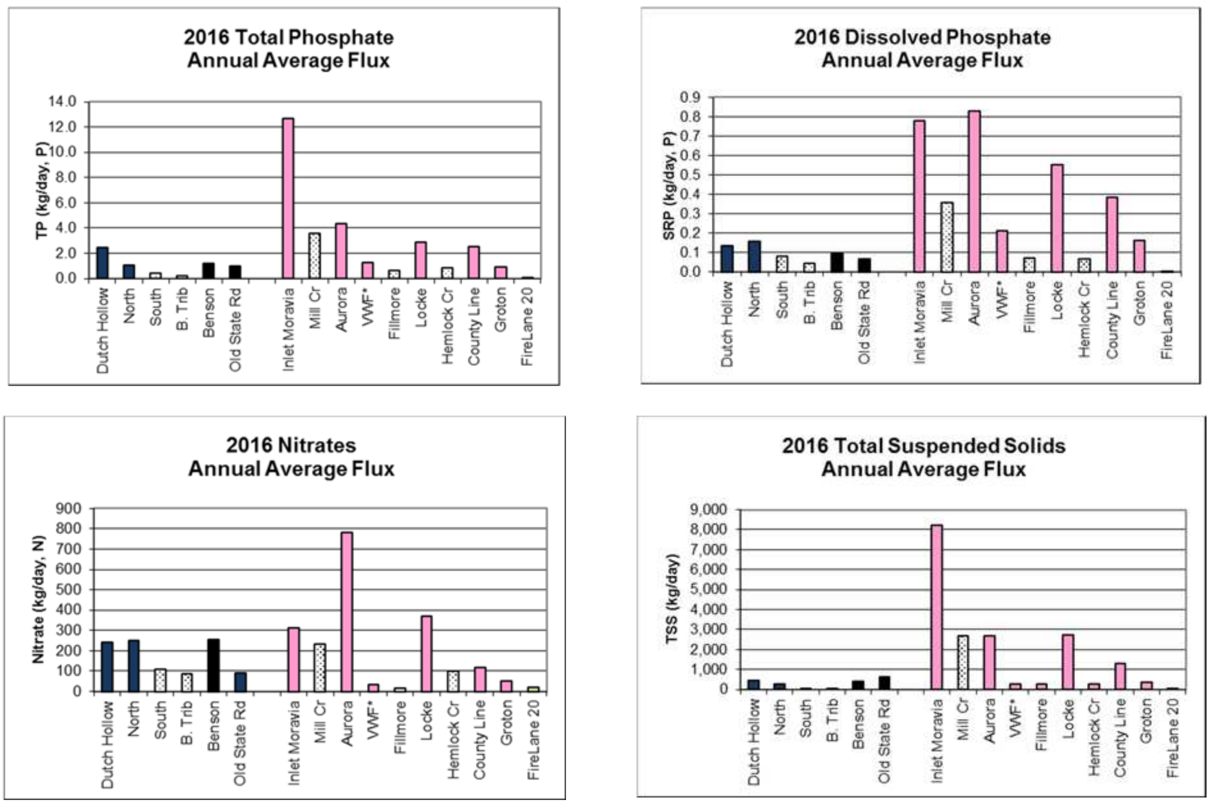


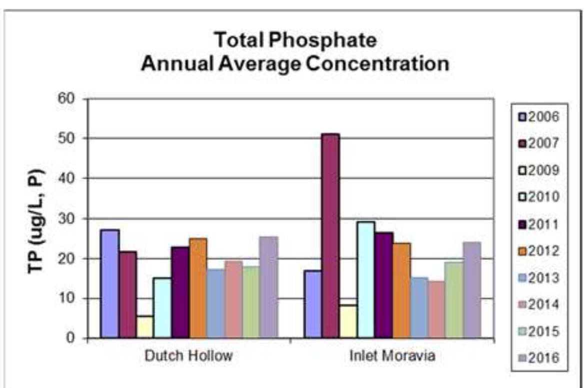
Fig. 25. Site averaged nutrient and sediment fluxes for Dutch Hollow (blue), Owasco Inlet (orange), and Fire Lane 20 (green). Tributary sites are stippled. Sites are arranged from downstream to upstream. Samples were not collected from the VFW site during the two largest "event" dates during 2016, which influenced the mean concentration and discharge and thus flux at this site

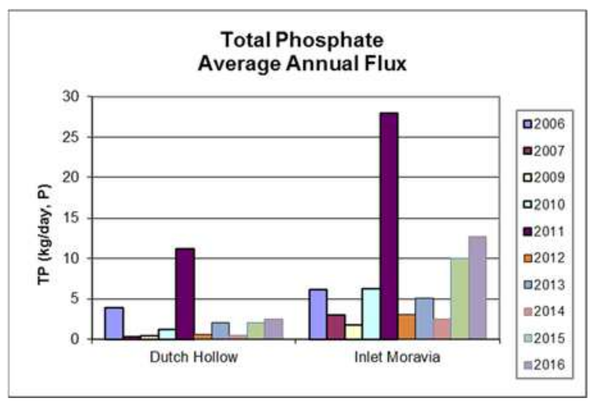
At the small end of the spectrum, fluxes at the Dutch Hollow Brook tributary sites (Benson and South sites) and Fire Lane 20 were smaller than the other sites in the survey. The small fluxes paralleled the smallest discharges at these sites. It follows that smaller watersheds with smaller discharges delivered the smallest fluxes, and larger watersheds with larger discharges delivered the largest fluxes. However, many small, 1st or 2nd order, tributaries (~40 in Fig. 1) like Fire Lane 20 drain into Owasco Lake. The combined TP load by all these small tributaries is comparable to the load from Dutch Hollow Brook.

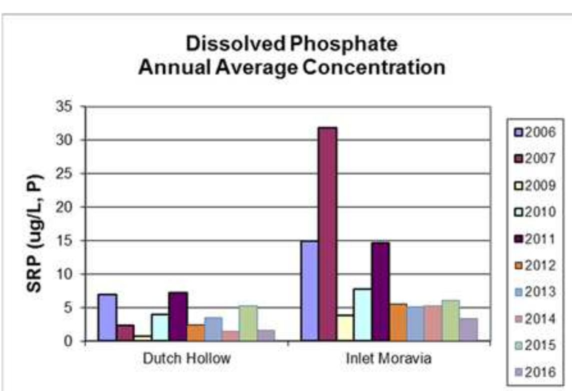
Nutrient fluxes increased slightly from the headwaters of Dutch Hollow Brook to the North Rd site, and SRP and nitrate decreased downstream of North Rd to the 38A site. The losses downstream of North Rd can be attributed to the parallel change in concentrations combined with smaller discharges measured at 38A. Perhaps some of dissolved nutrients were removed by instream vegetation and stream algae during this low flow year.

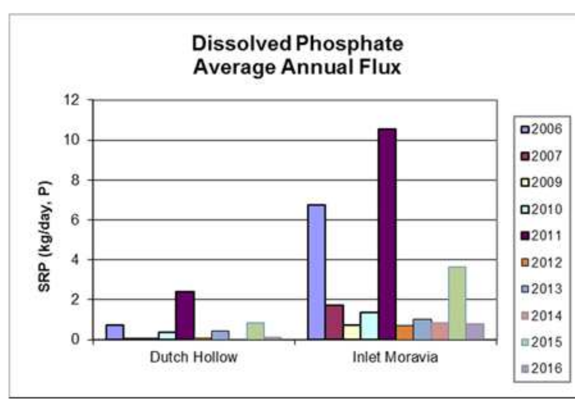
As in previous years, no one tributary added a significantly larger flux of nutrients. Thus, no one segment of this stream was the "primary" source of nutrients and sediments. Instead, Dutch Hollow Brook steadily gained nutrients along its entire course up to North Rd, a conclusion consistent with the pervasive nature of nonpoint sources throughout the watershed, and the drainage of agricultural land, animal feedlot operations, golf courses, suburban homes and other nonpoint sources. The implications are critical. To remediate Dutch Hollow Brook's nutrient loading is more challenging than "fixing" a point source like Groton's wastewater treatment facility because remediation must be applied throughout the entire watershed, influencing and demanding cooperation by every land owner in the watershed.

The Owasco Inlet fluxes increased downstream in a predictable manner and revealed similar patterns as earlier years (Fig. 25). The input by adjacent tributaries typically account for the increases in flux from one site to the next. The notable exception was a decrease in SRP and nitrates from Aurora to Rt 38. Both point and nonpoint sources of nutrients were detected but were less noticeable in the Owasco Inlet watershed in 2016 compared to previous years. Increases in stream phosphate from Groton to County Line were still apparent and reflected inputs from the Groton wastewater treatment facility. However, the facility's contribution to the total load was significantly smaller than earlier years. The small values at VFW are likely an artifact of not collecting samples from this sirte during the 4/13 & 10/24 sample dates. Larger annual fluxes detected at Locke support this conclusion.









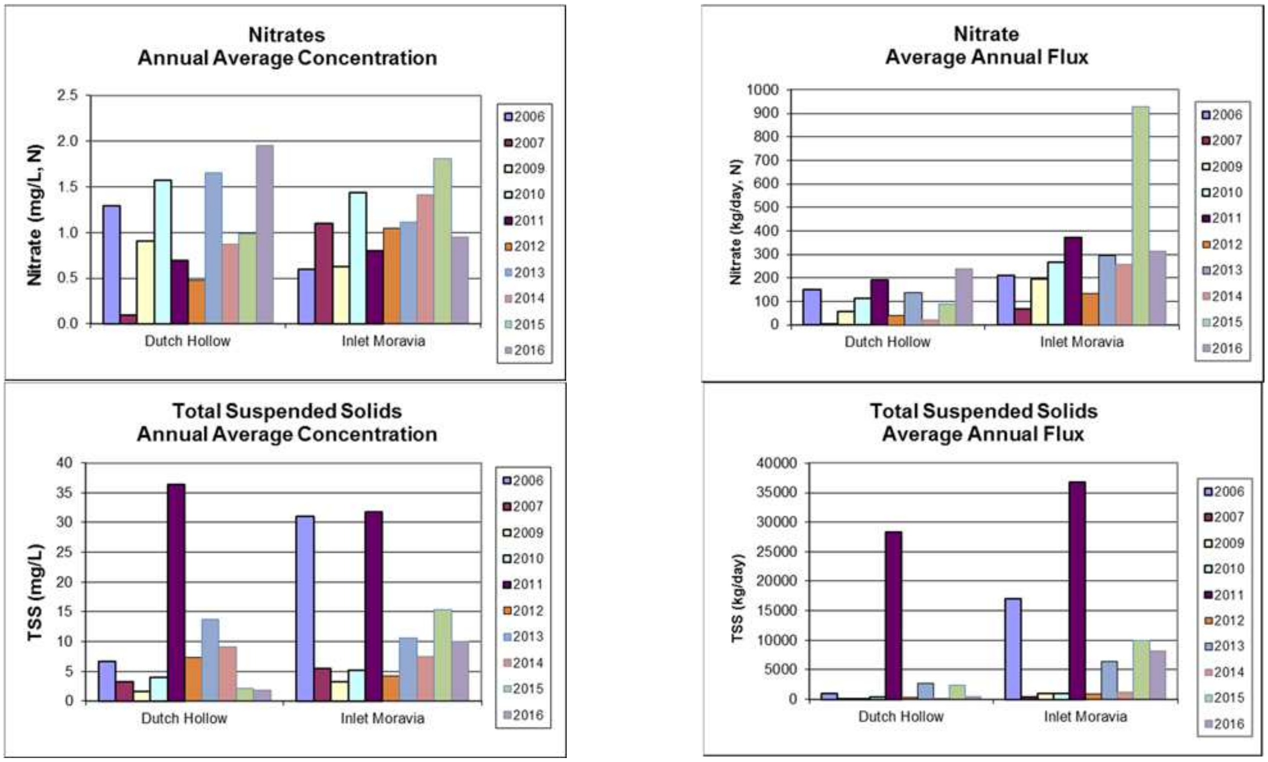
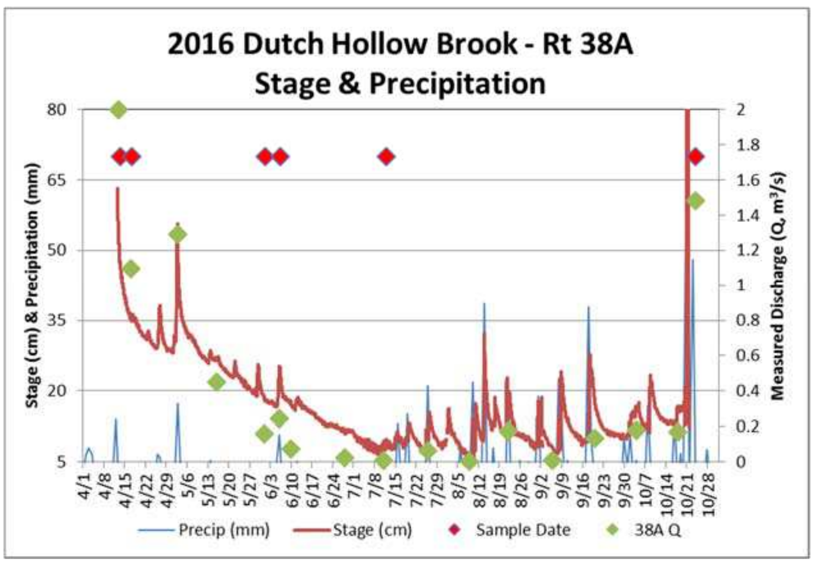


Fig. 26. Annual average stream grab sample concentrations (left) and fluxes (right).

EVENT SAMPLING ALONG DUTCH HOLLOW BROOK

Detailed Stage Data @ 38A along Dutch Hollow Brook: Data logger data was recovered from both loggers at the 38A and North Rd sites, and rating curves using the mean stage data were independently established for each site.

The 2016 38A and North Rd stage data revealed textbook responses to precipitation events (Fig. 27). Each increase in stage corresponded to a precipitation event, and the change in stream height ranged from 5 to more than 100 cm above base flow levels. Not all precipitation events induced a proportional stream response, especially during the spring when increases in stage were larger for similar sized precipitation events than the other seasons. The differences are interpreted to reflect seasonal changes in, for example, ground saturation, rainfall intensity, runoff/infiltration ratios and evapotranspiration. Similar seasonal and day to day, precipitation/event influenced changes in stage, conductivity and temperature were detected during the past four years as well although far fewer significant events were detected in 2016 than previous years (Figs. 27 & 28).



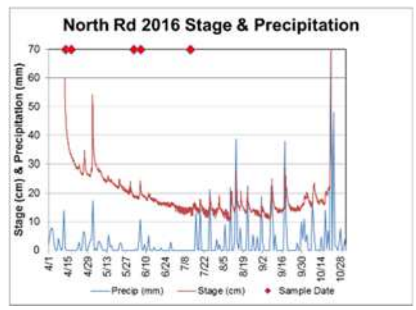


Fig. 27. Dutch Hollow Brook estimated discharge, precipitation, stream sample dates and measured discharge data: 2016 Rt 38A data (left); North Rd 2015 data, (right). Precipitation data was from NY-CY-8, a station within the DH watershed, part of CoCoRaHS collaboration.

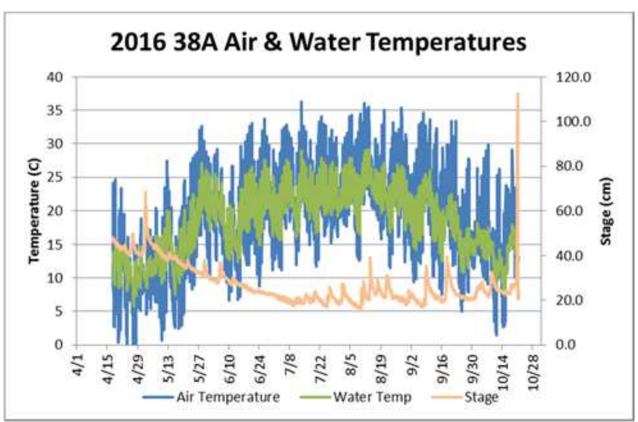


Fig. 28a. Data logger stage and water & air temperature data at 38A. The seasonal cold to warm to cold cycle prevails.

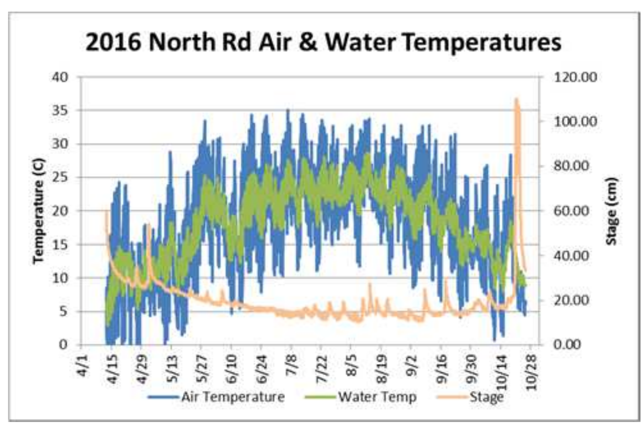


Fig. 28b. Data logger stage and water & air temperature data at North Rd. The seasonal cold to warm to cold cycle prevails.

Detailed "Event vs Base Flow" Results @ 38A: Despite being a "dry" year with noticeably fewer precipitation events, nutrients and sediments responded to the occasional event throughout the 2016 deployment (Fig. 29). Total suspended sediments (TSS) increased dramatically from an average base flow concentration of ~20 mg/L to an average event flow concentration of 370 mg/L, and rose to a maximum of 1,460 mg/L on 10/21. These large TSS concentrations were restricted to the runoff portion of the storm event, and declined quickly to base flow turbidities before the stream stage returned to base flow. It indicates that runoff events compared to base flow transported significantly more soil particles to and had a greater impact on water quality in the stream. The base flow concentrations were larger than previous years, and probably resulted from algae and rooted vegetation growing in the numerous pools of water. The peak TSS concentrations were significantly smaller than previous years, as well. The difference parallels the difference in rainfall between years.

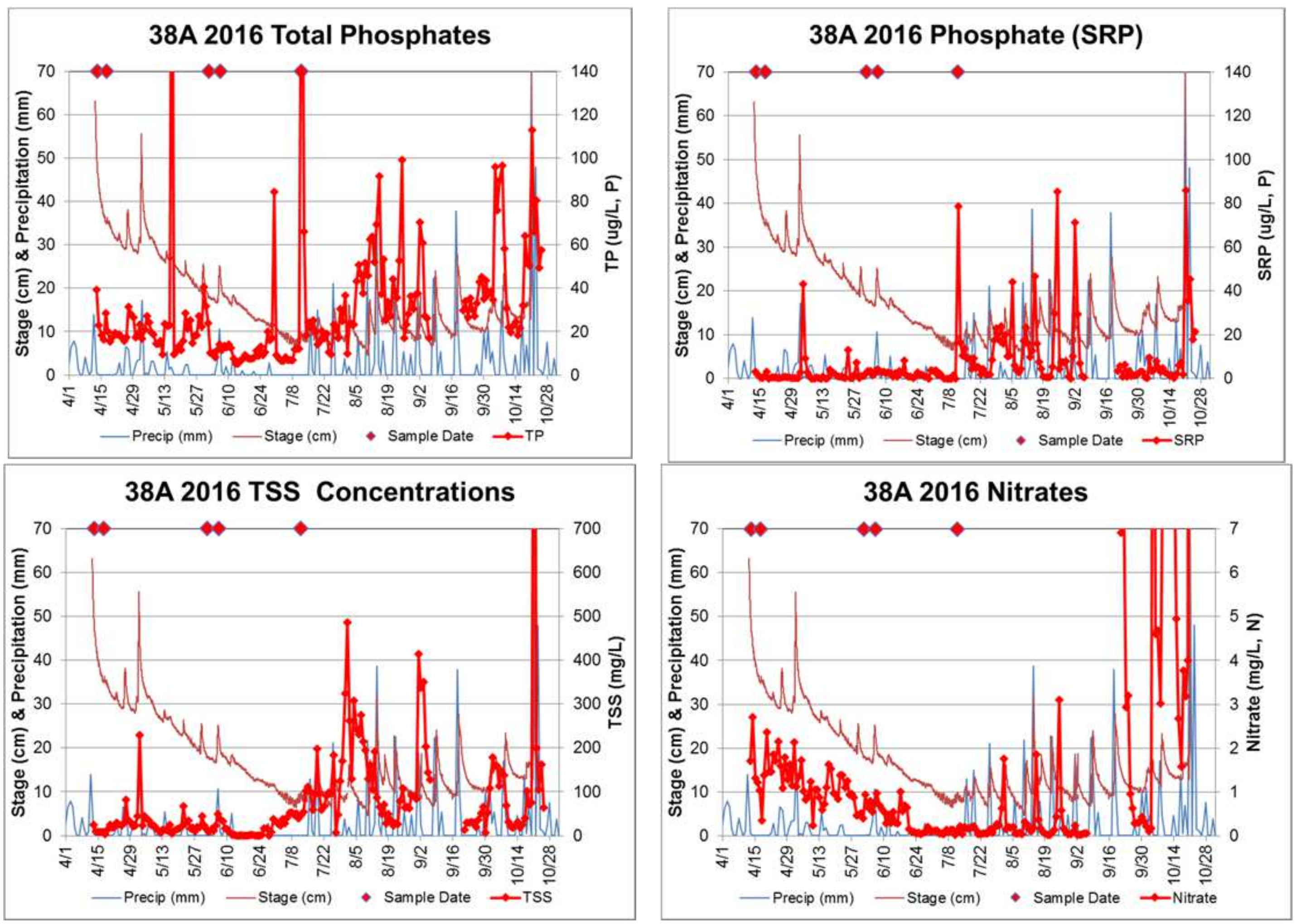


Fig. 29. Rt 38A nutrient and suspended sediment concentrations.

As mentioned in previous reports, the event *versus* base flow results suggests a number of potential remediation practices to reduce TSS impairments. For example, roadside ditches should be hydro-seeded and/or utilize other flow reducing structures to decrease water velocities and the erosion potential of the draining water. In agricultural areas, buffer strips of vegetation alongside each stream course, where the vegetation reduces the velocity of the runoff and allows particles to settle out before entering the stream. Installation of gully plugs and retention ponds in low lying areas provide another mechanism to retard the movement of suspended sediments before the runoff spills into the nearby stream. Alternatively, farmers could plant a winter crop cover, that reduces topsoil erosion from their fields during the late fall, winter and early spring seasons. This is most critical in the early spring when the soils are thawed and still saturated, conditions ripe for the largest erosion rates. These practices however remove tillable acreage from the farmer and/or require additional time on the fields to, e.g., plant winter cover crops, and thus reduce her/his annual income.

Total (TP) and dissolved (SRP) phosphates revealed event responses as well. Mean TP and SRP event concentrations were significantly larger than base flow concentrations, increasing from base flow means of 20.0 and 2.5 μg/L to event means of 49.8 and 22.6 μg/L, respectively. Maximum event concentrations were 270 μg/L for TP and 86 μg/L for SRP. Again, 2016 event concentrations suggest a direct linkage to and the importance of precipitation induced runoff events for phosphorus loading to the lake, even during this "dry" year. Thus, the remediation steps to reduce phosphate loading are similar to remediating suspended sediment, i.e., reduce the movement of soil particles from runoff events in the Owasco watershed.

Nitrates, once again, revealed a slightly different response to events than TSS, TP and SRP. The largest nitrate concentrations still correlated with events with mean event concentrations of 20.4 and base flow concentrations of 1.6 mg/L, however this difference was much smaller than those observed in the TSS, TP and SRP data. The increase to the peak concentration and subsequent decline to base flow conditions took slightly longer for nitrates as well. It indicates that runoff provided extra nitrates to the stream. However, the precipitation rejuvenated near-surface groundwater flow contributed a portion of the nitrate load as well, extending the nitrate response to the event as runoff flows faster than groundwater flow. Nitrates have a different event/base flow response than TSS, TP and SRP because nitrates are water soluble and not bound to particles, thus they can enter a stream by both runoff and groundwater routes. In contrast, phosphates are typically particle bound, thus groundwater does not transport TP, SRP and TSS. Please note, the nitrate base flow to event response was more subdued in 2016 than earlier years, suggesting a smaller impact from and/or depleted groundwater source due to the dry conditions.

Event vs. Base Flow Fluxes @ 38A: To calculate fluxes for the daily samples, a discharge must be determined for each sample. A best-fit, 2nd order, polynomial relationship between the bi-monthly discharge measurements at 38A ($r^2 = 0.99$) and North Rd sites ($r^2 = 0.95$) established a stage/discharge rating curve for both sites (Fig. 30). Even though previous years employed a linear relationship, a 2nd-order, polynomial fit provided a better match to 2016's low-flow data.

The fluxes of TSS, TP, SRP and nitrates were clearly event driven (Table 7, Fig. 31). In 2016, TSS, TP and SRP event *vs.* base flow fluxes at 38A averaged 25,844 *vs.* 137, 4.7 *vs.* 0.1, and 2.3 *vs.* 0.0 kg/day, respectively. During the entire 2016 deployment, Dutch Hollow provided 1,343,000 kg of sediment to the lake during events, and only 17,800 kg during base flow conditions. In a similar light, the 2016 events delivered 243 kg of TP and 118 kg of SRP to the lake compared to base flow contributions of 18 kg of TP and 2 kg of SRP. In conclusion, each year revealed significantly larger event than base flow loads for TSS, TP and SRP, and to a lesser degree nitrates along Dutch Hollow Brook (Table 7).

Annual changes were also observed. The 2016 event and base flow fluxes for TSS and TP were much smaller in 2016 than previous years, reflecting the reduced rainfall in 2016 (Fig. 32). This trend is even more striking when rainfall totals focus on April, May and June; a time frame when soils are saturated and thus directing more rain into runoff than infiltration, but thawed enough to enable soil erosion. Plant life is also absent or just rebounding from winter dormancy at this time, and thus are not available to retard runoff velocities and volumes from increase evapotranspiration. Farm fields are typically tilled bare of vegetation in preparation for planting increasing their potential for erosion at this time as well (Fig. 33).

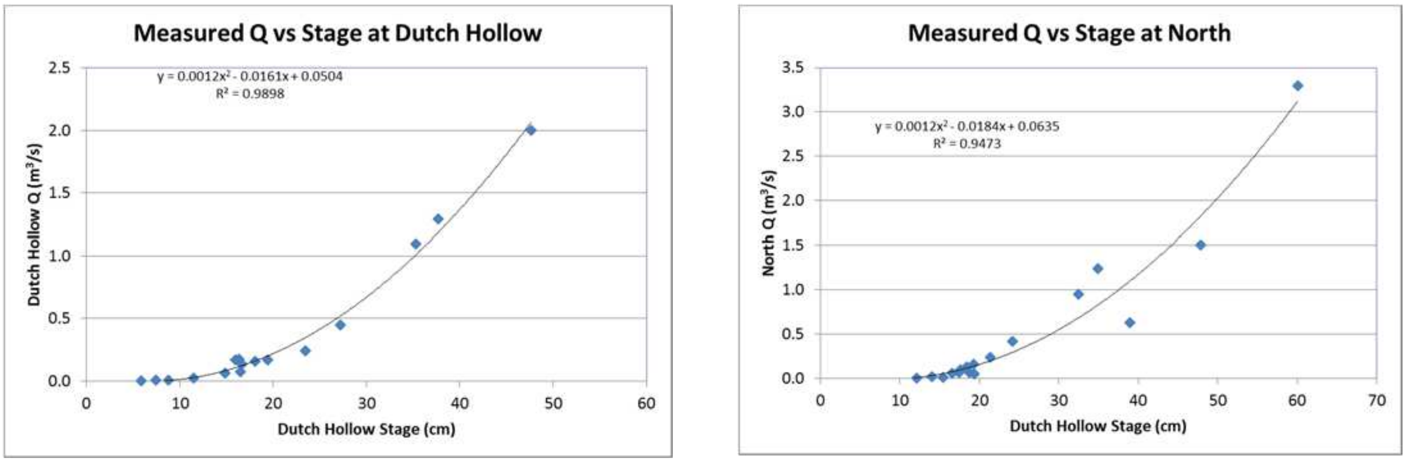


Fig. 30. Best fit correlations between bi-monthly measured discharge and data logger stage data at both 38A and North Rd sites.

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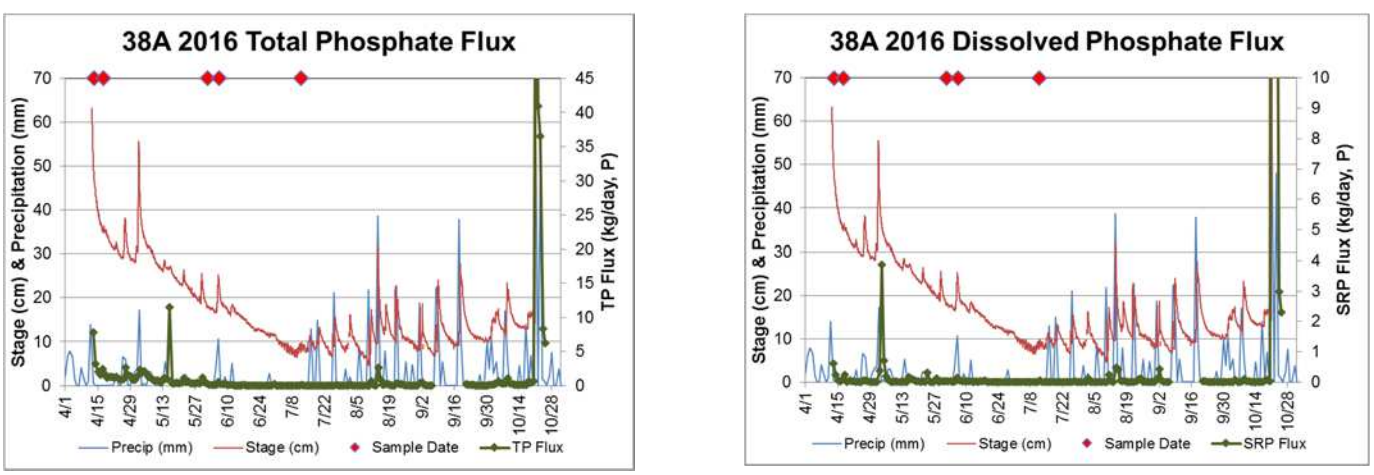
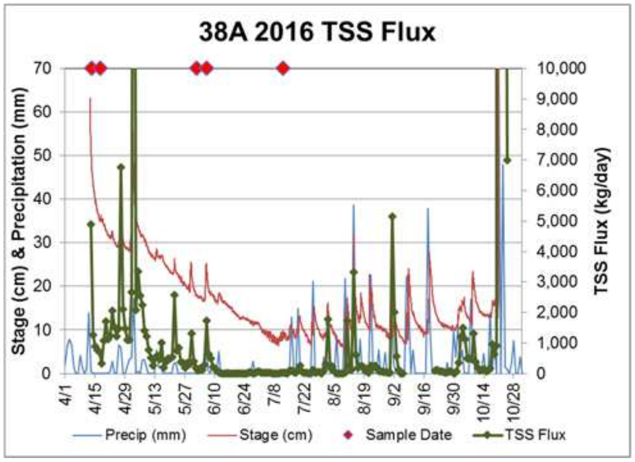
The event *versus* base flow data also indicate that grab samples underestimated annual fluxes down a stream. For example, the 2016 autosampler estimated a sediment mean flux of 8,850 kg/day, total phosphates 1.4 kg/day, dissolved phosphates 0.7 kg/day, and nitrates 1,300 kg/day; whereas the grab sampling estimated an annual mean flux of 470 kg/day for sediments, 2.5 kg/day for total phosphates, 0.1 kg/day for dissolved phosphates, and 240 kg/day for nitrates. The grab samples typically estimated smaller fluxes because these samples were usually biased to base flows. In 2016, however a larger percentage of the grab samples were collected during events causing the TP discrepancy. Regardless, grab samples could be used but are less reliable for detailed flux estimates compared to the daily data collected by the autosampler and data loggers. Instead grab samples are essential and reliable tools for stream segment analysis and the investigation of nutrient and sediment sources.





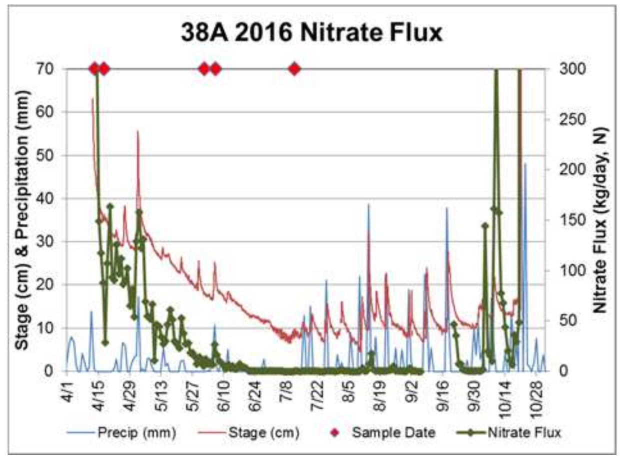


Fig. 31. Autosampler nutrient and suspended sediment fluxes.

Table 7: 2011 – 2015 Autosampler Fluxes at Dutch Hollow Brook.

2011 (6/9-11/4)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	8,700	75	2.7	1.7
Event (kg/day)	24,500	180	6.9	4.5
Base Flow (kg/day)	115	19	0.4	0.1
% by events	99%	84%	90%	96%
2012 (3/20-11/2)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	2,400	69	1.9	0.4
Event (kg/day)	6,850	150	4.0	0.6
Base Flow (kg/day)	190	28	0.9	0.2
% by events	95%	73%	70%	60%
2013 (4/10-10/29)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	7,550	270	4.4	1.3
Event (kg/day)	12,000	370	6.4	1.8
Base Flow (kg/day)	290	100	1.3	0.3
% by events	99%	85%	89%	91%
2014 (4/19-10/28)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	14,600	115	3.5	1.6
Event (kg/day)	36,000	185	6.5	3.2
Base Flow (kg/day)	300	67	1.5	0.5
% by events	99%	65%	74%	81%
2015 (4/19-10/28)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	35,600	180	3.7	2.3
Event (kg/day)	81,500	370	7.7	5.2
Base Flow (kg/day)	185	27	0.5	0.0
% by events	99%	93%	94%	99%
2016 (4/13-10/25)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	7,482	1,323	1.4	0.7
Event (kg/day)	25,844	4,602	4.7	2.3
Base Flow (kg/day)	137	11	0.1	0.0
% by events	99.5	99.8	97.1	99.2

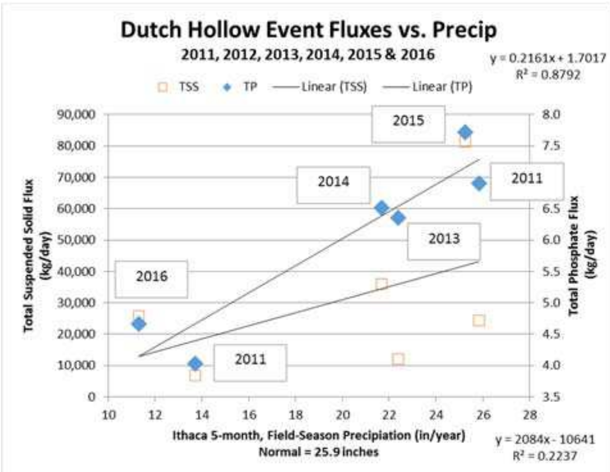


Fig. 32. Estimated annual total phosphorus loads vs field season (5-month) rainfall at the Ithaca Airport.

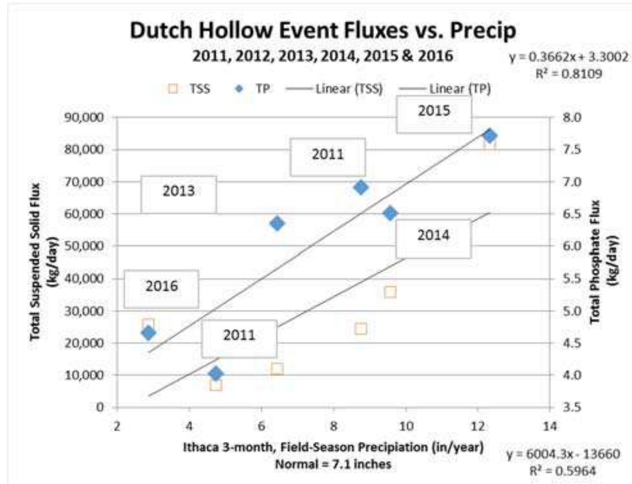


Fig. 33. Estimated annual total phosphorus loads vs May-June (3-month) spring-time rainfall at the Ithaca Airport.

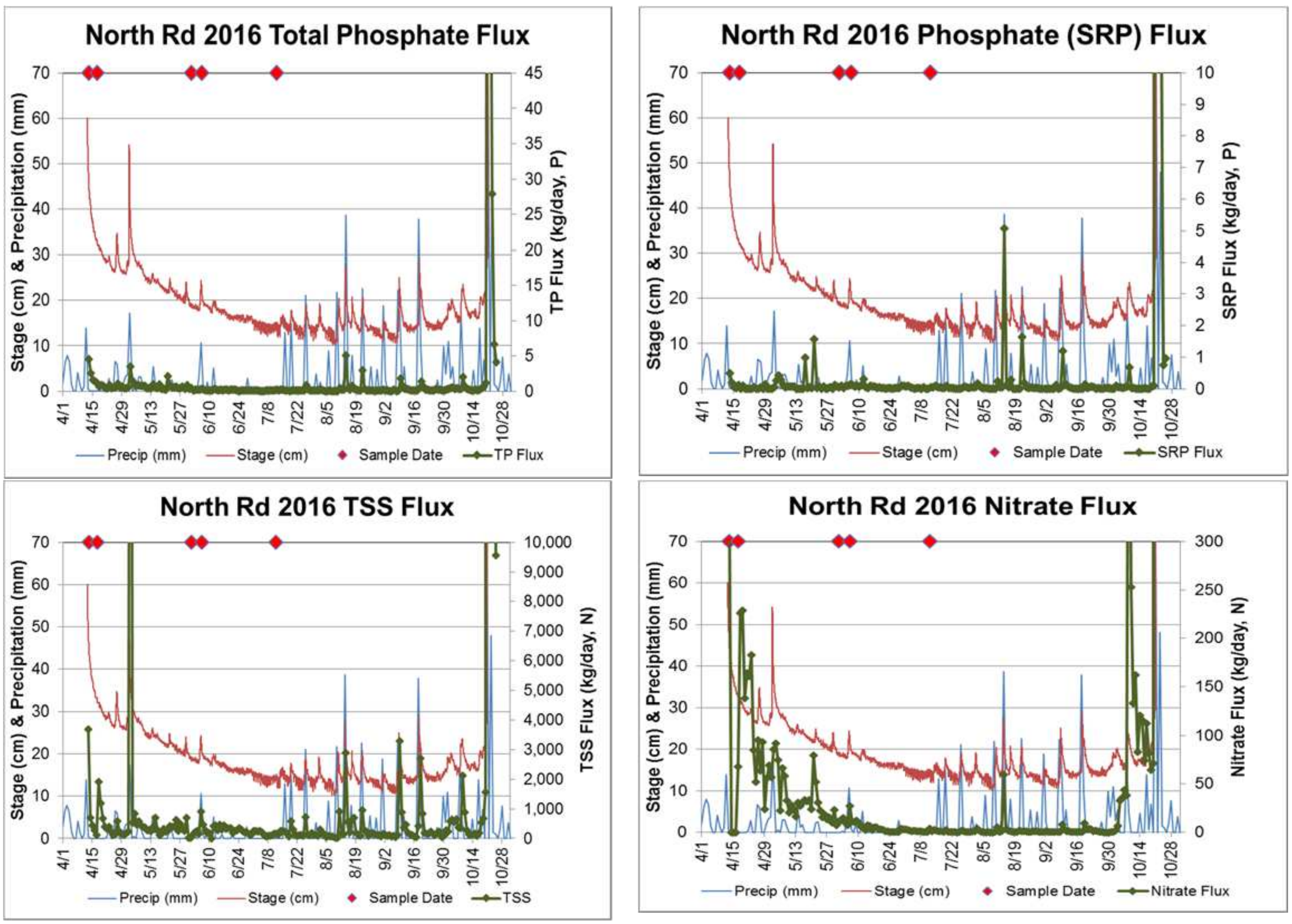


Fig. 34. North Rd nutrient and sediment fluxes.

DETAILED ANALYSIS @ NORTH RD:

A best fit, 2nd order, polynomial relationship was used to define the stage/discharge rating curve at North Rd. The detailed TSS, TP and SRP concentration data revealed event signatures at this site that paralleled those at 38A (Fig. 34, Table 8). This is not new. The fluxes, both event and base flow fluxes, were slightly but not significantly larger at the North Rd Site than downstream at Rt 38A. The primary difference was the amount of material delivered during the late October storm (10/21). In fact, without this event, event fluxes would not have exceeded base flow fluxes in 2016.

Table 8: 2014, 2015 & 2016 Daily Fluxes at 38A & North Rd.

38A (2014)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	10,500	83	2.3	0.7
Event (kg/day)	28,200	150	5.0	1.8
Base Flow (kg/day)	285	45	0.8	0.1
% by events	98%	66%	78%	88%
North Rd (2014)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	10,900	67	2.1	0.6
Event (kg/day)	22,000	100	3.5	1.1
Base Flow (kg/day)	270	35	0.8	0.2
% by events	99%	74%	81%	88%
38A (2015)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	35,600	180	3.7	2.3
Event (kg/day)	81,500	370	7.7	5.2
Base Flow (kg/day)	185	27	0.5	0.0
% by events	99%	93%	94%	99%
North Rd (2015)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	25,000	155	3.2	2.0
Event (kg/day)	64,000	310	7.4	4.5
Base Flow (kg/day)	168	38	0.5	0.1
% by events	99.7%	89%	94%	99%
38A (2016)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	7,482	1,323	1.4	0.7
Event (kg/day)	25,844	4,602	4.7	2.3
Base Flow (kg/day)	137	11	0.1	0.0
% by events	99.5	99.8	97.1	99.2
North Rd (2016)	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	8,847	1,610	1.8	1.3
Event (kg/day)	53,044	9,764	9.7	7.9
Base Flow (kg/day)	224	19	0.3	0.1
% by events	99.6	99.8	97.2	99.3

PHOSPHORUS BUDGET:

Phosphorus load reductions are critical to the health and water quality of Owasco Lake because phosphorus limits algal growth and thus impairs water quality and clarity. The development of blue-green algae blooms, some with life threatening concentrations of toxins, also highlight its importance. Clearly, stream loads dominate the inputs, even in “dry” years. However, the stream inputs are only one part of the equation. A complete budget must also include other inputs like atmospheric loading, onsite septic systems and lakeshore lawns. Outputs must also be calculated to estimate the net change in phosphorus for the lake (Fig. 35). The net change is paramount because the amount of phosphorus will increase in the lake, if inputs exceed outputs. Phosphorus will decrease in the lake, if inputs are less than outputs. Alternatively, phosphorus remains the same, i.e., at equilibrium, when inputs to equal outputs. To improve water quality, inputs of phosphorus must be smaller than outputs for a number of years (multiple water retention times). A sustained reduction allows existing phosphorus to leave by the outlet or be buried in the sediments, and eventually limit algal growth and improve water quality and clarity. The required "cleansing" time frame in the Owasco watershed is a decade or more.

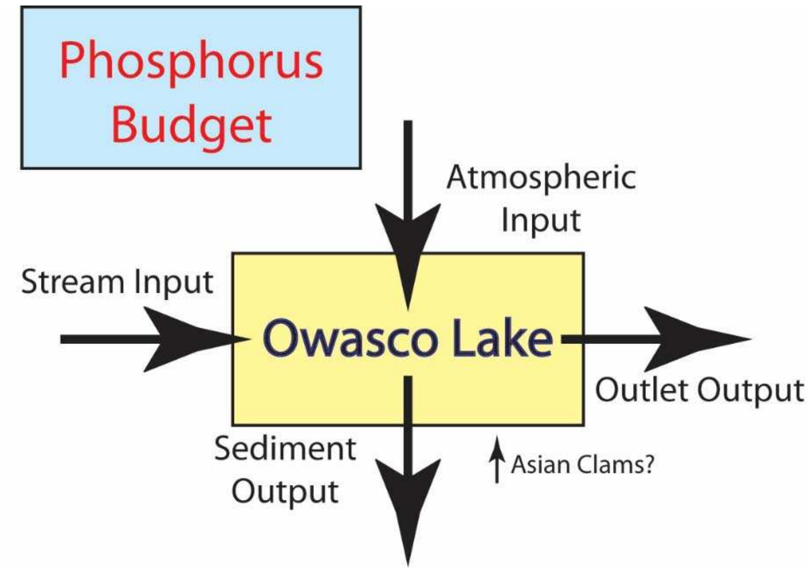


Fig. 35. The Owasco Lake phosphorus budget: Sources and sinks for phosphorus in Owasco Lake. Water quality improves if **inputs are less than outputs**, for a number of years.

The Inputs: The 38A autosampler estimated a mean total phosphate flux of 1.4 kg/day from Dutch Hollow Brook in 2016. Owasco Inlet delivered 12.7 kg/day based on the available 2016 stream grab data. The 2016 load from Owasco Inlet was estimated at 7.1 kg/day assuming a proportional change between the mean grab sample total phosphorus loads to the detailed autosampler loads from Dutch Hollow Brook. An extrapolation of fluxes and surface areas from Dutch Hollow Brook, Mill Creek, Hemlock Creek and Owasco Inlet to the entire Owasco watershed, estimated an input of 4.4 metric tons of phosphorus to the lake in 2016. This extrapolation incorporates all the 1^{st} and 2^{nd} order (small) tributaries like Fire Lane 20. The 2011 report estimated atmospheric and septic system inputs at 0.1 metric tons/year and ~1 metric tons/year. These estimates are again used below.

The total 2016 influx of phosphorus was estimated at 5.5 metric tons/year.

The Outputs: Phosphorus is lost from the lake through the Outlet in the form of algae, dissolved organic-rich compounds, organic-rich particulates, and the occasional larger organism (e.g., fish). Approximately 1.9 metric tons of phosphorus escaped out the Outlet in 2016 assuming a 2016 annual mean total phosphate concentration in the lake of 10.1 μg/L, and a 2016 mean daily discharge of 6.1 m^3/s through the Owasco Outlet (USGS Owasco Outlet Gauge #04235440). The 2011 report estimated the flux of phosphorus to the sediments of a few metric tons per year and this estimate is again used here. The earlier report cautioned that more work was required to firm up this sediment burial estimate, because the flux was based on only a few sediment cores.

The total 2016 efflux of phosphorus was estimated at 4.7 metric tons/year.

The Net Flux: Owasco Lake thus gained approximately 0.8 metric tons of phosphorus in 2016. Since 2009, the lake gained phosphorus during five years, lost phosphorus during two years, and was close to equilibrium in one year (Fig. 36). Since 2009, the mean annual input was 6.6 mtons/year, slightly more than the mean output of 5.9 mtons/year. The 2009 and 2010 annual nutrient fluxes were based on limited summer grab samples. Thus, their inputs should probably be much larger, and would then place these two years in a positive balance as well. The pervasive positive balance indicates that significant remediation efforts must take place to move Owasco Lake to a negative balance and eventually improve water quality.

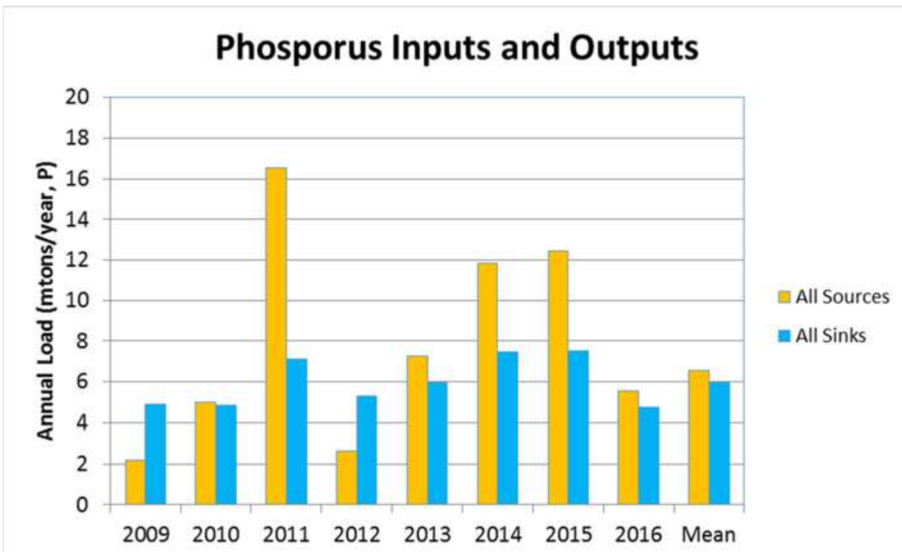


Fig. 36. Estimated annual total phosphorus inputs and outputs for Owasco Lake.

Finally, the large nutrient inputs in 2011, 2014 and 2015 were coincident with and probably "triggered" the recent BGA blooms. Even though coincidence does not prove causation, these three years of excessive loads were unique within this time frame. Assuming these large loads were the trigger, then the time is paramount to start large-sale nutrient loading reduction programs in the watershed. Otherwise the lake will continue to degrade and experience more BGA blooms into the future. The other Finger Lakes also revealed a deterioration in water quality parameters during the 2014 and 2015 "wet" years, and in some lakes coincided with the onset of BGA blooms[9].

[9] Halfman, J.D., 2017. Water quality of the eight eastern Finger Lakes, New York: 2005 – 2016. Finger Lakes Institute, Hobart and William Smith Colleges. 51 pg.

CONCLUSIONS & RECOMMENDATIONS:
This report confirms and expands on earlier findings.

- Owasco Lake is a borderline oligotrophic – mesotrophic lake. The improvements in water quality from 2011 through 2013 were lost in 2014 and 2015 but regained in 2016.
- Phosphorus is still the limiting nutrient for algae growth.
- The water quality degradation in 2014 and 2015 is attributed to the heavy rains in those years. The rebound in 2016 is attributed to the diminished rainfall in 2016.
- The water quality buoy provided a more robust view of water quality in the lake by detecting algal blooms and other events missed by the monthly lake surveys over the past three years.
- Blue-green algae concentrations were small at the open-water sites, much smaller than almost all of the nearshore blooms.
- Nearshore blue-green algae blooms were detected after the summer solstice when the lake was warm, calm or nearly calm, typically on a sunny day after an influx of nutrients from a recent runoff event and/or the seasonal decay of the epilimnion. No blooms were detected after water temperatures cooled below 15°C, mean daily sunlight declined below 150 $\mu E/cm^2$, and a strong wind event (> 20 mph). Funds should be secured to deploy this buoy in future years to confirm these correlations.
- Unfortunately, no one parameter consistently triggered the onset of nearshore blooms. Nearshore BGA, water temperature and wind (speed and direction) sensor arrays would establish a more robust spatial and temporal inventory for BGA blooms to learn more about their ecology.
- The excessive nutrient loads during 2014 and 2015 were also coincident with and perhaps triggered the onset of the large blooms of blue-green algae in Owasco and many other Finger Lakes. It suggests that the excess nutrients triggered the new era of BGA blooms, although coincidence does not dictate causation. It does however highlight the need to quickly and decisively abate nutrient loading to the lake.
- Segment analysis highlighted the lack of significant point sources along either Dutch Hollow Brook or Owasco Inlet. It highlighted successful remediation efforts, like reducing loads from the Groton wastewater treatment facility. Fortunately, 2016 was also a "dry" year, so the total nutrient and sediment loads to the lake from nonpoint agricultural sources were smaller than previous years.
- The event *versus* base flow analysis at Dutch Hollow Brook highlight the dominance of events and associated runoff of nonpoint sources to the delivery of phosphates and sediments to the lake. It also provided more accurate load estimates than grab samples, especially in those years when surveys were limited to the summer months. Event and base flow loads in 2016 were below those determined for earlier years and correlated very well to field-season and May-June rainfall. It pinpoints potential remediation strategies to decrease the erosive powers of runoff.
- Similar event signatures were observed at North Rd and Rt 38A along Dutch Hollow Brook. Differences between sites in 2016 were small and less significant than previous years due to the 2016 dry year.
- The estimated phosphate budget for Owasco Lake indicated that the lake gained some phosphorus in 2016 but gained much less phosphorus in this "dry" year than all but one year since 2011. The exception is 2012, another "dry" year, when sources were smaller than sinks.
- Streams were the primary source of nutrients and sediments to the lake.

- More BMPs should be installed, where necessary, to reduce nutrient and sediment loading from agriculturally-rich watersheds, while at the same time monitoring downstream of these remediation projects to assess their effectiveness. The critical areas to install BMPs along stream banks and in the low lying and other water saturated areas in each field.
- The financial burden to install the BMPs cannot be placed solely on the farmer and other landowners. Water quality is a watershed-wide issue. Everyone benefits from a cleaner lake. Thus everyone must support the remediation efforts.
- Please use the funds awarded to Cayuga Soil and Water and the Owasco Lake Watershed Association for such remediation efforts wisely.

ACKNOWLEDGEMENTS

The 2016 research was supported by Cayuga County Legislature, and a promise of funding from the Owasco lake Watershed Association. We thank members of the Cayuga County Planning Department, Cayuga County Water Quality Management Agency, Owasco Lake Watershed Management Council, Cayuga County Health Department, Owasco Watershed Lake Association, the Cayuga County Soil and Water District, the Institute for the Application of Geospatial Data, the Finger Lakes – Lake Ontario Watershed Protection Alliance, and NYS Department of Environmental Conservation for their help. Numerous individuals helped with many aspects of this study including Senator Mike Nozzolio, Barbara Halfman, Peter Spacher, Steven Cuddeback, Bill Graney, Mike Didio, Gary Searing, Ed Wagner, Keith Batman, Eileen O-Connor, Bruce Natale, Steve Lynch, Anthony DeCaro, Katie Jakaub, Charlie Green, Jim Beckwith, Bob Brower, Ron Podolak, Judy Wright, Doug Kierst, Andrew Snell, Timothy Schneider, Michele Wunderlich, Marion Balyszak, Lisa Cleckner, Roxanne Razavi, Martha Bond, Scott Kishbaugh, Todd Walter and David Eckhardt. Hopefully, I didn't forget to acknowledge someone, and my apologies to those I omitted.

Table 2. 2016 Lake Data.

2016 Owasco Lake Site Averaged and Date Averaged Data							
Site Averaged Surface Water Data							
Site	**Secchi Depth**	**Suspended Solids**	**Total Phosphate**	**Dissolved Phosphate**	**Nitrate**	**Silica**	**Chlorophyll**
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
1	5.7	2.0	16.8	0.7	0.5	1014.7	3.0
2	5.5	1.6	11.4	1.1	0.8	1030.3	4.0
Average	**5.6**	**1.8**	**14.1**	**0.9**	**0.7**	**1022.5**	**3.5**
Site Averaged Bottom Water Data							
Site	**Secchi Depth**	**Suspended Solids**	**Total Phosphate**	**Dissolved Phosphate**	**Nitrate**	**Silica**	**Chlorophyll**
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
1	---	1.0	10.6	0.6	1.0	1688.2	1.1
2	---	1.0	9.5	0.8	0.9	857.2	0.9
Average	**---**	**1.0**	**10.1**	**0.7**	**0.9**	**1272.7**	**1.0**
Date Averaged Surface Water Data							
Date	**Secchi Depth**	**Suspended Solids**	**Total Phosphate**	**Dissolved Phosphate**	**Nitrate**	**Silica**	**Chlorophyll**
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
5/24/16	7.7	0.6	12.9	1.5	0.8	756.7	0.9
6/14/16	6.3	1.1	12.3	0.3	0.7	1479.7	2.5
7/19/16	1.8	4.9	9.9	1.8	0.8	877.5	9.2
8/19/16	4.3	1.1	14.3	0.7	0.5	953.9	3.0
10/1/16	8.1	1.3	21.1	0.4	0.6	1044.7	2.1
Average	**5.6**	**1.8**	**14.1**	**0.9**	**0.7**	**1022.5**	**3.5**
Date Averaged Bottom Water Data							
Date	**Secchi Depth**	**Suspended Solids**	**Total Phosphate**	**Dissolved Phosphate**	**Nitrate**	**Silica**	**Chlorophyll**
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
5/24/16	--	0.6	13.9	0.6	0.6	857.2	0.7
6/14/16	--	0.8	10.2	1.0	0.9	1796.4	0.4
7/19/16	--	1.7	6.2	0.2	0.6	1883.2	1.3
8/19/16	--	0.9	8.4	1.2	0.8	1933.1	1.8
10/1/16	--	1.0	11.6	0.6	1.7	1971.0	0.6
Average	**---**	**1.0**	**10.1**	**0.7**	**0.9**	**1688.2**	**1.0**

Table 4. Annual Average Plankton Data from 2005 through 2016, and Daily Average Data for 2016.

Plankton Group	Diatoms							Dinoflagellates			Rotifers & Zooplankton						Blue Greens	
Plankton Species	Fragillaria %	Tabellaria %	Diatoma %	Asterionella %	Melosira %	Synedra %	Rhizoselenia %	Dinobryon %	Ceratium %	Coalcium %	Copepod %	Nauplius %	Keratella %	Polyarthra %	Vorticella %	Cladoceran %	Anabaena %	Mycrocystis %
2005 Average	34.9	1.4	0.0	9.9	0.2	5.6		14.6	4.5		0.9	1.1	2.5	3.2	10.3	2.8		0.3
2006 Average	24.3	1.7	0.0	7.1	1.4	0.7	2.6	41.5	0.7		0.2	0.1	2.4	0.8	0.3	0.6	0.1	3.8
2007 Average	30.0	0.5	0.0	23.3	0.2	2.1	3.8	12.9	0.7		0.4	0.4	0.6	0.4	3.8	2.8	0.4	7.7
2008 Average	52.3	0.1	0.0	14.6	0.2	0.1	1.2	18.7	0.6	0.2	0.4	0.5	0.3	0.9	4.3	0.6	0.4	1.5
2009 Average	9.7	7.1	0.0	12.3	0.2	1.0	7.8	26.6	0.7	2.0	0.7	0.6	3.6	0.7	4.3	2.1	3.4	4.8
2010 Average	36.8	0.5	0.0	19.1	0.2	1.4	0.7	4.6	0.0	2.6	0.6	0.8	3.3	0.7	3.2	5.6	0.1	6.1
2011 Average	26.0	14.1	0.0	15.0	0.4	1.4	15.0	5.3	0.5	1.8	0.9	0.7	2.8	1.0	3.9	2.0	0.2	2.6
2012 Average	27.0	25.5	0.0	10.9	13.0	2.2	1.1	8.1	0.3	0.2	0.5	0.5	0.3	1.5	0.9	0.6	0.3	0.8
2013 Average	27.6	0.3	26.9	3.9	3.8	0.0	5.9	0.0	0.1	2.1	0.5	0.9	1.3	2.4	1.2	4.1	0.3	0.6
2014 Average	21.8	0.3	5.8	15.2	0.2	1.5	2.5	20.2	0.1	0.0	2.7	2.7	1.1	6.4	1.8	1.1	0.1	2.6
2015 Average	28.6	7.5	1.0	20.2	0.3	0.8	3.9	3.7	0.1	0.1	0.7	0.9	1.8	3.5	0.8	3.1	0.1	7.3
5/24/16	14.1	9.6	3.4	25.5	4.9	0.0	0.0	4.3	0.0	0.0	0.0	1.6	0.3	11.0	0.0	0.7	0.0	0.0
6/14/16	9.8	2.5	27.3	19.0	0.9	0.3	0.0	5.7	0.0	0.0	0.0	0.3	6.6	11.8	0.0	1.0	0.0	0.0
7/19/16	28.4	0.0	0.0	21.0	0.0	0.0	0.0	48.1	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.0
8/19/16	2.8	1.9	2.9	1.6	0.4	1.0	1.2	0.0	0.2	0.5	2.9	3.0	11.8	1.4	8.5	5.2	10.7	23.2
10/1/16	2.2	0.0	0.0	1.3	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.9	0.9	0.0	0.4	0.0	3.1
2016 Average	11.5	2.8	6.7	13.7	1.2	0.3	0.2	11.7	0.0	0.1	0.7	1.0	4.0	5.0	1.7	1.5	2.1	5.3

Note: Only included plankton with at least 2% of the total counts on any survey day, in any year.

Table 5: Annual Average 2016 Lake Data from the Finger Lake Survey.

2016 Average Values (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.3 ± 1.3	7.7 ± 3.1	5.9 ± 1.4	4.3 ± 1.1	3.5 ± 0.9	5.6 ± 2.5	9.7 ± 4.1	3.2 ± 1.9
Total Suspended Solids (mg/L), Surface	4.7 ± 3.2	1.0 ± 0.8	0.8 ± 0.2	1.3 ± 0.5	1.6 ± 0.5	1.8 ± 1.7	1.0 ± 0.3	2.1 ± 1.5
Total Suspended Solids (mg/L), Bottom	4.7 ± 2.7	1.2 ± 0.7	0.7 ± 0.4	0.6 ± 0.3	2.6 ± 1.6	1.0 ± 0.4	0.5 ± 0.2	1.4 ± 0.5
Dissolved Phosphate (µg/L, SRP), Surface	3.8 ± 7.1	0.4 ± 0.2	0.4 ± 0.4	1.0 ± 1.6	1.8 ± 3.8	0.9 ± 1.2	1.3 ± 2.4	1.9 ± 6.0
Dissolved Phosphate (µg/L, SRP), Bottom	4.0 ± 6.7	0.7 ± 0.5	1.6 ± 1.6	2.8 ± 2.9	3.5 ± 3.2	0.7 ± 0.6	0.8 ± 1.4	1.3 ± 1.8
Total Phosphate (µg/L, TP), Surface	41.0 ± 32.3	18.0 ± 18.6	12.5 ± 11.3	15.1 ± 10.2	16.5 ± 12.7	14.1 ± 5.0	13.7 ± 9.5	16.1 ± 10.0
Total Phosphate (µg/L, TP), Bottom	41.0 ± 31.1	16.4 ± 20.7	17.7 ± 12.8	14.8 ± 9.5	21.4 ± 20.5	10.1 ± 3.1	11.4 ± 7.0	14.2 ± 12.6
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.2	0.7 ± 0.4	0.7 ± 0.3	0.3 ± 0.2	0.2 ± 0.2
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.2	0.8 ± 0.4	0.9 ± 0.4	0.5 ± 0.3	0.4 ± 0.3
Silica (SR µg/L), Surface	1269 ± 948	917 ± 271	1080 ± 279	205 ± 77	337 ± 79	1022 ± 265	359 ± 140	553 ± 285
Silica (SR µg/L), Bottom	1345 ± 951	1418 ± 378	1342 ± 359	452 ± 252	968 ± 296	1688 ± 452	808 ± 197	1119 ± 576
Chlorphyll a (µg/L), Surface	22.7 ± 17.4	1.8 ± 1.3	1.5 ± 1.1	2.7 ± 1.9	3.0 ± 2.0	3.5 ± 3.2	1.0 ± 0.7	3.0 ± 2.5
Chlorphyll a (µg/L), Bottom	17.2 ± 12.9	0.6 ± 0.5	0.7 ± 0.5	0.8 ± 0.5	1.2 ± 2.0	1.0 ± 0.6	0.6 ± 0.5	1.7 ± 1.1

Table 6. 2016 Stream Data.

2016 Stream Segment Analysis Data

Date & Location	Discharge (m^3/s)	Specific Conductance (µS/cm)	Water Temp (°C)	Nitrate (mg/L, N)	Suspended Solids (mg/L)	Total Phosphate (µg/L, TP as P)	Phosphate SRP (µg/L, SRP as P)
3/31/2016							
Dutch Hollow 38A	0.6	489	10.5	1.3	2.7	16.3	0.6
Dutch Hollow North Rd	0.7	469	10.6	0.9	1.8	11.9	1.3
Dutch Hollow Old State Rd	0.4	407	10.5	1.4	2.5	9.1	1.2
4/13/2016 - Q Data & Samples collected by Watershed Inspector's Office							
Dutch Hollow 38A	2.0	381	2.9	1.3	10.5	59.4	1.9
Dutch Hollow North Rd	1.5	372	2.9	2.1	9.7	33.8	1.5
Dutch Hollow South Trib	0.5	387	4.0	2.1	3.0	31.4	0.7
Dutch Hollow Benson Trib	0.1	595	3.1	5.1	4.4	35.9	6.6
Dutch Hollow Benson Rd	2.4	320	2.7	1.5	10.6	29.9	1.7
Dutch Hollow Old State Rd	1.6	314	5.9	1.0	26.2	35.0	1.6
Owasco Inlet Rt 38 Moravia	13.2	314	6.0	0.6	38.5	47.6	0.9
Mill Creek	5.7	351	5.3	0.9	31.9	38.7	2.9
Owasco Inlet Aurora St	flood	367	5.3	1.0	34.1	37.0	1.2
Owasco Inlet VFW	no sample collected form this site						
Fillmore Cr	0.9	332	4.3	0.2	12.7	28.1	3.2
Owasco Inlet Locke, downstream	4.8	367	5.9	1.8	34.5	22.5	1.9
Hemlock Cr	1.2	374	6.0	1.6	13.2	29.0	3.1
Owasco Inlet County Line	3.5	357	5.9	0.5	20.8	31.6	2.8
Owasco Inlet Groton	1.2	421	5.2	0.4	12.6	30.1	5.2
Fire Lane 20	not sampled						
discharge for Rt 38 on 4/13 from USGS gauge.							
6/1/2016							
Dutch Hollow 38A	0.2	522	17.6	0.4	1.0	15.5	2.0
Dutch Hollow North Rd	0.1	507	18.4	0.5	0.0	18.1	1.7
Dutch Hollow South Trib	0.0	535	16.2	1.5	0.2	16.1	4.0
Dutch Hollow Benson Trib	0.1	488	18.7	4.0	2.1	18.6	0.7
Dutch Hollow Benson Rd	0.0	739	18.6	0.8	1.8	20.3	7.7
Dutch Hollow Old State Rd	0.0	494	18.4	0.8	2.1	13.5	2.7
Owasco Inlet Rt 38 Moravia	1.0	458	18.8	1.6	1.3	19.9	4.4
Mill Creek	0.3	301	17.7	1.4	0.8	12.5	0.5
Owasco Inlet Aurora St	0.7	467	19.3	1.9	2.2	26.8	9.9
Owasco Inlet VFW	0.6	429	22.1	0.6	0.6	19.5	3.4
Fillmore Cr	0.0	279	29.3	0.6	0.2	9.7	0.5
Owasco Inlet Locke, downstream	0.5	465	20.9	0.1	2.4	18.6	2.1
Hemlock Cr	0.1	440	19.8	3.5	1.1	6.8	0.1
Owasco Inlet County Line	0.3	178	21.2	0.7	3.9	34.2	13.5
Owasco Inlet Groton	0.1	439	21.8	0.6	8.3	33.7	5.1
Fire Lane 20	0.0	540	17.5	4.2	0.7	7.2	1.4
6/6/2016							
Dutch Hollow 38A	0.2	527	19.4	0.6	6.0	21.9	1.7
Dutch Hollow North St	0.2	458	18.7	0.7	2.6	16.4	4.7
Dutch Hollow South Trib	0.0	520	17.5	1.1	2.2	16.8	9.0
Dutch Hollow Benson Trib	0.2	486	18.2	3.6	2.7	21.2	1.2
Dutch Hollow Benson Rd	0.0	686	18.8	0.8	5.0	36.9	14.3
Dutch Hollow Old State Rd	0.1	483	18.5	0.9	5.8	23.2	1.0
Owasco Inlet Rt 38 Moravia	2.0	402	18.7	1.1	11.0	33.3	4.7
Mill Creek	0.5	352	17.9	0.8	4.4	15.2	0.7
Owasco Inlet Aurora St	1.5	441	18.9	0.2	12.4	35.1	6.3
Owasco Inlet VFW	1.2	431	20.1	0.7	9.6	32.2	5.7
Fillmore Cr	0.0	236	24.4	0.4	1.1	13.2	0.4
Owasco Inlet Locke, downstream	1.1	441	20.0	0.6	17.0	40.7	8.3
Hemlock Cr	0.4	438	18.5	1.9	2.0	11.4	0.5
Owasco Inlet County Line	0.6	454	20.7	0.6	23.1	47.8	11.5
Owasco Inlet Groton	0.4	383	19.8	0.4	18.0	27.3	1.5
Fire Lane 20	0.0	554	18.1	2.8	1.6	29.5	1.8
6/28/2016							
Dutch Hollow 38A	0.0	496	21.4	0.1	2.4	11.3	0.9
Dutch Hollow North Rd	0.0	498	22.8	0.1	14.5	8.7	4.7
Dutch Hollow South Trib	0.0	581	19.6	0.5	0.5	17.8	2.5
Dutch Hollow Benson Trib	0.0	721	21.8	0.3	1.8	24.5	4.4
Dutch Hollow Benson Rd	0.0	511	22.4	0.1	4.1	1.5	1.8
Dutch Hollow Old State Rd	0.0	524	22.1	0.1	1.9	8.7	0.6
Owasco Inlet Rt 38 Moravia	0.5	503	22.3	0.1	2.3	9.1	2.3
Mill Creek	0.2	425	21.1	0.2	1.7	6.0	0.6
Owasco Inlet Aurora St	0.3	522	22.9	1.1	3.4	27.0	7.7
Owasco Inlet VFW	0.3	484	23.5	0.6	5.0	13.0	1.8
Fillmore Cr	dry						
Owasco Inlet Locke, downstream	0.3	497	24.4	0.3	2.4	5.6	1.2
Hemlock Cr	0.0	474	22.1	0.3	0.6	16.8	4.5
Owasco Inlet County Line	0.1	585	23.9	0.3	3.7	34.6	23.8
Owasco Inlet Groton	0.0	450	23.5	0.0	7.3	29.5	2.4
Fire Lane 20	0.0	537	20.5	5.1	2.7	18.7	11.0

Table 6. 2016 Stream Data (continued)

2016 Stream Segment Analysis Data (continued)							
7/11/2016							
Dutch Hollow 38A	0.0	496	17.9	0.0	0.6	14.4	0.0
Dutch Hollow North Rd	0.0	475	18.7	0.1	1.5	17.3	0.9
Dutch Hollow South Trib	dry						
Dutch Hollow Benson Trib	0.0	489	18.8	0.1	3.4	26.1	12.4
Dutch Hollow Benson Rd	0.0	808	18.7	0.1	1.6	12.5	0.0
Dutch Hollow Old State Rd	0.0	546	18.1	0.5	3.5	10.4	0.0
Owasco Inlet Rt 38 Moravia	0.4	504	19.2	0.6	1.5	10.1	3.9
Mill Creek	0.1	449	18.5	0.6	0.0	4.2	6.3
Owasco Inlet Aurora St	0.3	552	20.3	1.1	2.8	35.9	18.5
Owasco Inlet VFW	0.2	492	20.0	0.0	4.2	14.9	0.6
Fillmore Cr	dry						
Owasco Inlet Locke, downstream	0.1	511	21.5	0.5	2.3	12.2	0.0
Hemlock Cr	0.0	483	19.1	2.5	0.9	7.9	1.6
Owasco Inlet County Line	0.1	618	20.7	0.4	2.3	17.0	17.6
Owasco Inlet Groton	0.0	466	21.6	0.0	6.2	0.0	0.0
Fire Lane 20	0.0	539	19.0	3.2	0.5	12.0	12.7
10/24/2016 - Q Data & Samples collected by Watershed Inspector's Office							
Dutch Hollow 38A	1.5	not measured	not measured	9.3	6.6	30.5	3.4
Dutch Hollow North Rd	0.6			22.0	6.8	25.6	11.5
Dutch Hollow South Trib	0.3			17.2	2.7	29.2	13.3
Dutch Hollow Benson Trib	0.1			40.0	4.5	42.6	16.4
Dutch Hollow Benson Rd	0.7			19.6	6.3	16.8	2.6
Dutch Hollow Old State Rd	0.3			15.3	3.5	23.9	6.6
Owasco Inlet Rt 38 Moravia	6.5	Est from USGS Gauge		16.5	5.9	24.3	4.1
Mill Creek	0.8			12.5	3.3	17.7	8.8
Owasco Inlet Aurora St	2.3			20.9	12.9	28.1	13.0
Owasco Inlet VFW	no sample collected from this site						
Fillmore Cr	0.1			4.5	0.6	34.9	4.4
Owasco Inlet Locke, downstream	1.2			13.2	2.0	27.6	15.2
Hemlock Cr	0.3			14.1	7.2	68.0	2.6
Owasco Inlet County Line	0.4			15.1	5.5	49.0	6.6
Owasco Inlet Groton	0.3			7.1	5.8	34.3	12.4
Fire Lane 20	0.01			92.4	1.1	19.2	12.1
2016 Average Values							
Dutch Hollow 38A	0.7	484.4	15.8	2.0	4.5	25.5	1.6
Dutch Hollow North Rd	0.4	462.0	16.3	4.3	5.9	20.0	4.2
Dutch Hollow South Trib	0.2	505.8	14.3	4.5	1.7	22.3	5.9
Dutch Hollow Benson Trib	0.1	555.8	16.1	8.8	3.2	28.1	6.9
Dutch Hollow Benson Rd	0.5	612.8	16.2	3.8	4.9	19.7	4.7
Dutch Hollow Old State Rd	0.4	472.2	16.6	3.1	7.2	19.1	2.1
Owasco Inlet Rt 38 Moravia	3.9	436.2	17.0	3.4	10.1	24.1	3.4
Mill Creek	1.3	375.6	16.1	2.7	7.0	15.7	3.3
Owasco Inlet Aurora St	1.0	469.8	17.3	4.4	11.3	31.7	9.4
Fillmore Cr	0.3	282.3	19.3	1.4	3.7	21.5	2.1
Owasco Inlet VFW	0.6	459.0	21.4	0.5	4.9	19.9	2.9
Owasco Inlet Locke, downstream	1.5	454.0	18.0	3.3	11.6	21.7	5.3
Hemlock Cr	0.3	441.8	17.1	4.0	4.2	23.3	2.1
Owasco Inlet County Line	0.9	503.5	17.8	3.4	11.1	36.0	12.4
Owasco Inlet Groton	0.3	431.8	18.4	1.4	9.7	25.8	4.5
Fire Lane 20	0.0	542.5	18.8	21.5	1.3	17.3	7.8
2016 Average Fluxes				N kg/day	TSS kg/day	TP kg/day	SRP kg/day
Dutch Hollow 38A				110.3	254.4	1.4	0.1
Dutch Hollow North Rd				155.3	213.3	0.7	0.2
Dutch Hollow South Trib				66.7	25.4	0.3	0.1
Dutch Hollow Benson Trib				71.7	25.5	0.2	0.1
Dutch Hollow Benson Rd				171.5	219.5	0.9	0.2
Dutch Hollow Old State Rd				94.5	217.8	0.6	0.1
Owasco Inlet Rt 38 Moravia				1160.3	3406.0	8.1	1.1
Mill Creek				299.5	766.5	1.7	0.4
Owasco Inlet Aurora St				377.9	975.9	2.7	0.8
Fillmore Cr				31.6	81.7	0.5	0.0
Owasco Inlet VFW				25.4	243.5	1000.0	143.6
Owasco Inlet Locke, downstream				428.9	1522.3	2839.9	694.6
Hemlock Cr				117.2	122.5	685.3	60.8
Owasco Inlet County Line				270.4	885.4	2877.5	994.1
Owasco Inlet Groton				41.9	286.4	762.2	131.4
Fire Lane 20				8.4	0.5	0.0	0.0