OWASCO LAKE, NEW YORK, 2015 ANNUAL REPORT: WATER QUALITY & NUTRIENT SOURCE MONITORING, DETAILED DUTCH HOLLOW NUTRIENT LOADS & DETAILED WATER QUALITY BUOY DATA.

John D. Halfman[1,2,3], Roxanne Razavi[3], Nadia Harieux[3], Kathrine Coughlin[1,2] (WS'16), Abigayle Dylag[1,2] (WS'16), Ryan Ratsep[1,2] (H'17), & Nicole Tanquary[1,2] (WS'17)
Department of Geoscience[1] & Environmental Studies Program[2]
Finger Lakes Institute[3]
Hobart and William Smith Colleges
Geneva, NY 14456
Halfman@hws.edu

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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. The ongoing focus established a comprehensive monitoring program to: (1) document spatial and temporal trends in pertinent water quality / water clarity / limnological parameters; (2) bring particular focus to the extent and source of nutrients in the watershed, as their inputs to the lake promote algal growth and thus degrade water quality; and, (3) 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, and the Cayuga County Legislature.

Highlights of prior results include:

- The trophic status (productivity level) of Owasco Lake fluctuates above and below the oligotrophic – mesotrophic boundary.
- Phosphorus is the limiting nutrient in Owasco Lake, and any additional inputs of phosphorus would stimulate additional algal growth and degrade water quality.
- The lake recently experienced late-summer blooms of blue green algae. Blue green algae are a concern due to their affiliation with impaired / eutrophic water bodies, and some blue green species occasionally (not always) synthesize compounds that are toxic to humans and other warm blooded animals.
- Nutrient and sediment sources include point sources like wastewater treatment facilities and onsite wastewater (septic) systems, and non-point sources like animal and crop agriculture, soil erosion, stream bank erosion, fertilized lawns, roadside ditches, and construction activities.
- Streams and tributaries are the primary source of nutrients and sediments to the lake, even during "dry" years. Over 90% of the nutrient and sediment loads are delivered during precipitation/runoff events, especially in the spring.
- A DEC mandated reduction in phosphorus in the Groton Wastewater Treatment Facility effluent has reduced nutrient loading to the Owasco Inlet. The adoption of some agricultural best management practices in the watershed, establishment and follow

through on recommendations by the Watershed Inspector's Office and the Owasco Lake Watershed Management Council, have also reduced nutrient loading to the lake.

The 2011 through 2014 surveys expanded the summer season sampling to the early spring through late fall to investigate seasonal fluctuations in nutrient loading; and, initiated an event *versus* base flow analysis of nutrient and sediment loading at Dutch Hollow Brook.

- Seasonal sampling of Dutch Hollow and Owasco Inlet revealed larger spring and fall nutrient and sediment loads compared to the summer months, and indicated that the pre-2011 flux estimates, based only on summer samples, underestimated the actual annual loads to the lake.
- The event *versus* base flow analysis of Dutch Hollow Brook highlighted the dominance of precipitation induced runoff events on the delivery of nutrients and sediments from non-point sources to the lake.
- The 2011 - 2014 annual phosphorus budgets for Owasco Lake estimated larger inputs than outputs in all but the driest years. This is a concern because additional phosphorus stimulates more algal growth and degrades water clarity and quality.
- Phosphorus loads correlated to the amount of precipitation. The wettest years yielded largest loads, especially more precipitation during the spring.
- Phosphorus loading must be reduced to move Owasco Lake into a recovery phase, and better water quality. A minimum of five water retention times, i.e., decades, are required after a significant reduction of phosphorus inputs to Owasco Lake so that the lake can naturally cleanse itself of phosphorus and allow an improvement in water quality.

The water quality research is also passing into an exciting phase, as NY State funds were promised to Cayuga County Soil and Water Conservation District and Owasco Lake Watershed Association in 2015 to establish preliminary BMPs in the Owasco Lake watershed, and to monitor and model the effectiveness of the remediation efforts.

Here, we report on our 2015 results. Unfortunately, Cayuga County budget woes continued from 2014 and restricted the work plan for the second year in a row. In 2015, the number of stream sample dates was increased from the 2014 monitoring schedule. However, fewer sites were sampled in 2015 than 2014. The 2015 plan continued the detailed, event *versus* base flow analysis of Dutch Hollow Brook at the 38A and North Street sites albeit at a longer sample periodicity. Additional funds from Cayuga County Soil and Water Conservation District initiated one more detailed analysis site at Martin Road, roughly halfway between 38A and North Street. Finally, support from the Emerson Foundation enabled the deployment and maintenance of the FLI meteorological and water quality monitoring buoy through 2015, the development and maintenance of the near real-time meteorological and water quality data internet site for the buoy, and high school educational outreach modules based on the buoy data. Auburn teachers have already taken advantage of this outreach.

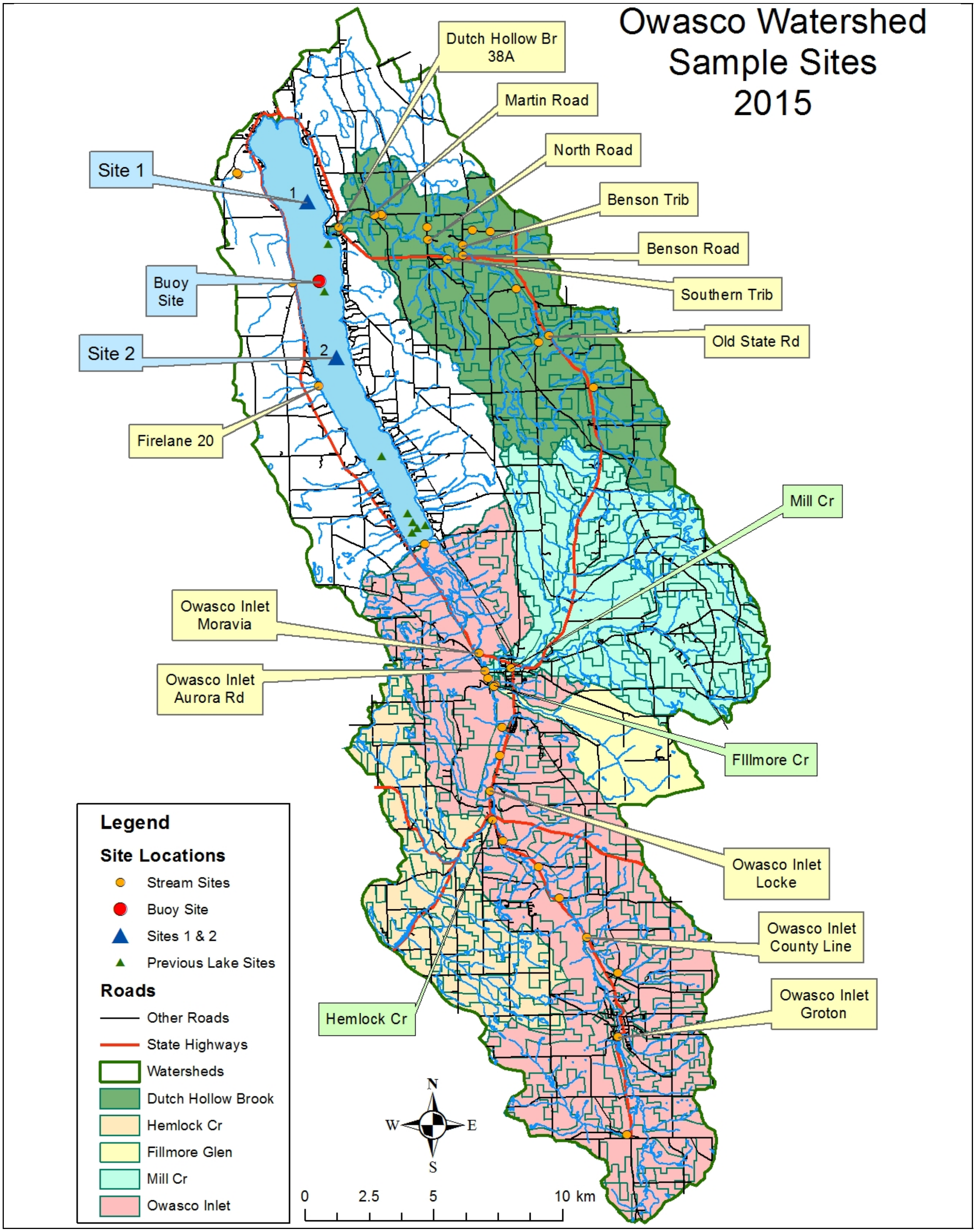

Fig. 1. The 2015 lake and stream sites. The 2015 stream sites focused on previously sampled sites within Dutch Hollow Brook and the Owasco Inlet. The small tributary near the terminus of Fire Lane 20 was also sampled.

METHODS

The sample sites and field/laboratory methods used in 2015 were similar to the 2011 – 2014 programs.

Owasco Lake: The 2015 lake survey sampled Sites 1 and 2 on a monthly basis from late May through late September (Table 1, Fig. 1). These are the same sites utilized since the 2005 survey, and are representative of the open water limnology in Owasco Lake. The specific 2015 survey dates were: 5/26, 6/24, 7/22, 8/19 & 9/28, similar to the 2014 survey.

The 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. 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 CTD's dissolved oxygen sensor malfunctioned during the first cruise but was repaired in time for the third survey. The plankton collected by each tow were preserved in an alcohol-formalin solution until identification and enumeration back in the laboratory. Water samples were analyzed onsite for temperature (°C), conductivity (specific conductance, μS/cm), pH 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

Owasco Buoy: In 2015, the FLI meteorological and water quality monitoring buoy manufactured by YSI/Xylem was deployed at its mid-lake site from 4/21 through 10/26 (Fig. 1, & 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, a measurement proportional to salinity), dissolved oxygen (mg/L & % saturation, by optical sensor), turbidity (NTUs by backscattering), and fluorescence (μg/L, by light emission after excitation by all algae, chlorophyll-a, and different emissions specifically by blue green algae, BGA PC). Each profile collected data every 1.5 meters along the water column 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 4/21 until 5/19, on 6/11 and 10/21 in 2015.

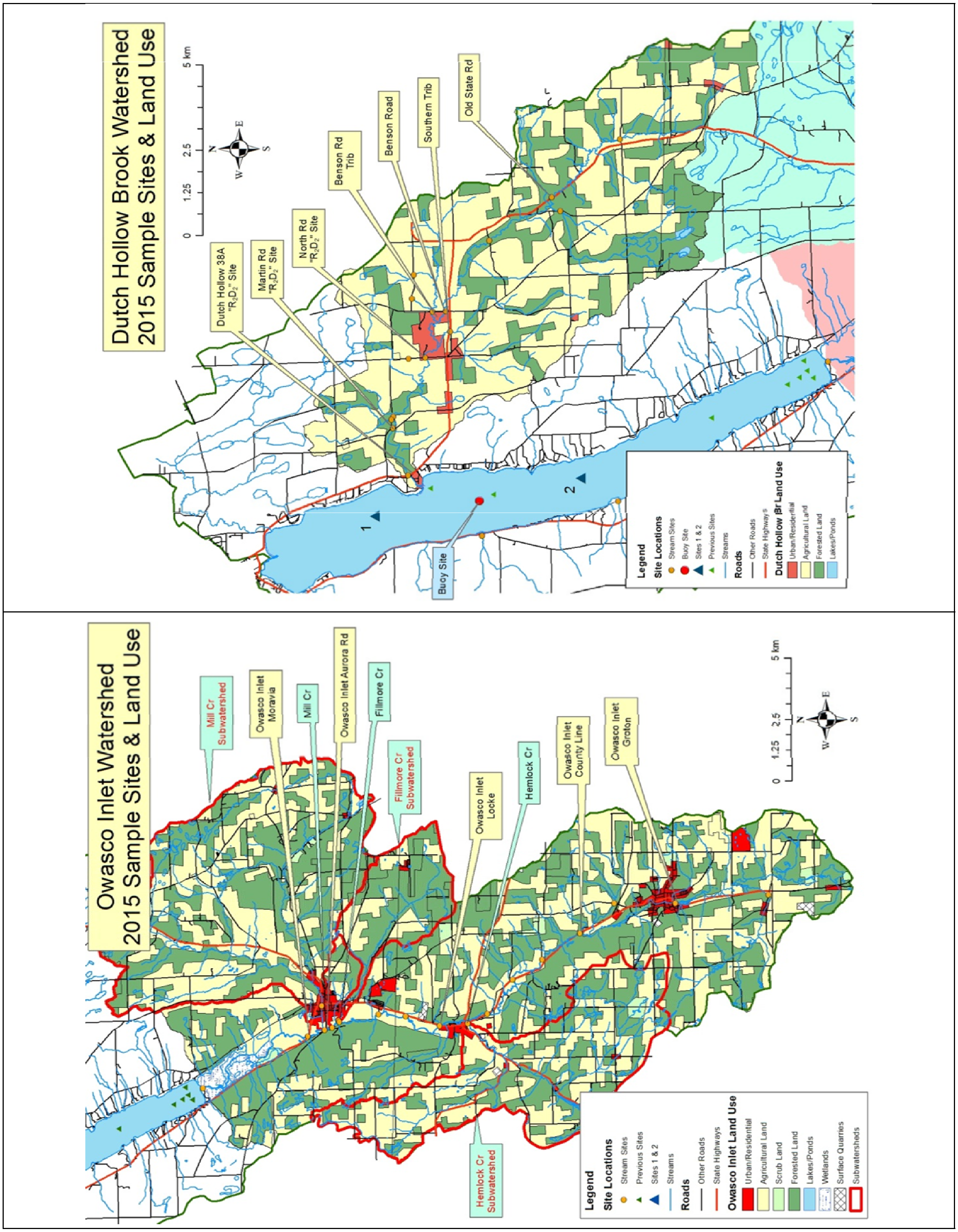

Fig. 2. 2015 site locations (yellow boxes) and land use within Dutch Hollow Brook and Owasco Inlet watersheds. Subwatersheds are designated by green boxes.

Owasco Streams: The 2015 stream monitoring focused on Dutch Hollow Brook, Owasco Inlet, and a small tributary at the end of Fire Lane 20 on the west side of the watershed. The stream sites were visited four times, on 5/5, 6/3, 6/17 & 7/3, for onsite analyses and collection of water samples for nutrient and sediment analyses back in the laboratory.

Dutch Hollow Brook was sampled at seven sites in 2015 (Figs. 1 & 2). Progressing upstream, five sites were sequentially located along the main stream at Rt 38A, Martin Rd, North St, 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.

Owasco Inlet was sampled at eight sites in 2015 (Figs. 1 & 2). Proceeding upstream, five sites were sequentially located along the main stream at just downstream of Moravia on Rt 38, at Aurora St in Moravia, north of Locke, at the County Line, and upstream of Groton (near Spring St). Three tributaries, Mill, Fillmore, and Hemlock Creeks, were also sampled just upstream from where they join the Inlet. We also sampled the small creek at the end of Fire Lane 20.

Stream discharge, temperature, conductivity, dissolved oxygen, pH and alkalinity were measured onsite using hand-held probes or field titration kits. Water samples were also collected and analyzed in the laboratory for total phosphate, dissolved phosphate, nitrate and total suspended sediment 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). The previously utilized Marsh-McBirney flow meter malfunctioned and was replaced by a HACH instrument (HACH purchased Marsh-McBirney). 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 38A, Martin Rd and North St sites. 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 (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: Earlier research had shown that event (precipitation/runoff induced flow) and base flow (groundwater supported flow) are two critical stream states to understand. When it rains, runoff rapidly adds water to a stream, which swells into an event (perhaps a flood). The increase in stage/discharge typically peaks (highest stage, largest discharge) a few hours to a few days after the rainstorm. It takes time for the rainfall to travel from its point of impact on the ground, across the landscape to the stream, and then flow downstream to the site. The response or lag time from the precipitation event to the event peak is a function of the watershed size and shape (geomorphology), connections to the groundwater system, and duration and intensity of the precipitation events. When the precipitation wanes and runoff dissipates, the stream stage/discharge exponentially declines but at a slower pace than the initial rise because this portion of the "event" is fed progressively by less runoff, that adds precipitation induced, near-surface, groundwater flow, and groundwater flow is much slower than the surface runoff. As both runoff and the rejuvenated groundwater wane, the stream eventually flows at a lower discharge, its base flow, fed exclusively by groundwater inputs. Both states are critical, because event flow highlights the sources of, e.g., phosphorus and sediment, from non-point sources like agricultural areas and lawns, whereas base flow highlights the input of, e.g., water soluble nitrates and phosphorus, from point sources like wastewater treatment facilities and groundwater input.

A Teledyne ISCO automated water sampler and two *In Situ* Aqua Troll 200 data loggers were deployed at the Rt 38A site in the Dutch Hollow Brook watershed from 4/6 to 10/25 to investigate the impact of event and base flows on the delivery of nutrients and sediments to the lake (Figs. 3a & 3b). Two more automated samplers and data loggers were deployed upstream from Rt 38A at Martin Road and at North Street to investigate event *versus* base flow variability along Dutch Hollow Brook.

At all three sites, the autosamplers were programmed to collect 1-L of water every eight hours (noon, 8 pm and 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 weekly. An 8-hour sample frequency was maintained for the suspended sediment effort. However, insufficient funding forced a reduction in the nutrient analyses to daily samples (4 am) at all three sites. It also forced a further nutrient analysis reduction to just total phosphates during the fall (8/24 – 10/26) at the North Street and Martin Road sites.

The data loggers were programmed to record stream stage (height), temperature and specific conductance every hour. The stage data and weekly stream discharge measurements established a rating curve, the relationship between stream height and stream discharge to estimate a stream discharge for every ISCO water sample. However, all but the Martin Road data logger failed in 2015, and 8-hr discharge data was instead extrapolated from this single dataset to the other sites using the best-fit relationship between the weekly measured stream discharge data. Over the 202 day deployment (542, 8-hr samples) in 2015 at 38A and North Street, and 171 day deployment (515, 8-hr samples) at Martin Road, three days (6/14, 8/31 & 9/1) of samples were lost at 38A due to power failures, one week of samples (6/3 – 6/9) were lost at North St due to a sampler programming error, and deployment was delayed until 5/6 at Martin Road due to delays in the CCSWCD subcontract thus equipment purchase, and resolution of initial equipment issues. A week of samples (10/6 – 10/13) was lost by a faulty hose connection.

Fig. 3a. Servicing “R_2D_2” the *Teledyne* ISCO automated water sampler located at the Rt 38A site. It collected 1-liter of water every 8-hrs and was serviced weekly.

Fig. 3b. An *In Situ* Aqua Troll 200 data logger. It logged stream height (to estimate hourly stream discharge), temperature and specific conductance of the stream on an hourly interval.

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. The remaining sample 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, 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 level and reported as date averaged relative percentages.

LAKE MONITORING RESULTS & DISCUSSION

Lake CTD Profiles: The 2015 water temperature profiles were typical for any late spring through early fall transition (Fig. 4). The 5/26 profiles revealed the initial establishment of seasonal stratification, when the less dense and warmer epilimnion (surface water) overlies the denser and uniformly cold hypolimnion (bottom water). Epilimnetic temperatures ranged from 12ºC (~50ºF) in late-May to 25ºC (~75ºF) in June, and cooled to 20ºC by the last cruise of the survey (9/29). Hypolimnetic temperatures remained a uniform 5ºC (~39ºF) through the survey. The hypolimnion temperatures were ~1ºC cooler in 2014 and 2015 than earlier years, most likely reflecting the very cold preceding winters.

Epilimnetic salinity (specific conductance) ranged from ~310 to 330 μS/cm in 2015 (~150 ppm TDS). Like previous years, epilimnetic salinity in 2015 decreased from the largest detected values in the late spring through the summer and fall by ~20 μS/cm (~10 ppm TDS) as the epilimnion was progressively diluted by less saline precipitation and stream runoff. The 2015 early spring specific conductance was slightly larger than those detected in previous years, and it continues the increasing trend started in 2014. The change in salinity is interpreted to reflect the extent of road salt application during the preceding winters, e.g., a large salinity in 2015 due to more snowfall and road salt. The 2015 hypolimnetic specific conductance data were just above 340 μS/cm and remained relatively uniform over time and depth (Fig. 4). These values were also 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 the previous winters probably maintained the slightly larger hypolimnetic salinity in 2015 & 2014 than earlier years.

The 2015 epilimnetic dissolved oxygen (DO) concentrations from the last three cruises remained between 8 and 10 mg/L, and near 100% saturation (Fig. 4). However, hypolimnetic DO concentrations were progressively depleted below saturation through the stratified season to just above 4 mg/L (~40% saturation) in the upper hypolimnion and 6 mg/L (~50% saturation) in the lowest hypolimnion by late summer. These lowest saturation levels approached the threshold for respiratory stress in sensitive organisms. The decrease is interpreted to reflect hypolimnetic bacterial respiration and decomposition of dead algae. The depletion was slightly more severe in 2015 than earlier years.

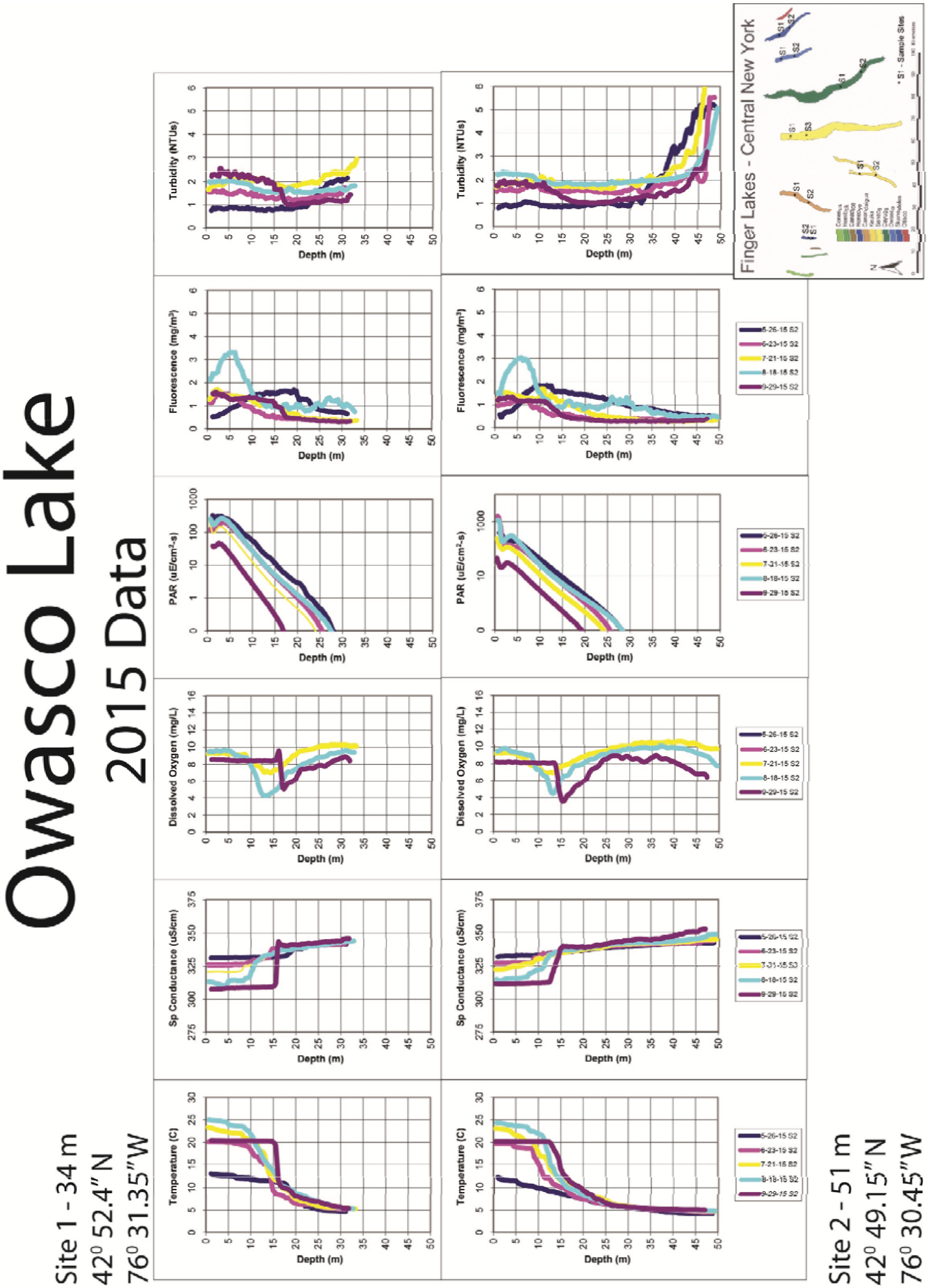

Fig. 4. Owasco 2015 CTD profiles from Sites 1 & 2. The PAR (light) data are plotted on an exponential scale, so that exponential changes with water depth appear as straight lines. The dissolved oxygen sensor was being repaired during the first two cruises

Profiles of photosynthetic available radiation (PAR), i.e., light intensity, in 2015 were similar to earlier results (Fig. 4). Available light decreased exponentially with water depth from a maximum intensity of a few 100 to a few 1,000 $\mu E/cm^2$-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% 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. 4). Peak concentrations exceeded 3 μg/L (mg/m^3) on 8/18, but were lower, between 1 and 2 μg/L on the other survey dates. The 2015 epilimnetic data were slightly smaller than 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. 4). Turbidities consistently rose to 4 to 6 NTUs near the lake floor at Site 2. These turbidities were larger than those observed in earlier years, especially the large concentrations detected in the lake floor nepheloid layer.

Turbidity sources include runoff from precipitation events and snow melt, resuspension of nearshore lake floor sediments during wind/wave events, algal populations, or settling dead algae along the lake floor. The spring runoff events clearly brought turbid water to the lake (Fig. 5). Most of this sediment probably settled in the nearshore environment near the stream or tributary mouths. Then, these sediments would be resuspended by the occasional wind events and associated turbulence from waves during the remainder of the year. The continued supply of suspended sediments maintained the high turbidities in the water column through the 2015 field season.

Fig. 5. Turbid plume originating from Long Point (5/12/15). Photo by Dave Wasileski.

2015 Limnology & Trophic Status: The Secchi disk, chlorophyll, nutrient and suspended sediment data indicated that the lake was not a health threat, as nitrate concentrations were typically below 1 mg/L and an order of magnitude (10 times) below the 10 mg/L maximum contaminant level (MCL) established by the EPA (Table 2 in appendix, Fig. 6). Annual mean chlorophyll concentrations in the epilimnion was below 4 μg/L, just below the 4 to 6 μg/L threshold being considered by the DEC to protect potable water bodies[1]. However, the August and September epilimnetic chlorophyll results were within this potable water body protection threshold. Neither was the lake impaired due to phosphorus, as the annual mean total phosphate concentration was 15.5 μg/L, below the 20 μg/L total phosphate (TP) threshold established for impaired water bodies by the DEC. The 5/26 TP concentration was the only exception with a TP date-averaged lake concentration of 23.7 μg/L. The 5/26 reading was coincident with the spring rains. The TSS concentrations ranged from 1.5 to 2.6 mg/L and averaged 2.1 mg/L. Secchi disk depths ranged from 3.0 to 4.1 meters, and averaged 4.1 meters.

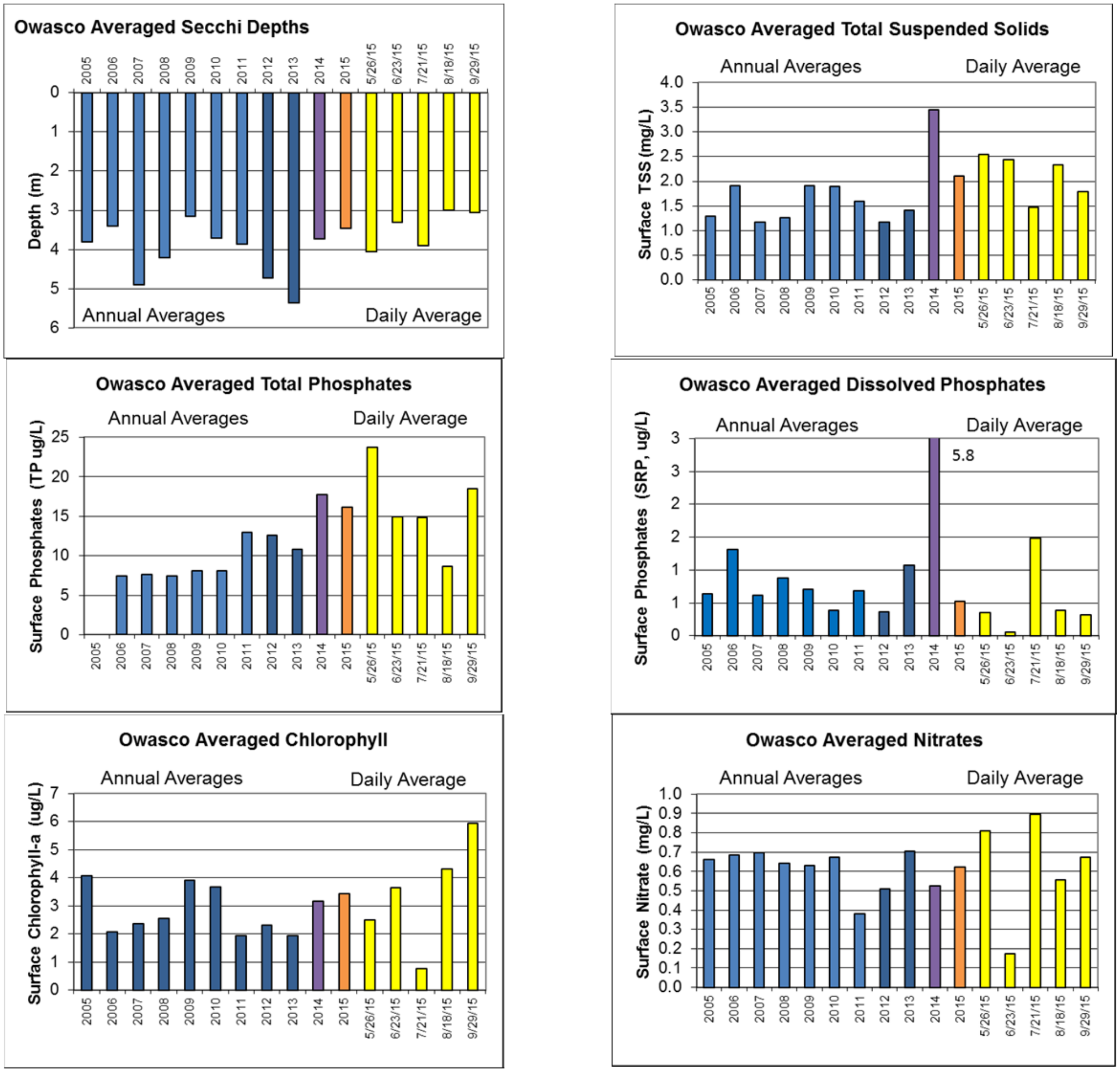

Fig. 6. Annual average surface water data since 2005 (blue), for 2015 (orange), and daily average surface water data from each 2015 survey date (yellow).

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[1] 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.

Annual mean total phosphate concentrations have increased since 2005 to 2015 from 8 to over 15 μg/L with a slight dip in 2013 (Fig. 6). Dissolved phosphate concentrations were larger in 2006, 2011, 2013 and 2015 than other years, but never as large as those in 2014. The large 2014 mean value was biased by a sample collected immediately after the intense May rains. Chlorophyll-a concentrations were larger in 2009, 2010, 2014 and 2015 (3.9, 3.7, 3.2 & 3.5, respectively) than other years (1.9 to 2.3 mg/L). Total suspended sediment (TSS) were second largest in 2015 (2.1 mg/L) following the largest concentrations in 2014 (3.5 mg/L) than any other previous year (< 2.0 mg/L). Secchi disk depths were shallower in 2015 (3.5 m) than every year since 2009 (Fig. 6). The data suggest improving water clarity from 2009 through 2013 but declining water clarity afterwards. The major trigger for 2014 and 2015 was probably the larger rains, and associated nutrient loads.

In 2015, the trophic status of Owasco Lake was slightly above the oligotrophic/ mesotrophic boundary, similar to 2014 designation. Both 2014 and 2015 were worse than the preceding three years. The 2015 annual average nitrate and chlorophyll-a data place Owasco Lake slightly below the oligotrophic/mesotrophic trophic boundary (Table 3, Fig. 6). The annual mean Secchi disk depth, TP concentration and hypolimnetic dissolved oxygen concentration placed Owasco Lake just in the mesotrophic range. Thus, the trophic status of Owasco Lake remains borderline oligotrophic-mesotrophic. Over the past few years, it was slightly more oligotrophic from 2011 through 2013, but returned back to a mesotrophic state in 2014. 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.

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 2015 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

A few additional observations about the limnological data are noteworthy. First, the dissolved phosphate to nitrate ratio in the lake, the two nutrients that could limit algal growth, averaged 1:1,200 in 2015. The P:N ratio required by algae is 1:7 (Redfield Ratio). The measured ratios indicate that phosphate was 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 are augmented by other sources of available nitrogen to the lake (acid rain nitrates). Second, variability was observed in every parameter from one survey date to the next (Fig. 6). It highlights, for example, that algal blooms do not last the entire summer but are instead episodic and last for a week or two at a time, and suggests that the lake should be monitored on a daily or weekly basis to detect these shorter time-frame events (see buoy section below). Third, the dissolved nutrient concentrations revealed a small increase from the epilimnion to the hypolimnion, e.g., annual mean surface and bottom water concentrations for soluble reactive phosphate were 0.4 and 0.5 μg/L, nitrate 0.5 and 0.7 mg/L, and silica 700 and 1,400 μg/L, and the chlorophyll-a concentrations revealed a small decrease from 3.8 and 0.7 μg/L from the epilimnion to the hypolimnion. The trends reflected the seasonal uptake of nutrients by algae in the epilimnion, and the release of nutrients by bacterial decomposition back to the water in the hypolimnion.

Plankton Data: The phytoplankton (algal) species in Owasco Lake during 2015 were dominated by diatoms, primarily *Flagillaria* and *Asterionella*, with smaller numbers of *Diatoma*, *Melosira*, *Tabellaria*, *Rhizoselenia*, and *Synedra* (Table 4 in appendix, Fig. 7). Like previous years, *Asterionella* and *Fragillaria* dominated in the spring, *Tabellaria* replaced *Asterionelia* in the early summer, *Dinobryon* dominated in the late summer, and *Asterionella* and *Rhizoselenia* 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 *Copepods*, *Nauplius*, *Polyarthra* and *Vorticella* with some cladocerans, like *Cercopagis*, the fishhook water flea. Zebra and quagga mussel larvae were also detected in the plankton tows. *Mycrocystis* (a blue green alga) also dominated the plankton counts in the open water during the fall.

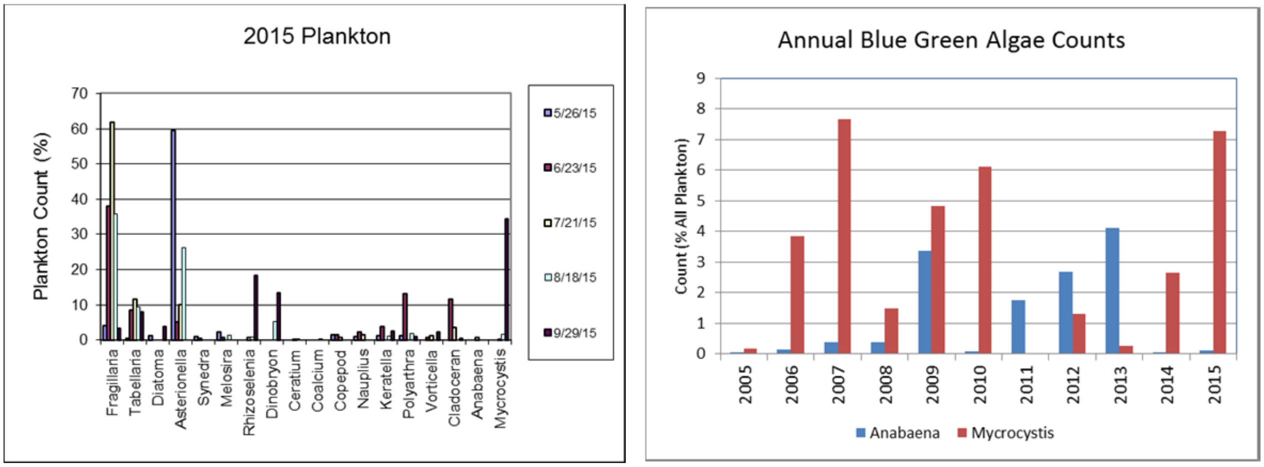

Fig. 7. Date averaged plankton data for 2015 (left) and the mean annual abundance of blue green algae species since 2005 (right).

Blue green algae (BGA) were always detected in the open water of Owasco Lake since 2005. However, the annual percentages never exceeded 10% for the dominant BGA at these open water sites (Fig. 7). Typically the largest proportions were restricted to the late summer and/or early fall, with *Mycrocystis* representing up to 40% of the plankton counts in 2007, 2010, 2014 and 2015, and *Anabaena* making up 30% of the late-summer counts in 2013. Since 2012, major blooms of BGA have been increasingly detected along the shore. The blooms are not unique to Owasco Lake. In fact, major BGA blooms were confirmed for Conesus (3 weeks), Honeoye (7 weeks), Canandaigua (4 weeks), Seneca (6 weeks), and over 250 lakes in New York State. Even more disturbing is that many blooms contained toxins above the World Health Organization advisory threshold of 1 μg/L for safe drinking water. The BGA section below has more details.

Finger Lake Water Quality Ranks: The 2015 Finger Lakes water quality rankings still place Owasco Lake as one of the worst lakes among the eight easternmost Finger Lakes (Table 5 in appendix, Figs. 8 & 9). 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. These rankings are similar to other comparative water quality / trophic state methods like the oligotrophic-eutrophic states, Carlson's Trophic Indices (combines chlorophyll-a, total phosphorus and Secchi depth data). In 2015, Owasco was ranked lower than Canandaigua, Keuka, Skaneateles and Seneca Lakes, similar or slightly better than Cayuga Lake and better than Honeoye and Otisco Lakes. Interestingly, all of the lakes revealed the worst ranking in 2014 and again in 2015 (although not to the same extent) compared to 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 the past two years.

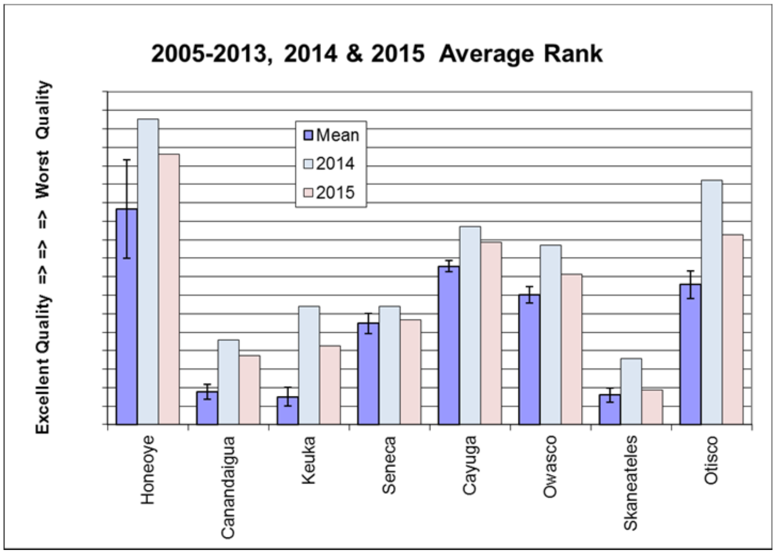

Fig. 8. Annual Water Quality Ranks from 2005 – 2015 for the eight easternmost Finger Lakes. The "mean" dark blue bar averaged the 2005 - 2013 ranks for each lake. A 1σ standard deviation is shown.

The change in water quality among lakes is due to a number of competing and intertwined factors that were detailed in previous reports. The degree of water quality protection legislation and its implementation are important to protect the lakes from nutrient and sediment loading issues. Nutrient loading stimulates algal growth and degrades water quality. So does ecological pressures by zebra and quagga mussels, Asian clams and *Cercopagis*, the fishhook water flea.

PRELIMINARY BUOY DATA

The FLI meteorological and water quality monitoring buoy was redeployed in Owasco Lake during the 2015 field season. It revealed higher resolution but otherwise consistent changes in the water column as previously described (Fig. 10). Epilimnetic (surface water) temperatures increased from mid-May through early August to 25ºC (77ºF), then fluctuated between 22.5 and 25ºC to 9/9 until cooling down to 13ºC (55ºF) by the end of the deployment (Fig. 10). These changes are expected and related to the daily, weekly and seasonal changes in climate/weather patterns. Hypolimnetic temperatures slowly increased from 4 to 5.6ºC (39ºF) during the deployment. In comparison to 2014, the epilimnion was slightly warmer but the hypolimnion was slightly colder in 2015 than 2014. The timing of the epilimnetic temperature change varied. The epilimnion warmed to 25ºC by early July in 2014, a month before it warmed to a similar temperature in 2015. The seasonal cooling in the fall started earlier in 2014 as well, i.e., the surface waters cooled below 10ºC by mid-September in 2014 but was two weeks later in 2015. The change probably reflected the faster onset and longer duration of the very cold winter season in 2015 than 2014.

The depth of the thermocline, the boundary between the epilimnion and hypolimnion, gradually increased through the field season from under 10 m to over 20 m. The decrease was faster during September and October reflecting the vertical mixing of surface water as it cools into the fall to deeper water with similar temperatures at depth in the water column, i.e., the gradual decay of summer stratification. It also revealed daily oscillations in response to internal seiche activity. The thermocline depth behaved in a similar manner in 2014.

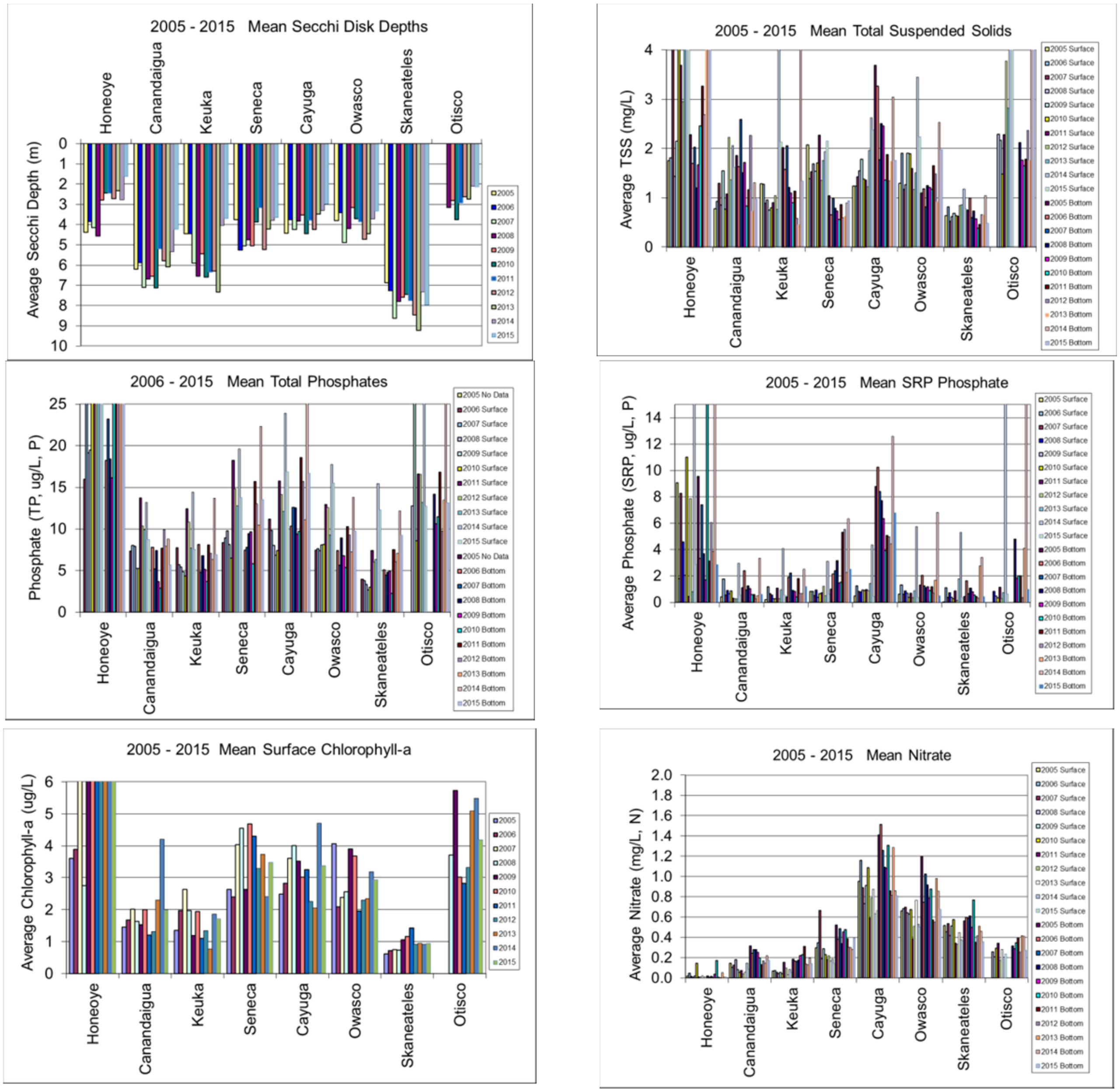

Fig. 9. Annual mean limnological data from selected Finger Lakes. When appropriate, the values for Owasco Lake utilized data from the 5-month, summer-season Finger Lakes survey.

The epilimnetic specific conductance data decreased from just over 330 μS/cm in early June by 20 μS/cm by early October and increased by ~10 μS/cm until recovery (10/26: Fig. 10). 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 mix to deeper depths in the fall. The hypolimnion salinity increased from ~340 μS/cm by 10 μS/cm from deployment to early October, then decreased by a few μS/cm until recovery. A similar trend was observed in 2014, although salinities were slightly larger in 2015 than 2014 as mentioned and consistent with the CTD results above.

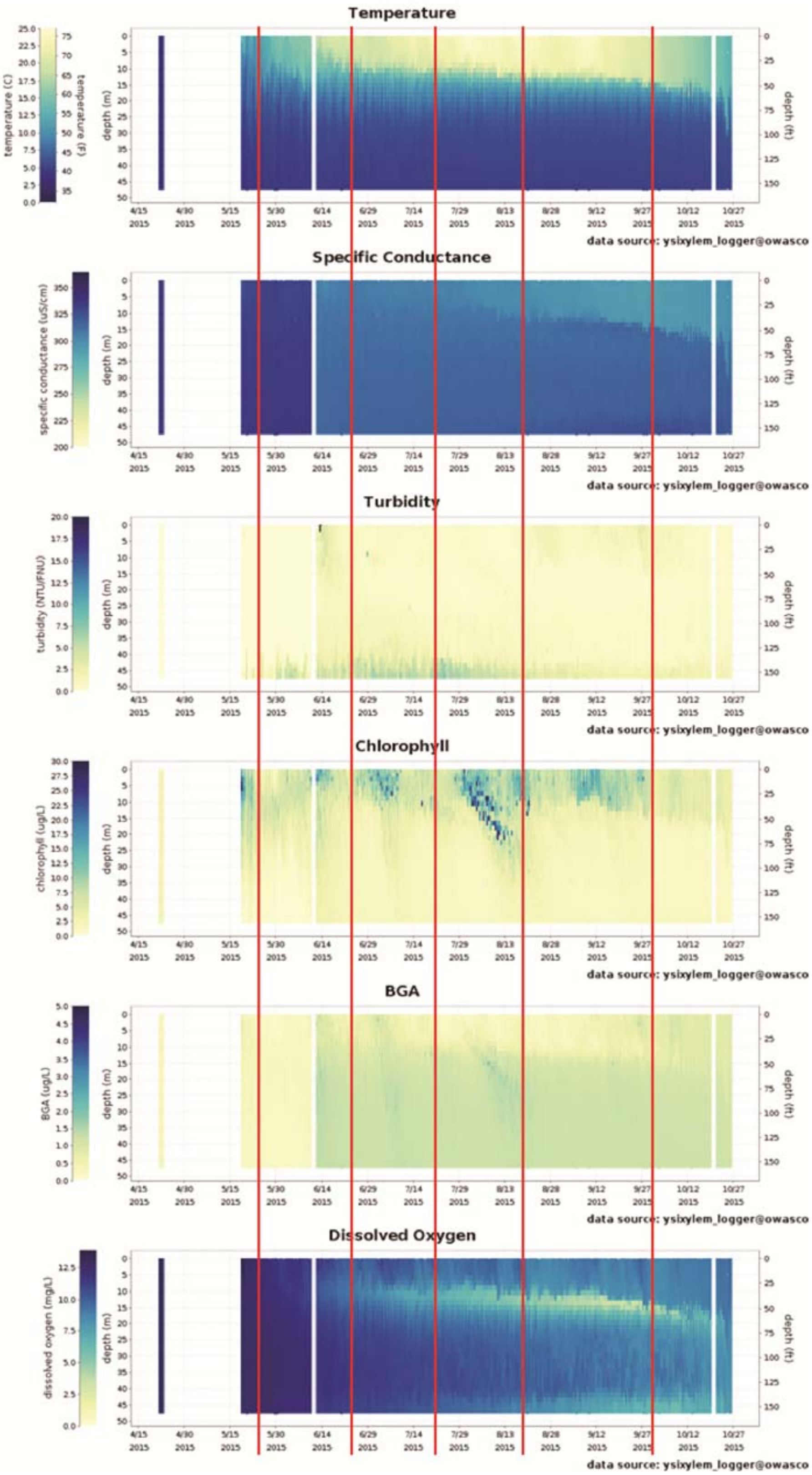

Fig. 10. Preliminary buoy data from 2015. Note, algal concentrations shown above are over-estimates. The correct concentrations should be 3.6 times smaller than shown above. The relative changes are precise. The red lines depict the monthly monitoring cruise dates.

The turbidity in the epilimnion decreased through the early spring by 2 NTUs to ~1 NTU, then increased in late August and early September to values between 2 & 3 NTUs (Fig. 10). The early spring turbidities most likely reflect the runoff from spring rains and subsequent resuspension events, whereas the late summer turbidities probably reflect the increase in algal populations, as storm and wind events were more prevalent in the early spring and declined in late August and early September. Lake floor turbidities increased through the spring and early summer to 6 NTUs and declined to 2 NTUs afterwards, again the change is interpreted to reflect the early spring rains and wind/wave resuspension events supplying suspended sediment to the nepheloid layer in the early part of the field season. In contrast, turbidities were 2 NTUs or smaller through most of the 2014 field season, suggesting a larger impact by runoff and resuspension in 2015 than 2014.

The chlorophyll-a concentrations changed significantly from ~1 to over 5 μg/L on different temporal scales (Fig. 10). One to two week long blooms with concentrations exceeding 3 μg/L were detected in mid-June, late July/early August and early September. The algae were typically concentrated within the upper 20 m of water, i.e., through the epilimnion and upper hypolimnion, however the late July bloom extended into the hypolimnion to depths of 25 to 30 meters. The June/July blooms most likely responded to the large rains and associated nutrient runoff. The September and October algae probably gained extra nutrients from the thermal decay of the season stratification, and mixing of nutrient-rich hypolimnetic waters into the epilimnion. In contrast, the CTD fluorescence and surface chlorophyll data from the monthly surveys missed the majority of the June & July blooms.

The blue green algae sensor detected an increase in BGA concentration during the June and July blooms and again during September (Fig. 10). However, BGA concentrations at the buoy never exceeded 1 μg/L, compared to the occasional nearshore concentration of over 4,000 μg/L (DEC and Watershed Inspector data, by permission). The low open-water BGA concentrations near the buoy site were confirmed by 1 μg/L and lower concentrations by a number of mid-July and early August samples collected by the Watershed Inspector and other local residents. The BGA sensor also correctly responded to calibration fluids before, during and after deployment. The discrepancy therefore reflects the surface and nearshore hugging distribution of BGA, as the buoy BGA sensor is never shallower than 1 meter and is deployed in a central, open-lake location. It suggests that the minimal response of the BGA sensor in 2014 was also due to the mid-lake deployment of the buoy.

Finally, epilimnetic dissolved oxygen (DO) concentrations were at or near saturation throughout the deployment (Fig. 10). DO concentrations in the upper hypolimnion and along the lake floor were slowly depleted during the 2015 summer stratified season until September, and then slowly rose until the end of the deployment. Specifically, DO concentrations decreased from nearly saturated concentrations in early June to 30% below saturation just below the thermocline and decreased to 45% saturation along the lake floor by the end of September just after the major algal blooms, and rose to 60% saturation by the end of the deployment. Throughout the remainder of the hypolimnion, DO was depleted to 50 to 60% saturation. The depletion reflects the respiration of algae by bacteria, zooplankton and other animals at these depths. The subsequent increase may be due to the mixing of saturated epilimnetic waters with the hypolimnion during the seasonal decay of the epilimnion in the fall. A similar pattern in DO was observed in 2014 but the depletion was more severe, i.e., 30% compared to 40%, and extended later into the fall, i.e., into September compared to into August, in 2015 than 2014.

BLUE GREEN ALGAE AND HARMFUL ALGAL BLOOMS

Owasco Lake experienced significant blue green algal blooms in 2015. Blue green algae (BGA) contain gas vacuoles that enable them to float at or near the surface of a lake, whereas, other algae live at deeper depths, and out of sight of humans in boats or onshore. The resulting surface-water scum of BGA is unsightly and smells. BGA do this to outcompete other algal species for available light. The scum does not remain at the surface in the open water. During the day, their photosynthesis of carbohydrates during the day forces BGA sink out of sight by mid-day. Subsequent BGA respire, consume carbohydrates, and generate gas, and BGA buoyantly rise to the surface by early morning. In the nearshore, sinking BGA accumulate at the lake floor, thus continuing to degrade water quality during the day.

Some BGA species can "fix" atmosphere nitrogen (N_2) for their source of nitrogen, whereas most other forms of algae including some forms of BGA cannot "fix" N_2 and are instead dependent on the dissolved forms of nitrogen like nitrate (NO_3^-) to photosynthesize organic matter. Fixing nitrogen provides fixers an ecological edge in nitrogen-starved lakes like Honeoye. Nitrogen starvation is not a concern in Owasco Lake. BGA disrupt food chain dynamics, because they are avoided, i.e., preferentially not eaten, by zooplankton and fish.

Most importantly, some species of BGA produce toxins. Those that can produce toxins do not synthesize the toxins all the time. When they do, they are called harmful algal blooms (HABs). Thus BGAs are health threats to humans and other warm blooded animals. Different toxins impact the liver, nervous, and/or gastrointestinal systems. 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 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[2]. No federal regulatory standards or guidelines for cyanobacteria (BGA) or their toxins exist in drinking water in the US. The NYS DEC refers to the WHO guideline but has yet to set a firm concentration threshold.

Blue green algae have always been detected in the plankton community since the earliest FLI surveys in 2005, but only as a small percentage of the plankton community. This has recently changed. Since 2012, BGAs and HABs populations have increased[3]. The number of DEC confirmed BGA occurrences in Owasco Lake 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 2015 (7/10 – 10/16). The past two years detected the largest concentrations of BGAs and HABs as well, up to 1,100 μg/L in 2014 and over 4,500 μg/L in 2015 with toxin concentrations exceeding 1,000 μg/L (Fig. 11). To date, the public water supplies have managed to block the impact of the BGAs and HABs from their delivery of clean drinking water. Lakeshore residents

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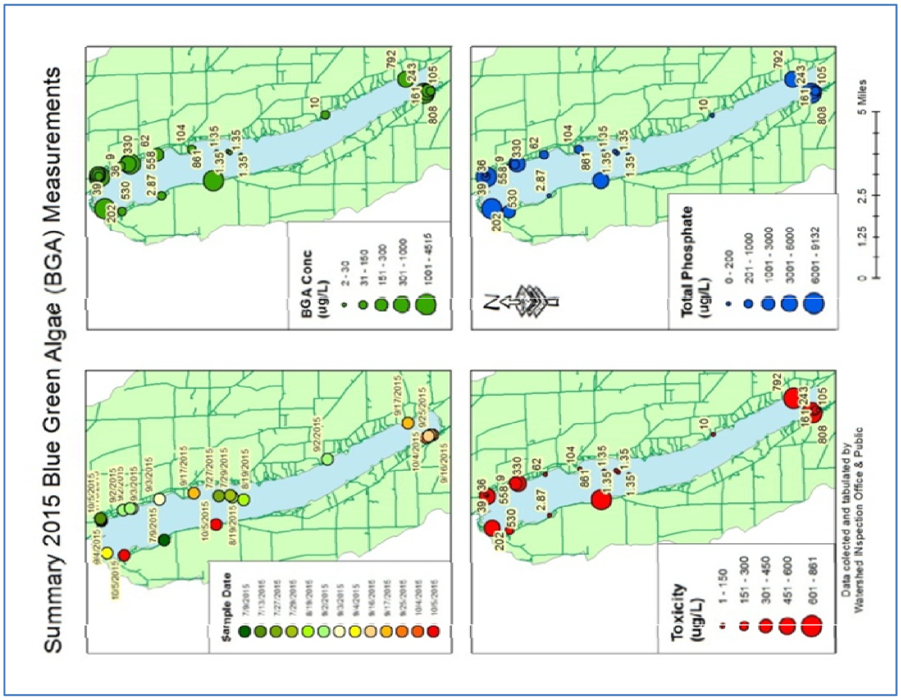
[2] WHO, 2011. Guidelines for Drinking Water Quality. 4th Edition. World Health Organization. Switzerland.

[3] http://www.dec.ny.gov/chemical/83332.html

however should make sure their private water systems can cope with removing BGAs from the drinking water. It is not easy[4].



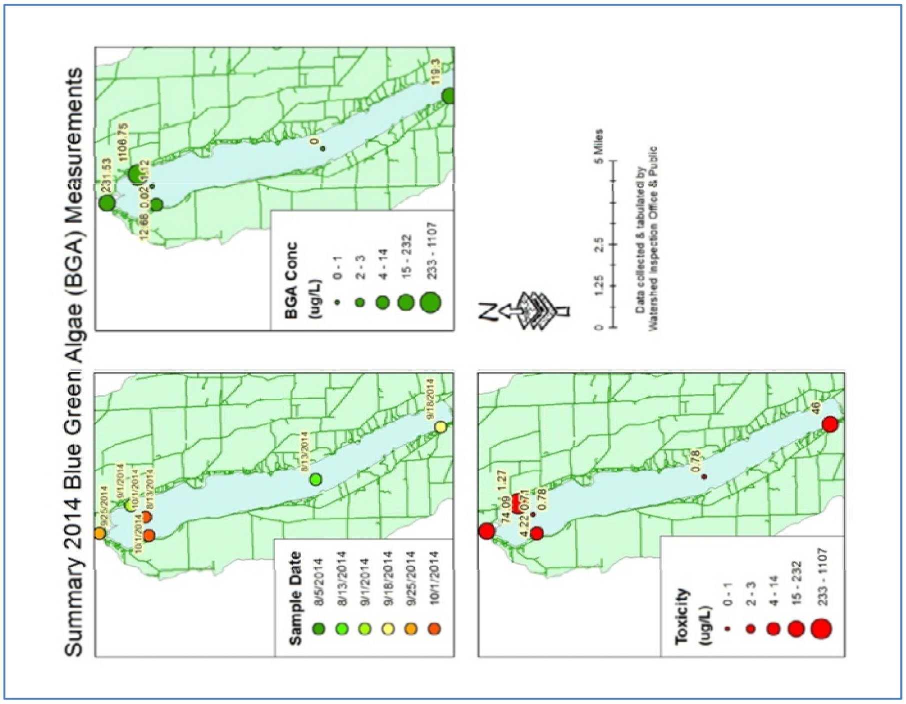


Fig. 11. Maps of the BGA bloom dates, and concentrations of BGA, toxins and total phosphates (data from the Owasco Lake Watershed Inspector & DEC, with permission).

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

A few generalizations can be gleaned from the 2014 & 2015 data (reproduced by permission, Watershed Inspector's Office and Scott Kishbaugh, DEC). The BGA blooms started in August and persisted until October in 2014, but started earlier (July) and persisted later into October in 2015. In both years, BGA blooms were detected around the lake without any noticeable spatial or temporal pattern except that they were concentrated along the shoreline, and sparse in the open water. BGA concentrations ranged from below 1 to over 4,500 μg/L, the larger values in both years during September and into early October during 2015. Toxin concentrations ranged from undetected to over 1,000 μg/L in the nearshore samples, and remained at or below 1 μg/L in the open lake. The total phosphorus concentrations in these blooms ranged from 0 to over 9,000 μg/L in 2015. Strong correlations were observed between BGA concentrations and toxicity ($r^2 = 0.6$), and BGA concentrations and total phosphate concentrations ($r^2 = 0.6$).

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 stimulants by 1,000 times. An alternative means to increase the concentration of something is to decrease the volume of water surrounding that something.

Natural mechanisms to accomplish a reduction in volume are available. Perhaps an open-water bloom was corralled against the shoreline by a light wind into a smaller area. Once against the shoreline, the lake floor would also restrict the bloom's depth and thus restrict/reduce the blooms volume of water. A bloom's depth would also decrease when it buoyantly accumulates at the surface in the early morning hours. Accurate wind speed and direction data along with depth profiles of BGA concentrations during the formation of the bloom is 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.

Potential hypotheses on the timing and occurrence of the BGA blooms can be tested with the available buoy meteorological and water quality data. Scientists believe that BGA blooms prefer:

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

However, predicting their occurrence is a challenge for scientists due to the large number of BGA species and the diversity of their habitats. The complexity turns the prediction game problematic. Lake specific criteria may be more attainable, however.

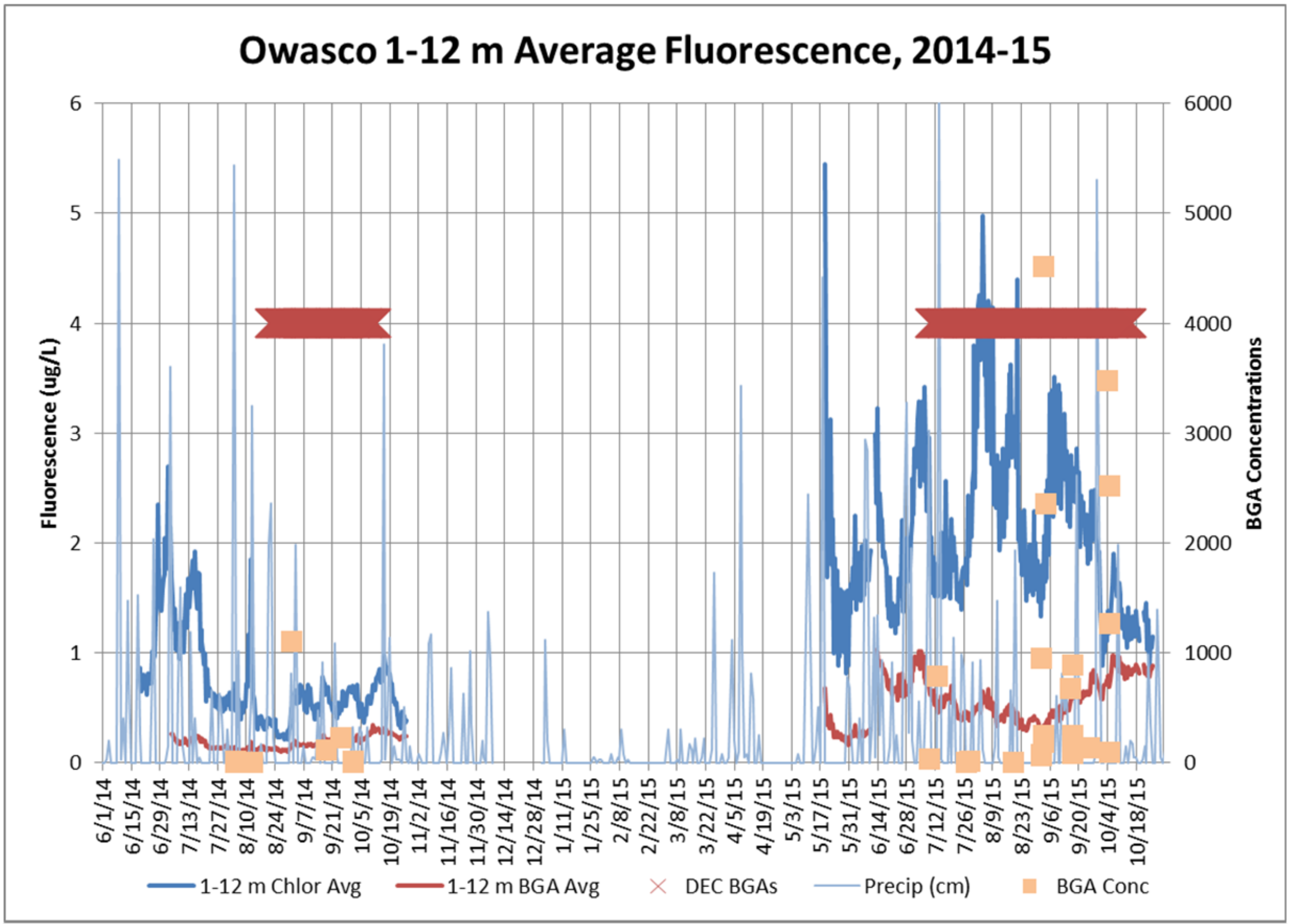
The last two years of buoy data shed some light on the occurrence and development of BGA blooms in Owasco Lake (Fig. 12). These figures plot mean epilimnetic total algal and BGA fluorescence, surface, average and bottom water temperature, mean daily air temperature, mean daily available sunlight, and mean daily wind speed through 2014 and 2015. The weeks Owasco Lake was listed on the DEC website for BGA occurrence, the algal 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 were superimposed on the buoy data to look for any obvious correlations.

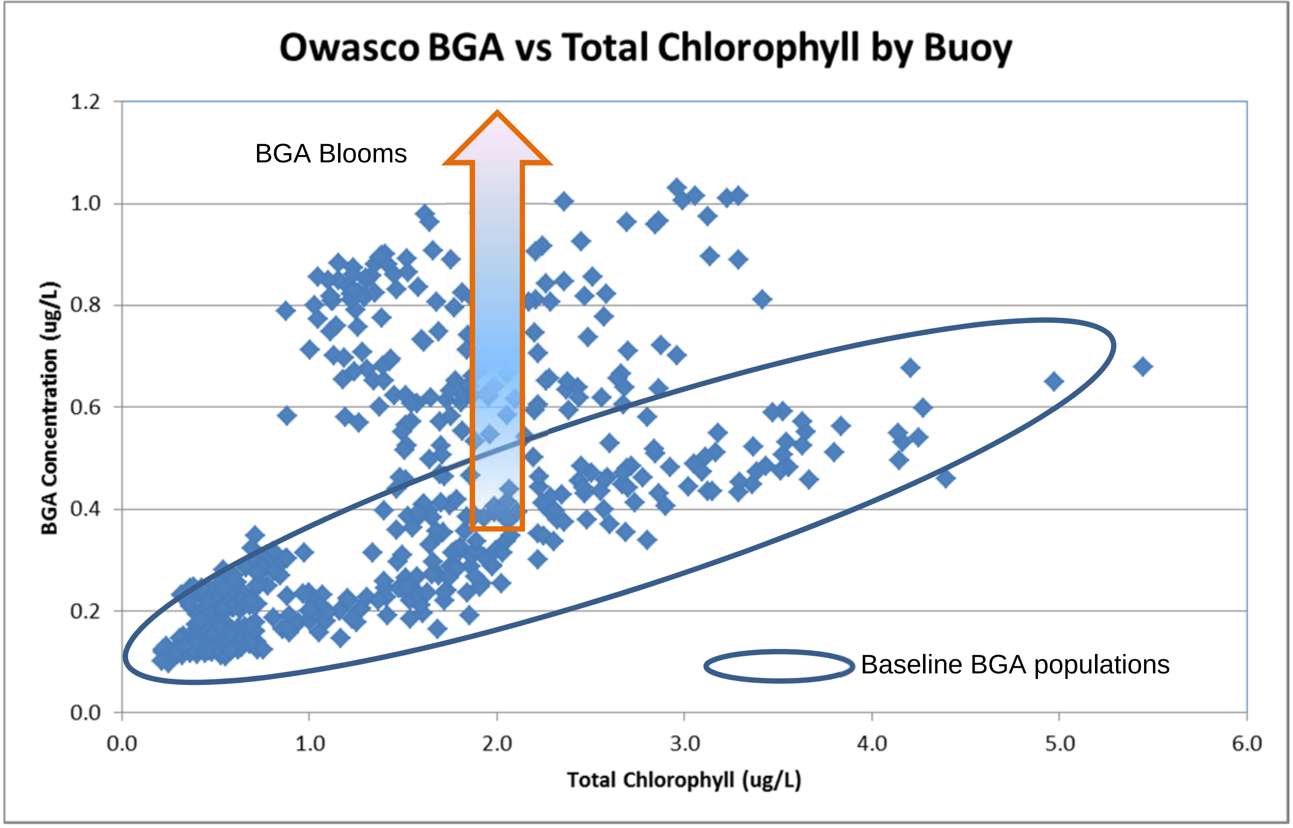
Buoy Total Algae and BGA Fluorescence: Minimal correlations are observed between the buoy fluorescence data and the BGA occurrence and concentration data (Fig. 12). The lack of a correlation is not disturbing though because the buoy measures open water parameters, and the bulk of the BGA data was from nearshore locations. Two additional trends are worth noting though. The buoy detected more algae in the lake, both larger bloom concentrations and more frequent blooms, in 2015 than 2014. Thus, lake conditions in 2015 was more favorable for algal and BGA growth than 2014. Interestingly, baseline BGA concentrations are proportional to total chlorophyll (Fig. 12). It suggests that BGA species are always in the plankton population in a low (~10% of total plankton) percents waiting for the “ideal” stimulus (or stimuli) to bloom. Data points that extend above the baseline correlation to larger BGA concentrations, i.e., BGA dominated populations are potential open water blooms.

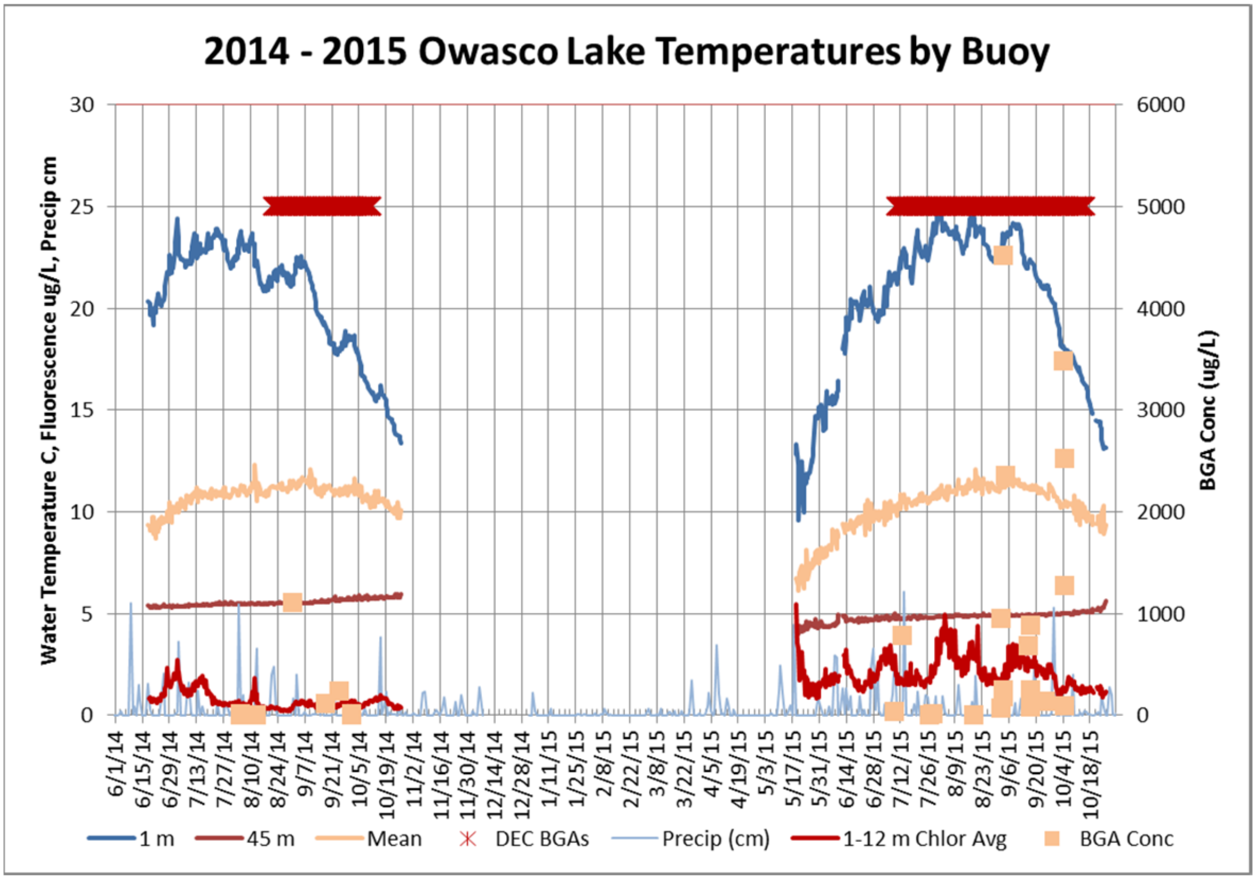
Lake Temperature: BGA blooms started at the end of the warmest surface waters in 2014, and at the beginning of the warmest (>23°C) surface waters in 2015 (Fig. 12). In both years, they continued until the surface water cooled below 15°C. A mean water column temperature, revealing the strength of thermal stratification, does not appear to correlate with the timing of BGA data as well. It suggests that water temperature alone does NOT trigger the onset of a bloom. The lake only needs to be warm enough so another forcing function (or functions) can trigger each bloom. Cold water, below 15°C, appears to terminate BGA blooms.

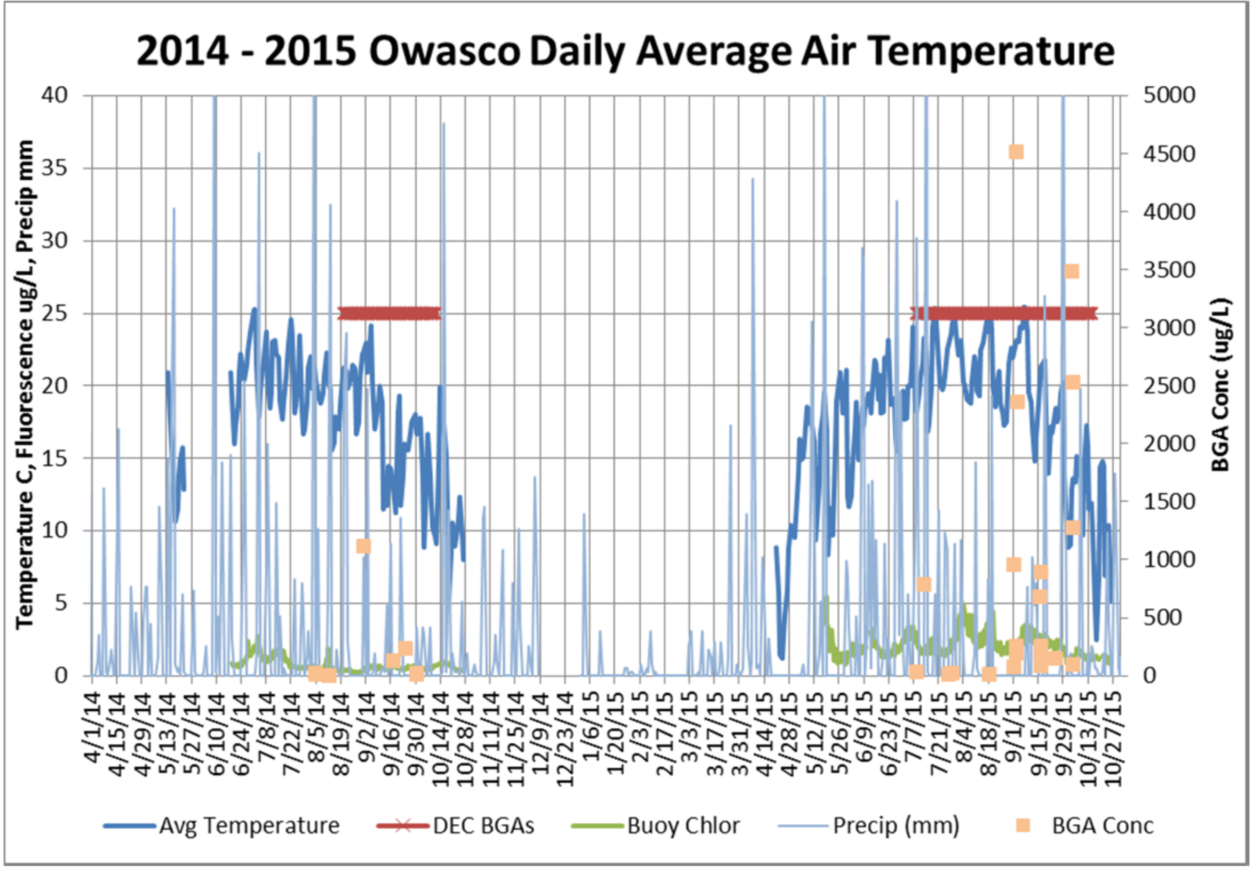
Air Temperatures: Like water temperatures, the BGA blooms started at the end of the warmest air temperatures in 2014, but near the beginning of the warmest air temperatures in 2015 (Fig. 12). Blooms ended when the air temperature cooled below 10°C. Thus, warmer air does not trigger blooms but cold air is consistent with cold water which terminates bloom activity.

Available Sunlight: Sunlight intensity reflects the day/night daily cycle, and is modulated on the short-term by the extent of cloud cover during any given day and over the long term by the sun’s seasonal position in the sky. The BGA blooms always started after the peak insolation, i.e., after summer solstice, and end when daily average insolation (sunlight) decreases below 150 $\mu E/cm^2$ (Fig. 12). Perhaps BGA outcompete other algae in periods of lower light because they can float closer to the surface. The shoreline BGA concentration data suggest that BGA blooms happen a day or two after cloudy/drizzly/rainy weather when clear, sunlit, skies reappear. Perhaps the rain and its associated runoff brought in nutrients to help stimulate the bloom during the following sunny days. Moreover, the declining light and associated cooling and decay of the epilimnion mix nutrient-rich hypolimnetic waters to the surface, and thus provide another means to stimulate BGA blooms.


Owasco 1-12 m Average Fluorescence, 2014-15


Owasco BGA vs Total Chlorophyll by Buoy


2014 - 2015 Owasco Lake Temperatures by Buoy
Water Temperature C, Fluorescence ug/L, Precip cm
BGA Conc (ug/L)
0
5
10
15
20
25
30
0
1000
2000
3000
4000
5000
6000
6/1/14
6/15/14
6/29/14
7/13/14
7/27/14
8/10/14
8/24/14
9/7/14
9/21/14
10/5/14
10/19/14
11/2/14
11/16/14
11/30/14
12/14/14
12/28/14
1/11/15
1/25/15
2/8/15
2/22/15
3/8/15
3/22/15
4/5/15
4/19/15
5/3/15
5/17/15
5/31/15
6/14/15
6/28/15
7/12/15
7/26/15
8/9/15
8/23/15
9/6/15
9/20/15
10/4/15
10/18/15
1 m
45 m
Mean
DEC BGAs
Precip (cm)
1-12 m Chlor Avg
BGA Conc


2014 - 2015 Owasco Daily Average Air Temperature
Temperature C, Fluorescence ug/L, Precip mm
BGA Conc (ug/L)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
4/1/14
4/15/14
4/29/14
5/13/14
5/27/14
6/10/14
6/24/14
7/8/14
7/22/14
8/5/14
8/19/14
9/2/14
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9/30/14
10/14/14
10/28/14
11/11/14
11/25/14
12/9/14
12/23/14
1/6/15
1/20/15
2/3/15
2/17/15
3/3/15
3/17/15
3/31/15
4/14/15
4/28/15
5/12/15
5/26/15
6/9/15
6/23/15
7/7/15
7/21/15
8/4/15
8/18/15
9/1/15
9/15/15
9/29/15
10/13/15
10/27/15
Avg Temperature
DEC BGAs
Buoy Chlor
Precip (mm)
BGA Conc

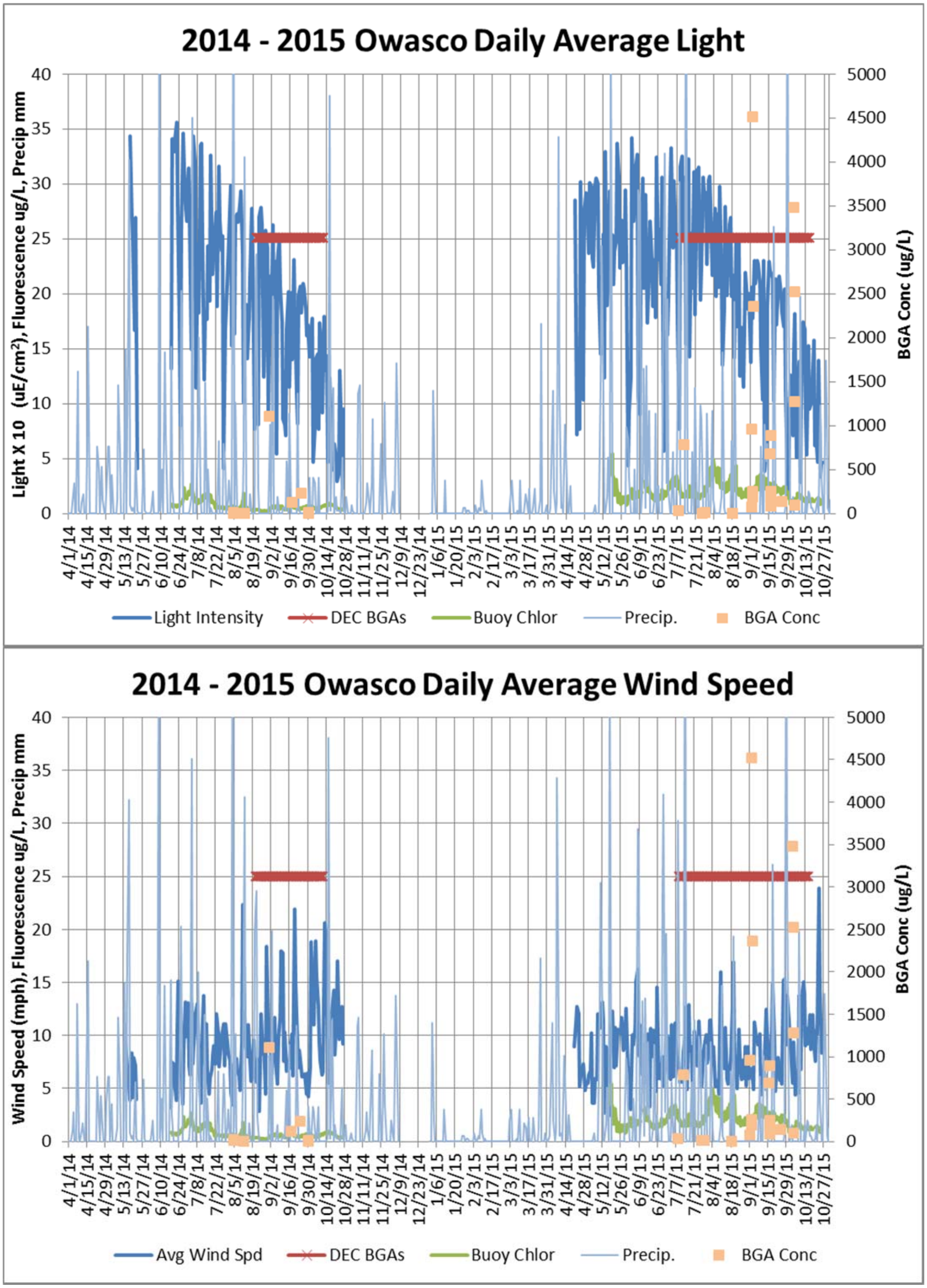

Fig. 12. Average daily total fluorescence, blue green algae fluorescence, water temperature, air temperature, light intensity (sunlight) and wind speed from the Owasco Monitoring Buoy vs measured BGA parameters.

Rainfall: In both years, BGA blooms dominated during a dry spell after a period of rainfall (Fig. 12). It suggests that the rainfall and associated runoff brought in sufficient nutrients to stimulate a bloom, and "waited" for the subsequent sunny day and required light to bloom.

Wind Speed: 2015 was not as windy as 2014, especially when BGA blooms were detected (Fig. 12). The wind speed in 2015 was at or below 10 mph with only a few days with wind speeds above 15 mph (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 is more likely during calm to light-breeze days, and larger wind speeds retarded BGA blooms. Alternatively, the larger winds turbulently mixed the BGA away from the shoreline and into deeper water, and out of sight thus undetected by humans. It probably also mixed the BGA into a larger volume of water, thus decreasing its concentration.

Summary: The available buoy derived water quality and meteorological data suggest that BGA blooms occur between the summer solstice and a few weeks after the fall equinox during or just after the warmest water temperatures (>23ºC). They favor periods of calm or nearly calm weather. A recent runoff event and associated nutrient loads typically precedes each bloom. The decay of the epilimnion in the fall season can also bring hypolimnetic nutrients to the lake's surface and stimulate bloom growth. It would be interesting to see if they persist as controls of BGA blooms in Owasco Lake in future years.

All of these observations/correlations are tentative at this time but it is a start. These factors are coincident with BGA blooms but coincidence does not mean causation. These associations also lack a unique event to trigger the large blooms detected in 2014 and 2015 as previous summers also experienced calm days with some rain and sun near the end of the summer. More importantly, do not lose the larger focus here. We must strive to eliminate the blooms and not just predict when they may occur. The ultimate means to limit any algae bloom is to limit nutrients in the watershed.

STREAM MONITORING RESULTS & DISCUSSION

Stream Discharge: Stream discharge data in 2015 from the four survey dates in 2015 ranged from nearly dry (0.00) conditions at Fire Lane 20 to 8.4 m^3/s along Owasco Inlet at Moravia (Table 6 in appendix, Fig. 13). The measured weekly discharge data at Dutch Hollow Brook ranged from 0.02 to 3.29, with a mean of 0.99 m^3/s at 38A, ranged from 0.02 to 3.62, with a mean of 0.91 at Martin Rd, and 0.00 to 3.95, and a mean of 0.92 m^3/s at North St. These flows revealed a typical seasonal variability but a larger annual mean than previous years.

Spatial patterns in discharge were consistent over time. Mean and individual discharge measurements were larger at those sites with a larger drainage basin upstream from the site on any given sample day in 2015 (Fig. 14, $r^2 = 0.95$). 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 5.0, 1.2, 2.3, 0.8 and 0.6 m^3/s, respectively. Discharge was always larger at successively downstream sites along Owasco Inlet but occasionally not true for Dutch Hollow Brook.

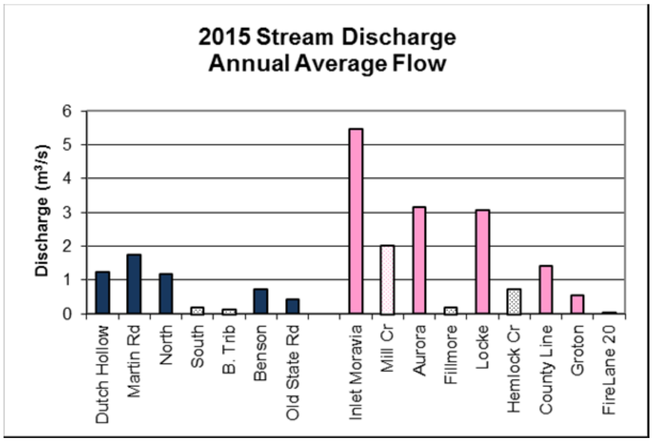

Fig. 13. Annual average stream discharge at each stream site in the Dutch Hollow Brook (purple), Owasco Inlet (pink) and Fire Lane 20 watersheds based on the 4 grab sample survey dates. Tributary sites are stippled. Sites are arranged, left to right, from downstream to upstream.

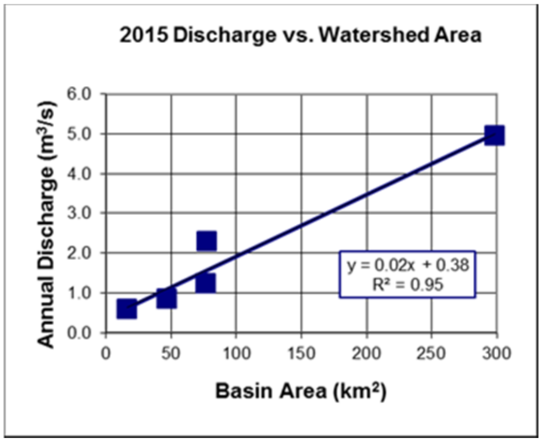

Fig. 14. Discharge vs. Basin Size.

Within Dutch Hollow Brook, mean annual discharge at each downstream 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 from North St and farther upstream. For example, the sum of the mean annual discharge at North St was similar to the sum of the discharges at South, Benson, Lacy Tributaries and Benson Rd sites. However, the segment analysis / grab sample mean discharge data suggests that the downstream 38A site had a smaller mean discharge than Martin Rd. In contrast, 38A had a larger discharge than Martin Rd 75% of the time but discharge from North St to Martin Rd increased only 67% of the time based on the weekly discharge data (Fig. 15). More importantly, discharge at Rt 38A was only larger than Martin Rd and North St during events. It suggests that surface runoff persistently contributes to and increases stream discharge during events from North down to Rt 38A. In contrast, the discharge at Martin Rd was larger than North St during base flow, and thus groundwater contributes to the stream between North St and Martin Rd. Adding to the complexity, stream water must infiltrate into the ground farther downstream, i.e., into the deltaic sands and gravels downstream of Martin Rd towards Rt 38A during base flow. The difference between the grab samples and the weekly data discharge is because grab samples focused on base flow not event flow.

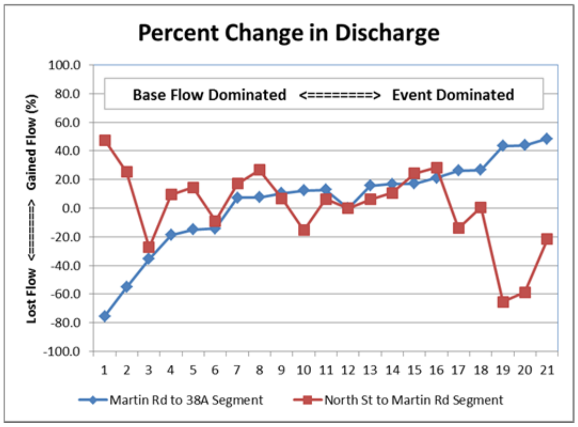

Fig. 15. The percent change in discharge from North to Martin and Martin to 38A along Dutch Hollow Brook.

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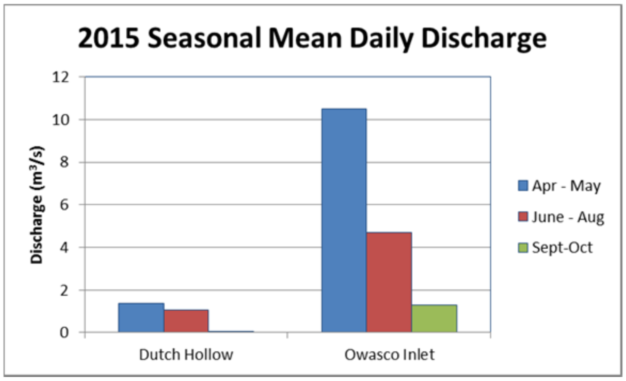
Within Owasco Inlet, tributary inputs typically accounted for the observed downstream increases in discharge. For example, the discharge did not significantly change along the main stream sites lacking tributaries; whereas, the mean discharge at the downstream Locke site was close to the sum of the mean discharge upstream of Locke and Hemlock Creek. The discharge at Moravia (at Rt 38) was nearly equal to the combined discharge at Mill Creek, a tributary to Owasco Inlet, and at Aurora St, the next upstream site. Tributary inputs, discharge by the Groton Wastewater Treatment Facility, and/or groundwater inputs probably controls the increase from Groton to County Line, and County Line to Locke.

Seasonal Variability: Using the weekly discharge data for Dutch Hollow at the Rt 38A site and the USGS gauge data for Owasco Inlet, the largest discharges of 2015 were detected in the spring and smallest in the fall (Fig. 16). The spring dominance in flow was also detected in previous years and the seasonal pattern always paralleled the seasonal change in precipitation and evapotranspiration (Fig. 17).



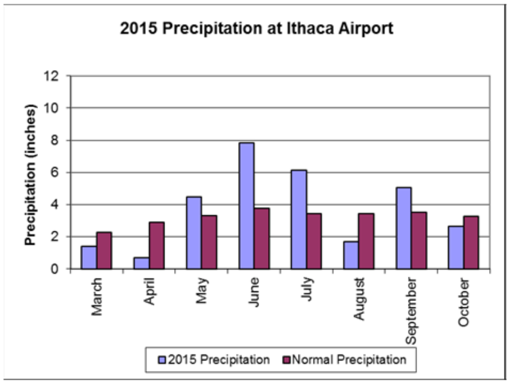
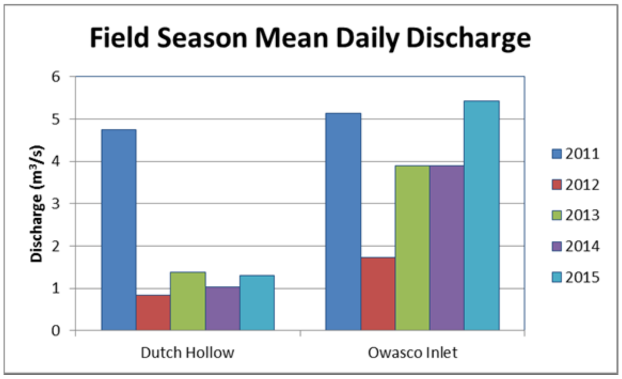


Fig. 16. Seasonal averaged stream discharge for the Rts. 38A and 38 sites, the terminal sites on Dutch Hollow Brook and Owasco Inlet, respectively.

Fig 17. Monthly 2015 and "normal" precipitation totals for the Ithaca Airport.

Differences to Earlier Years: 2015 detected the largest discharges since 2011 (Fig. 18). However, this simple comparison is misleading, because some years had more sample dates than other years, and the distribution of dates within any one year was not uniform across the year. These differences are explained by parallel changes in precipitation. The 2011, the 8-month, field season, precipitation total was very close to normal measured at Ithaca Airport (Fig. 19). In contrast, 2012 was 12 inches below normal, thus it was relatively dry year, and 2013 and 2014 were in between these two extremes. 2015 had more rainfall than the preceding three years. It designates 2013 and 2014 as the "in between" years, 2011 and 2015 as the "wet" years, and 2012 as the "dry" year. Thus, major differences in discharge paralleled changes in precipitation.



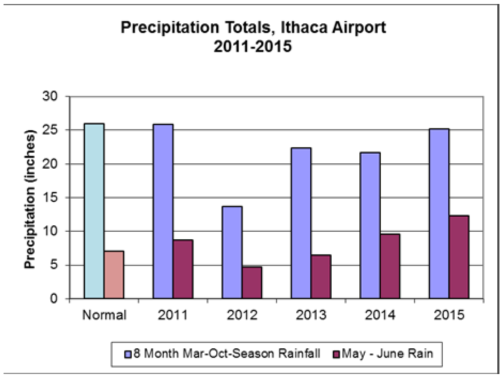


Fig. 18. Field season average stream discharge for the Rts. 38A and 38 sites. This plot used the estimated Dutch Hollow and daily Owasco Inlet discharge data.

Fig. 19. Annual precipitation totals during the 8-month, March – October, field season, and during May & June at the Ithaca Airport.

These differences are most concerning when a larger amount of the annual rainfall falls during May and April. This time period is when runoff and soil erosion potential is largest due to saturated and typically unplanted/bare landscapes. Note that what are called “wet” years in this report are climatologically “normal” years to a meteorologist.

The Owasco Inlet (USGS Gauge, 4235299) field-season, annual discharge of 5.4 m^3/s revealed a “wet” year for 2015 compared to 5.7, 3.0, 4.6 and 3.8 m^3/s in 2011, 2012, 2013 and 2014, respectively (Fig. 20). 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 and 9.2 m^3/s for 2011 through 2015, respectively. Clearly, 2013 and 2014 were “in between” and perhaps more typical for Owasco Lake compared to the 2011 and 2015 “wet”, and 2012 “dry” years.

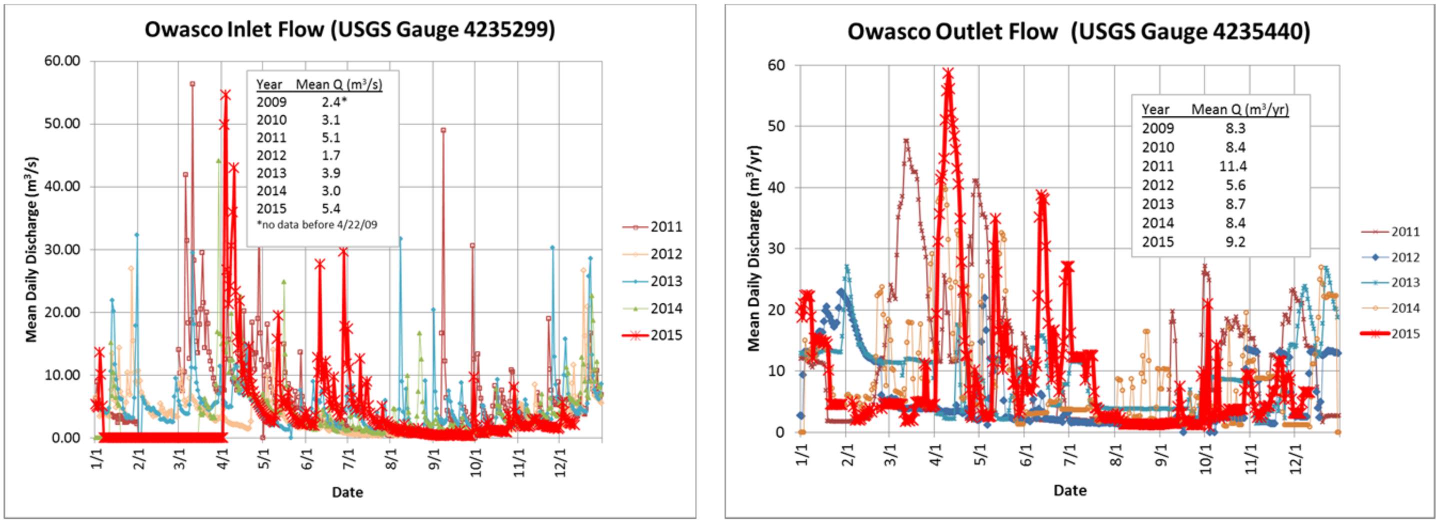


Fig. 20. Annual average stream discharge for the Owasco Inlet near Moravia – USGS Stream Gauge 4235299 and the Owasco Outlet – USGS Stream Gauge 4235440.

Stream Concentration Data: Total phosphate (TP) concentrations in 2015 ranged from 7 to nearly 39 μg/L, and averaged 17 μg/L in Dutch Hollow Brook, and ranged from 6 to 28 μg/L, and averaged 16 μg/L in Owasco Inlet (Table 6 in appendix, Fig. 21). Along Dutch Hollow Brook, the 38A, North, South, Benson Rd and Benton Rd tributary sites revealed the largest annual mean TP concentrations of ~17 to 20 μg/L, whereas the Martin Rd and Old State Rd sites revealed slightly smaller mean TP concentrations (14 μg/L). Of note, the Benson tributary did not have the largest TP concentration as in pre-2014 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. It may also mean that the heavy rains in 2014 and 2015 flushed out the bulk of the easily erodible soils from the susceptible parts of the watershed and thus minimized the differences between specific sites in the watershed in 2015.

Total suspended sediment (TSS) concentrations were also largest at the 38A, Martin, North, Benson Rd and Old State Rd sites. The agriculturally-rich tributaries, South and Benson Rd tributaries, were lowest. A notable change in TSS from North St to Rt 38A, was also not observed in 2015 as in pre-2014 years. It suggests that agricultural BMPs are decreasing runoff in this watershed or the easily erodible materials were already flushed.

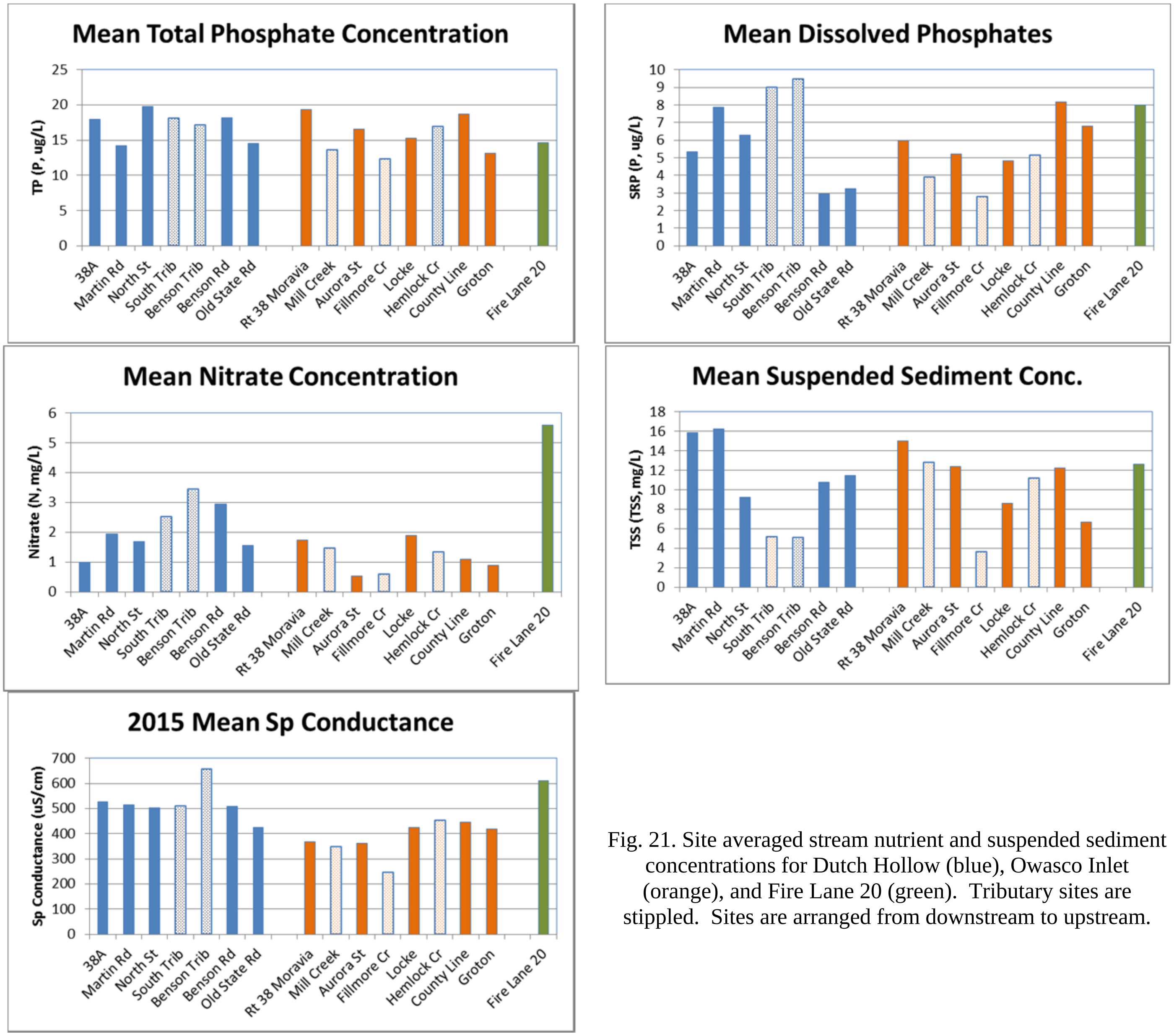


Fig. 21. Site averaged stream nutrient and suspended sediment concentrations for Dutch Hollow (blue), Owasco Inlet (orange), and Fire Lane 20 (green). Tributary sites are stippled. Sites are arranged from downstream to upstream.

Elevated dissolved phosphate (SRP), nitrate and specific conductance (salinity) concentrations were detected at the South and Benson tributary sites compared to the other sites but the difference was much less than earlier years. This data suggests that the agricultural impact on these tributaries was less noticeable.

Along the Owasco Inlet, measured concentrations were only slightly smaller but less variable than 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 increase between Groton and County Line. The TP and SRP concentrations were 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, other than Fillmore Creek had the smallest concentrations.

Fire Lane 20 was first sampled in 2012, and sampled every year since. It revealed the largest salinities and nitrate concentrations but similar TSS, TP and SRP concentrations than as other sites. It appears that the agricultural impact on this watershed by the spreading of manure has decreased in 2015 compared to earlier years, or the easily eroded materials were already flushed.

Stream Fluxes: Owasco Inlet revealed larger fluxes of nutrients and sediments than Dutch Hollow Brook (TP 8.3 vs. 1.9 kg/day; SRP 2.6 vs. 0.6 kg/day; TSS 6,400 vs. 1,700 kg/day; N 750 vs. 100 kg/day, respectively, Fig. 22). Similar concentrations of nutrients and sediments, 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 are sensitive to discharge and basin size.

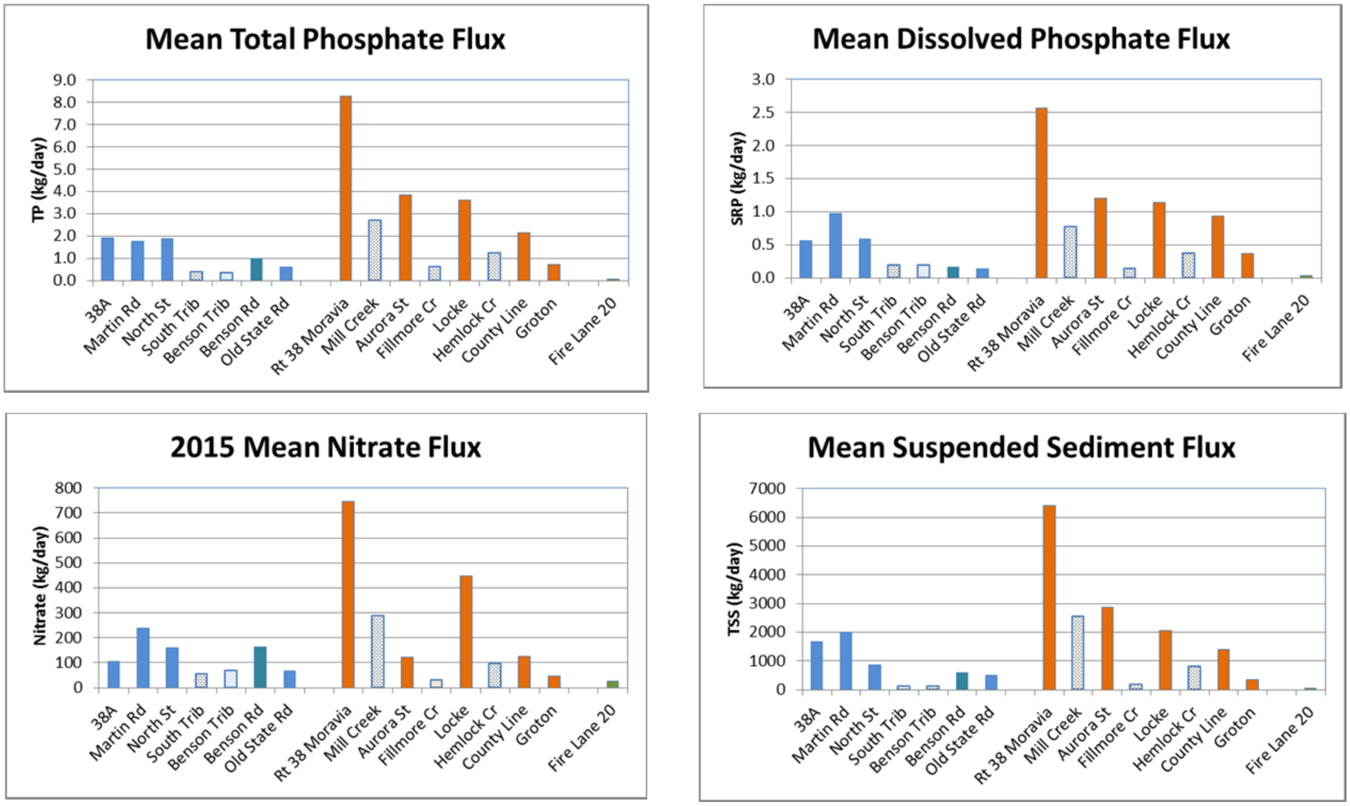


Fig. 22. Site averaged nutrient and sediment fluxes for Dutch Hollow (blue), Owasco Inlet (orange), and Fire Lane 20 (green). Tributary sites are stippled. Sites are arranged from downstream to upstream.

At the small end of the spectrum, fluxes at the Dutch Hollow Brook tributary sites (Benson and South sites) and Fire Lane 20 site 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. If these tributaries have similar TP loads as Fire Lane 20, then the combined TP load by all these small tributaries would be comparable to the load from Dutch Hollow Brook.

The Martin Rd site along Dutch Hollow Brook revealed a significantly larger, annual mean, grab-sample fluxes than any other segment (Fig. 22). The North St mean fluxes are similar to the fluxes at Rt 38A. The difference is related to the larger grab-sample discharges measured at

Martin Rd, because grad sample dates were primarily detecting base flow conditions. The discharge data suggest that water and perhaps dissolved materials were lost to the groundwater between Martin Rd and Rt 38A sites, especially into the deltaic gravels and sands just upstream from the Rt 38A site.

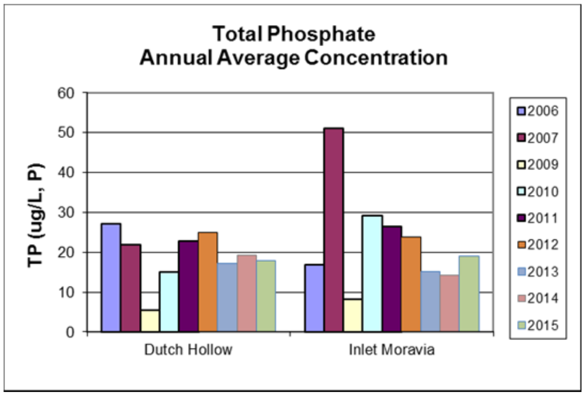
Otherwise, nutrient fluxes steadily increased from the headwaters to the North St site. No one tributary added a significantly larger flux of nutrients either. Thus, no one segment of this stream was the “primary” source of nutrients and sediments. Instead, Dutch Hollow Brook steadily gained nutrients along its entire course, a conclusion consistent with the pervasive nature of non-point sources throughout the watershed, and the drainage of agricultural land, animal feedlot operations, golf courses, suburban homes and other non-point sources of nutrients. 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.

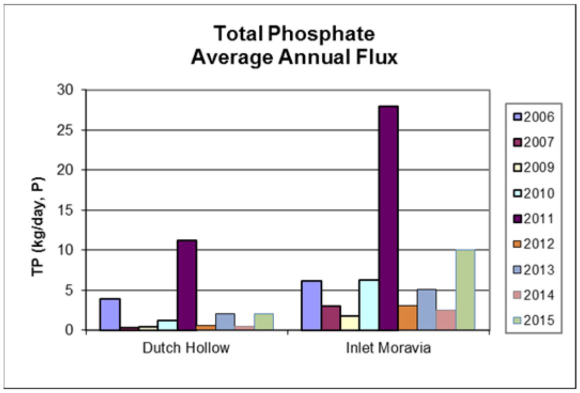
The Owasco Inlet fluxes increased downstream in a predictable manner and revealed similar patterns as earlier years (Fig. 22). The input by adjacent tributaries typically account for the increases in flux from one site to the next. Both point and non-point sources of nutrients were detected but were less noticeable in the Owasco Inlet watershed in 2015 compared to previous years. Increases in phosphate were still apparent from the Groton wastewater treatment facility but their contribution to the total load was significantly smaller than earlier years. The Moravia WWTF does not appear to add significant loads to the Inlet. The high flows in 2015 may have masked specific point sources.

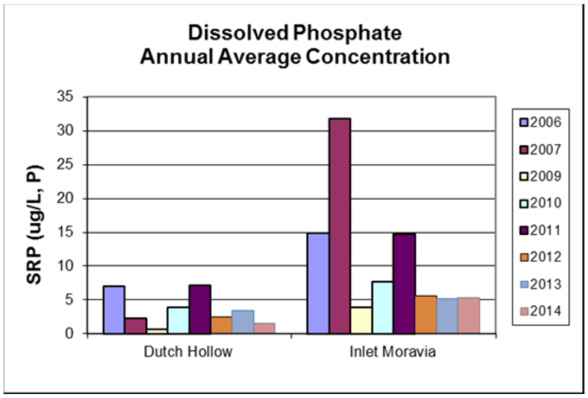
Seasonal and Longer-Term Variability: Seasonal change cannot be assessed with the 2015 early summer dataset. Annual average data reveal changes from one year to the next that are consistent with changes in precipitation (Fig. 23).

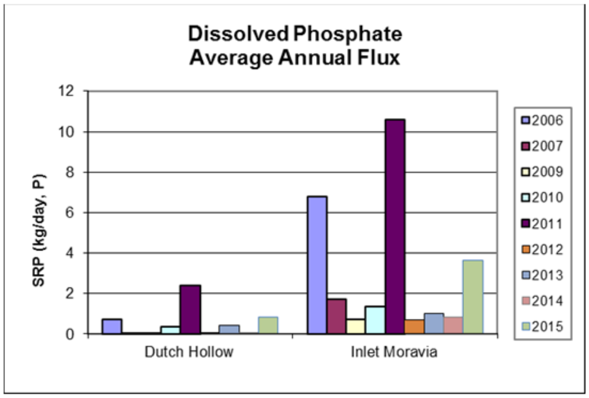
EVENT SAMPLING ALONG DUTCH HOLLOW BROOK

Detailed Stage Data @ 38A along Dutch Hollow Brook: This year was tough on the instrumentation. The CTD's DO sensor needed repairs, two Marsh-McBirney stream flow velocity meters broke, handheld conductivity, DO and pH meters required care, an automated water sampler required repairs, and four of the five stage/conductivity/temperature data loggers malfunctioned during deployment. The data in the failed loggers, that were essential for the detailed flux calculations, were not recoverable. To overcome this loss of data, stage data from the Martin Rd site and its stage/discharge correlation was extrapolated to North St and 38A sites, the other two sites with automated water samplers. The extrapolation utilized the proportional relationship between the measured weekly stream discharge data collected at each site. This methodology requires a word of caution. The results and more importantly any comparison between sites might be biased by the proportional extrapolation. Finally, the array of three autosamplers along Dutch Hollow Brook was designed to determine the effectiveness of BMPs along the meandering section of the stream to retard streambank erosion. Unfortunately, funding to build the BMPs never materialized in time for the 2015 field season and thus the BMPs were not installed. The sample array was kept in place though because it could still investigate the variability in nutrient and sediment delivery along this stream segment.









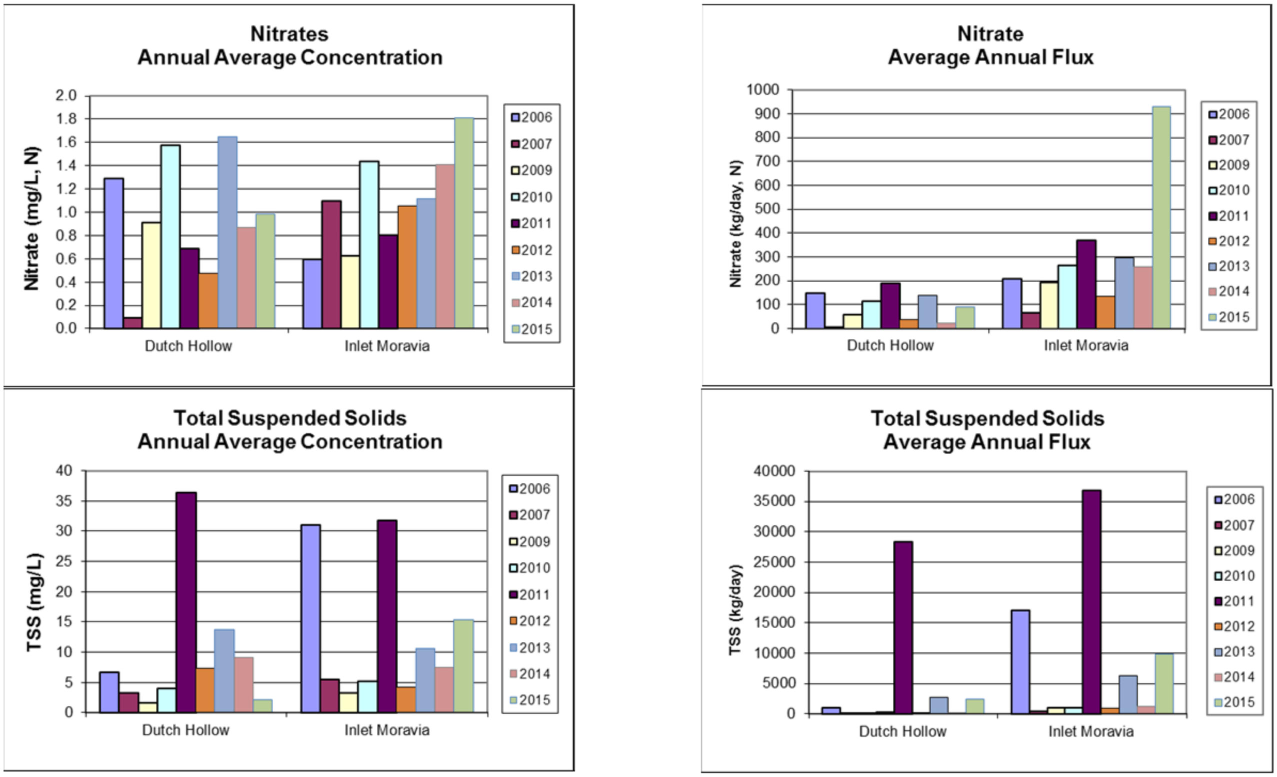


Fig. 23. Annual average concentrations (left) and fluxes (right).

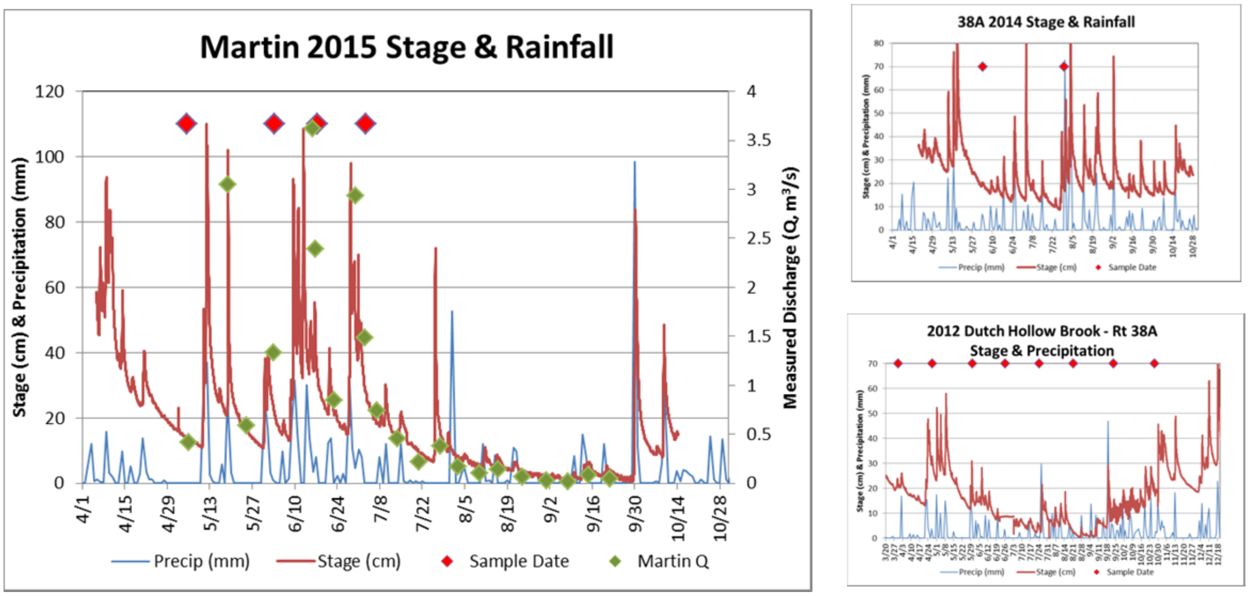


Fig. 24. Dutch Hollow Brook data logger stage, precipitation, sample dates and measured discharge data, 2015 Martin Rd data left; Rt 38A 2014 and 2012 data, right. Precipitation data was from NY-CY-8, a station within the watershed, part of the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS).

The 2015 Martin Rd stage data revealed textbook responses to precipitation events (Fig. 24). Each increase in stage corresponded to a precipitation event. The increase in stage for each 2015 event was from 5 to more than 100 cm, larger than the increases observed in the past four years. 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 (Figs. 25 & 26).

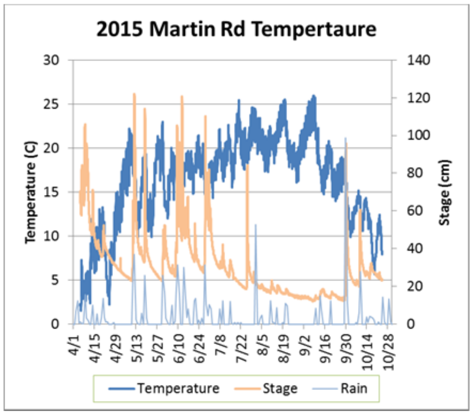


Fig. 25. Data logger water temperature data. The seasonal cold to warm to cold cycle prevails.

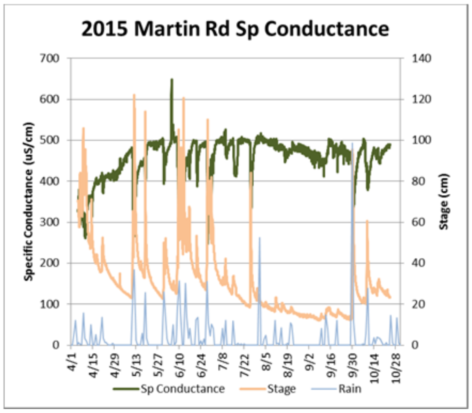


Fig. 26. Data logger salinity data. Stream salinity decreased during events, the groundwater inputs diluted by the rainfall.

Detailed "Event vs Base Flow" Results @ 38A: Nutrients and sediments revealed a significant response to precipitation events throughout the 2015 deployment as in previous years (Fig. 27). Total suspended sediments (TSS) increased dramatically from base flow concentrations of 0 to 20 mg/L to an average event flow concentration of 1,182 mg/L, and rose to a maximum of 2,548 mg/L on 6/2. 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 2015 peak TSS concentrations were second only to 2014, the difference over previous years parallels the difference in rainfall between years. A significant amount of sediment was transported and delivered to the lake in 2014 and 2015.

The event *versus* base flow results suggests a number of potential remediation practices to reduce TSS impairments. For example, buffer strips of vegetation alongside each stream course, where the vegetation reduces the velocity of the runoff and allows particles to settle out instead of 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 use a winter crop cover, and let this vegetation reduce topsoil erosion from their fields during the late fall, winter and early spring seasons, especially where the fields are more saturated with water. 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 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 52 and 5.4 μg/L to event means of 112 and 75 μg/L, respectively. Maximum event concentrations were 225 μg/L for TP and 114 μg/L for SRP. Again, the 2015 event concentrations suggest a direct linkage to and the importance of precipitation induced runoff events for phosphorus loading to the lake. 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.

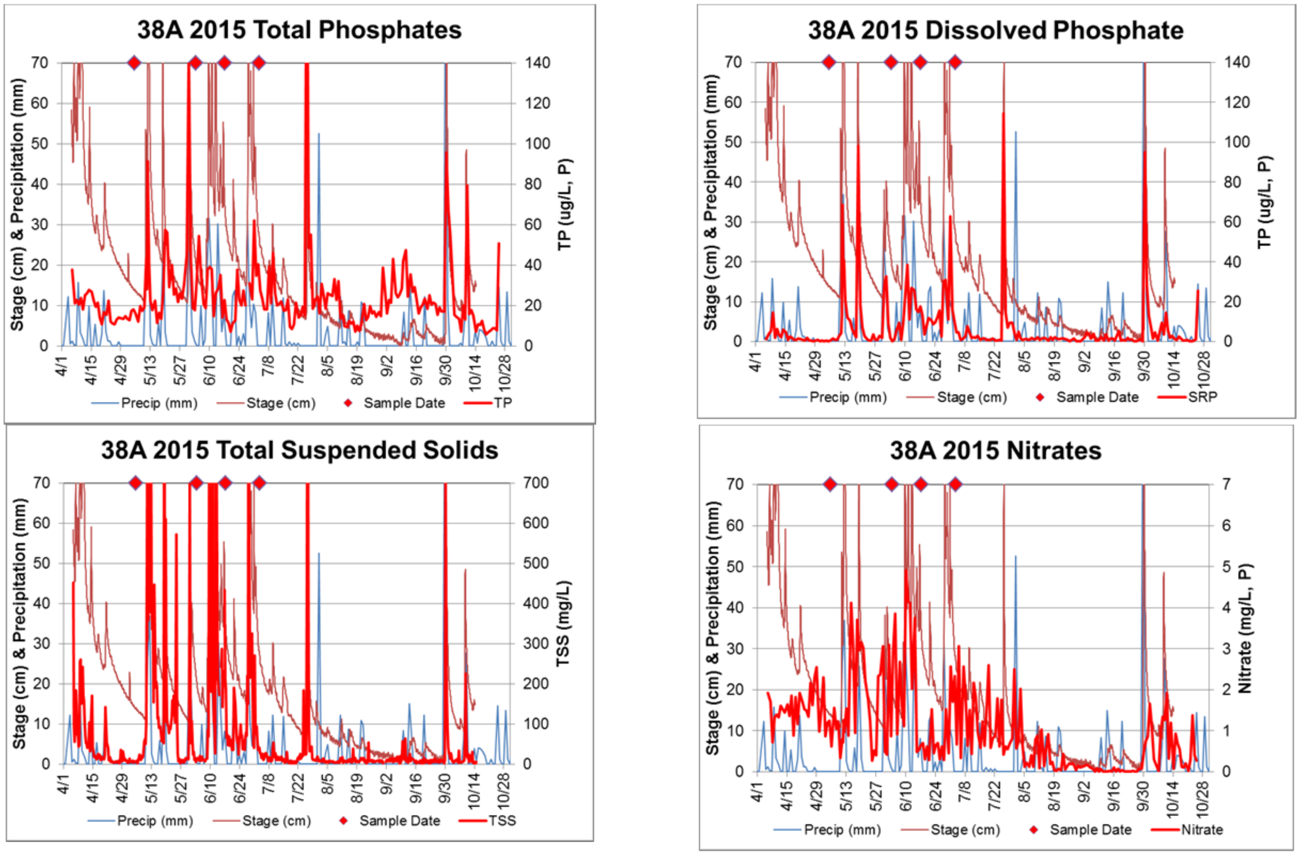


Fig. 27. Autosampler nutrient and suspended sediment concentrations.

Nitrates, once again, revealed a different response to events than TSS, TP and SRP. The largest nitrate concentrations still correlated with events with mean event concentrations of 5.4 and base flow concentrations of 3.0 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 longer for nitrates as well. It indicates that runoff provided extra nitrates to the stream. However, the rejuvenated near-surface groundwater flow contributed a significant portion of the nitrate load as well, extending the nitrate response to the event. 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 runoff and groundwater routes. In contrast, phosphates are typically particle bound, thus groundwater does not transport TP, SRP and TSS.

Event versus Base Flow Fluxes @ 38A: To calculate fluxes, a discharge must be determined for each sample. As mentioned earlier, a best-fit, linear relationship between the weekly discharge measurements at Martin Rd and 38A sites ($r^2 = 0.94$) and the stage/discharge rating curve at Martin Rd estimated hourly discharge data for 38A (Fig. 28, $r^2 = 0.94$).

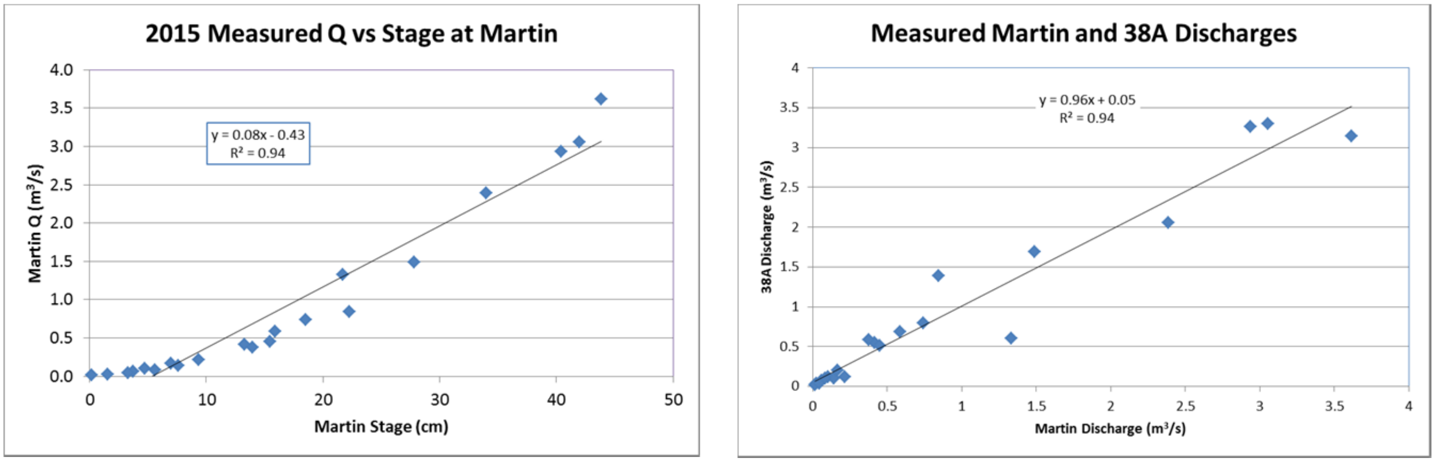


Fig. 28. Estimation of Dutch Hollow Brook 8-hour autosampler discharges from Martin Rd stage, weekly discharge measurements, and a comparison of weekly discharge data from Martin Rd and Rt 38A to estimate the autosampler fluxes at 38A.

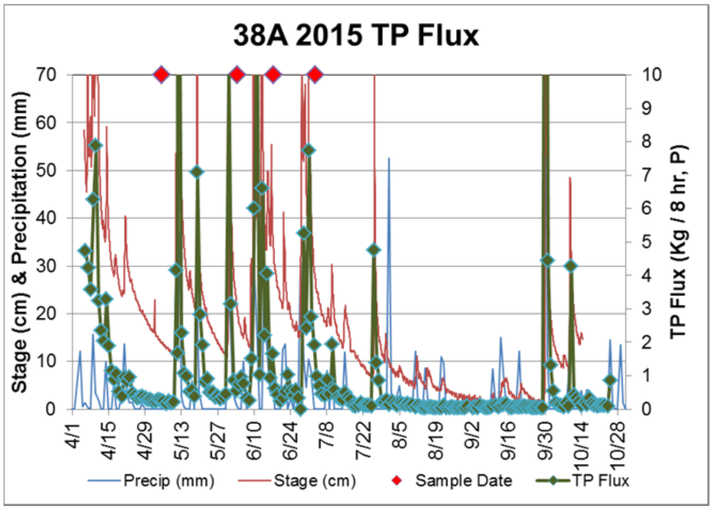
The fluxes of TSS, TP, SRP and nitrates were clearly event driven over the past five years (Table 7, Fig. 29). In 2015, TSS, TP and SRP event *vs.* base flow fluxes averaged 36,000 *vs.* 300, 6.5 *vs.* 1.5, and 3.2 *vs.* 0.5 kg/day, respectively. During the entire 2015 field season, Dutch Hollow provided 7,300,000 kg of sediment to the lake during events, and only 21,000 kg during base flow conditions. In a similar light, the 2015 events delivered 690 kg of TP and 460 kg of SRP to the lake compared to base flow contributions of 52 kg of TP and 5 kg of SRP.

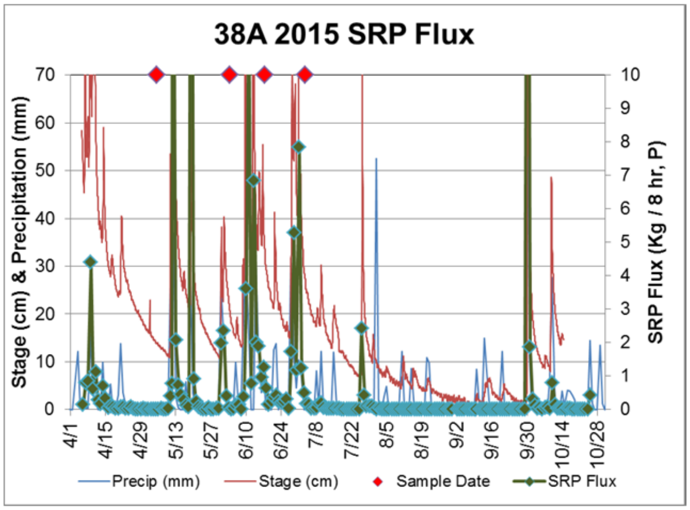
Annual changes were also observed. The 2015 event TP and TSS fluxes were much larger than previous years, reflecting the larger rainfall in 2015 (Fig. 30). This trend is even more striking when rainfall totals focus on May and April; a time frame when soils are saturated sending more rain to runoff but thawed enough to enable soil erosion, plant life is absent or just rebounding from winter dormancy so not to retard runoff flows and increase evapotranspiration. This is especially critical for farm fields made bare in preparation for planting or were recently planted (Fig. 31). The fluxes in 2011 would have been much larger, if the sampler was deployed earlier in the spring rather than waiting until early June, based on the amount of rainfall and runoff down the Owasco Inlet in 2011 compared to other years.

The event *versus* base flow data also consistently indicate that grab samples underestimate annual fluxes down a stream. For example, the 2015 autosampler estimated a sediment mean flux of 36,100 kg/day, total phosphates 3.7 kg/day, dissolved phosphates 2.3 kg/day, and nitrates 180 kg/day; whereas the grab sampling estimated an annual mean flux of 1,670 kg/day for sediments, 1.9 kg/day for total phosphates, 0.6 kg/day for dissolved phosphates, and 104 kg/day for nitrates. The grab samples estimated smaller fluxes because they were biased to base flows. Therefore, grab samples are not reliable for detailed flux estimates but instead are essential and reliable tools for stream segment analysis and the investigation of nutrient and sediment sources. In conclusion, each year revealed significantly larger event over base flow loads for TSS, TP and SRP, and to a lesser degree nitrates along Dutch Hollow Brook (Table 7).

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%





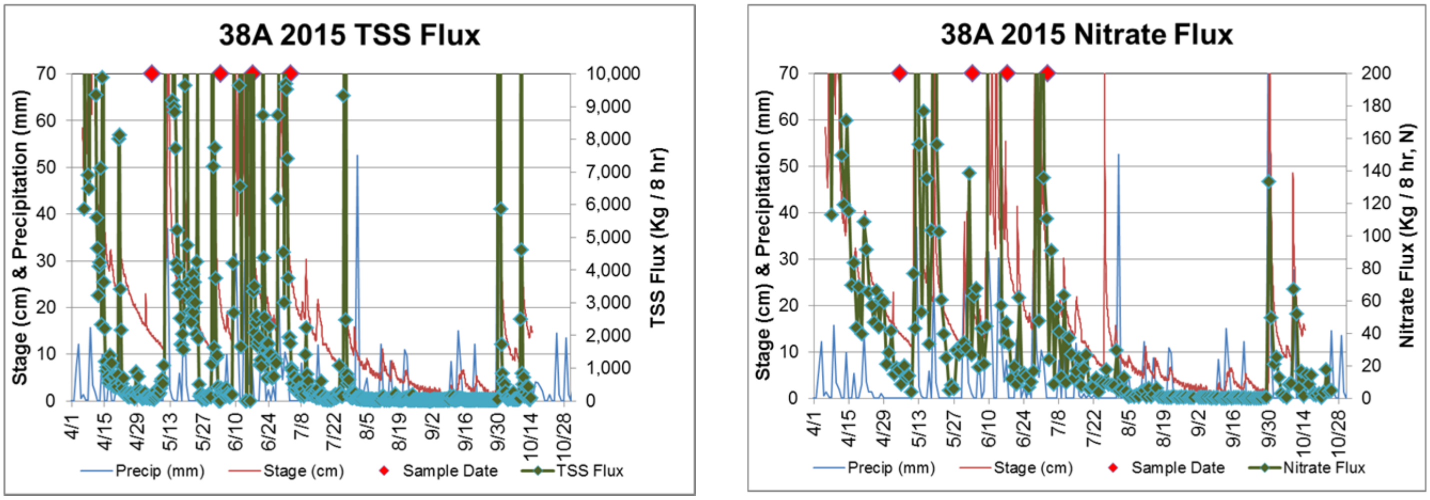


Fig. 29. Autosampler nutrient and suspended sediment fluxes.

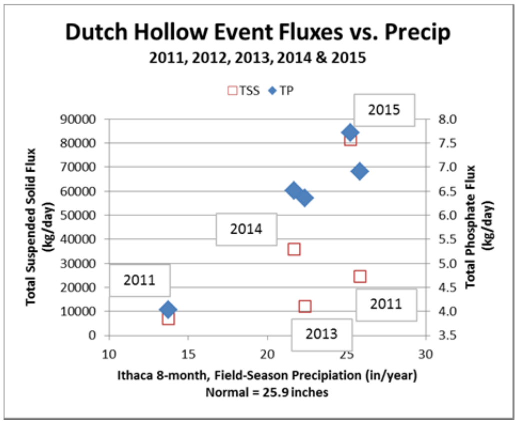


Fig. 30. Estimated annual total phosphorus loads vs 8-month field season rainfall at the Ithaca Airport.

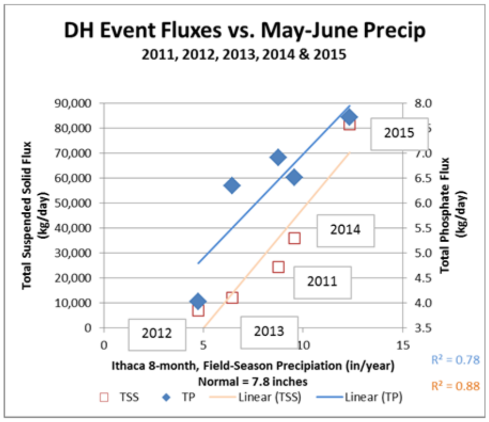


Fig. 31. Estimated annual total phosphorus loads vs May-June rainfall totals at the Ithaca Airport .

DETAILED ANALYSIS @ MARTIN ROAD AND NORTH STREET SITES:

Three autosamplers were deployed at the 38A, Martin Rd and North St sites along the lower reach of Dutch Hollow Brook (Fig. 32). As mentioned above, the Martin Rd stage data and its weekly discharge data defined a rating curve to estimate the detailed autosampler fluxes at Martin Rd. Like Rt 38A, the Martin Rd rating curve was also used to estimate the detailed autosampler fluxes at North St using a proportional relationship between the weekly discharge data at these two sites (Figs. 28 & 33). As anticipated, the sample array shed some light on the nutrient and sediment dynamics along this segment of the stream.

The detailed TSS, TP and SRP concentration data revealed event signatures at all three sites (Fig. 34, Table 8). Nitrate event signatures were observed but subdued in comparison to TSS, TP and SRP. This is not new.

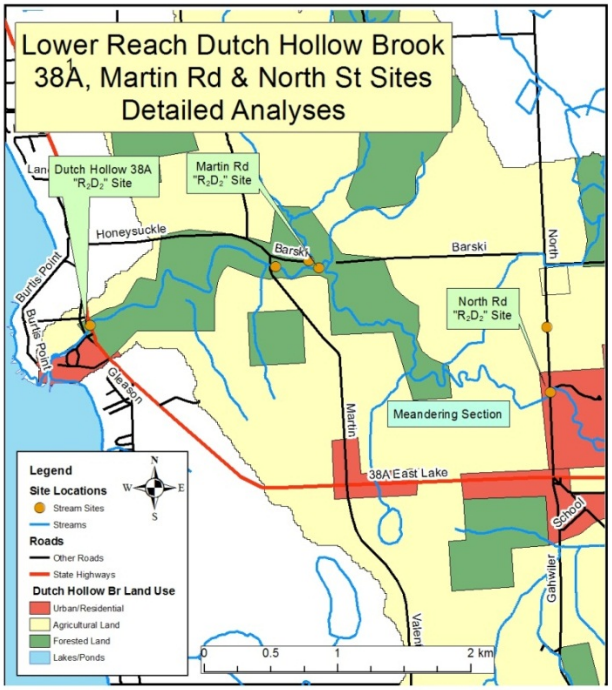


Fig. 32. Dutch Hollow Brook lower reach showing the location of the 38A, Martin Rd and North St autosamplers.

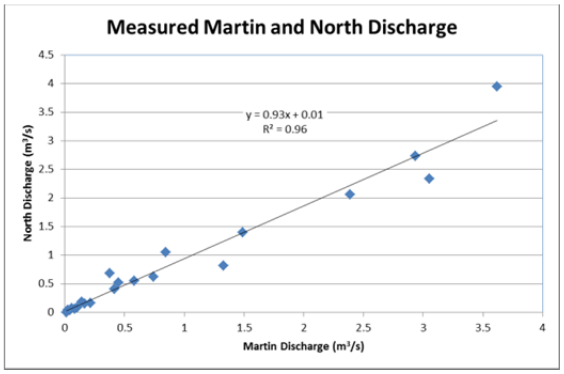


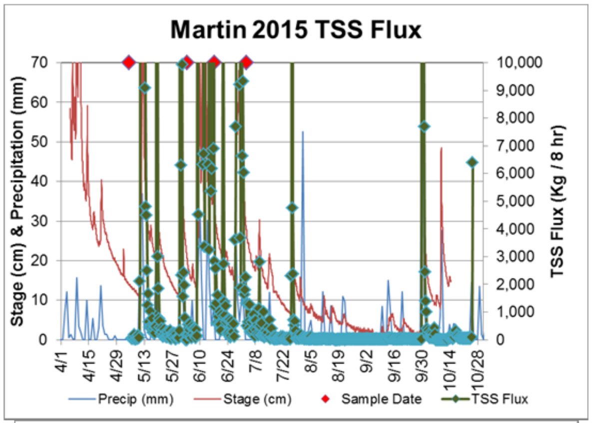
Fig. 33. Measured weekly discharge data from Martin Rd and North St, used to estimate hourly discharge data at North St for the North St autosampler flux calculations.

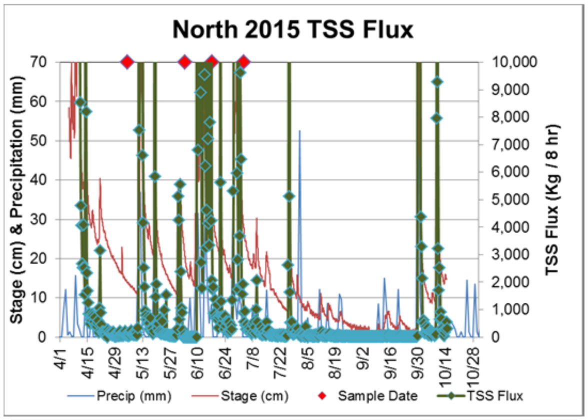
The fluxes did change somewhat along this segment of the stream (Fig. 34, Table 8). The TSS and TP event fluxes were largest at the Martin Rd Site. Perhaps the excess loads originated from the small tributaries and/or stream bank erosion along the sharp meander bends and incised river banks between North St and Martin Rd. The more vegetated and less channelized downstream section between Martin Rd to 38A, could have trapped some of this load. The difference was subdued during base flow. In contrast, SRP fluxes were largest at the 38A and North St sites, suggesting that some of the SRP was scavenged by the extra particles near Martin Rd and turned into TP. Soluble phosphorus was released farther downstream, perhaps reflecting bacterial decay of organic matter. Nitrate remained the same along the North to Martin segment but increased between Martin and Rt 38A. It also suggests that bacterial decay of the organics along this lower reach.

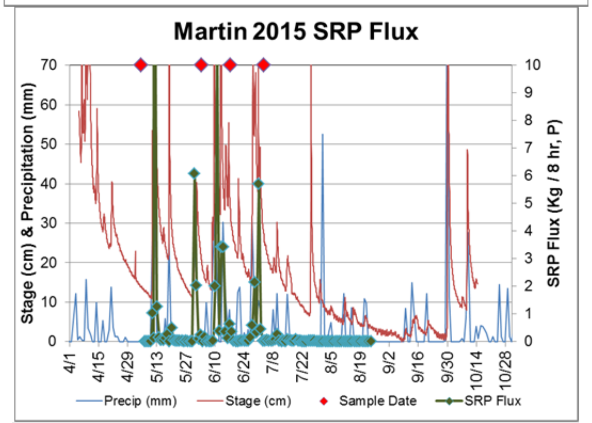
Table 8: 2015 Fluxes at 38A, Martin Rd & North St.

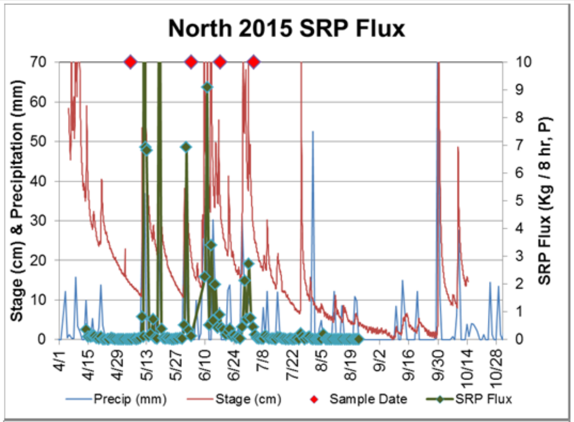
38A	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	35,600	180	3.7	2.3
Event (kg/day)	81,500	370	7.7	5.2
Base Flow (kg/day)	185	27	0.5	0.0
% by events	99%	93%	94%	99%
Martin Rd	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	40,800	168	5.5	1.9
Event (kg/day)	104,000	308	10.3	3.8
Base Flow (kg/day)	127	30	0.7	0.1
% by events	99.9%	91%	94%	98%
North St	**TSS**	**Nitrate**	**TP**	**SRP**
Mean (kg/day)	25,000	155	3.2	2.0

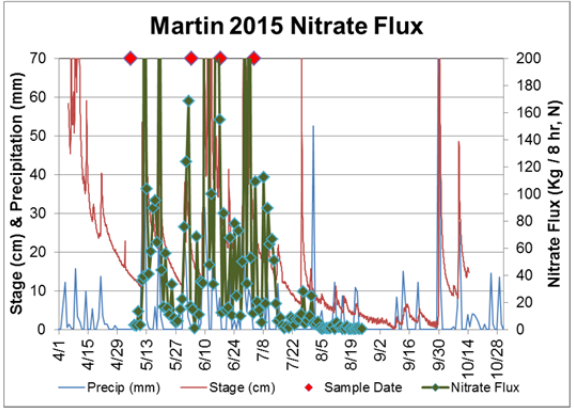
Event (kg/day)	64,000	310	7.4	4.5
Base Flow (kg/day)	168	38	0.5	0.1
% by events	99.7%	89%	94%	99%

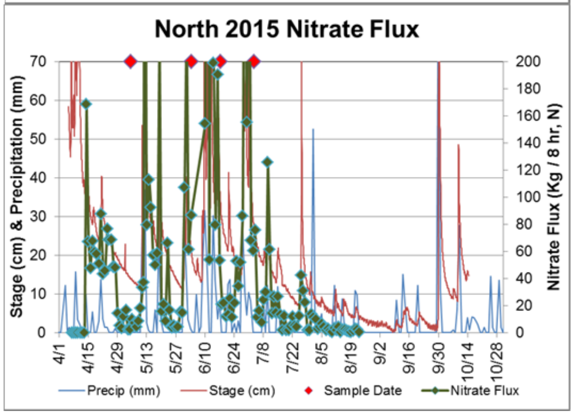

Martin 2015 TSS Flux


North 2015 TSS Flux


Martin 2015 SRP Flux


North 2015 SRP Flux


Martin 2015 Nitrate Flux


North 2015 Nitrate Flux

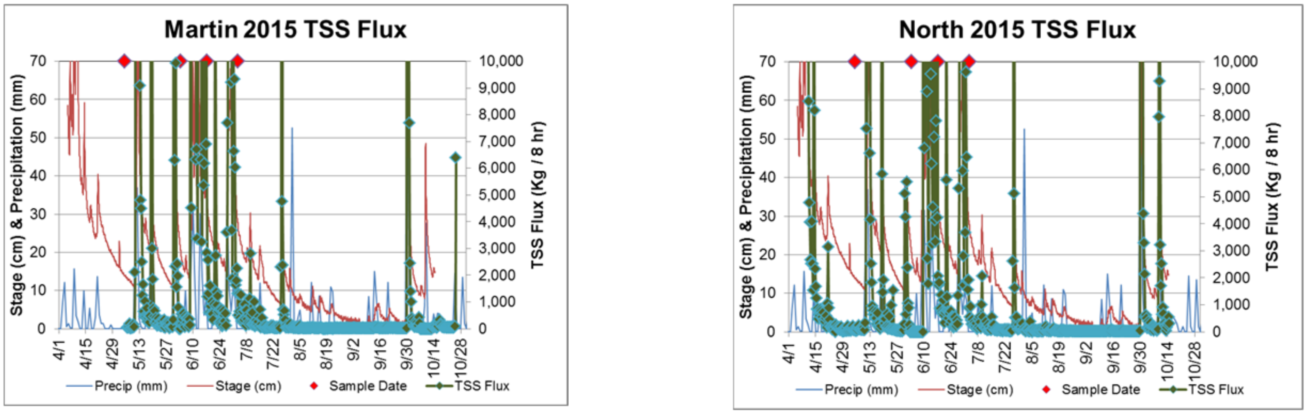


Fig. 34. Martin Rd (left) and North St (right) suspended sediment, total phosphate, dissolved phosphate and nitrate fluxes.

PHOSPHORUS BUDGET:

Phosphorus load reductions are critical to the health and water quality of Owasco Lake because it limits algal growth and improved water clarity thus water quality. 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 potential 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. P will decrease in the lake, if inputs are less than outputs. Alternatively, P 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). The sustained reduction would allow existing phosphorus to leave by the outlet or be buried in the sediments, and thus limit algal growth and ultimately improve water clarity. The required "cleansing" time frame in the Owasco watershed is a decade or more.

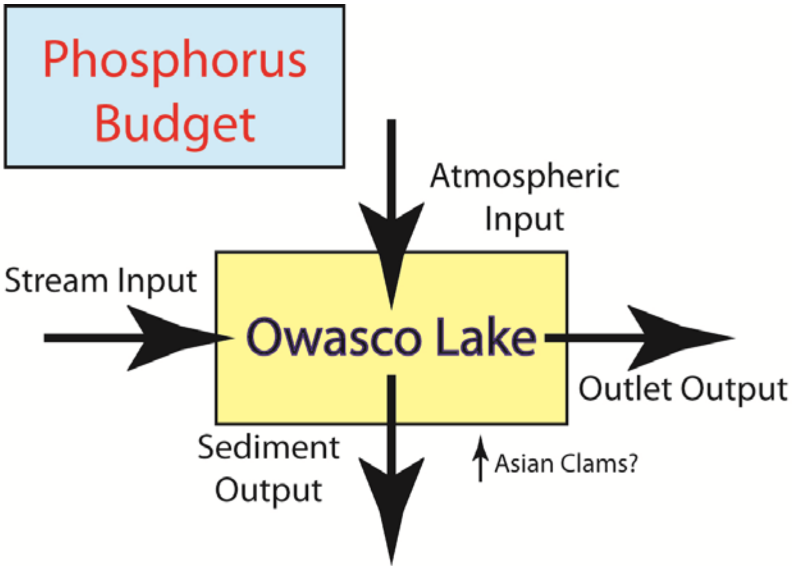


Fig. 35. The Owasco Lake phosphorus budget: Sources and sinks for phosphorus in Owasco Lake. Water quality improves if **inputs are less than outputs**, for a number of years.

The Inputs: The autosampler estimated a mean total phosphate flux of 3.7 kg/day from Dutch Hollow Brook in 2015. Owasco Inlet delivered 10 kg/day based on the available 2015 stream grab data. However, this flux was restricted to base flow samples and is thus artificially small. The load for Owasco Inlet was estimated at 18.2 kg/day assuming a proportional change between the mean grab sample total phosphorus loads to the detailed autosampler loads from Dutch Hollow Brook. A proportional 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 11.4 metric tons of phosphorus in 2015. This extrapolation incorporates all the 1st and 2nd 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 2015 estimated total influx of phosphorus was 12 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 4.7 metric tons of phosphorus was lost out the Outlet in 2015 assuming an 2015 annual mean total phosphate concentration in the lake of 16.1 μg/L, and a 2015 mean daily discharge of 9.2 m^3/s through the Owasco Outlet (USGS Owasco Outlet Gauge #04235440). The 2011 report estimated the flux of phosphorus buried in the sediments of a few metric tons of phosphorus each 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 2014 estimated efflux was 7.5 metric tons/year.

The Net Flux: Owasco Lake thus gained approximately 4.5 metric tons of phosphorus in 2015. Since 2009, the lake gained phosphorus during four years, lost phosphorus during two years, and was close to equilibrium in one year (Fig. 36). Since 2006, the mean annual input was 6.6 mtons/year, slightly more than the mean output of 5.9 mtons/year. The lake was more likely in a positive balance for six of the past seven years because 2009 and 2010 loads were based on limited summer grab samples. This seven year history indicates that significant remediation efforts must take place to move Owasco Lake to a negative balance and eventually improve water quality.

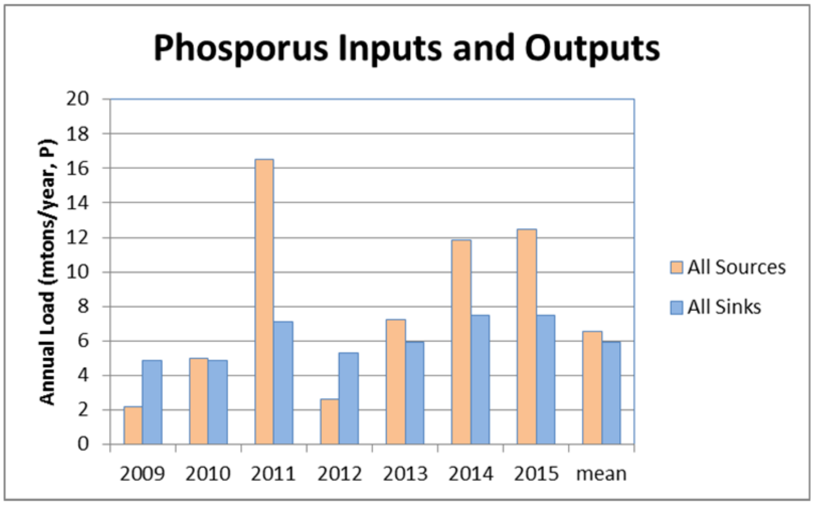


Fig. 36. Estimated annual total phosphorus inputs and outputs for Owasco Lake.

Finally, the large nutrient inputs in 2014 and 2015 were coincident with and probably provided the “trigger” for the recent BGA blooms. Even though coincidence does not prove causation, these two years of excessive loads were unique through the past decade. Assuming these large loads caused 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 into the future. Remember, 2014 and 2015 were meteorologically “normal” rainfall years. Imagine what might happen with more than normal rainfall? Everyone must work through the steps outlined in the watershed plan. Do NOT wait until tomorrow.

CONCLUSIONS & RECOMMENDATIONS:

This report confirms and expands on earlier findings.

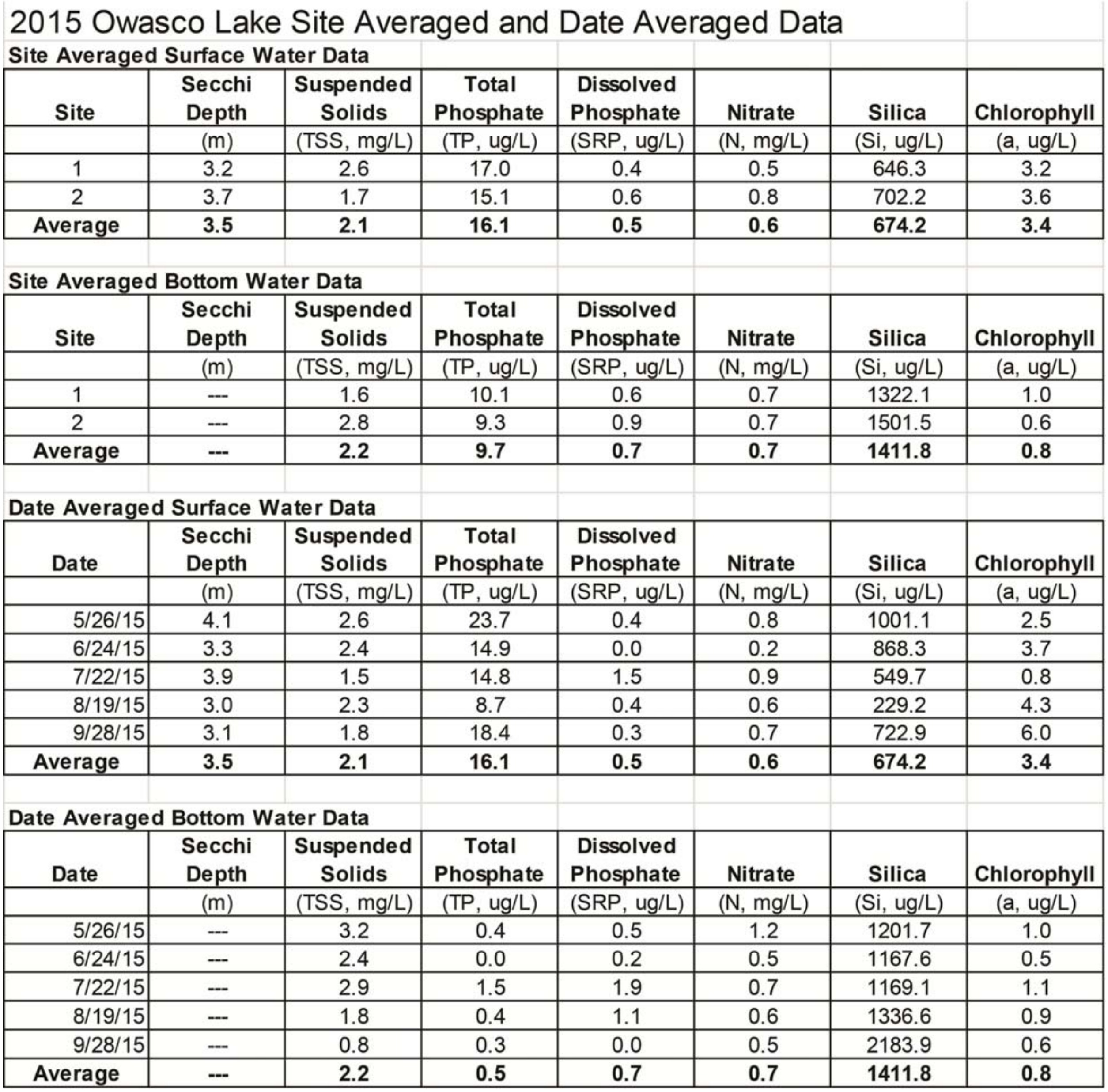
- As in previous years, Owasco Lake is a borderline oligotrophic – mesotrophic lake. The improvements in water quality in 2011 through 2013 were lost in 2014 and 2015.
- The water quality degradation in 2014 and 2015 is attributed to the heavy rains in those years.
- The preliminary data from a newly acquired 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 samples.
- The buoy data indicate that blue green algae blooms happened after the summer solstice when the lake was calm or nearly calm, stimulated by an influx of nutrients from runoff events and/or the seasonal decay of the epilimnion. Funds should be secured to deploy this buoy in future years to confirm these correlations.
- Segment analysis highlighted the lack of significant sources along either Dutch Hollow Brook or Owasco Inlet. It suggests that some success was achieved in establishing BMPs, in that recent data revealed minimal and/or proportionally reduced inputs from the wastewater treatment facilities, and agricultural areas. Unfortunately, 2015 was a “wet” year, so the total nutrient and sediment loads to the lake were still significant.
- The event *versus* base flow analysis at Dutch Hollow Brook highlight the dominance of events and associated runoff of non-point 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. Loads and differences between event and base flow loads in 2015 were above those estimated for earlier years and correlated very well to field-season and May-June rainfall.
- Similar event signatures were observed at Martin Rd, North St and Rt 38A along the Dutch Hollow Brook watershed. Sediment and total phosphorus loads were largest at Martin Rd suggesting tributary or stream bank erosion sources between North and Martin Rd, and sinks farther downstream. Dissolved phosphorus and nitrate loads increased downstream of Martin Rd, suggesting bacterial decomposition of the organics along this reach.
- The estimated phosphate budget for Owasco Lake indicates that the lake gained a large amount of phosphorus in 2015. In fact it gained phosphorus every year since the “dry” year in 2012.
- Streams were the primary source of nutrients and sediments to the lake.
    - 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 are 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 should help support the remediation effort.
  - Everyone should make sure that the funds promised to the Cayuga County Soil and Water Conservation District and to the Owasco Lake Watershed Association for this purpose do NOT get lost in Albany. These funds provide a great start to the continued battle to preserve and protect Owasco Lake for future generations.
- The excessive nutrient loads during 2014 and 2015 were coincident with the large blooms of blue green algae. It suggests that the excess nutrients triggered the BGA events, although coincidence does not dictate causation. It does however highlight the need to quickly and decisively abate nutrient loading to the lake.

ACKNOWLEDGEMENTS

The 2015 research was supported by Cayuga County Legislature, Cayuga County Soil and Water Conservation District and the Emerson Foundation. 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, and NYS Department of Environmental Conservation for their help. Numerous individuals helped with many aspects of this study including Senator Mike Nozzolio, Barbara Halfman, 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, Michele Wunderlich, Marion Balyszak, Lisa Cleckner, 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. 2015 Lake Data.



2015 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	3.2	2.6	17.0	0.4	0.5	646.3	3.2
2	3.7	1.7	15.1	0.6	0.8	702.2	3.6
Average	**3.5**	**2.1**	**16.1**	**0.5**	**0.6**	**674.2**	**3.4**

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	---	1.6	10.1	0.6	0.7	1322.1	1.0
2	---	2.8	9.3	0.9	0.7	1501.5	0.6
Average	**---**	**2.2**	**9.7**	**0.7**	**0.7**	**1411.8**	**0.8**

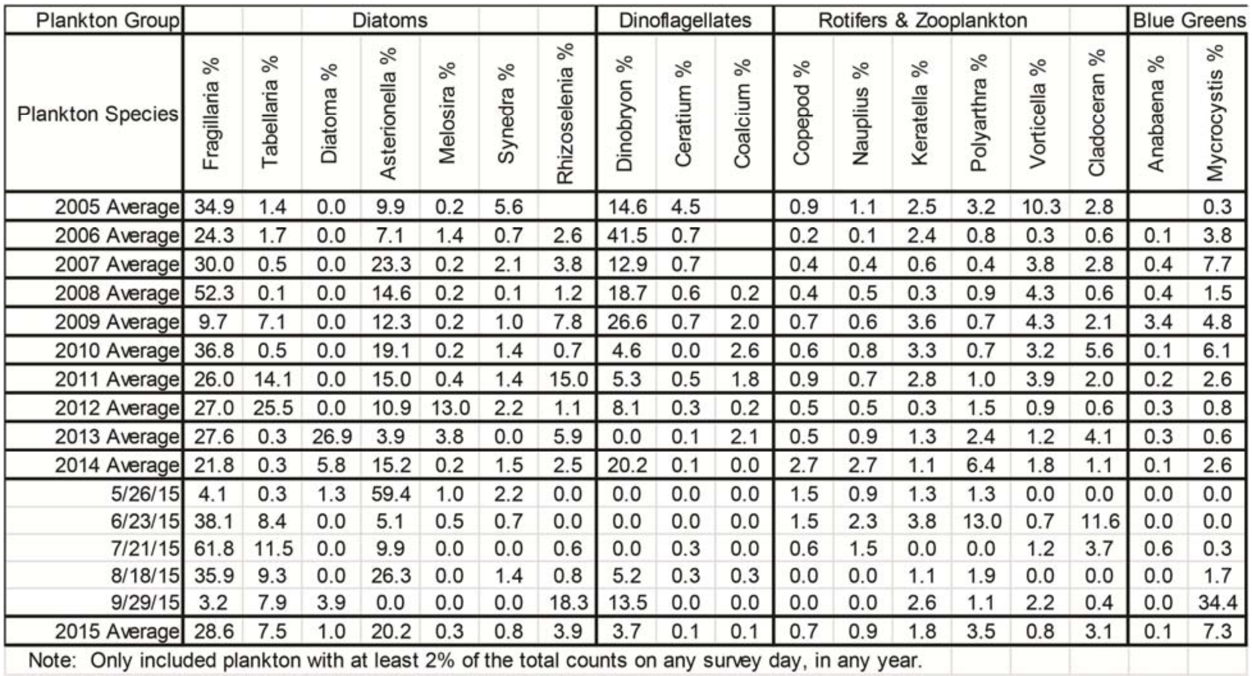
Date Averaged Surface Water Data

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)
5/26/15	4.1	2.6	23.7	0.4	0.8	1001.1	2.5
6/24/15	3.3	2.4	14.9	0.0	0.2	868.3	3.7
7/22/15	3.9	1.5	14.8	1.5	0.9	549.7	0.8
8/19/15	3.0	2.3	8.7	0.4	0.6	229.2	4.3
9/28/15	3.1	1.8	18.4	0.3	0.7	722.9	6.0
Average	**3.5**	**2.1**	**16.1**	**0.5**	**0.6**	**674.2**	**3.4**

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)
5/26/15	---	3.2	0.4	0.5	1.2	1201.7	1.0
6/24/15	---	2.4	0.0	0.2	0.5	1167.6	0.5
7/22/15	---	2.9	1.5	1.9	0.7	1169.1	1.1
8/19/15	---	1.8	0.4	1.1	0.6	1336.6	0.9
9/28/15	---	0.8	0.3	0.0	0.5	2183.9	0.6
Average	**---**	**2.2**	**0.5**	**0.7**	**0.7**	**1411.8**	**0.8**

Table 4. Annual Average Plankton Data from 2005 through 2015, and Daily Average Data for 2015.



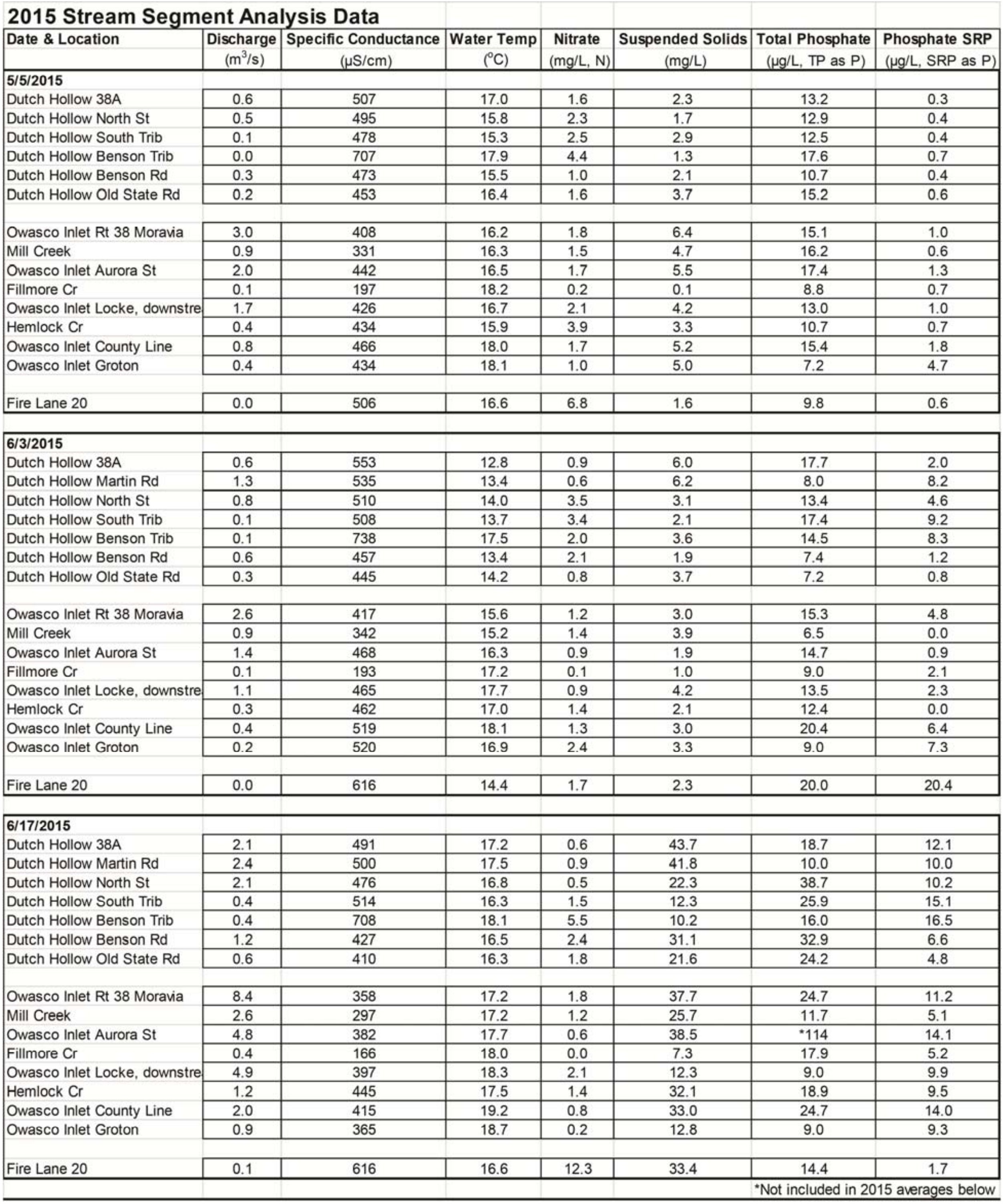
Plankton Group	Diatoms							Dinoflagellates			Rotifers & Zooplankton						Blue Greens	
Plankton Species	Fragillaria %	Tabellaria %	Diatoma %	Asterionella %	Melosira %	Synedra %	Rhizoselenia %	Dinobryon %	Ceratium %	Coalcium %	Copepod %	Nauplius %	Keratella %	Polyarthra %	Vorticella %	Cladoceran %	Anabaena %	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
5/26/15	4.1	0.3	1.3	59.4	1.0	2.2	0.0	0.0	0.0	0.0	1.5	0.9	1.3	1.3	0.0	0.0	0.0	0.0
6/23/15	38.1	8.4	0.0	5.1	0.5	0.7	0.0	0.0	0.0	0.0	1.5	2.3	3.8	13.0	0.7	11.6	0.0	0.0
7/21/15	61.8	11.5	0.0	9.9	0.0	0.0	0.6	0.0	0.3	0.0	0.6	1.5	0.0	0.0	1.2	3.7	0.6	0.3
8/18/15	35.9	9.3	0.0	26.3	0.0	1.4	0.8	5.2	0.3	0.3	0.0	0.0	1.1	1.9	0.0	0.0	0.0	1.7
9/29/15	3.2	7.9	3.9	0.0	0.0	0.0	18.3	13.5	0.0	0.0	0.0	0.0	2.6	1.1	2.2	0.4	0.0	34.4
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

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

Table 5: Annual Average 2015 Lake Data from the Finger Lake Survey.

2015 Average Values (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	1.6 ± 1.1	4.2 ± 1.5	3.7 ± 1.5	3.6 ± 1.8	3.0 ± 0.8	3.3 ± 0.5	8.0 ± 1.6	2.1 ± 0.5
Total Suspended Solids (mg/L), Surface	6.6 ± 3.0	1.6 ± 1.0	2.1 ± 1.3	2.2 ± 0.9	2.4 ± 0.4	2.2 ± 0.9	0.8 ± 0.2	5.9 ± 4.9
Total Suspended Solids (mg/L), Bottom	5.7 ± 3.4	1.0 ± 0.4	1.3 ± 1.1	0.9 ± 1.1	1.8 ± 1.2	2.0 ± 1.0	0.5 ± 0.3	4.7 ± 5.3
Dissolved Phosphate (µg/L, SRP), Surface	2.9 ± 5.6	0.5 ± 0.5	0.5 ± 0.4	0.6 ± 0.8	0.4 ± 0.4	0.4 ± 0.3	0.4 ± 0.2	0.6 ± 1.1
Dissolved Phosphate (µg/L, SRP), Bottom	2.8 ± 4.3	0.6 ± 0.6	1.2 ± 2.0	2.4 ± 2.0	6.2 ± 3.8	0.5 ± 0.5	0.4 ± 0.2	0.9 ± 0.8
Total Phosphate (µg/L, TP), Surface	31.6 ± 13.9	8.7 ± 2.8	7.6 ± 5.2	13.8 ± 4.8	16.9 ± 4.9	15.5 ± 6.7	12.3 ± 2.2	12.7 ± 7.6
Total Phosphate (µg/L, TP), Bottom	32.7 ± 13.3	5.7 ± 2.1	6.9 ± 3.7	13.5 ± 5.7	16.7 ± 8.8	9.8 ± 2.8	9.2 ± 3.5	13.1 ± 6.7
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.2	0.7 ± 0.3	0.5 ± 0.4	0.4 ± 0.4	0.2 ± 0.2
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.2	0.1 ± 0.1	0.4 ± 0.4	0.8 ± 0.7	0.7 ± 0.7	0.4 ± 0.2	0.3 ± 0.2
Silica (SR µg/L), Surface	595 ± 296	797 ± 155	734 ± 172	195 ± 105	300 ± 185	697 ± 295	417 ± 111	315 ± 170
Silica (SR µg/L), Bottom	614 ± 327	1026 ± 330	932 ± 299	386 ± 163	796 ± 231	1394 ± 495	714 ± 198	1328 ± 524
Chlorphyll a (µg/L), Surface	19.0 ± 15.3	2.6 ± 1.0	2.7 ± 1.6	3.7 ± 2.5	5.4 ± 2.4	3.8 ± 1.8	1.1 ± 0.6	4.3 ± 1.9
Chlorphyll a (µg/L), Bottom	12.9 ± 9.6	0.5 ± 0.1	0.5 ± 0.2	1.6 ± 2.3	0.5 ± 0.1	0.7 ± 0.3	0.7 ± 0.3	2.6 ± 1.3

Table 6. 2015 Stream Data.

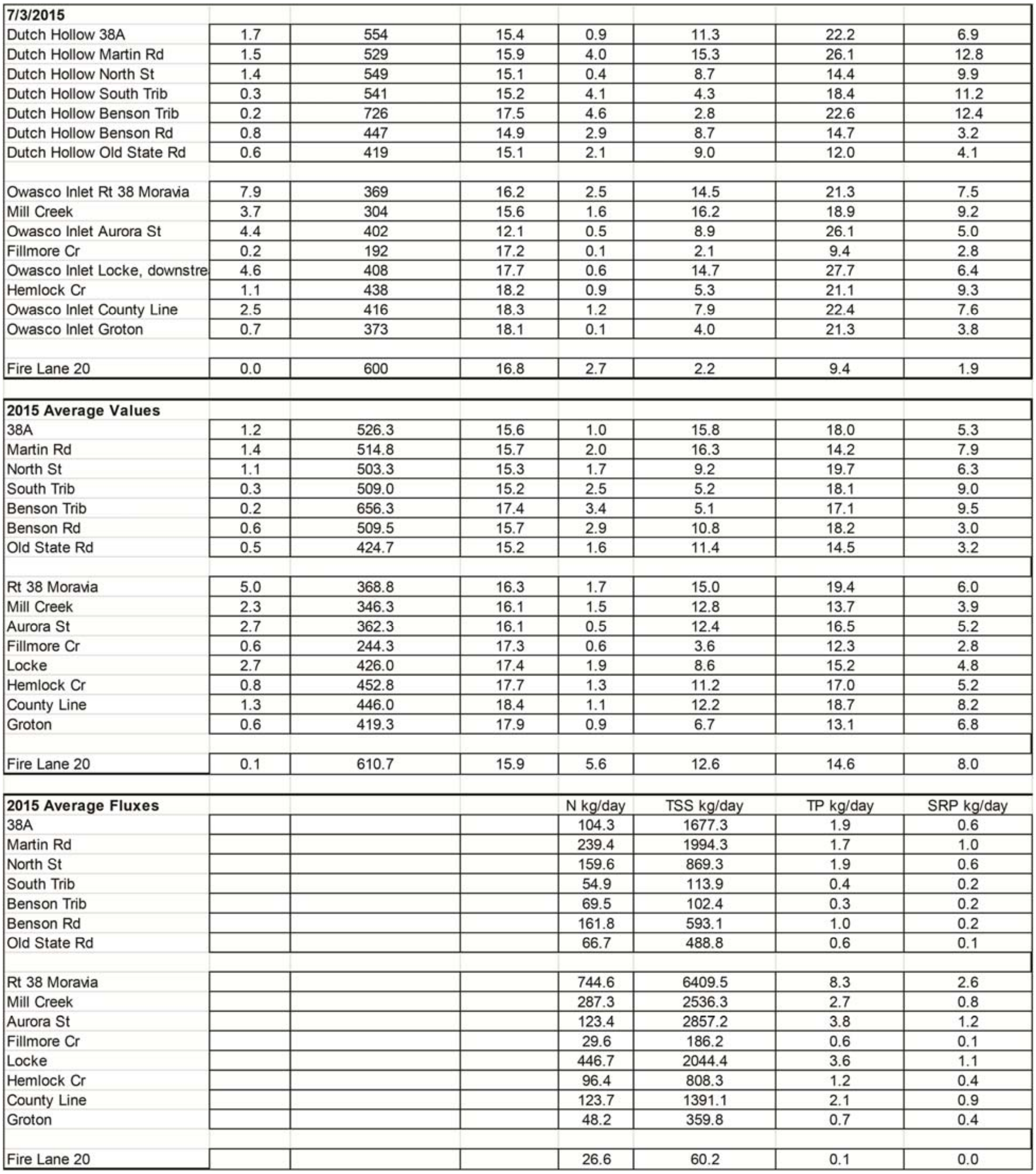


2015 Stream Segment Analysis Data

Date & Location	Discharge (m^3/s)	Specific Conductance (µS/cm)	Water Temp (^{o}C)	Nitrate (mg/L, N)	Suspended Solids (mg/L)	Total Phosphate (µg/L, TP as P)	Phosphate SRP (µg/L, SRP as P)
5/5/2015							
Dutch Hollow 38A	0.6	507	17.0	1.6	2.3	13.2	0.3
Dutch Hollow North St	0.5	495	15.8	2.3	1.7	12.9	0.4
Dutch Hollow South Trib	0.1	478	15.3	2.5	2.9	12.5	0.4
Dutch Hollow Benson Trib	0.0	707	17.9	4.4	1.3	17.6	0.7
Dutch Hollow Benson Rd	0.3	473	15.5	1.0	2.1	10.7	0.4
Dutch Hollow Old State Rd	0.2	453	16.4	1.6	3.7	15.2	0.6
Owasco Inlet Rt 38 Moravia	3.0	408	16.2	1.8	6.4	15.1	1.0
Mill Creek	0.9	331	16.3	1.5	4.7	16.2	0.6
Owasco Inlet Aurora St	2.0	442	16.5	1.7	5.5	17.4	1.3
Fillmore Cr	0.1	197	18.2	0.2	0.1	8.8	0.7
Owasco Inlet Locke, downstre	1.7	426	16.7	2.1	4.2	13.0	1.0
Hemlock Cr	0.4	434	15.9	3.9	3.3	10.7	0.7
Owasco Inlet County Line	0.8	466	18.0	1.7	5.2	15.4	1.8
Owasco Inlet Groton	0.4	434	18.1	1.0	5.0	7.2	4.7
Fire Lane 20	0.0	506	16.6	6.8	1.6	9.8	0.6
6/3/2015							
Dutch Hollow 38A	0.6	553	12.8	0.9	6.0	17.7	2.0
Dutch Hollow Martin Rd	1.3	535	13.4	0.6	6.2	8.0	8.2
Dutch Hollow North St	0.8	510	14.0	3.5	3.1	13.4	4.6
Dutch Hollow South Trib	0.1	508	13.7	3.4	2.1	17.4	9.2
Dutch Hollow Benson Trib	0.1	738	17.5	2.0	3.6	14.5	8.3
Dutch Hollow Benson Rd	0.6	457	13.4	2.1	1.9	7.4	1.2
Dutch Hollow Old State Rd	0.3	445	14.2	0.8	3.7	7.2	0.8
Owasco Inlet Rt 38 Moravia	2.6	417	15.6	1.2	3.0	15.3	4.8
Mill Creek	0.9	342	15.2	1.4	3.9	6.5	0.0
Owasco Inlet Aurora St	1.4	468	16.3	0.9	1.9	14.7	0.9
Fillmore Cr	0.1	193	17.2	0.1	1.0	9.0	2.1
Owasco Inlet Locke, downstre	1.1	465	17.7	0.9	4.2	13.5	2.3
Hemlock Cr	0.3	462	17.0	1.4	2.1	12.4	0.0
Owasco Inlet County Line	0.4	519	18.1	1.3	3.0	20.4	6.4
Owasco Inlet Groton	0.2	520	16.9	2.4	3.3	9.0	7.3
Fire Lane 20	0.0	616	14.4	1.7	2.3	20.0	20.4
6/17/2015							
Dutch Hollow 38A	2.1	491	17.2	0.6	43.7	18.7	12.1
Dutch Hollow Martin Rd	2.4	500	17.5	0.9	41.8	10.0	10.0
Dutch Hollow North St	2.1	476	16.8	0.5	22.3	38.7	10.2
Dutch Hollow South Trib	0.4	514	16.3	1.5	12.3	25.9	15.1
Dutch Hollow Benson Trib	0.4	708	18.1	5.5	10.2	16.0	16.5
Dutch Hollow Benson Rd	1.2	427	16.5	2.4	31.1	32.9	6.6
Dutch Hollow Old State Rd	0.6	410	16.3	1.8	21.6	24.2	4.8
Owasco Inlet Rt 38 Moravia	8.4	358	17.2	1.8	37.7	24.7	11.2
Mill Creek	2.6	297	17.2	1.2	25.7	11.7	5.1
Owasco Inlet Aurora St	4.8	382	17.7	0.6	38.5	*114	14.1
Fillmore Cr	0.4	166	18.0	0.0	7.3	17.9	5.2
Owasco Inlet Locke, downstre	4.9	397	18.3	2.1	12.3	9.0	9.9
Hemlock Cr	1.2	445	17.5	1.4	32.1	18.9	9.5
Owasco Inlet County Line	2.0	415	19.2	0.8	33.0	24.7	14.0
Owasco Inlet Groton	0.9	365	18.7	0.2	12.8	9.0	9.3
Fire Lane 20	0.1	616	16.6	12.3	33.4	14.4	1.7

*Not included in 2015 averages below

Table 6. 2015 Stream Data (continued)



7/3/2015							
Dutch Hollow 38A	1.7	554	15.4	0.9	11.3	22.2	6.9
Dutch Hollow Martin Rd	1.5	529	15.9	4.0	15.3	26.1	12.8
Dutch Hollow North St	1.4	549	15.1	0.4	8.7	14.4	9.9
Dutch Hollow South Trib	0.3	541	15.2	4.1	4.3	18.4	11.2
Dutch Hollow Benson Trib	0.2	726	17.5	4.6	2.8	22.6	12.4
Dutch Hollow Benson Rd	0.8	447	14.9	2.9	8.7	14.7	3.2
Dutch Hollow Old State Rd	0.6	419	15.1	2.1	9.0	12.0	4.1
Owasco Inlet Rt 38 Moravia	7.9	369	16.2	2.5	14.5	21.3	7.5
Mill Creek	3.7	304	15.6	1.6	16.2	18.9	9.2
Owasco Inlet Aurora St	4.4	402	12.1	0.5	8.9	26.1	5.0
Fillmore Cr	0.2	192	17.2	0.1	2.1	9.4	2.8
Owasco Inlet Locke, downstre	4.6	408	17.7	0.6	14.7	27.7	6.4
Hemlock Cr	1.1	438	18.2	0.9	5.3	21.1	9.3
Owasco Inlet County Line	2.5	416	18.3	1.2	7.9	22.4	7.6
Owasco Inlet Groton	0.7	373	18.1	0.1	4.0	21.3	3.8
Fire Lane 20	0.0	600	16.8	2.7	2.2	9.4	1.9
2015 Average Values							
38A	1.2	526.3	15.6	1.0	15.8	18.0	5.3
Martin Rd	1.4	514.8	15.7	2.0	16.3	14.2	7.9
North St	1.1	503.3	15.3	1.7	9.2	19.7	6.3
South Trib	0.3	509.0	15.2	2.5	5.2	18.1	9.0
Benson Trib	0.2	656.3	17.4	3.4	5.1	17.1	9.5
Benson Rd	0.6	509.5	15.7	2.9	10.8	18.2	3.0
Old State Rd	0.5	424.7	15.2	1.6	11.4	14.5	3.2
Rt 38 Moravia	5.0	368.8	16.3	1.7	15.0	19.4	6.0
Mill Creek	2.3	346.3	16.1	1.5	12.8	13.7	3.9
Aurora St	2.7	362.3	16.1	0.5	12.4	16.5	5.2
Fillmore Cr	0.6	244.3	17.3	0.6	3.6	12.3	2.8
Locke	2.7	426.0	17.4	1.9	8.6	15.2	4.8
Hemlock Cr	0.8	452.8	17.7	1.3	11.2	17.0	5.2
County Line	1.3	446.0	18.4	1.1	12.2	18.7	8.2
Groton	0.6	419.3	17.9	0.9	6.7	13.1	6.8
Fire Lane 20	0.1	610.7	15.9	5.6	12.6	14.6	8.0
2015 Average Fluxes				N kg/day	TSS kg/day	TP kg/day	SRP kg/day
38A				104.3	1677.3	1.9	0.6
Martin Rd				239.4	1994.3	1.7	1.0
North St				159.6	869.3	1.9	0.6
South Trib				54.9	113.9	0.4	0.2
Benson Trib				69.5	102.4	0.3	0.2
Benson Rd				161.8	593.1	1.0	0.2
Old State Rd				66.7	488.8	0.6	0.1
Rt 38 Moravia				744.6	6409.5	8.3	2.6
Mill Creek				287.3	2536.3	2.7	0.8
Aurora St				123.4	2857.2	3.8	1.2
Fillmore Cr				29.6	186.2	0.6	0.1
Locke				446.7	2044.4	3.6	1.1
Hemlock Cr				96.4	808.3	1.2	0.4
County Line				123.7	1391.1	2.1	0.9
Groton				48.2	359.8	0.7	0.4
Fire Lane 20				26.6	60.2	0.1	0.0