OWASCO LAKE, NEW YORK: WATER QUALITY & NUTRIENT SOURCES, 2014 FINDINGS.

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INTRODUCTION

Since the initial water quality survey of the eastern Finger Lakes in 2005 by the Finger Lakes Institute, Owasco Lake and its watershed has been the focus for additional research due to the lake's poor water quality in comparison to neighboring Finger Lakes. The goals were to establish a consistent and comprehensive monitoring program to document spatial and temporal trends in pertinent water quality / water clarity / limnological parameters; bring particular focus to the extent and source of nutrients in the watershed, as their inputs to the lake promote algal growth thus degrade water quality; and, promote the development of comprehensive and effective watershed management policies to improve water quality in Owasco Lake. This multi-year effort was supported in the past by the Fred L. Emerson Foundation, Auburn, NY, New York State secured by New York Senator Michael Nozzolio, the Owasco Lake Watershed Association (OWLA), the Town of Fleming, and most recently 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 has 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 a few 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. The majority of the input happens during precipitation/runoff events.
- 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 newly established Watershed Inspector and the Watershed Council, have also reduced nutrient loading to the lake.

The 2011, 2012 and 2013 surveys added two new initiatives: It 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 the terminus of 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 indicates 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 - 2013 annual phosphorus budgets for Owasco Lake estimated an input of 2.6 to 16 metric tons of phosphorus per year, a loss of 6 to 7 metric tons of phosphorus per year, and a net input-output balance that fluctuated from an annual loss of 1.8 metric tons from the lake to a gain of roughly 12 metric tons of phosphorus to the lake.
- The phosphorus loads in 2011, 2012 and 2013 correlated to the amount of precipitation. The wettest years yielded larger loads.
- The implications are clear. Phosphorus loading must be reduced into the future 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 to naturally cleanse itself of phosphorus and improve water quality.

The water quality research is also passing into an exciting phase, as NY State funds were secured to establish preliminary BMPs in the Dutch Hollow Brook watershed in 2015, and to monitor and model the effectiveness of the remediation efforts.

Here, we report on our 2014 results. Unfortunately, Cayuga County 20% budget cuts altered the proposed work plan. In 2014, the number of sample dates was reduced from the proposed lake and stream monitoring schedule. However, more sites were sampled in the Dutch Hollow Brook and Owasco Inlet watersheds to pinpoint additional nutrient and sediment sources. The 2014 plan continued the detailed, event *versus* base flow, analysis of Dutch Hollow Brook at the 38A site; and, initiated a second event *versus* base flow analysis of Dutch Hollow Brook upstream of the 38A site at North Street. This study was made possible through the continued support by the Cayuga County Legislature with supplemental funds from the Owasco Lake Watershed Association to help offset Cayuga County a portion of the budget cuts in 2014.

METHODS

The sample sites and field/laboratory methods used in 2014 were similar to the 2011 – 2013 programs.

Owasco Lake: The 2014 lake survey sampled Sites 1 and 2 on a monthly basis from late May through early October (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 2014 survey dates were: 5/21, 6/16, 7/16, 8/13, & 10/1, three fewer surveys than the previous five years.

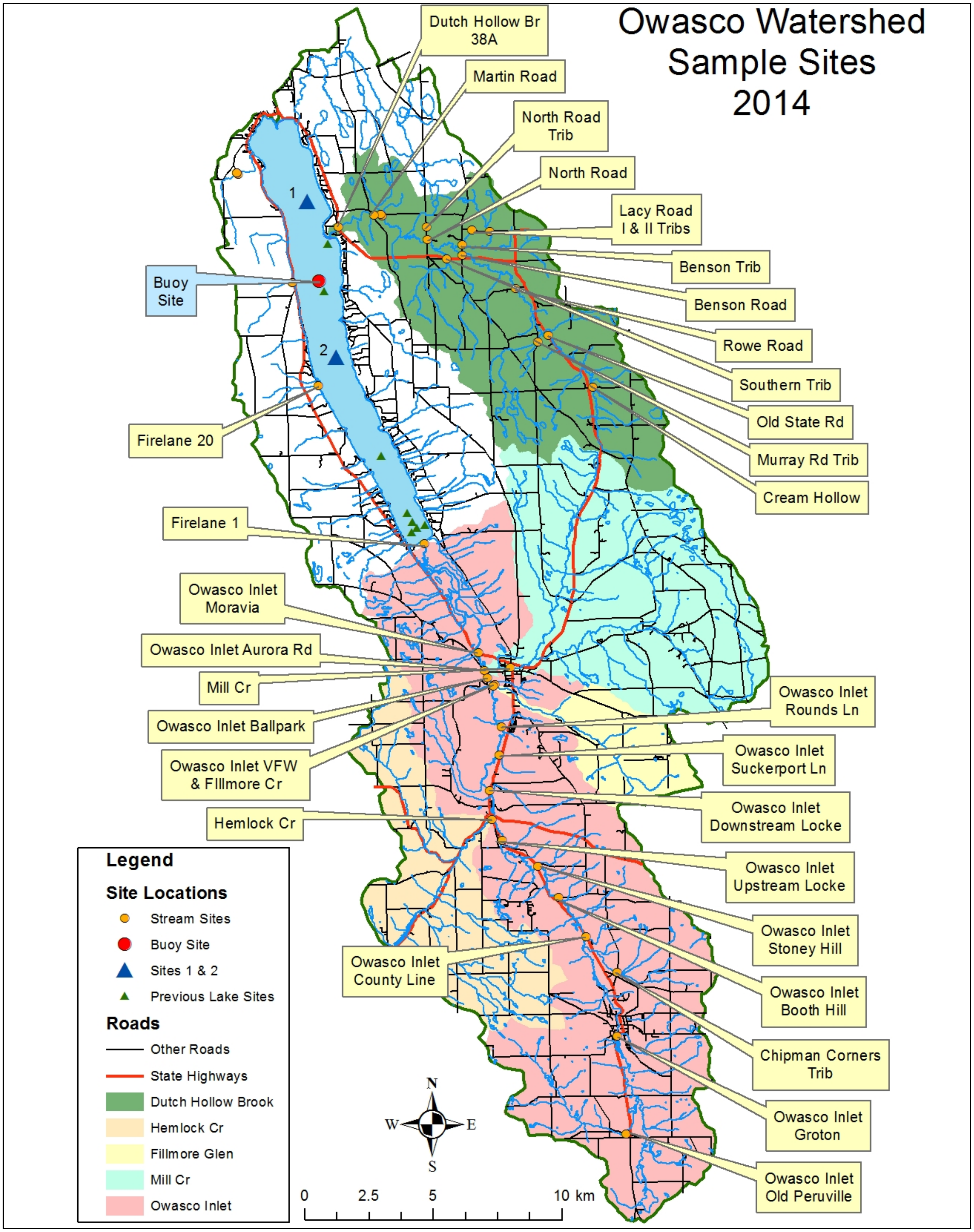

Fig. 1. The 2014 lake and stream sites. Many more stream sites were sampled but only sampled twice during the 2014 field season. Dutch Hollow Brook and the Owasco Inlet drain the two largest portions of the Owasco watershed at 77 km^2 and 299 km^2, respectively.

The field methods were nearly identical to our earlier lake research. A CTD water quality profile, secchi disk depth, vertical plankton tows (80-μm mesh), and surface and bottom water samples were collected at each site. The horizontal plankton tow was discontinued in 2014 due to its similar results to the vertical tow in the past. 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 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

Owasco Buoy: In 2014, a newly acquired water quality monitoring buoy (YSI/Xylem pontoon platform buoy) was deployed from 6/18 through 10/27 mid-lake, near Site C, between Burtis Point and Site 2 (Fig. 1). It was deployed mid-summer after resolving equipment issues associated with the new purchase. The buoy collected 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, sensors for total algae, chlorophyll-a, and blue green algae, BGA PC). Each profile collected data every 1.5 meters along the water column using a YSI/Xylem EXO2 sonde water quality logger. The buoy also contained a suite of meteorological sensors that recorded hourly air temperature, barometric pressure, relative humidity, light intensity and wind speed and direction. All of the data were periodically transferred to HWS by cellular phone ~30 minutes after collection.

Owasco Streams: The 2014 stream monitoring focused on Dutch Hollow Brook, Owasco Inlet and a small tributary at the end of Fire Lane 20. Dutch Hollow Brook was sampled on 6/3 and 7/30, Owasco Inlet on 6/4 and 8/1, and Fire Lane 20 on 8/1 for onsite analyses and collection of water samples for nutrient and sediment analyses in the laboratory.

Dutch Hollow Brook was sampled at twelve sites in 2014, seven more than 2013 (Figs. 1 & 2). Progressing upstream, seven sites were sequentially located on the main stream at Rt 38A, Martin Rd, North St, Benson Rd, Rowe Rd, near Old State Rd, and Cream Hollow Rd. Five unnamed tributaries in the watershed were also sampled. The North St tributary was sampled just north of the North St site. The South tributary was sampled along Rt 38A. The Benson tributary was sampled along Benson Rd just north of the Benson Rd site. Lacy Rd tributary was sampled along Lacy Rd at two locations, near the western-most farm on 6/3 and farther east on 7/30, because the first site was filled in between sample dates. Finally, the Murray Rd tributary was sampled at Murray Rd.

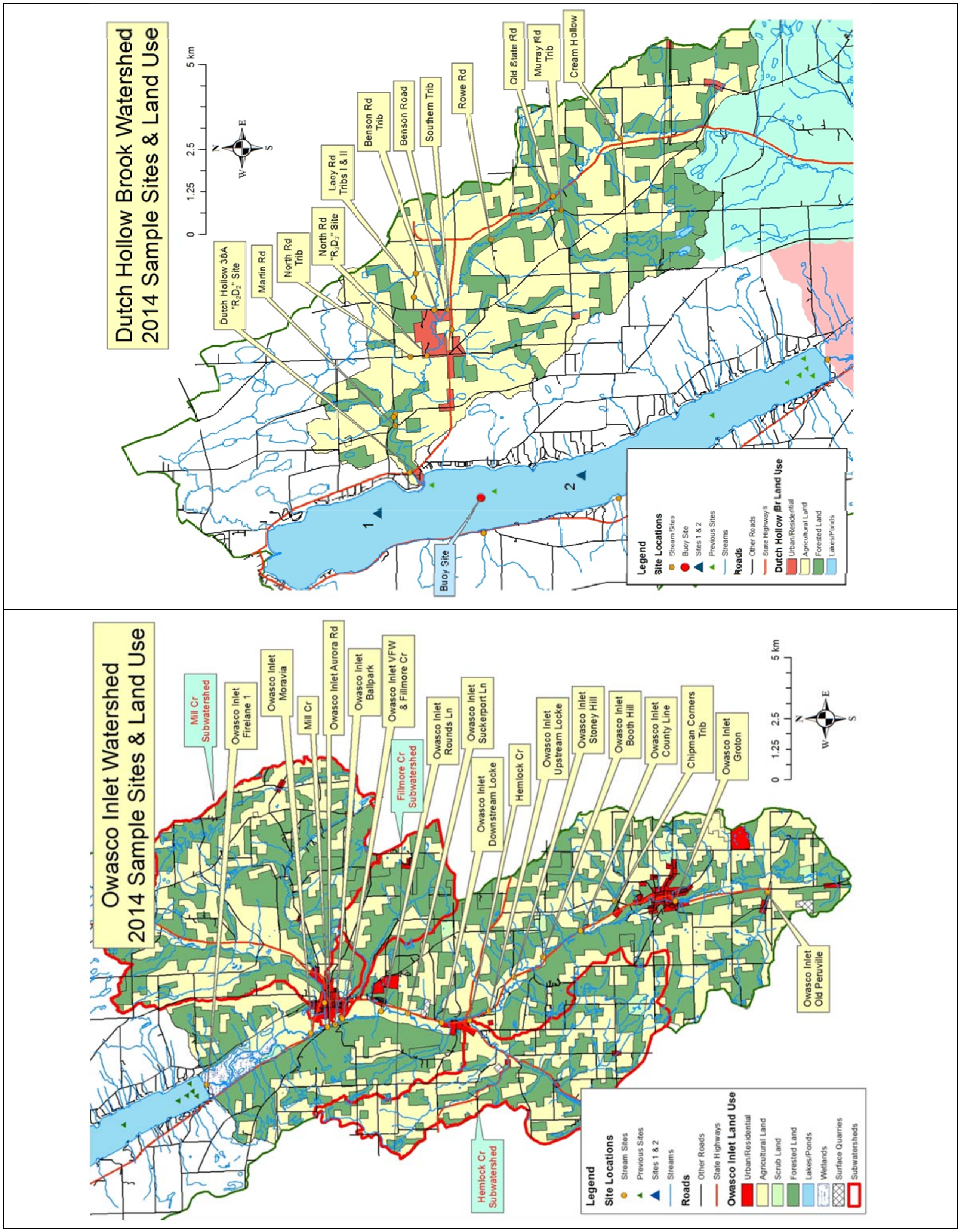

Fig. 2. 2014 site locations and land use within Dutch Hollow Brook and Owasco Inlet watersheds.

Owasco Inlet was sampled at seventeen sites in 2014, seven more than 2013 (Figs. 1 & 2). Proceeding upstream, thirteen sites were sequentially located along the main stream at just downstream of Moravia on Rt 38, at Aurora St in Moravia, adjacent to the Aurora St ball fields (Ballpark site), adjacent to the VFW fairgrounds just upstream of the Fillmore Cr confluence, at Rounds Ln, at Suckerport Ln, just north of Locke, just south of Locke, at Stoney Hill Rd, at Booth Hill Rd, at the County Line, just upstream of Groton (near Spring St), and along Old Peruville Rd. Mill, Fillmore, and Hemlock Creeks and an unnamed tributary at Chipman Corners Rd were also sampled. We propsed to sample the Owasco Inlet at Fire Lane 1 but the stream was too wide and too deep for measurement. We also sampled the creek at 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 Marsh-McBirney flow meter). Both velocity and stream depth were measured at five or ten 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 and North St sites. Stream discharge (water volume per unit time, e.g., m^3/s) is required for the flux (loading) calculations of, e.g., phosphates, suspended sediments, nitrates, and other parameters, 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: 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 countryside to the stream, and then flow downstream to the site. The response or lag time from the precipitation 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 more and more by 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 4/20 to 10/28 to investigate the impact of event and base flows on the delivery of nutrients and sediments to the lake (Figs. 3a & 3b). Another automated sampler and data logger was deployed 3.5 km upstream from Rt 38A at North Street from 6/3 through 10/28 to investigate event *versus* base flow variability along Dutch Hollow Brook. Its deployment was delayed until June due to budget limitations. Supplemental funds from OWLA continued deployment beyond the proposed summer season through the entire fall.

At both 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. Stream discharge was measured weekly. The samplers were serviced on the same schedule to bring water samples back to the laboratory for analysis. As in previous years, every 8-hr event sample but only daily base flow (4 am) samples were analyzed in 2014, because event concentrations and fluxes revealed quick and substantial sample to sample change, whereas base flow concentrations and fluxes revealed minimal sample to sample change in in prior years. Events were differentiated from base flow by total suspended sediment concentrations. The data loggers recorded 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. Over the 191 day (575, 8-hr samples) deployment in 2014 at 38A, and 147 day (442, 8-hr samples) deployment at North St, one week of samples (7/29 through 8/1) were lost at North St due to a flood that tipped over the sampler.

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 saved for total phosphate 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. 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 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 RESULTS & DISCUSSION

Lake CTD Profiles: The 2014 water temperature profiles were and typical for any late spring through early fall transition (Fig. 4). The first profiles, 5/21 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 12º C in late-May to almost 23º C in in June, and cooled to 19º C by the end of the survey (10/1). Hypolimnetic temperatures remained a uniform 6 to 7º C through the survey. Since 2009 through 2013, the epilimnion and hypolimnion were slightly warmer (by 1 to 2º C) than pre-2009 temperatures warming up to 27º C or warmer. The recent warming was perhaps related to global warming, annual climatic variability or the timing of the sample dates. However, the lake never warmed up above 23º C in 2014 and probably reflected the very cold winter, cool and rainy spring and cool summer.

Epilimnetic salinity (specific conductance) ranged from ~300 to 325 μS/cm in 2014. Like previous years, epilimnetic salinity in 2014 decreased from the largest detected values in the late spring (~325 μS/cm) through the summer and fall by ~25 μS/cm as the epilimnion was progressively diluted by less saline precipitation. The 2014 early spring conductivities and the stratified season decrease in conductivity was slightly less than those detected in 2011, but more typical of other years. The extent of the decrease in any given year paralleled the amount precipitation, e.g., the largest decrease was during 2011, a "wet" year. The hypolimnetic specific conductance data were just above 340 μS/cm and remained relatively uniform over time and depth (Fig. 4). The use of more road de-icing salt from the larger and more frequent snowfall the previous winter probably caused the slightly larger hypolimnetic salinity in 2014 than 2013.

A recent evaluation of chloride and other major ion data through the Finger Lakes region revealed that sodium (Na) and chloride (Cl) concentrations in regional streams and lakes correlated to the density of roads in the watershed (Halfman, 2014[1]). Century-scale chloride concentration trends in Skaneateles, Hemlock and Canadice Lakes and 20^+ years of data from Otisco, Owasco, Canandaigua, Keuka, and Hemlock Lakes parallel the use of road de-icing salts through northeastern US with notable increases in the 1960s and 1990s (Fig. 5). It strongly suggests that road de-icing salts, (NaCl), were the primary source of Na and Cl to the lakes. Other sources of the dissolved ions to the lake were most likely from the natural weathering of soils, tills and bedrock, other biogeochemical reactions, and human sources like barn yards, brought to the lake by runoff and/or groundwater flow. Halfman thanks the generosity of Glenn Jolly, USGS, and the Rochester and Syracuse Water Departments for use of their historical chloride data.

The 2014 epilimnetic dissolved oxygen (DO) concentrations decreased from 12.5 to ~8.5 mg/L from the spring to late summer, responding to the increase in surface water temperatures (Fig. 4). The concentrations remained at or near 100% saturation. However, hypolimnetic DO concentrations were progressively depleted below saturations through the stratified season to just above 6 mg/L (~50% saturation) in the upper and lower hypolimnion by the 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. It was less severe in 2014 than earlier years.

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[1] Halfman, 2014. An 2014 Update on the Chloride Hydrogeochemistry in Seneca Lake, New York. Finger Lakes Institute Report. 27 pg.

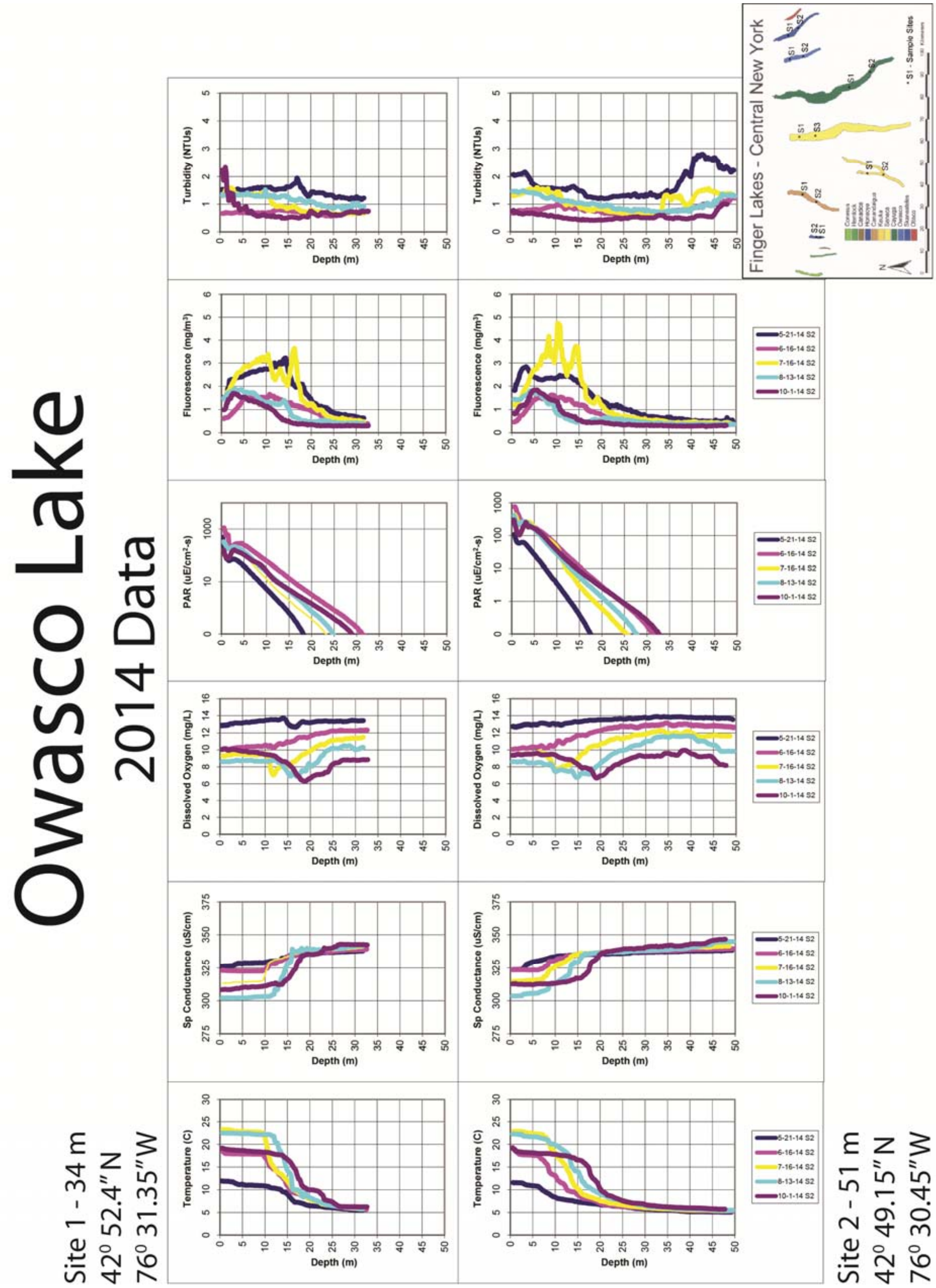


Fig. 4. Owasco 2014 CTD profiles from Sites 1 & 2. The PAR (light) data are plotted on an exponential scale, so that exponential changes with water depth appear as straight lines.

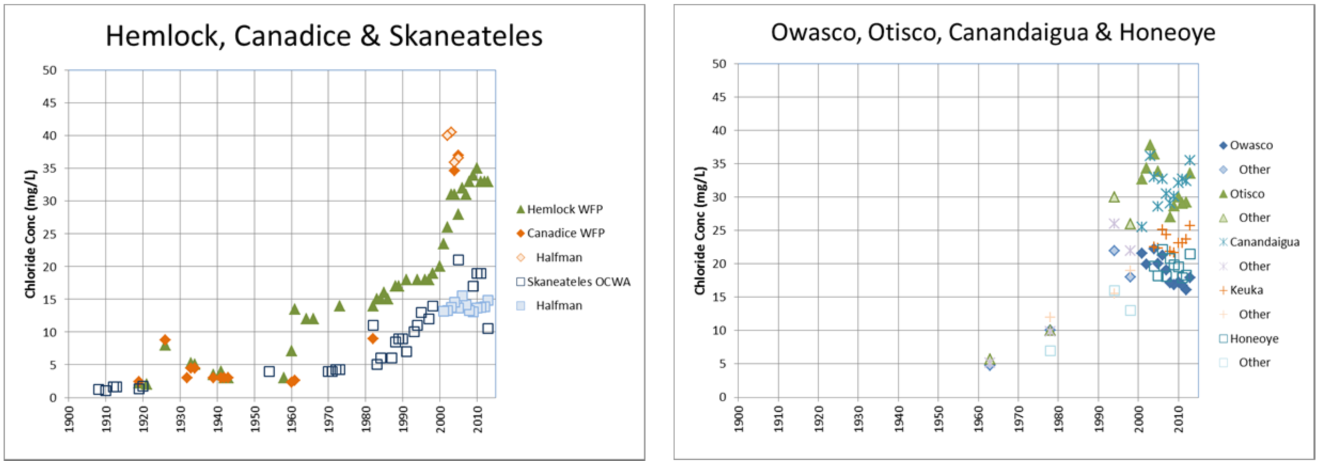


Fig. 5. Historical annual average chloride data from various Finger Lakes. Historical patterns in Seneca and Cayuga Lakes were different due to their deeper depths and the added influence of groundwater and salt mining activities.

Photosynthetic available radiation (PAR), or light intensity profiles in 2014 were similar to earlier results (Fig. 4). They decreased exponentially with water depth from a maximum intensity of a few 100 to a few 1,000 μE/cm^2-s at the surface to 1% of surface light intensities within the epilimnion at water depths of 10 to 15 m. The 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. 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. 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.

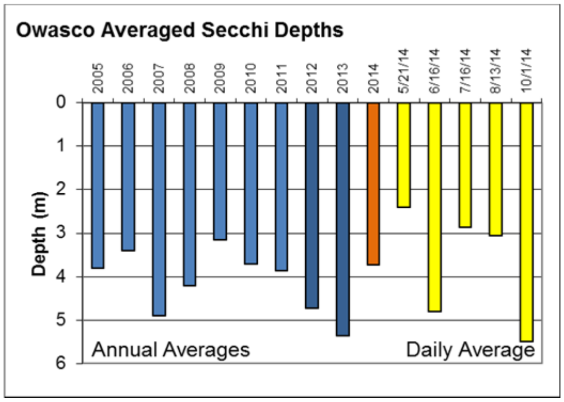
Fluorescence, a measure of algal concentrations, revealed peaks in chlorophyll abundance within the epilimnion approximately 5 to 15 m below the lake's surface (Fig. 4). Peak concentrations exceeded 3 and approached 5 μg/L (mg/m^3) on 5/21 and 7/16, but were lower, between 1 and 2 μg/L on the other survey dates. The 2014 data were similar or slightly smaller than previous years. Hypolimnetic concentrations were consistently below 1 μg/L. An early summer bloom is unusual for Owasco Lake and may reflect algal growth after nutrient inputs from heavy rains in late May. Many of the Finger Lakes experienced larger chlorophyll concentrations in May due to this event as well.

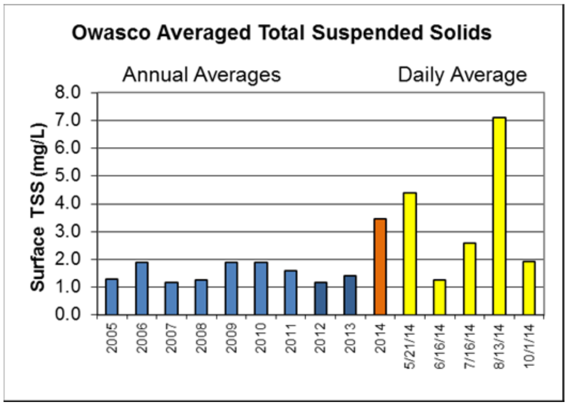
A Feb 3, 2014 manure spreading event on a snow-covered and frozen field above the western shore of the lake probably helped stimulate the observed early spring blooms. Using the following tenuous and simplistic assumptions with no on-site confirmation of these amounts and/or utilization of the phosphorus in the manure by the soil, i.e., manure density of 0.5 kg manure/liter, phosphorus proportion of 2 g P/kg manure, spread approximately 0.1 m thick on a surface area of 200,000 m^2, then this event released a few metric tons of phosphorus to the snow, that probably made it to the lake. This release is the same order of magnitude as the annual input of phosphorus by streams to the lake. Winter spreading is problematic. In contrast, spreading during the spring, summer and/or fall is managed because the nutrients are theoretically utilized by plant growth before they move off the field. The natural processes are complex.

The turbidity profiles revealed uniform or nearly uniform turbidities just above 1 NTU 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). The late May survey profile was the exception with much larger turbidities. The large May turbidities were unusual for Owasco Lake and reflect some combination of the suspended sediment inputs due to the heavy May rains and/or the early spring spreading and runoff of manure along the western shore.

Limnology & Trophic Status of Owasco Lake: The secchi disk, chlorophyll, nutrient and suspended sediment data indicated that the lake was not a health threat, as nitrate concentrations were below 1 mg/L and an order of magnitude (10 times) below the 10 mg/L MCL established by the EPA (Table 2 in appendix, Fig. 6). Neither was the lake impaired, as the annual mean total phosphate concentration was near 18 μg/L, below the 20 μg/L total phosphate (TP) threshold established for impaired water bodies by the DEC. The 5/21 TP concentration was the only exception with a TP date-averaged lake concentrations of 29 μg/L. These 5/21 reading are consistent with the large May rain event and/or manure spreading. The TSS readings ranged from 1.3 to 7.1 mg/L and averaged 3.5 mg/L. Large concentrations were detected on 5/21 and 8/13. Both surveys were after heavy rains that probably stimulated the large TSS readings and the large TSS annual average. Surface chlorophyll-a concentrations ranged from 1.2 to 4.9 μg/L, and averaged 3.2 μg/L. Secchi disk depths ranged from 2.4 to 5.5, averaged 3.7 meters.

Annual mean total phosphate concentrations increased from 2005 to 2011 (8 to 13 μg/L), decreased to 10.8 μg/L by 2013 but increased again to nearly 18 μg/L in 2014 (Fig. 6). Dissolved phosphate concentrations were larger in 2006, 2011 and 2013 than other years, and especially large in 2014. The large 2014 mean was due to the abnormally large concentrations detected in 5/21, and decreasing concentrations to more typically values by 8/13. Chlorophyll-a concentrations were larger in 2009 and 2010 than other years (3.9 and 3.7 to ~2 μg/L; 1.9 and 1.9 to ~1.2 mg/L) although 2014 was also large (3.2 μg/L). Total suspended sediment (TSS) were largest in 2014 than any other previous year, nearly 18 mg/L. Secchi disk depths were shallower in 2014 (3.4 m) than every year since 2009 (Fig. 6). These trends were consistent with increased algal productivity from 2008 through 2010 that subsequently declined during 2014. The data suggest slightly better water quality in the lake before and after 2010 and 2011, and water quality declined in 2014. The major difference between 2014 and previous years was the abnormal late May sample, probably due to the May rain event and/or the release of manure along the western shore.





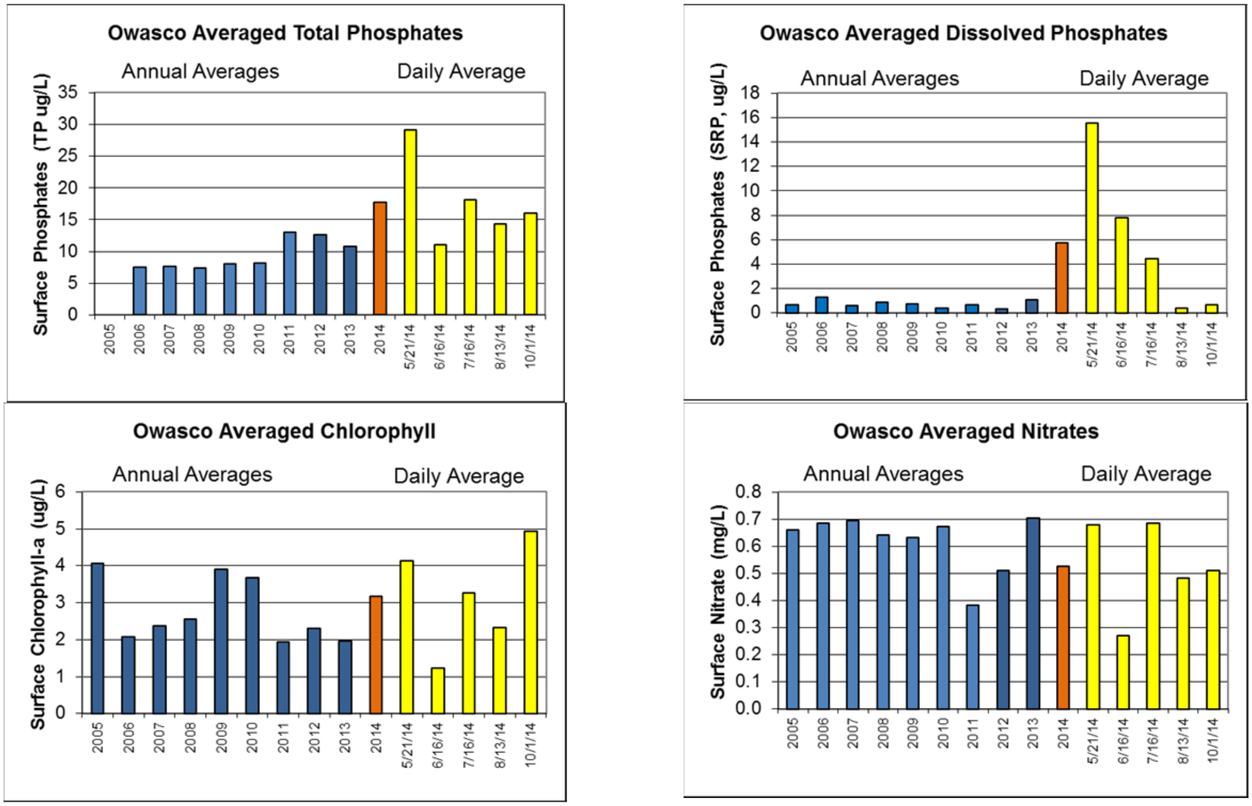


Fig. 6. Annual average surface water data (blue bars, orange for 2014), and daily average surface water data from each 2013 survey date (yellow bars).

The trophic status of Owasco Lake deteriorated in 2014. The 2014 annual average nitrate and chlorophyll-a concentrations place Owasco Lake just below the oligotrophic/mesotrophic trophic boundary (Table 3, Fig. 6). The annual mean Secchi disk depths, TP concentrations and hypolimnetic dissolved oxygen concentrations placed Owasco Lake just into the mesotrophic range. Thus, the trophic status of Owasco Lake remains borderline oligotrophic-mesotrophic. It appeared to become slightly more oligotrophic from 2011 through 2013, but returned back to a mesotrophic system 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 2014 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 1:91 and were between 1:44 to 1:1,140 in 2014. 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 only one source of nitrogen to the lake (acid rain nitrates). The large concentration of dissolved phosphates detected in 5/21 allowed for more algal growth in May-June of 2014, and a decline in overall water quality from the previous two years. It also stimulated the greatest depletion of nitrates in the lake as annual mean P:N ratios were significantly lower in 2014 than any previous year (next lowest was in 2006). 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 and chlorophyll-a concentrations a small decrease from the epilimnion to the hypolimnion, e.g., annual mean surface and bottom water concentrations for soluble reactive phosphate were 5.8 and 6.8 μg/L, nitrate 0.5 and 0.9 mg/L, silica 550 and 1,255 μg/L, and chlorophyll-a 3.2 and 0.6 μg/L, respectively. 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. The slug of phosphorus detected in early May probably caused the larger than normal SRP concentrations.

Plankton Data: The phytoplankton (algal) species in Owasco Lake during 2013 were dominated by diatoms, primarily *Flagillaria* and *Asterionella*, with smaller numbers of *Diatoma*, *Melosira*, *Tabellaria* and *Synedra* (Table 4 in appendix, Fig. 7). Like previous years, *Asterionella* and *Fragillaria* dominated in the spring, *Diatoma* replaced *Asterionelia* in the early summer, *Dinobryon* dominated in the late summer, and *Fragillaria* and *Asterionella* 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 spiny water flea. Zebra and quagga mussel larvae were also detected in the plankton tows.

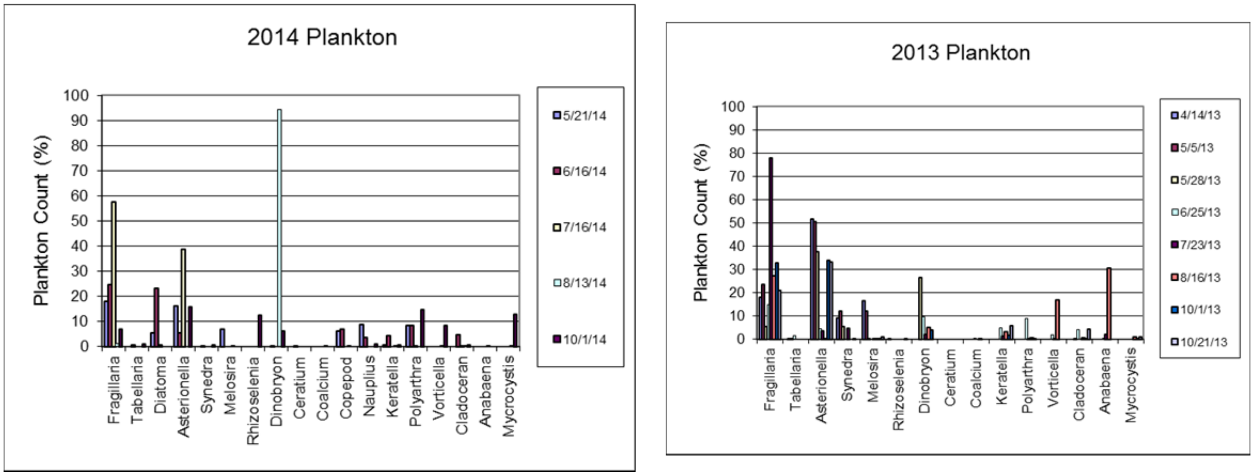


Fig. 7. Date averaged plankton data for 2014 and 2013.

Over the past six years, a few blue green algae genera have increased in abundance during the late summer, with *Mycrocystis* representing up to 40% of the phytoplankton during late-summer blooms in 2007 & 2010, and *Anabaena* making up 30% of the late-summer blooms in 2013. In 2014, another late summer bloom of *Mycrocystis* was detected. The increase in blue green algae is disturbing, because they are common in eutrophic systems. Blue greens contain gas vacuoles that enable them to float at or near the surface of the lake and thus allow them to outcompete other algal species for the available light in a very productive, algal-rich and turbid lake. The resulting surface-water scum of blue green algae is unpleasant, unsightly and smells. In contrast, other groups of algae live at deeper depths, and out of sight of humans at the surface or onshore. Blue greens disrupt food chain dynamics, because blue greens are avoided, i.e., preferentially not eaten, by zooplankton and fish (apparently they taste "yucky"). Additionally, some species of blue greens are toxic to humans and other warm blooded animals. Lab tests by NYS DEC on samples we collected during the July and August surveys did not detect any toxic compounds. The threat however suggests that Owasco Lake needs a daily monitoring tool, like the meteorological and limnological monitoring buoy recently purchased by FLI, as the modern technology can detect the presence of blue green from other algae and thus provide a means to warn users, boaters and swimmers, and restrict the lake's use as a source of drinking water.

PRELIMINARY BUOY DATA

A water quality monitoring buoy was deployed in Owasco Lake between Burtis Point and Site 2. It revealed higher resolution but otherwise consistent changes in the water column as described above (Fig. 8). Epilimnetic (surface water) temperatures increased from mid-June through early July to 24° C, then decreased up to the end of the deployment (10/28) as expected due to the season change in solar gain and evaporative and radiative loss of energy across the lake's surface. Hypolimnetic temperatures remained constant. The thermocline, the boundary between the epilimnion and hypolimnion, depth gradually increased through the field season from under 10 m to over 20 m. The decrease was faster during September and October reflecting the cooler thus denser surface water mixed vertically to deeper and similar temperature depths in the water column prompting the gradual decay of summer stratification. It also revealed daily oscillations in response to internal seiche activity. The buoy data more robustly detected the timing and magnitude of the epilimnion thermal onset, maximum and decay, and internal seiche activity day long scale oscillations in the depth of the thermocline that were not observed in the monthly monitoring.

The epilimnetic specific conductance data decreased through the early summer to early August from 330 to 315 μS/cm and then increased slightly to 325 μS/cm until October, the date of buoy recovery. The decrease reflects the dilution of the epilimnion by stream inputs and rainfall. The subsequent decrease reflects the mixing of slightly more saline upper hypolimnetic water as the surface waters cool in the fall. The hypolimnion salinity remained constant. Again, the buoy detected more than the monthly surveys.

The turbidity did not change very much. Larger turbidities, ~ 2 to 3 NTUs, were observed in early August (8/5 – 8/7), perhaps reflecting more algae at this time or a rainfall event. Either the events were small during the deployment and not detected in the middle of the lake, or perhaps the TSS scale needs tweaking to observe finer details.

The chlorophyll-a concentrations changed significantly from near 0 to over 10 μg/L on different temporal scales. A major bloom with concentrations exceeding 10 μg/L was detected in late June and early July, and another in mid-August. The algae were concentrated within the upper 20 m of water, i.e., through the epilimnion and upper hypolimnion. The early blooms persisted for a week or more, while the August bloom only for 4 or 5 days. Less algae were detected through the rest of August until algae concentrations increased slightly, up to 3 μg/L, through the

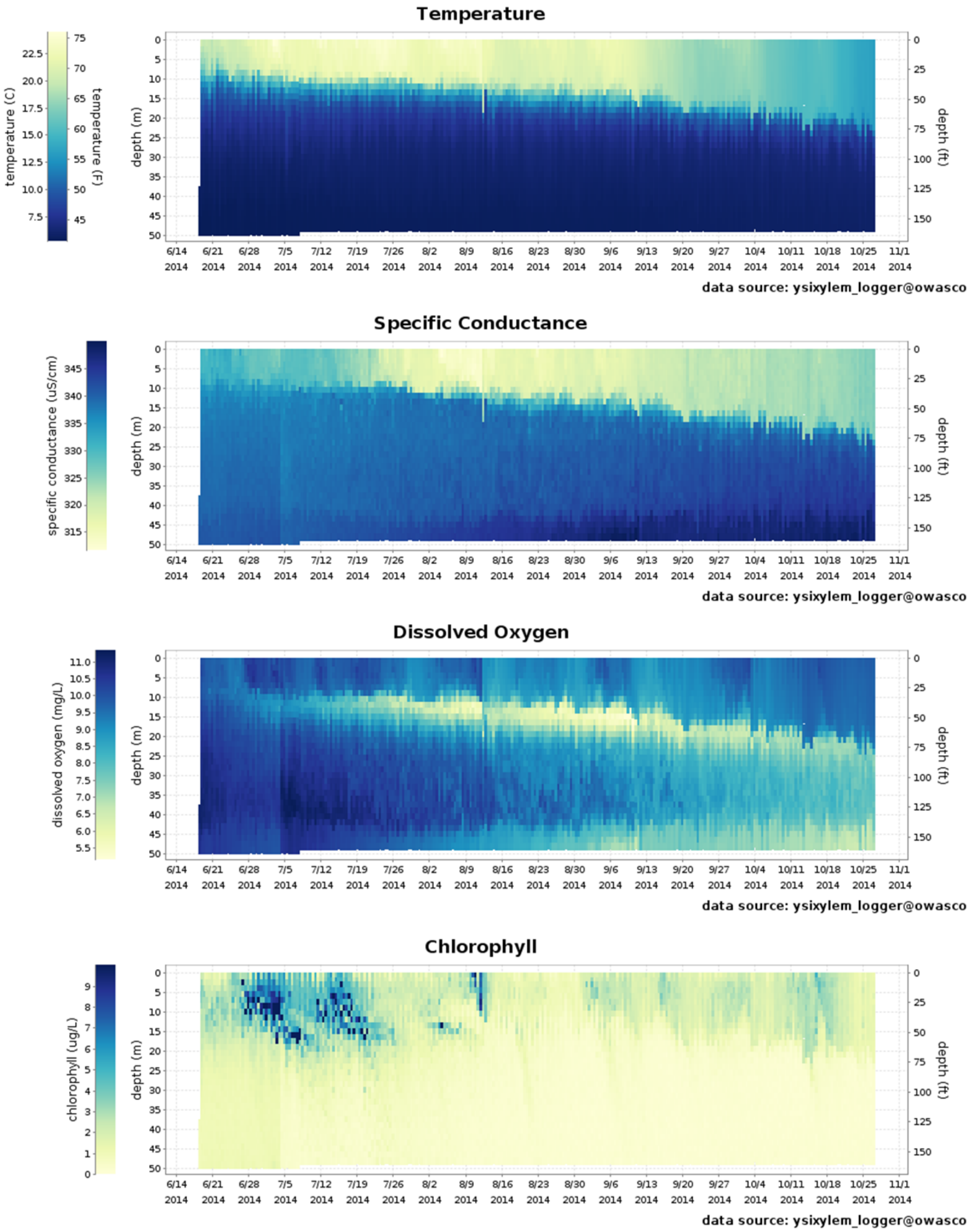


Fig. 8. Preliminary buoy data from 2014.

remainder of the deployment. The June/July bloom most likely responded to the large dissolved phosphate concentrations. The September and October algae benefited 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 bloom. Again, the buoy detected more than the monthly surveys.

The blue green algae sensor did not detect major changes through the deployment. It could reflect the surface and nearshore hugging distribution of blue green algae, or perhaps the scale needs tweaking to observe finer details.

Finally, epilimnetic dissolved oxygen (DO) concentrations were at or near saturation throughout the deployment. DO in the hypolimnion was depleted below saturation. Significant depletion of oxygen down to ~40% below saturation was detected at and just below the thermocline. The depletion reflects the respiration of algae by bacteria, zooplankton and other animals at this depth. The depletion reached a maximum in August, just after the major algal blooms. DO was also increasingly depleted along the lake floor down to ~40% saturation through the stratified season, and pinpoints another region of bacteria respiration. Throughout the remainder of the hypolimnion, DO was depleted to 50 to 60% saturation. Again the buoy detected more detail than the monthly surveys, and highlights the need for its deployment into the future to more completely investigate the change in water quality from one year to the next.

COMPARISON TO OTHER FINGER LAKES

Skaneateles, Otisco and Owasco Lake CTD Comparison: The seasonal variability in temperature, salinity (specific conductance), dissolved oxygen, PAR (light), turbidity and algae (fluorescence) between Owasco, Skaneateles and Otisco Lakes were still a function of basin morphology, watershed and lake surface area, depth, the percentage of agricultural land, and the degree of watershed protection (Fig. 9). The biologically related CTD parameters, fluorescence, dissolved oxygen, and PAR (light penetration), revealed the borderline oligotrophic-mesotrophic state of Owasco Lake which was in between the oligotrophic Skaneateles and eutrophic Otisco.

Finger Lake Water Quality Ranks: The 2014 Finger Lakes water quality rankings still placed Owasco Lake as one of the worst lakes among the eight easternmost Finger Lakes (Table 5 in appendix, Figs. 10 & 11). The ranks were based on annual average secchi disk depths, and surface water concentrations of chlorophyll-a, total and dissolved phosphate, nitrate and total suspended sediments collected by the monthly, May through October, FLI survey. In 2014, Owasco revealed a poorer rank than Canandaigua, Keuka, Skaneateles and Seneca Lakes, a similar rank as Cayuga Lake but a better rank that Honeoye and Otisco Lakes. All of the lakes revealed the worst ranking in 2014 compared to earlier years. This was especially true for Keuka Lake. It indicates that the unusual late spring rains and the associated event stimulated nutrient and sediment loading degraded water quality in all the lakes this past year. Thus, the 2014 water quality degradation in Owasco Lake in late May was not just due to the early spring manure spill along the western portion of the watershed but also the heavy May rains in the region.

The change in water quality between lakes is due to a number of factors. The degree of water quality protection legislation and its implementation are important. For example, the Skaneateles, Canandaigua and Keuka watersheds have adopted a number of stringent regulations that protect and maintain the pristine nature of their lakes. The percentage of agricultural land and changes in precipitation from year to year in each watershed influenced these ranks as well.

Other factors like population, watershed size and lake volume did not correlate to its water quality rank.

Besides “bottom-up”, nutrient loading induced degradation in water quality, exotic species like zebra and quagga mussels, Asian clams and/or *Cercopagis*, the spiny water flea, play a “top-down” water quality role as well. Zebra and quagga mussels filter feed on plankton. Thus, they effectively remove algae and other plankton from the lake, and thus “improve” water clarity and water quality. In contrast, Asian clams “pump” phosphorus into the epilimnion from the sediments promoting algal growth and degrading water quality. The spiny water flea also stimulates water quality degradation by feeding on herbaceous (plant eating) zooplankton and thus decreasing algal predation and fostering mid-summer algal blooms.

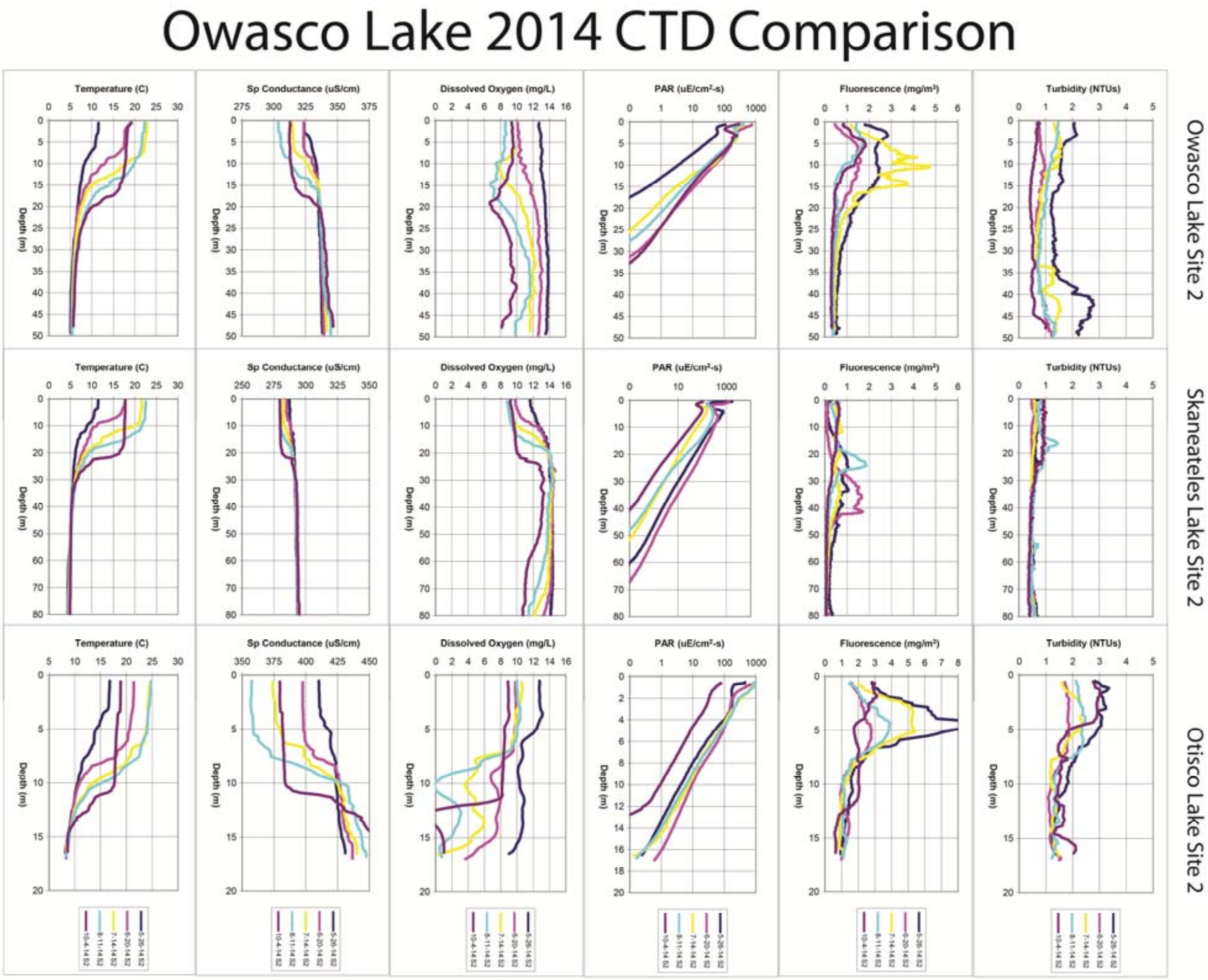


Fig. 9. 2014 CTD Profiles from Owasco (top), Skaneateles (middle) and Otisco (bottom) Lakes. The PAR (light) data are plotted on an exponential scale, so that exponential changes with water depth appear as straight lines.

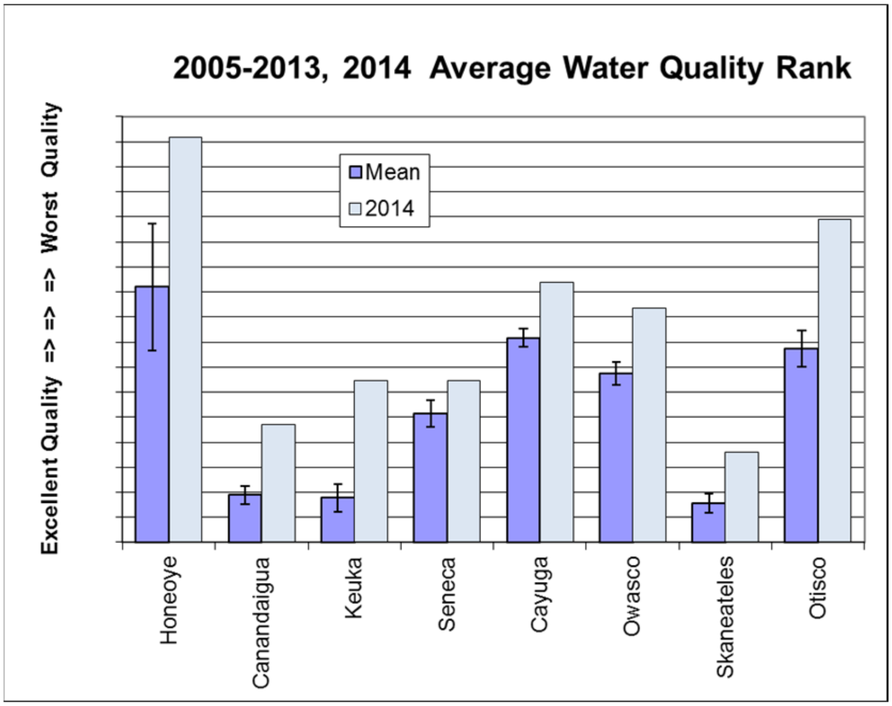
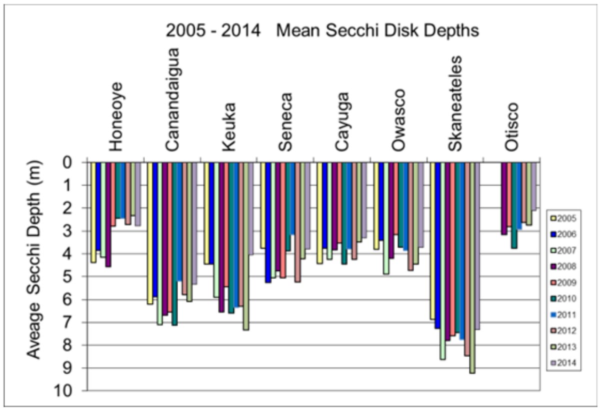
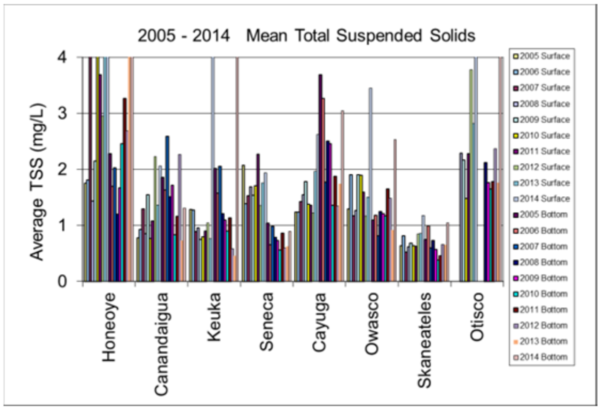
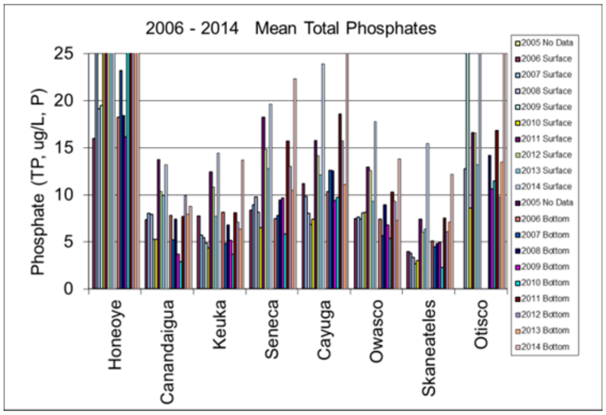
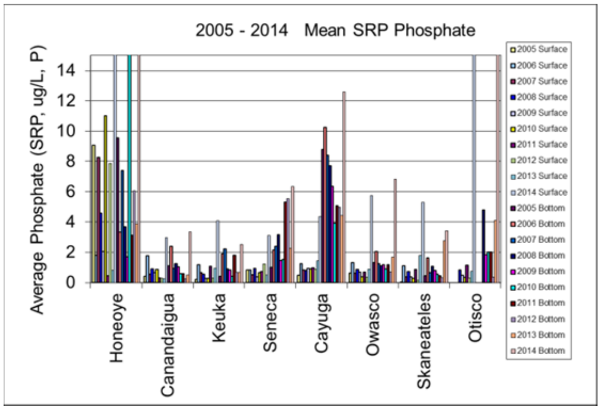


Fig. 10. Annual Water Quality Ranks from 2005 – 2014 for the eight easternmost Finger Lakes. The “mean” dark blue bar averaged the previous 9 years of ranks for each lake with a 1σ standard deviation shown.









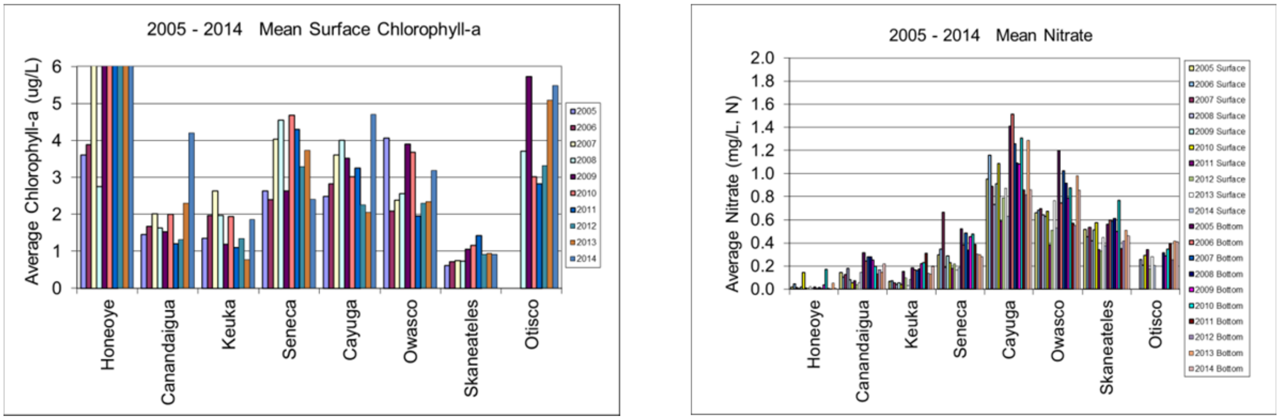


Fig. 11. Annual mean limnological data from selected Finger Lakes. The values for Owasco Lake only utilized data from the 5-month, summer-season, Finger Lakes survey.

STREAM RESULTS & DISCUSSION

Stream Discharge: Measured stream discharge in 2014 on the two survey dates ranged from nearly dry (0.00) conditions at Lacy Road to 2.3 m^3/s along Owasco Inlet at Moravia (Table 6 in appendix, Figs. 12 & 13). Annual mean flows are smaller in 2014 than earlier years. However the difference probably reflected the samples restricted to the summer season as the 2014 results are similar to the June and July results from earlier years. The measured weekly discharge data at Dutch Hollow ranged from 0.1 to 1.9, with a mean of 0.60 m^3/s at 38A and 0.1 to 1.6, and mean 0.54 m^3/s at North St. These flows were more typical of the seasonal variability and annual means observed at Dutch Hollow Brook detected in previous years.

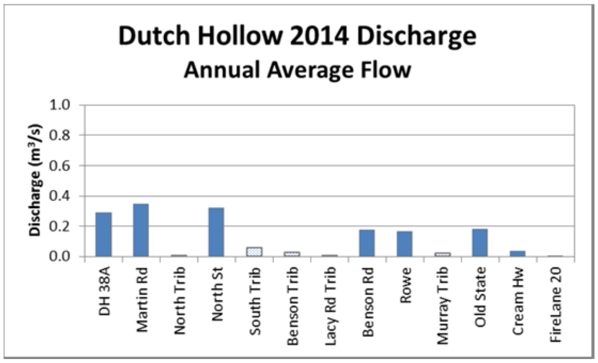


Fig. 12. Annual average stream discharge at each stream site in the Dutch Hollow Brook watershed. Fire lane 20 data is in blue. Tributary sites are stippled. Sites are arranged, left to right, from downstream to upstream.

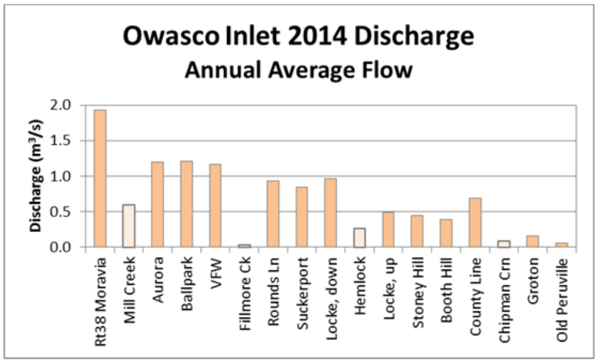


Fig. 13. Annual average stream discharge at each stream site in the Owasco Inlet watershed. Tributary sites are stippled. Sites are arranged, left to right, from downstream to upstream.

Spatial patterns in discharge were consistent over the past few years. For example, 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 2014 (Fig. 14, $r^2 = 0.98$). The annual mean measured discharge of Owasco Inlet (299 km^2), Dutch Hollow Brook (77 km^2), Hemlock (47 km^2) and Mill Creeks (78 km^2) were 1.9, 0.3, 0.3 and 0.6 m^3/s, respectively. This trend was also true for the two sites with detailed data, 38A and North St, along Dutch Hollow Brook.

Within Dutch Hollow Brook, mean annual discharge at each downstream site equaled or was slightly larger than the sum of the discharges at the next upstream site and any tributaries entering along the segment. 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.

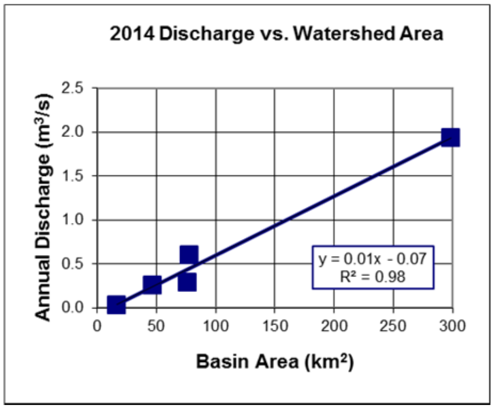


Fig. 14. Discharge vs. Basin Size.

Within Owasco Inlet, tributary inputs typically accounted for the observed downstream increases in discharge as well. 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 must control the increase from Groton to County Line but not measured for confirmation. Stream water appears to be lost, perhaps to the ground, between County Line and Booth Hill. Interestingly, no change was observed between Locke downstream and Aurora sites in 2014, an observation that is not consistent with detectable losses along this segment in previous years. The change may reflect the restricted number of survey dates in the summer of 2014.

Seasonal Variability: Seasonal data are not available in 2014 for comparison. Using the weekly discharge data for Dutch Hollow and the USGS gauge data for Owasco Inlet, the largest discharges of 2014 were detected in the spring and smallest in the summer or fall (Fig. 15). The 2014 pattern in flow was similar to previous years and paralleled the seasonal change in precipitation and evapotranspiration (Fig. 16).

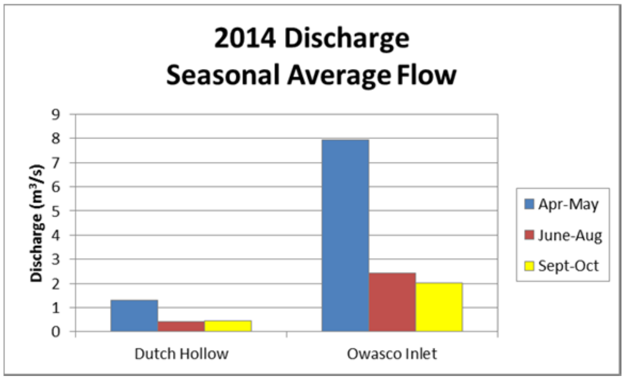


Fig. 15. Seasonal averaged stream discharge for the Rts. 38A and 38 sites, the terminal sites on Dutch Hollow Brook and Owasco Inlet, respectively.

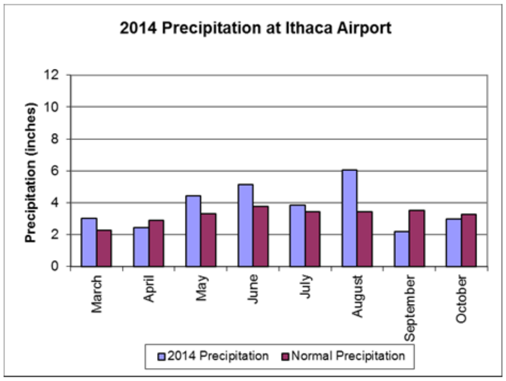


Fig 16. Monthly 2014 and “normal” precipitation totals for the Ithaca Airport.

Differences to Earlier Years: In a comparison to earlier years, the measured discharges in 2014 were smaller than the past five years (0.3 m^3/s compared to 0.9, 0.4, 2.5, 0.7, and 0.7 m^3/s, from 2013 through 2009, respectively). However, this simple comparison is misleading, because the 2014 sampling was restricted to two summer dates compared to monthly or bi-monthly spring through fall data in earlier years. This difference will probably influence the grab-sample concentrations and fluxes from 2014 as well.

The 2011 annual average April through October weekly discharge data at Dutch Hollow Brook and the April through October mean daily USGS gauge data for Owasco Inlet was 3 to 5 times larger than those measured in 2012, but only 1.3 to 3 times as large than those measured in 2013 and 2014 (Fig. 17). These differences are explained by changes in precipitation. The 2011, the 8-month, field season, precipitation total was very close to normal measured at Ithaca Airport (Fig. 18). In contrast, 2012 was 12 inches below normal, thus it was relatively dry year, and 2013 and 2014 were in between these two extremes. It designates 2013 and 2014 as the "in between" years, 2011 as the "wet" year, and 2012 as the "dry" year. Thus, major differences in discharge parallel and most likely were dictated by changes in precipitation. Interestingly, 2014 had more early spring rainfall than 2013 and 2012. The extra May rains and early spring manure spreading dictated the late spring/early summer degraded water quality in 2014 compared to 2013 and 2012.

The Owasco Inlet (USGS Gauge, 4235299) 8-month, field season discharge data also revealed an "in between" mean annual discharge of 3.9 m^3/s for 2014 compared to 5.1, 1.2, and 3.9 m^3/s in 2011, 2012 and 2013, respectively (Fig. 19). Similar variability was observed for the Owasco Outlet (USGS Gauge, 4235440). Annual mean daily outflows were 8.3, 8.4, 11.4, 8.4, 8.3 and 8.7 m^3/s for 2009 through 2014, respectively. Clearly, 2013 and 2014 were "in between" and perhaps more typical for Owasco Lake compared to the 2011 the "wet" and the 2012 "dry" year.

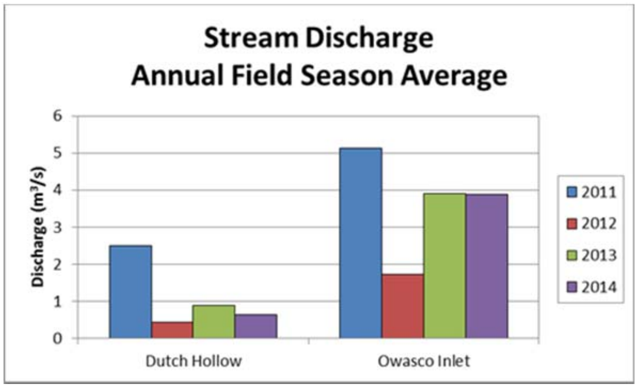


Fig. 17. Annual average stream discharge for the Rts. 38A and 38 sites. This plot used the weekly Dutch Hollow and daily Owasco Inlet flow data.

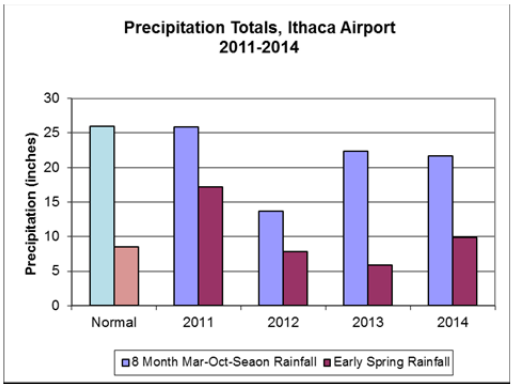


Fig. 18. Annual precipitation totals during the 8-month, March – October, field season at the Ithaca Airport.

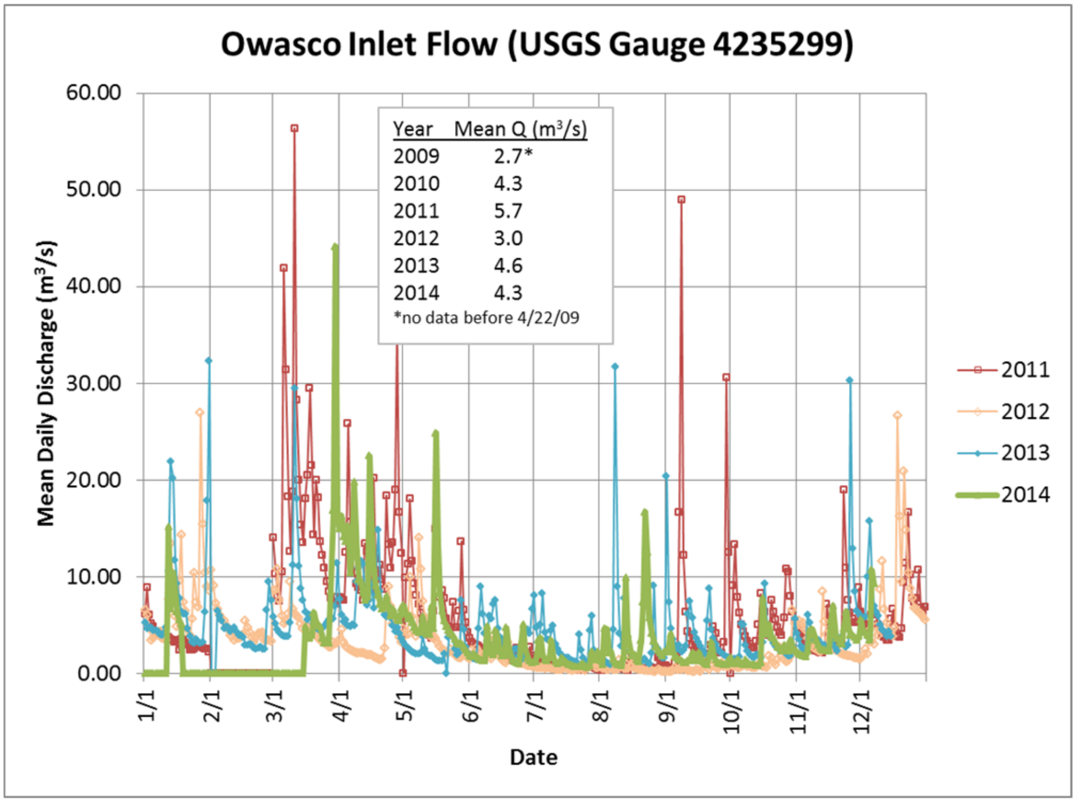
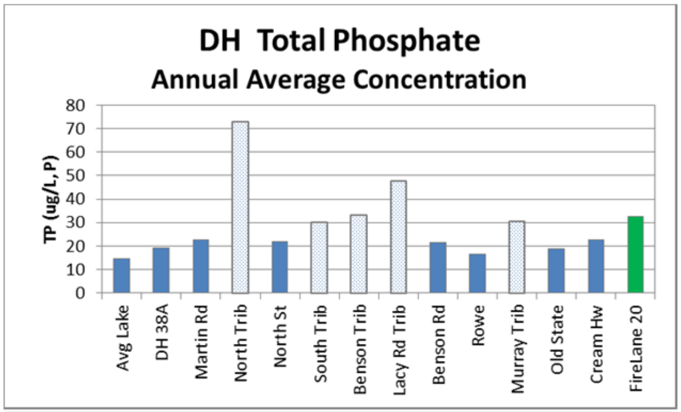
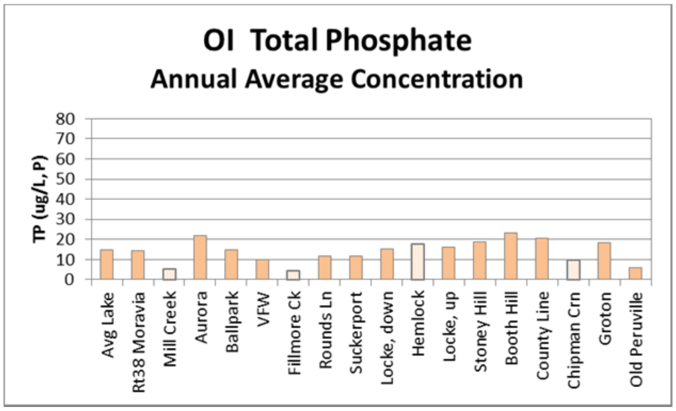


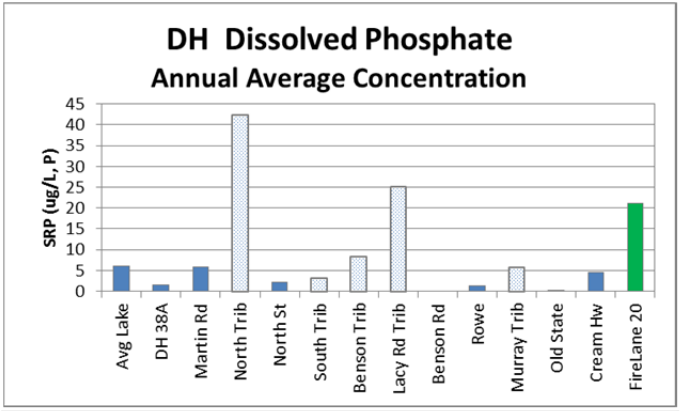
Fig. 19. Annual average stream discharge for the Owasco Inlet near Moravia – USGS Stream Gauge 4235299.

Stream Concentration Data: Total phosphate (TP) concentrations in 2014 ranged from 0 to nearly 90 μg/L, and averaged 30 μg/L in Dutch Hollow Brook. They ranged from 1 to 36 μg/L, and averaged 14 μg/L in Owasco Inlet (Table 6 in appendix, Fig. 20). Within Dutch Hollow Brook watershed, the North, South, Benson Rd and Lacy Rd tributary sites revealed the largest annual mean TP concentrations of ~30 to 73 μg/L, whereas the Rowe and Old State Rd sites revealed the smallest mean TP concentrations (~17 μg/L). The small, agriculturally-rich tributaries, e.g., North, South and Lacy Tributaries, revealed the largest TP concentrations; whereas, Rowe Rd and Old State Rd drain more forested land. The Benson tributary did not have the largest TP concentration as in previous years. Thus, it suggests that recent remediation efforts within the Benson Tributary watershed, i.e., at Young's Farm decreased nutrient loading from this segment of the watershed. Surprisingly, Murray Tributary was also large, larger than past years for this forested watershed. Perhaps this reflects sampling a rain event on 6/3, one of only two sample days, compared to sampling during base flow conditions on a monthly or bi-monthly schedule, artificially increasing the annual mean from 2014 for this site.

Total suspended sediment (TSS) concentrations were also largest at the North, South and Lacy Tributaries that drain agricultural landscapes. TSS detected at Benson Tributary was not as large. A notable increase in TSS from North St to Rt 38A, was also not observed in 2014 as in past years. Perhaps it reflected a bias to the limited number of summer samples.


DH Total Phosphate
Annual Average Concentration
TP (ug/L, P)
80
70
60
50
40
30
20
10
0
Avg Lake
DH 38A
Martin Rd
North Trib
North St
South Trib
Benson Trib
Lacy Rd Trib
Benson Rd
Rowe
Murray Trib
Old State
Cream Hw
FireLane 20


OI Total Phosphate
Annual Average Concentration
TP (ug/L, P)
80
70
60
50
40
30
20
10
0
Avg Lake
Rt38 Moravia
Mill Creek
Aurora
Ballpark
VFW
Fillmore Ck
Rounds Ln
Suckerport
Locke, down
Hemlock
Locke, up
Stoney Hill
Booth Hill
County Line
Chipman Crn
Groton
Old Peruville


DH Dissolved Phosphate
Annual Average Concentration
SRP (ug/L, P)
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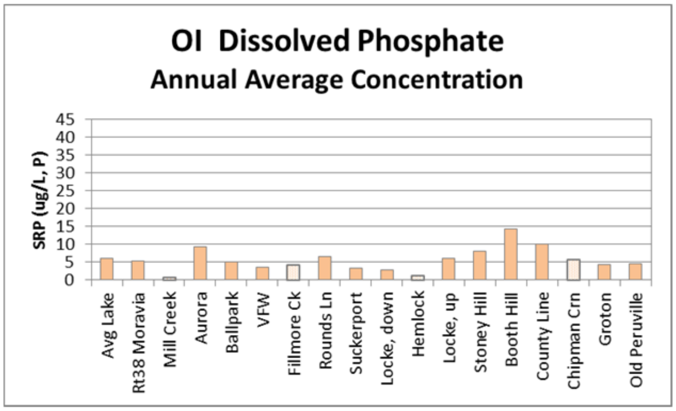
40
35
30
25
20
15
10
5
0
Avg Lake
DH 38A
Martin Rd
North Trib
North St
South Trib
Benson Trib
Lacy Rd Trib
Benson Rd
Rowe
Murray Trib
Old State
Cream Hw
FireLane 20


OI Dissolved Phosphate
Annual Average Concentration
SRP (ug/L, P)
45
40
35
30
25
20
15
10
5
0
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Rt38 Moravia
Mill Creek
Aurora
Ballpark
VFW
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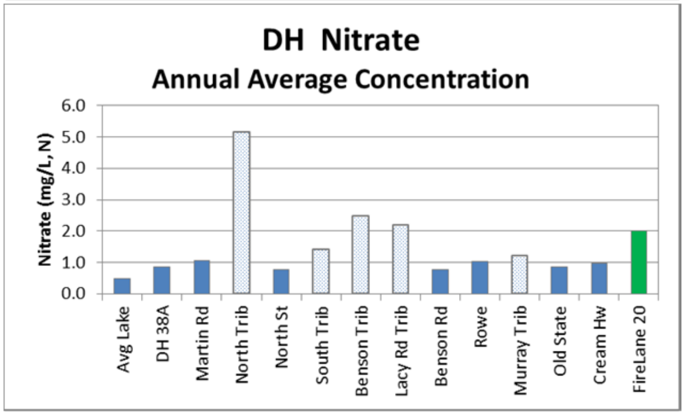
County Line
Chipman Crn
Groton
Old Peruville


DH Nitrate
Annual Average Concentration
Nitrate (mg/L, N)
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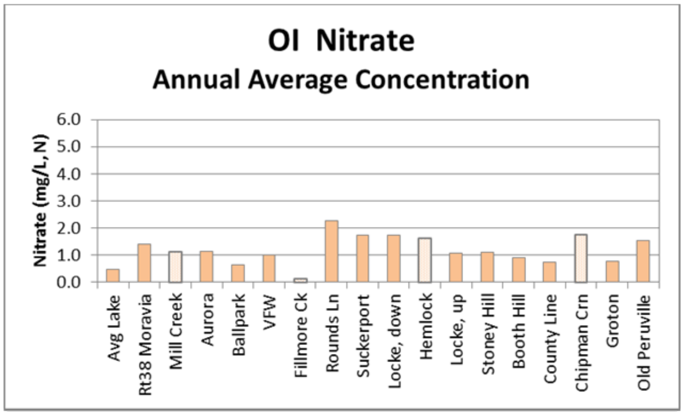
5.0
4.0
3.0
2.0
1.0
0.0
Avg Lake
DH 38A
Martin Rd
North Trib
North St
South Trib
Benson Trib
Lacy Rd Trib
Benson Rd
Rowe
Murray Trib
Old State
Cream Hw
FireLane 20


OI Nitrate
Annual Average Concentration
Nitrate (mg/L, N)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Avg Lake
Rt38 Moravia
Mill Creek
Aurora
Ballpark
VFW
Fillmore Ck
Rounds Ln
Suckerport
Locke, down
Hemlock
Locke, up
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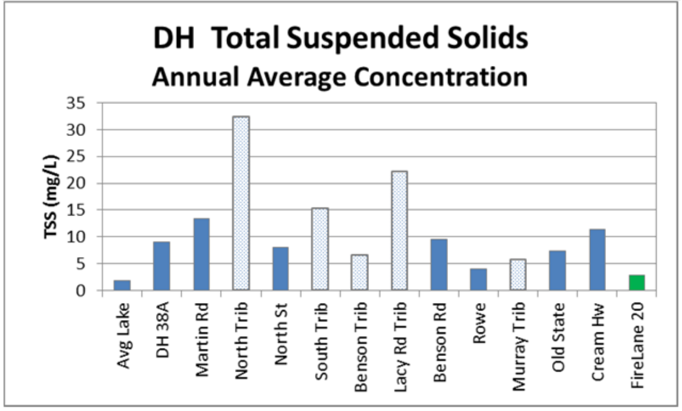
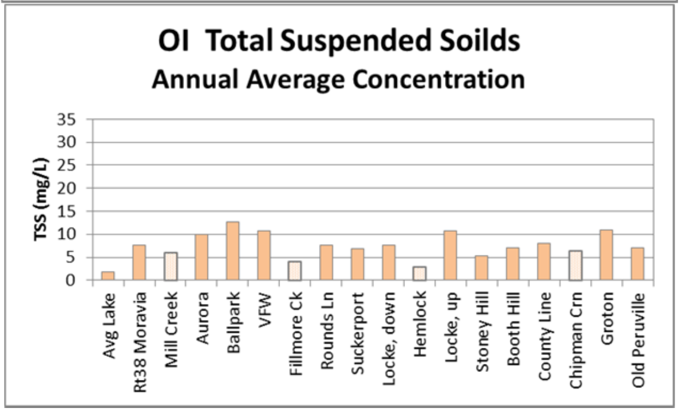
County Line
Chipman Crn
Groton
Old Peruville


DH Total Suspended Solids
Annual Average Concentration
TSS (mg/L)
35
30
25
20
15
10
5
0
Avg Lake
DH 38A
Martin Rd
North Trib
North St
South Trib
Benson Trib
Lacy Rd Trib
Benson Rd
Rowe
Murray Trib
Old State
Cream Hw
FireLane 20


OI Total Suspended Soilds
Annual Average Concentration
TSS (mg/L)
35
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Avg Lake
Rt38 Moravia
Mill Creek
Aurora
Ballpark
VFW
Fillmore Ck
Rounds Ln
Suckerport
Locke, down
Hemlock
Locke, up
Stoney Hill
Booth Hill
County Line
Chipman Crn
Groton
Old Peruville

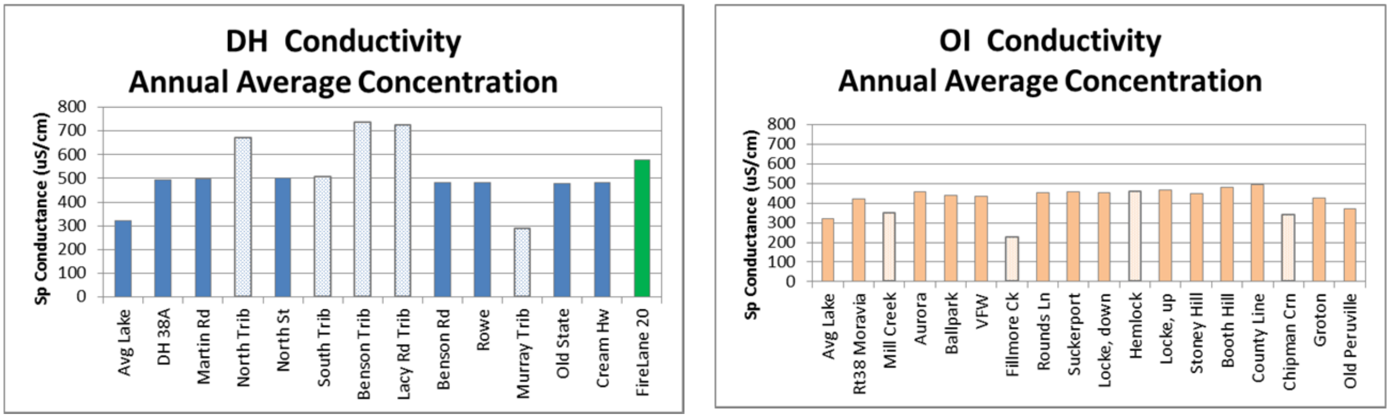


Fig. 20. Site averaged stream nutrient and suspended sediment concentrations. Dutch Hollow sites are in blue, Owasco Inlet sites in orange, Fire Lane 20 in green. Tributary sites are stippled. Sites are arranged from downstream to upstream.

Elevated dissolved phosphate (SRP), nitrate and specific conductance (salinity) concentrations were detected at North, Lacy and Benson tributary sites compared to the other sites as well. The data collectively indicate that these tributaries were impacted by agricultural land upstream of the site (nearby barn yard drainage and cattle grazing in the stream). It also suggests remediation efforts are working upstream of the Benson tributary site. More BMPs should be established in the other agricultural regions.

Along the Owasco Inlet, measured concentrations were smaller and less variable than Dutch Hollow Brook. Mean annual TP and SRP concentrations increased slightly from Groton to Booth Hill, and from VWF/Ballpark to Aurora, as past years. Remember samples were collected in the summer during low flow conditions, highlighting inputs from point sources along this segment, like the Moravia and Groton wastewater treatment facilities. The extra tributary sites indicated that tributaries along these segments also added phosphorus to the Inlet, and the WWTFs are not the sole reason for the observed increases.

The smallest TP and SRP concentrations were detected at Mill, Fillmore, Hemlock Creeks and the tributary at Chipman Corners Rd (TP of 5.4, 4.5, 17 and 10 μg/L, respectively) and were similar or slightly smaller than previous years. The lower concentrations in 2014 are attributed to the restricted summer sampling. The lower concentrations at Mill contributed to the observed dilution of/decrease in TP and SRP from Aurora to Rt 38.

Mean annual total suspended sediment (TSS) concentrations revealed smaller concentrations in the tributaries and larger concentrations along the main stream. Along the Inlet, TSS concentrations increased between the Stone Hill and Locke upstream sites and the Rounds Ln to Ballpark sites. A source was not obvious. Perhaps stream bank erosion along the incised and poorly armored meanders between these sites or farming practices along the stream course were a source of sediments. TSS decreased between Groton to County Line sites, between the two Locke sites and between Ballpark to Rt 38 sites. The main stream was most likely diluted by tributaries along these segments, e.g., Chipman Corners, Hemlock and Mill Creeks. The additional sites pinpointed the sources of the fluctuations. Nitrates were largest at Chipman Corners, Hemlock Creek, and Rounds Ln, perhaps reflecting the agriculturally-rich land use, thus nitrate-rich groundwater upstream of these sites.

Fire Lane 20 was first sampled in 2012, and sampled again in 2013 & 2014 (only the 2nd survey date in 2014). It revealed the largest salinities, TP, SRP, nitrate concentrations after the agriculturally-rich North, Lacy and Benson drainages within the Dutch Hollow watershed. The TSS was small for this one base flow sample date, as expected. The larger salinities and nutrient concentrations were presumably due to the agricultural and manure-spreading activities upstream. I suspect that these salinities, nutrient and TSS concentrations would have been much larger immediately after the runoff of the spread manure, but stream data are not available for confirmation.

Stream Fluxes: Owasco Inlet revealed larger fluxes of nutrients and sediments than Dutch Hollow Brook (TP 2.5 vs. 0.5 kg/day; SRP 0.8 vs. 0.05 kg/day; TSS 1,200 vs. 230 kg/day; N 260 vs. 22 kg/day, respectively, Fig. 21). Similar or slightly smaller concentration 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.

At the small end of the spectrum, fluxes at the Dutch Hollow Brook tributary sites (North, Lacy & Murray Rd sites) and Fire Lane 20 site were very small, smaller than the other sites in the survey, even though some of the largest concentrations were detected at these sites. 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 total phosphate loads as Fire Lane 20, then the combined total phosphate 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. 21). The North St mean fluxes was typically larger than the fluxes at Rt 38A as well but not as large as the Martin Rd fluxes. It is unclear why this is but it may reflect difficulties in measuring stream discharge at the two upstream sites. The Murray Rd site had the largest discharges. Perhaps water and dissolved materials are also 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. The input by adjacent tributaries typically account for the increases in flux from one site to the next. 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.

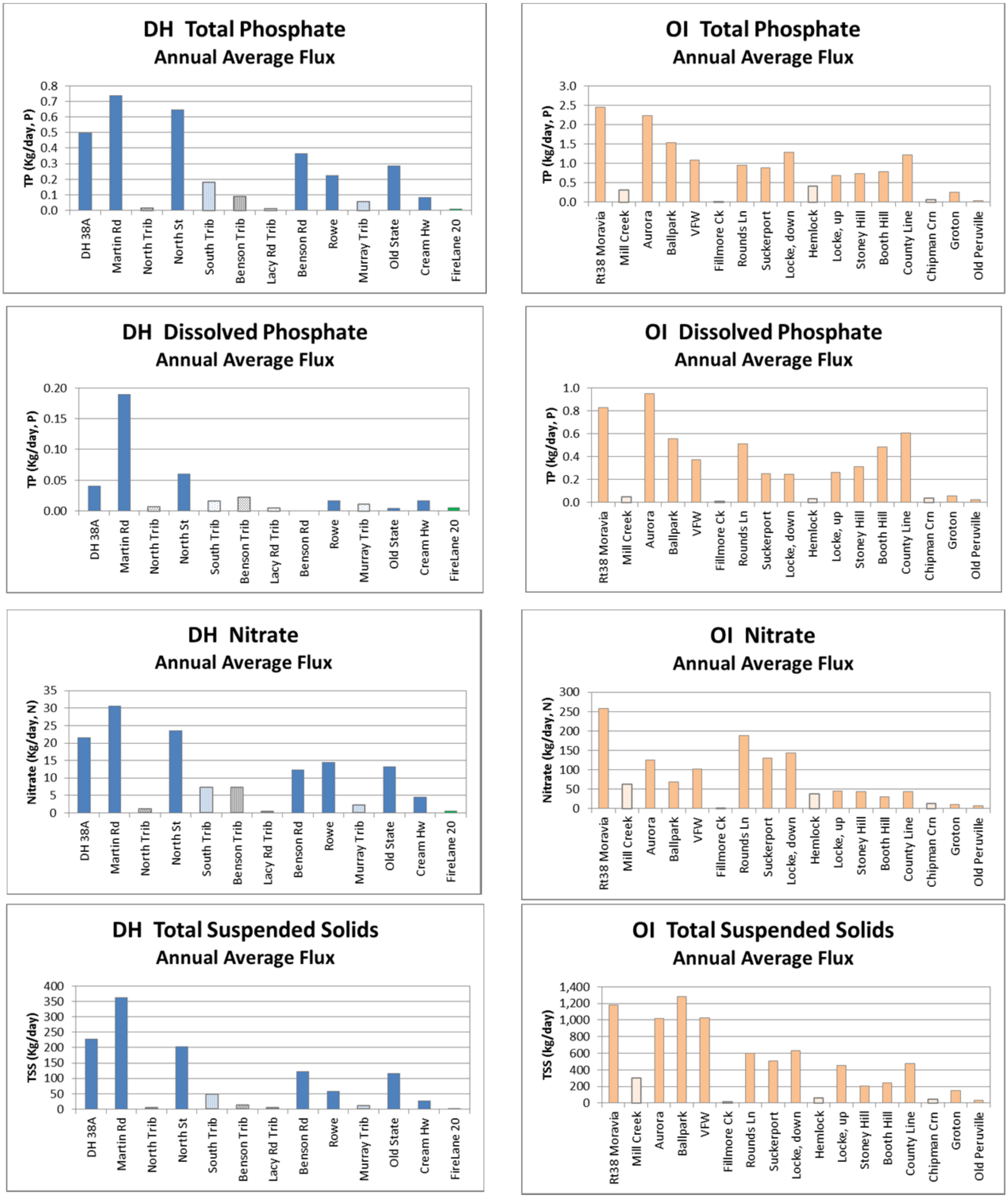


Fig. 21. Site averaged nutrient and sediment fluxes. Dutch Hollow sites are in blue, Owasco Inlet sites in orange, and tributary sites are stippled. Sites are arranged from downstream to upstream.

The additional sites sampled in 2014 provided new information on potential sources of nutrients and sediments. The largest concentrations were detected in the smallest tributaries and thus pinpoint more areas for remediation. For example, keep the cows out of the North St tributary, and reduce barn yard drainage into the Lacy Rd tributary. In fact, the Lacy Rd tributary sampled on 6/3 was filled in by the second visit on 7/30. All of these sites should be sampled again in 2015 to conform these observations.

In contrast, the phosphate and sediment fluxes along the Owasco Inlet increased predominately along two segments, from Groton to County Line (increases of Nitrate 30, TP 0.9, SRP 0.5, & TSS 300 kg/day) like in 2013. They also increased from Ballpark to Aurora (Nitrate 60, TP 0.7, & SRP 0.3 kg/day; Fig. 21) in 2014 but not 2013. These increases and changes in loads were smaller in 2014 than in the past, and probably reflected summer-only sampling in 2014 compared to spring through fall samples in earlier years.

Both increases were previously attributed to the addition of phosphate by the Groton and Moravia wastewater treatment facilities. If true then the increase in phosphate was small and indicates that remediation efforts by the Groton and Moravia facilities work! In 2013 and 2014, the Groton to County Line segment provided 20 to 30% of the total phosphorus load emitted by the Owasco Inlet to the lake, whereas in 2007, this segment provided nearly 90% of the total load. Folks in Groton should be proud of their reductions. The percentage was larger in 2014 than 2013, because 2014 samples focuses on summer, low flow, dates, compared to spring through fall samples in 2013.

In 2012, phosphate fluxes were observed to increase between the VFW and Aurora sites and hypothesized to originate from nutrient-rich effluent from the Moravia wastewater treatment facility. The 2013 and 2014 data from the Ballpark site refutes this hypothesis. It appears that phosphate also originate from between the VWF and Ballpark sites. Thus Moravia WWTF is not solely to blame for this increase. It suggests that sediment-bound phosphates were also eroded from the poorly armored, meandering stream segment upstream of the Moravia WWTF, and the WWTF's impact on water quality was minimal.

In summary, the stream segment analyses detected new non-point sources in the Dutch Hollow Brook watershed and perhaps the loss of stream water to the ground along the meandering and incised Martin Rd to Rt 38A segment. Both point and non-point sources of nutrients were detected in the Owasco Inlet watershed. 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. This segment's source may be stream bank erosion along this segment of the Inlet, and poses a question for additional study. All of these sites should be sampled again in 2015 to conform these observations.

Seasonal and Longer-Term Variability: Seasonal change cannot be assessed with the 2014 summer only dataset. Mean annual fluxes in 2014 appear smaller than those reported in earlier years (Fig. 22). However, the difference between 2014 and previous years can be attributed to differences in the summer-only sampling in 2014. This conclusion is supported by a comparison between the grad sample and detailed autosampler data (see below).

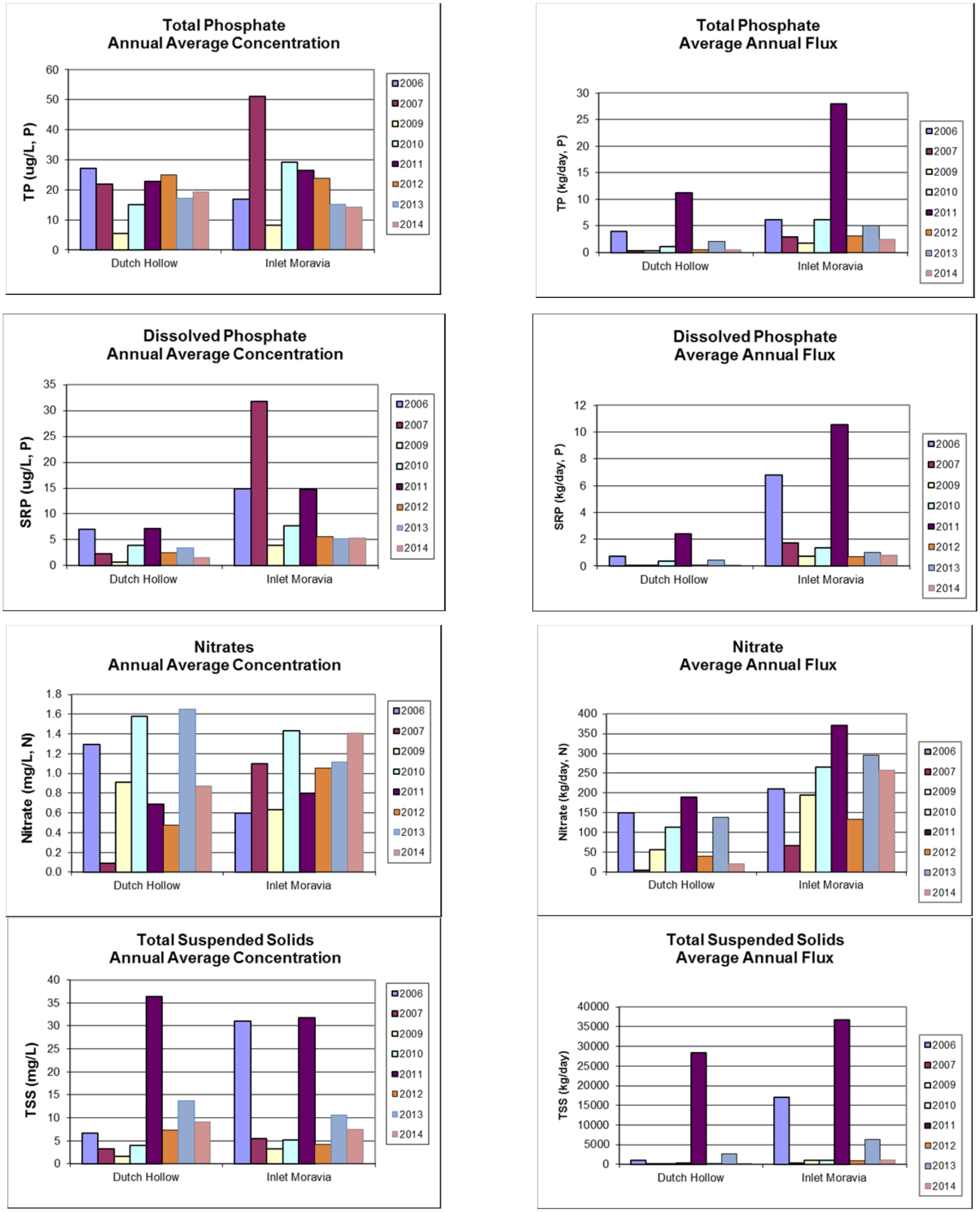


Fig. 22. Annual average concentrations (left) and fluxes (right).

EVENT SAMPLING AT DUTCH HOLLOW BROOK

Detailed Stage Data @ 38A along Dutch Hollow Brook: The 2014 data logger stage data revealed textbook responses to precipitation events, spring-time ground saturation, and the seasonally larger summer evapotranspiration (Fig. 23). Each increase in stage corresponded to a precipitation event. The increase in stage for each 2014 event was from 5 to more than 60 cm, similar to the increases observed in 2011 and 2013, but larger than those in 2012. 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. This is identical to the earlier stage data results.

Similar seasonal and day to day, precipitation/event influenced changes in stage, conductivity and temperature detected during the past four years (Figs. 24 – 27).

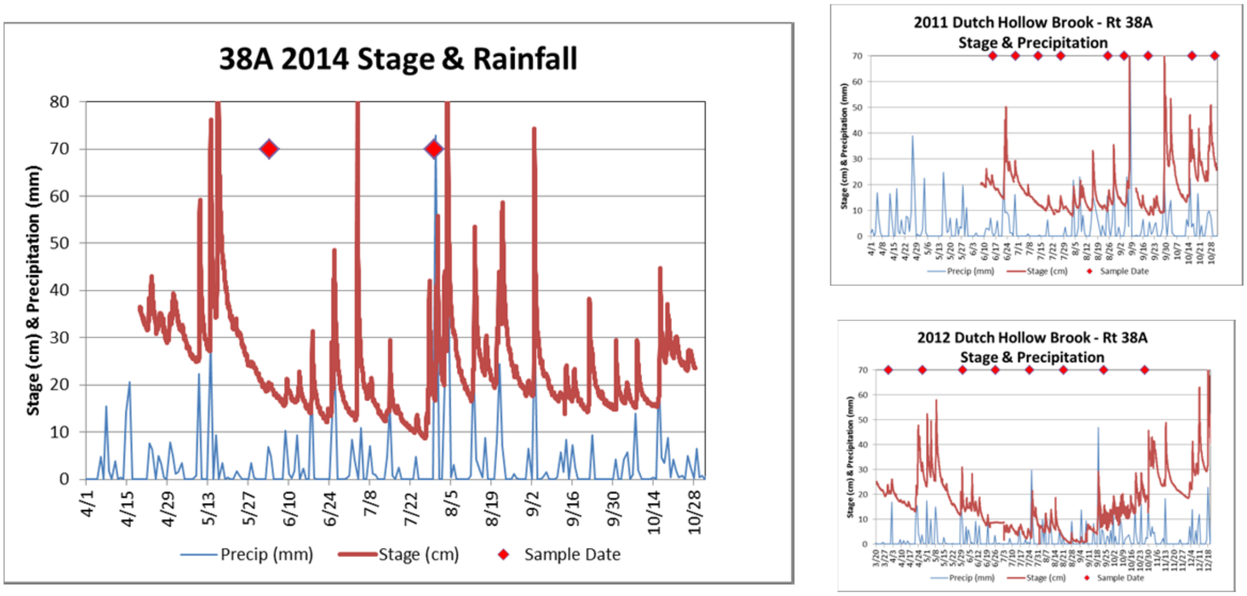


Fig. 23. Dutch Hollow Brook data logger stage, precipitation and sample dates, 2014 data left; 2011 and 2012 data, right. Precipitation data was from NY-CY-8, a station within the watershed, and part of the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS).

Detailed "Event vs Base Flow" Results @ 38A: Like the previous three years, nutrients and sediments revealed significant responses to precipitation events throughout the 2014 deployment (Fig. 28). Total suspended sediments (TSS) increased dramatically from base flow concentrations of near 0 to 20 mg/L to an average event flow concentration of 840 mg/L, and rose to a maximum of 3,400 mg/L during a 73 mm precipitation event on 7/3. 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 has a greater impact on water quality in the stream. The 2014 peak TSS concentrations were between those measured in 2011 and 2012, and larger than 2013, the difference parallels the difference in rainfall between these four years.

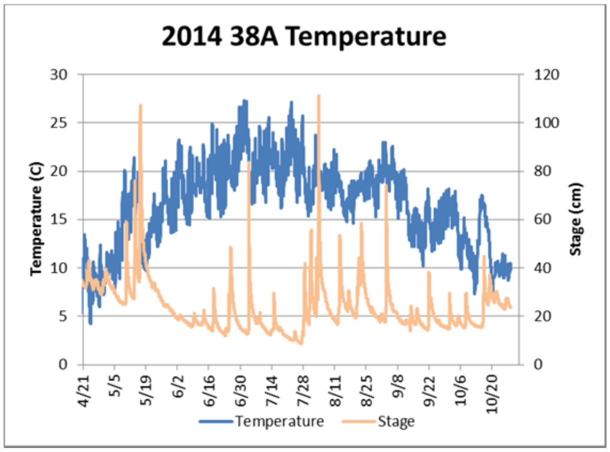


Fig. 24. Data logger water temperature data. The seasonal cold to warm to cold cycle prevails.

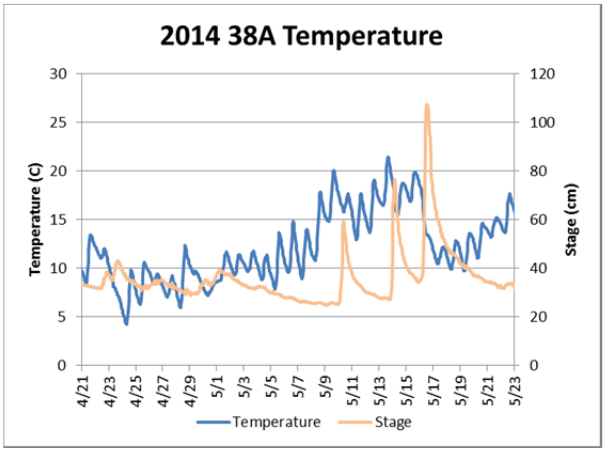


Fig. 25. Daily warm (day) to cold (night) fluctuations in water temperature.

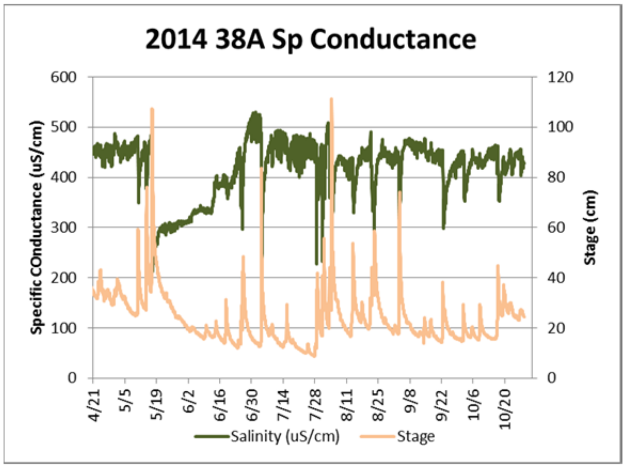


Fig. 26. Data logger salinity data. Stream salinity decreased during events, the groundwater inputs diluted by the rainfall.

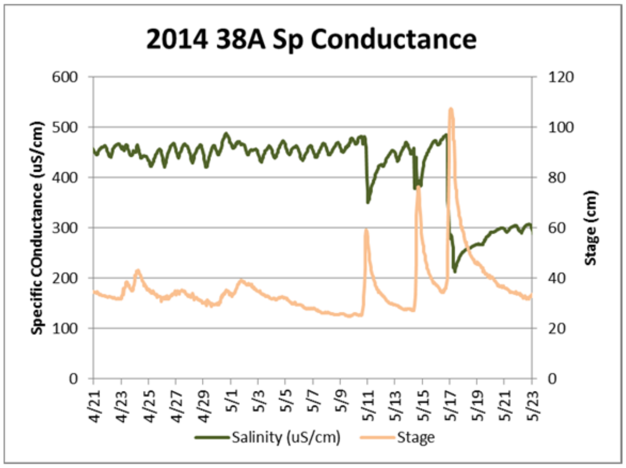


Fig. 27. Daily fluctuations in water salinity.

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 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 70 and 23 μg/L to event means of 150 and 75 μg/L, respectively. Maximum event concentrations were ~ 260 μg/L for TP and 170 μg/L for SRP. The number of events and event concentrations in 2013 & 2014 were in between those detected in 2011 and 2012. Again, the “in between” nature of the 2013 & 2014 loads suggest a direct linkage to and the importance of precipitation induced runoff events for phosphorus loading to the lake. Thus, the remediation

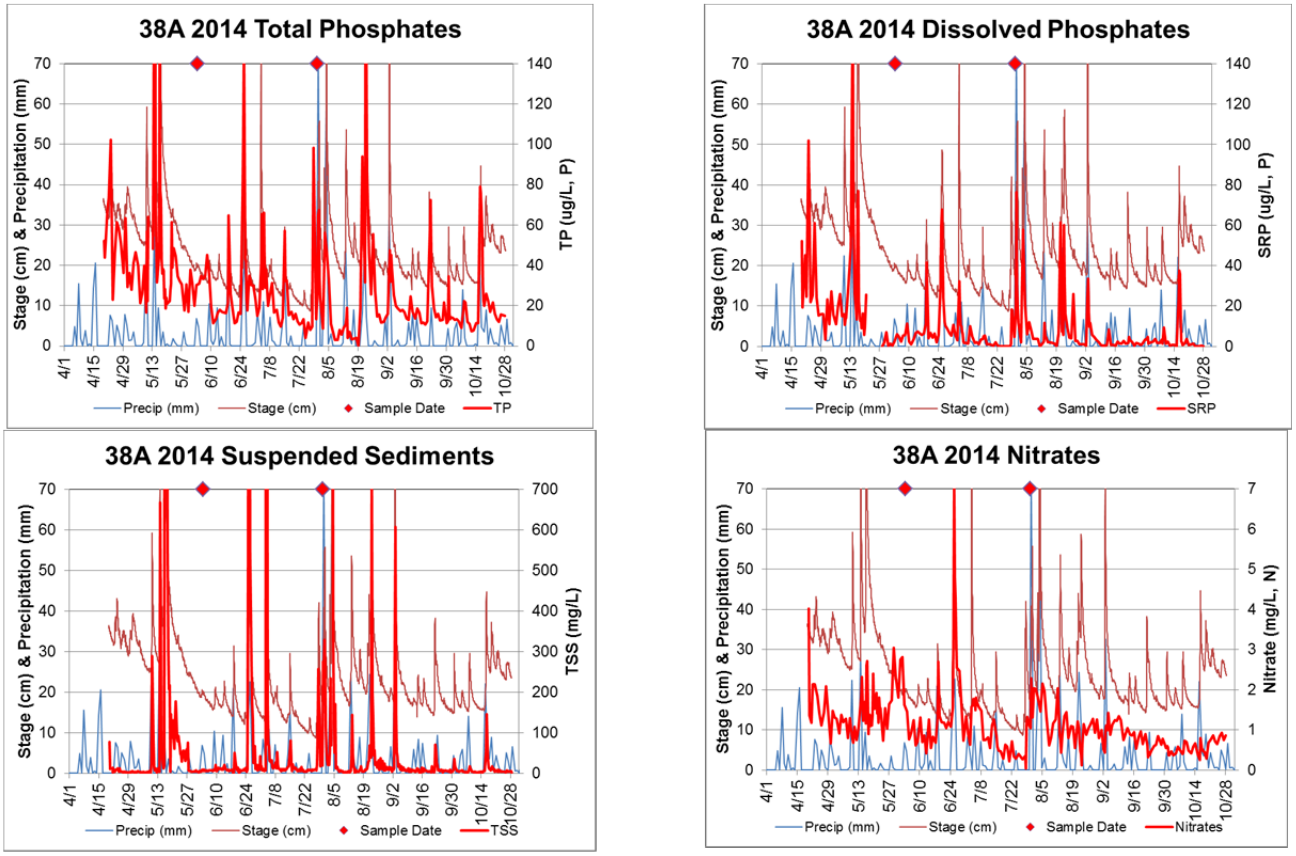


Fig. 28. Autosampler nutrient and suspended sediment concentrations.

steps to reduce phosphate loading are similar to remediating suspended sediment, i.e., reduce the movement of soil particles from runoff events in the Owasco watershed.

Nitrates, once again, revealed a different response to events. The largest nitrate concentrations still correlated with events with mean event concentrations of 4.3 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 nitrates to the stream. However, the rejuvenated near-surface groundwater flow contributed nitrates as well, extending the nitrate response to the event and nitrates enter the stream during base flow as well. 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. A best-fit, linear relationship between the weekly discharge measurements and stage data at Rt 38A estimated hourly discharge data (Fig. 29, $r^2 = 0.93$).

The fluxes of TSS, TP, SRP and nitrates were clearly event dependent over the past four years (Table 7, Fig. 30). In 2014, TSS, TP and SRP event fluxes averaged 36,000, 6.5 and 3.2 kg/day, respectively. TSS, TP and SRP base flow fluxes were much smaller, only 300, 1.5 and 0.5 kg/day, respectively. During the entire 2014 field season, Dutch Hollow provided 2,800,000 kg of sediment to the lake during events, and only 34,000 kg during base flow conditions. In a

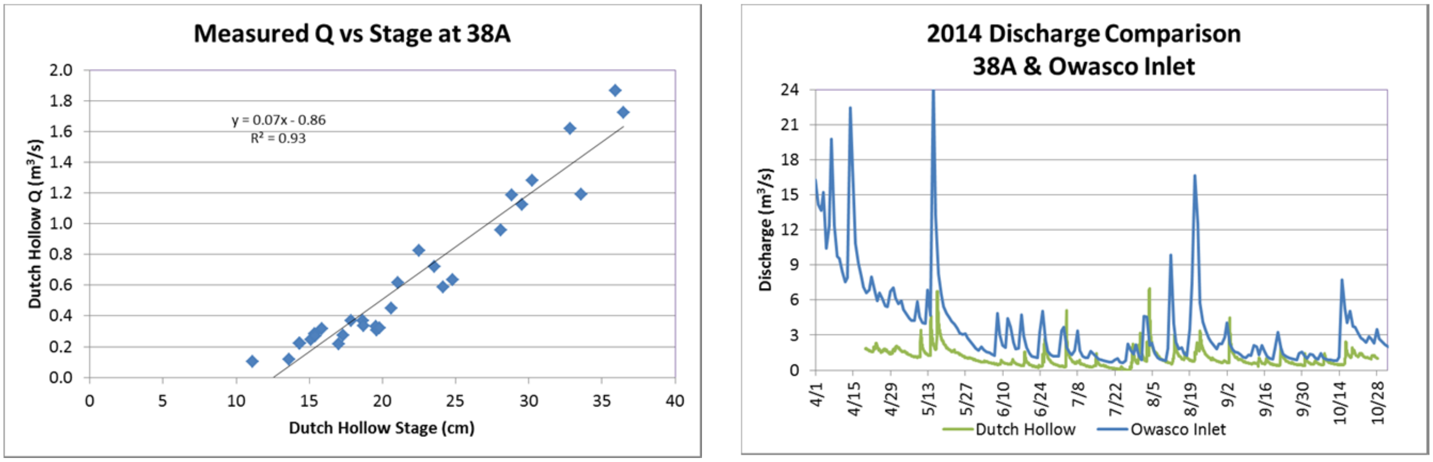


Fig. 29. Estimation of Dutch Hollow Brook 8-hour autosampler discharges from Dutch Hollow Brook stage, weekly discharge measurements, and daily USGS discharge data from Owasco Inlet (Station ID 04235299)

similar light, the 2014 events delivered 500 kg of TP and 305 kg of SRP to the lake compared to base flow contributions of 175 kg of TP and 60 kg of SRP over the course of the study. Annual changes were also observed. The 2014 event fluxes were in between those in 2011 and 2012 and more similar to those in 2013. The dominance of 2011 is somewhat surprising because the autosampler was deployed for three fewer months in 2011 than the following years. Clearly, rainfall rules these fluxes.

In conclusion, all four years revealed a significant increase in event over base flow loads for TSS, TP and SRP, and to a lesser degree nitrates along Dutch Hollow Brook, and dictate once again the importance to reduce the delivery of nutrient and sediments by runoff events to ultimately improve water quality in the lake (Table 7).

Table 7: 2011 – 2014 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%

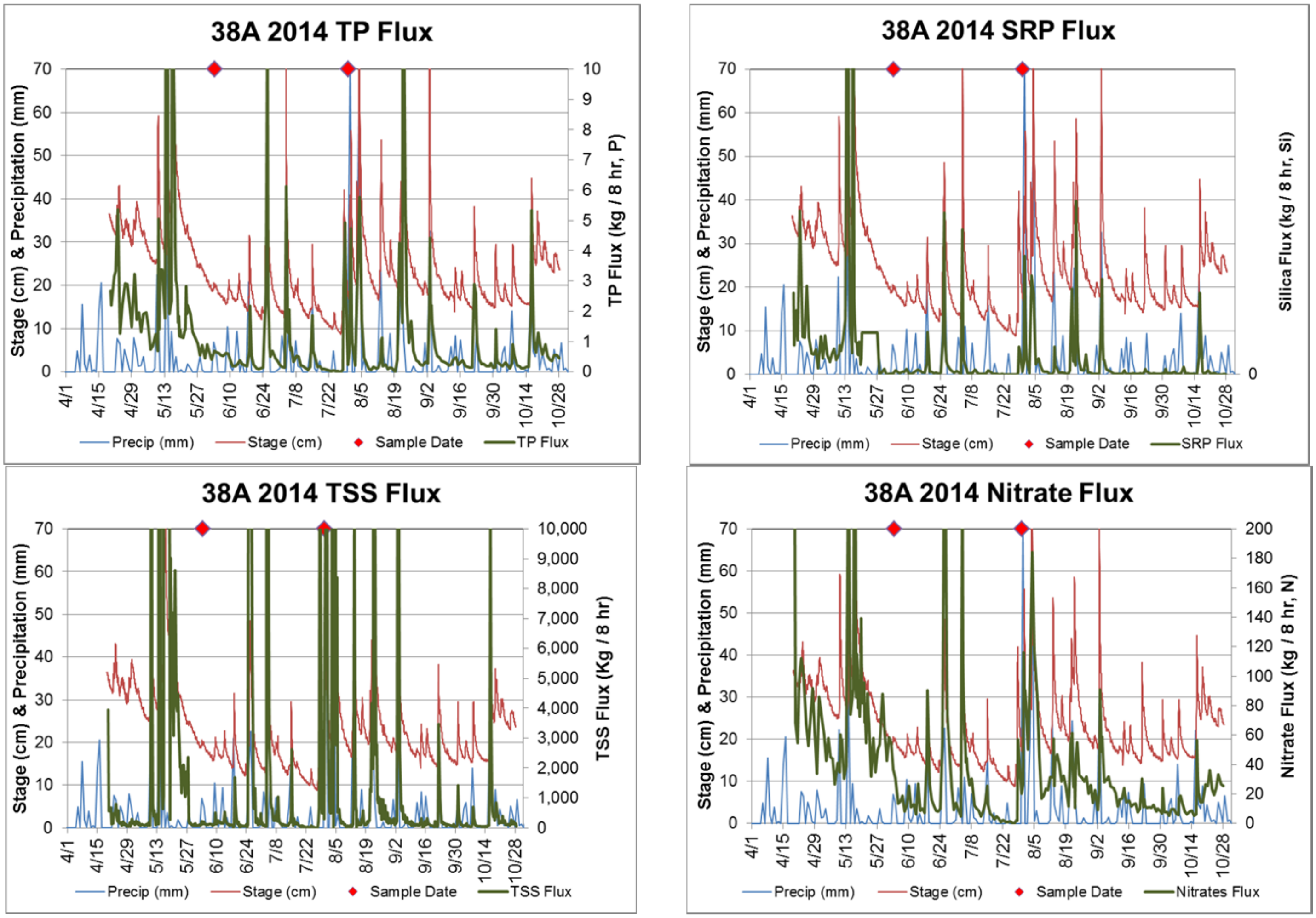


Fig. 30. Autosampler nutrient and suspended sediment fluxes.

All four years of event *versus* base flow data also clearly indicated that grab samples underestimated annual fluxes down a stream. For example, the 2014 autosampler estimated a sediment mean flux of 14,600 kg/day, total phosphates 3.5 kg/day, dissolved phosphates 1.6 kg/day, and nitrates 115 kg/day; whereas the grab sampling estimated an annual mean flux of 230 kg/day for sediments, 0.5 kg/day for total phosphates, 0.1 kg/day for dissolved phosphates, and 22 kg/day for nitrates. The grab samples estimated smaller fluxes because they were biased to base flows. This bias was most apparent in 2014 because the sample dates were also biased to the summer and its seasonally smaller concentrations. Therefore, grab samples are not reliable for detailed flux estimates. However, grab samples are essential and reliable tools for stream segment analysis and the investigation of nutrient and sediment sources.

DETAILED ANALYSIS @ NORTH ST SITE:

Data loggers were deployed at the North Street and Benson Tributary sites for an event response comparison to the downstream Rt 38A site. All three sites revealed time synchronous stage events during the four-month long deployment (Fig. 31). A detailed comparison of the peak flow stage height and duration of the peak flow is not possible using stage only data because the stage to discharge relationship is overprinted by the site's non-proportional x-sectional areas.

North St and 38A sites had the necessary weekly discharge measurements to compare the flows and fluxes. Largest peak discharges but quicker returns to base flow conditions were observed at the upstream North St site as expected (Fig. 31). The response reflects a smaller area of land upstream in the watershed from the North St site than the Rt 38A site. Thus, rainfall was delivered faster to the North St site after the rainfall event due to the smaller travel distances for each rainwater molecule than 38A.

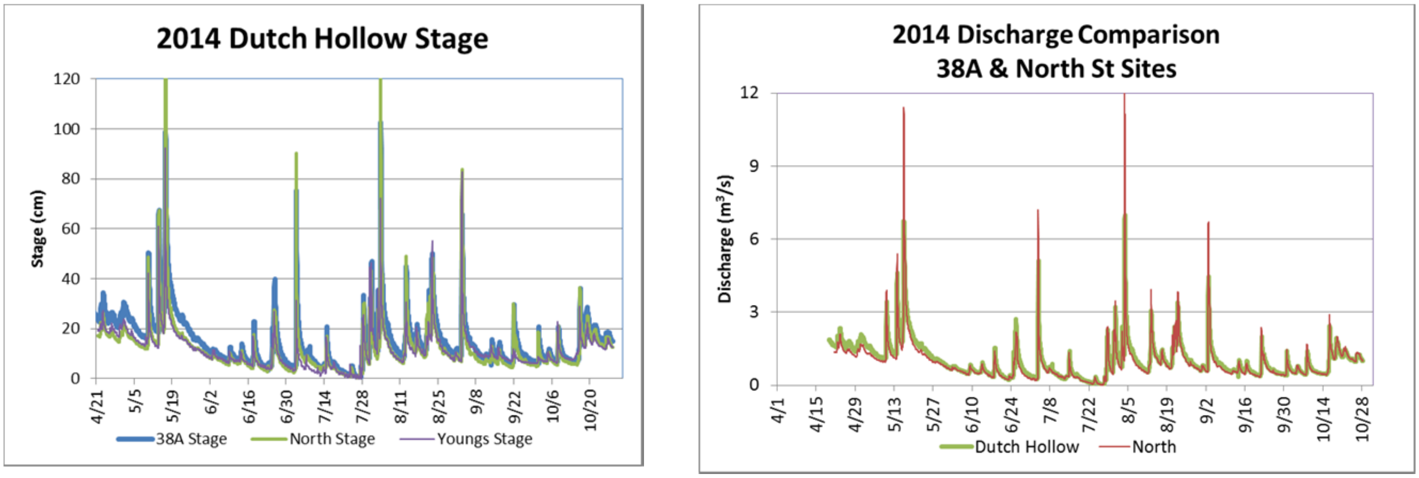


Fig. 31. 38A, North and Benson Stage data, left, and 38A and North discharge data, right

The TSS, TP and SRP concentrations revealed event signatures at both the 38A and North St sites (Fig. 32, Table 8). Nitrate event signatures were also observed but subdued, as expected. The event fluxes of TSS, TP, SRP and nitrates were slightly larger at 38A than North St (Fig. 32, Table 8). The base flow fluxes were similar. Thus, some sediment, phosphorus and nitrate must enter the stream between the North and 38A sites during events. Two likely sources include the small tributaries, e.g., North St Tributary, which will be very flashy during events and more likely to run dry between events, and stream-bank erosion along this particularly intense meandering stretch of the stream, which will be most intense during the largest flood events. The uncertainty precludes elimination of the relative contribution of agricultural versus stream bank erosion sources. A deployment of a third autosampler at Martin Rd may resolve this uncertainty.

Table 8. Rt 38A and North St Detailed Study Comparison in Dutch Hollow Brook.

Mean Fluxes				
38A: June – October Data	**TSS**	**Nitrate**	**TP**	**SRP**
All Data (kg/day)	10,500	83	2.3	0.7
Event (kg/day)	28,200	150	5.0	1.8
Base Flow (kg/day)	285	45	0.8	0.1
% by events	98%	66%	78%	88%
North St: June – October Data	**TSS**	**Nitrate**	**TP**	**SRP**
All Data (kg/day)	10,900	67	2.1	0.6
Event (kg/day)	22,000	100	3.5	1.1
Base Flow (kg/day)	270	35	0.8	0.2
% by events	99%	74%	81%	88%

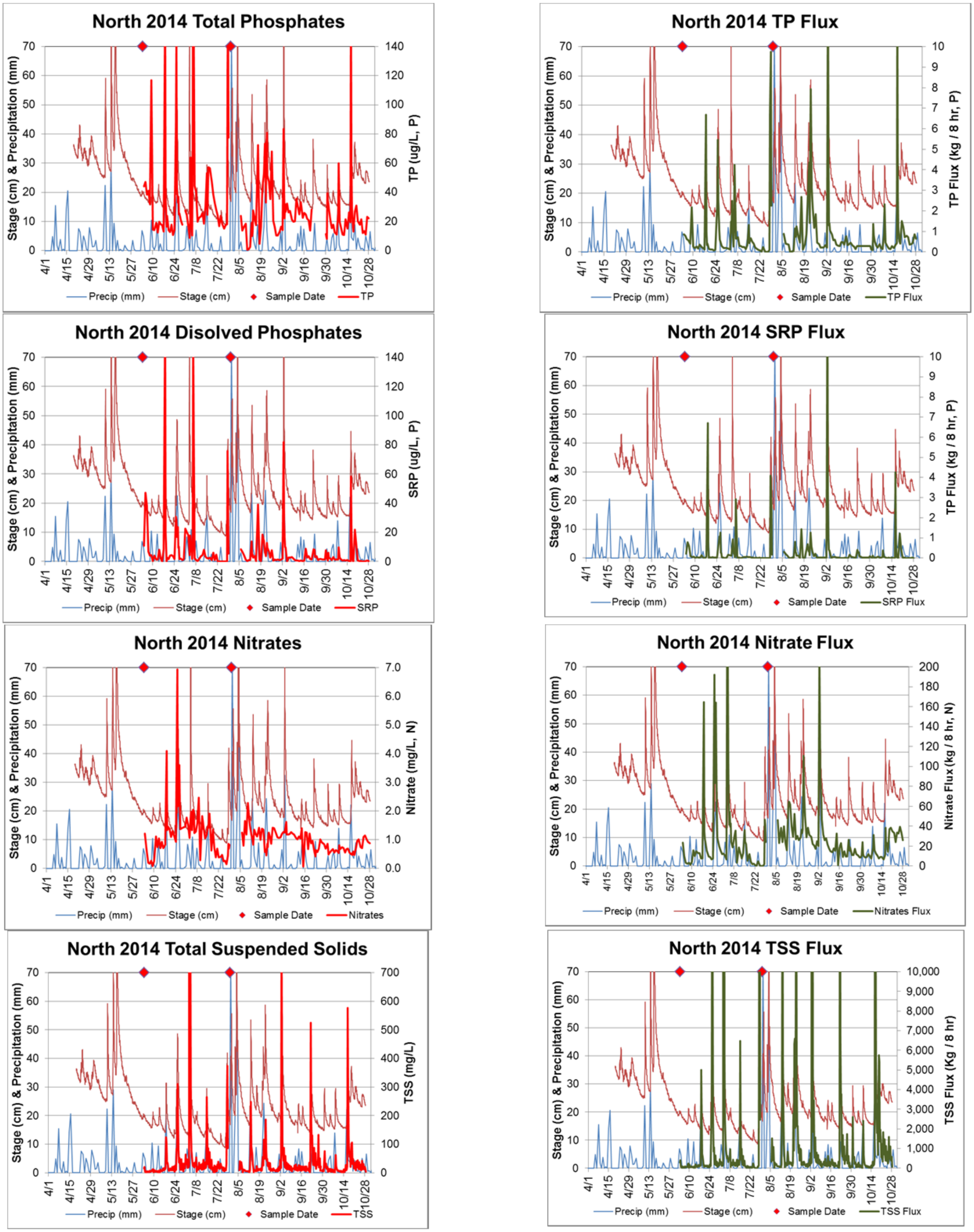


Fig. 32. North St suspended sediment, total phosphate, dissolved phosphate and nitrate concentration data, left. Suspended sediment, total phosphate, dissolved phosphate and nitrate fluxes, right.

PHOSPHORUS BUDGET:

Phosphorus load reductions are critical to the health and water quality of Owasco Lake because it limits algal growth. For example, reductions in Owasco Inlet inputs from 2006 to 2007 improved water quality in the southern end of the lake. Phosphorus originates from plant and animal agriculture, municipal wastewater treatment facilities and other sources. The detailed sampling of Dutch Hollow Brook indicated that precipitation events stimulate the majority of the nutrient and sediment loading to the lake. 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. 33). The primary outputs from the lake include the outflow of phosphorus-rich materials through the Owasco Outlet and the burial of phosphorus as organic matter or attached to the clay particles into the sediments.

The net change is critical because the amount of phosphorus will increase in the lake, if inputs exceed outputs. It will decrease in the lake, if inputs are less than outputs. Alternatively, it 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.

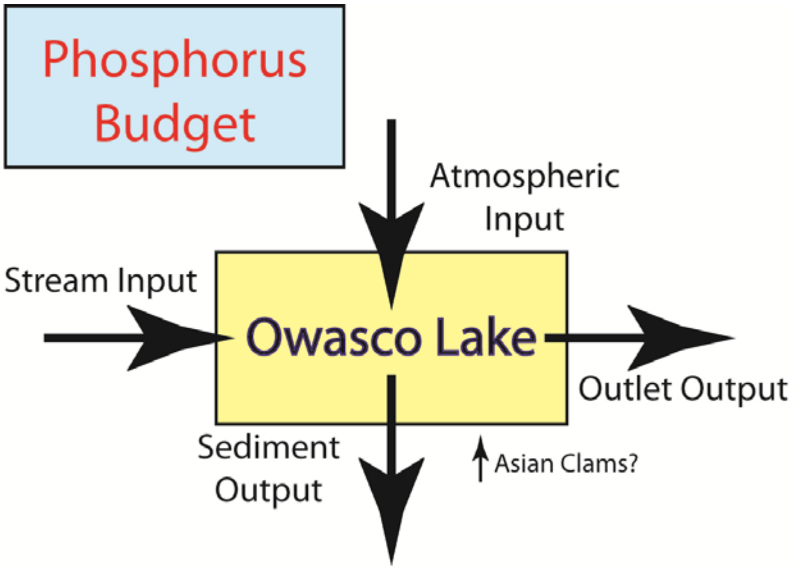


Fig. 33. The Owasco Lake phosphorus budget: Sources and sinks for phosphorus in Owasco Lake. Water quality improves if **inputs are less than outputs**, for a number of years.

The Inputs: The autosampler estimated a mean total phosphate flux of 3.5 kg/day from Dutch Hollow Brook in 2014. Owasco Inlet delivered 2.5 kg/day based on the available 2014 stream grab data. However, this flux was restricted to two summer sample dates and is thus artificially small. The load for Owasco Inlet was estimated at 17.5 kg/day assuming a proportional change between the mean grab sample total phosphorus loads to the detailed autosampler loads from Dutch Hollow . Alternatively, the input was 8.6 kg/day assuming proportional change from annual summer loads to the annual spring through fall load over the past three years for the Owasco Inlet. Clearly, an autosampler should be deployed at Moravia Rt 38 site for an entire field season to determine which estimate is better. But it is cost prohibitive with the current monitoring budget. Using the 17.5 kg/day load, a proportional extrapolation of fluxes and surface areas from Dutch Hollow, Mill Creek, Hemlock and Owasco Inlet to the entire Owasco Lake watershed, estimated an input of 11 metric tons of phosphorus in 2014 (Fig. 34). This extrapolation incorporated all the 1st and 2nd order (small) tributaries like Fire Lane 20. The stream loads change from year to year (Fig. 35). The annual watershed loads correlate to the amount of rainfall during the March through October field seasons. 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 2014 estimated 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 5.0 metric tons of phosphorus was lost out the Outlet in 2014 assuming an 2014 annual mean total phosphate concentration in the lake of 17.7 μg/L, and a 2014 mean daily discharge of 8.7 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 7.8 metric tons/year.

The Net Flux: Owasco Lake thus gained approximately 4.2 metric tons of phosphorus in 2014. The past six years of data indicate that the lake was in a positive balance during three years, a negative balance in two years, and was close to equilibrium in one year (Fig. 35). Since 2006, the mean annual input is 6.6 mtons/year, slightly more than the mean output of 6.0 mtons/year. However, the lake was more likely in a positive balance for five of the past six years because 2009 and 2010 loads were based on limited summer grab samples. This six year history indicates that significant remediation efforts must take place to move Owasco Lake to a negative balance and eventually improve water quality. The timeframe is long, i.e., multiple water retention times, or in Owasco's case decades, to naturally flush out the excess phosphorus once the lake enters a sustained negative balance. Otherwise, the lake will continue to experience a stagnation or decline in water quality into the future with more algal blooms with more blue green algae.

Seeing that streams dominated phosphorus inputs in "dry", "in between" and "wet" years, it follows that streams are always the primary source of phosphorus to the lake, and nutrient reduction efforts must focus on the delivery of phosphorus by streams. The 2013 and 2014 data indicate that the wastewater treatment facilities are doing a good job at nutrient abatement, and now is the time to focus on nutrient reduction from agricultural and other non-point sources. However the financial burden to install these remediation practices cannot be placed solely on the farmer. Water quality is a watershed-wide issue. Everyone benefits from a cleaner lake. Thus everyone should help support the remediation effort.

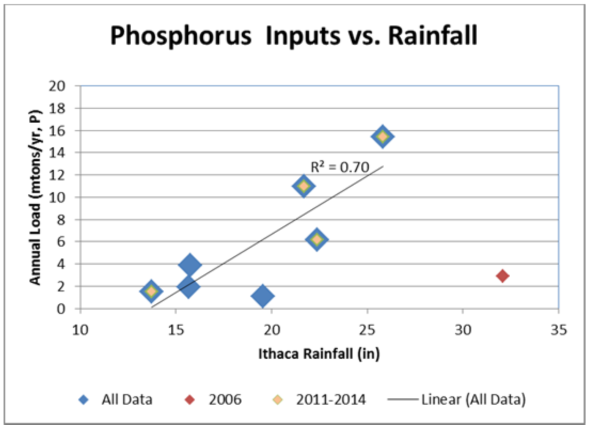


Fig. 34. Estimated annual total phosphorus loads vs rainfall at the Ithaca Airport.

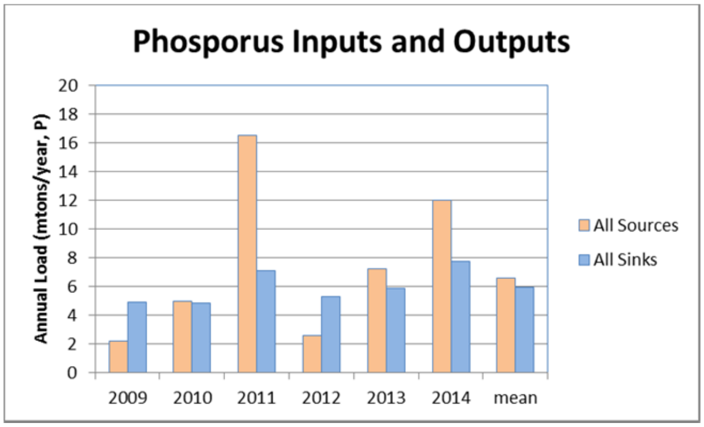


Fig. 35. Estimated annual total phosphorus inputs and outputs.

CONCLUSIONS & RECOMMENDATIONS:

This report confirms and expands on earlier findings.

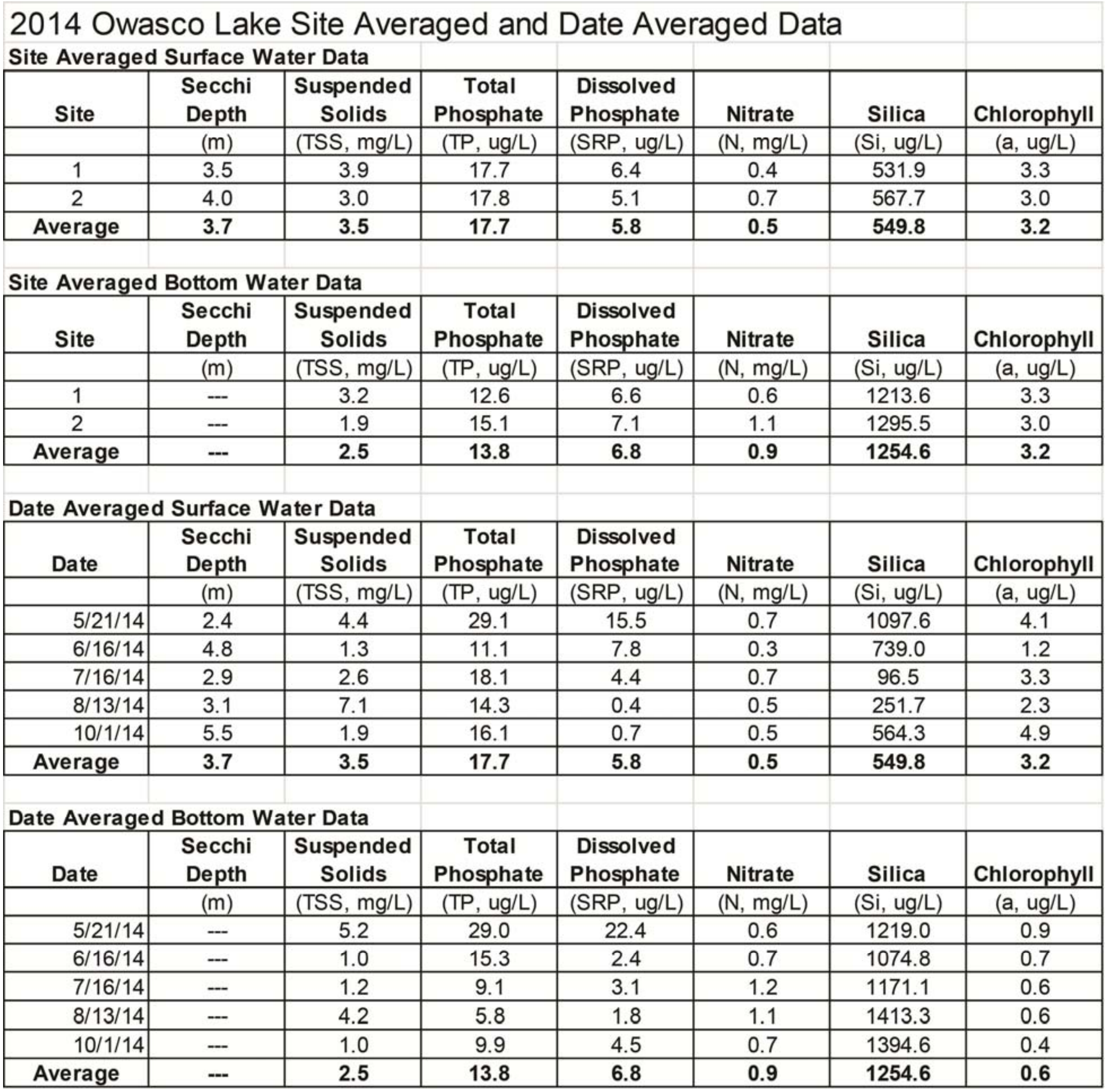
- As previously observed, Owasco Lake is a borderline oligotrophic – mesotrophic lake. The small improvements in water quality since 2011 were lost in 2014.
- The water quality degradation in 2014 is attributed to the heavy May rains throughout the region, and the input of nutrients from the unfortunate disposal of animal manure on frozen ground.
- 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. Funds should be secured to deploy this buoy in future years.
- Segment analysis included many more sites and highlighted the importance of new non-point sources in the Dutch Hollow Brook, and both point and non-point sources in the Owasco Inlet. Some success is apparent, in that recent data revealed minimal and/or greatly reduced inputs from the wastewater treatment facilities.
- The event *versus* base flow analysis at Dutch Hollow Brook highlighted 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 2014 were just above those estimated for 2013, and loads in both years were "in-between" those in 2011 and 2012. Loads correlated to field-season rainfall.
- Event signatures were also observed in the detailed investigation at North St in the Dutch Hollow Brook watershed. Phosphate and sediment fluxes at North St were similar or slightly smaller than those detected downstream at Rt 38A, suggesting that small tributaries and/or stream bank erosion provides nutrients and sediments to the main stream between these two sites. An additional autosampler deployed at Martin Rd would resolve this uncertainty.
- Another autosampler should be deployed at Moravia to more accurately estimate total loads down the Inlet.
- The estimated phosphate budget for Owasco Lake indicates that inputs were larger than outputs in 2014, and the lake was probably in a positive balance through many of the past six years. The clear exception was 2012, the "dry" year.

- Streams were the primary source of nutrients and sediments to the lake, even in the 2012 “dry” year.
    - 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.
    - To this end, state funds were acquired by Cayuga County Soil and Water District and OWLA to install preliminary BMPs during 2015 within the Dutch Hollow Brook watershed. This is very encouraging, and we must monitor and model the effectiveness of these practices.

ACKNOWLEDGEMENTS

The 2014 research was supported by Cayuga County Legislature and the Owasco Lake Watershed Association. We thank members of the Cayuga County Planning Department, Cayuga County Water Quality Management Agency, Owasco Lake Watershed Management Council, Cayuga County Health Department, Owasco Watershed Lake Association, the Cayuga County Soil and Water District, the Institute for the Application of Geospatial Data, 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, 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, Marion Balyszak, Lisa Cleckner, Martha Bond, Todd Walter and David Eckhardt. Hopefully, I didn’t forget to acknowledge someone, and my apologies to those I omitted.

Table 2. 2014 Lake Data.



2014 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	3.5	3.9	17.7	6.4	0.4	531.9	3.3
2	4.0	3.0	17.8	5.1	0.7	567.7	3.0
Average	**3.7**	**3.5**	**17.7**	**5.8**	**0.5**	**549.8**	**3.2**

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	---	3.2	12.6	6.6	0.6	1213.6	3.3
2	---	1.9	15.1	7.1	1.1	1295.5	3.0
Average	**---**	**2.5**	**13.8**	**6.8**	**0.9**	**1254.6**	**3.2**

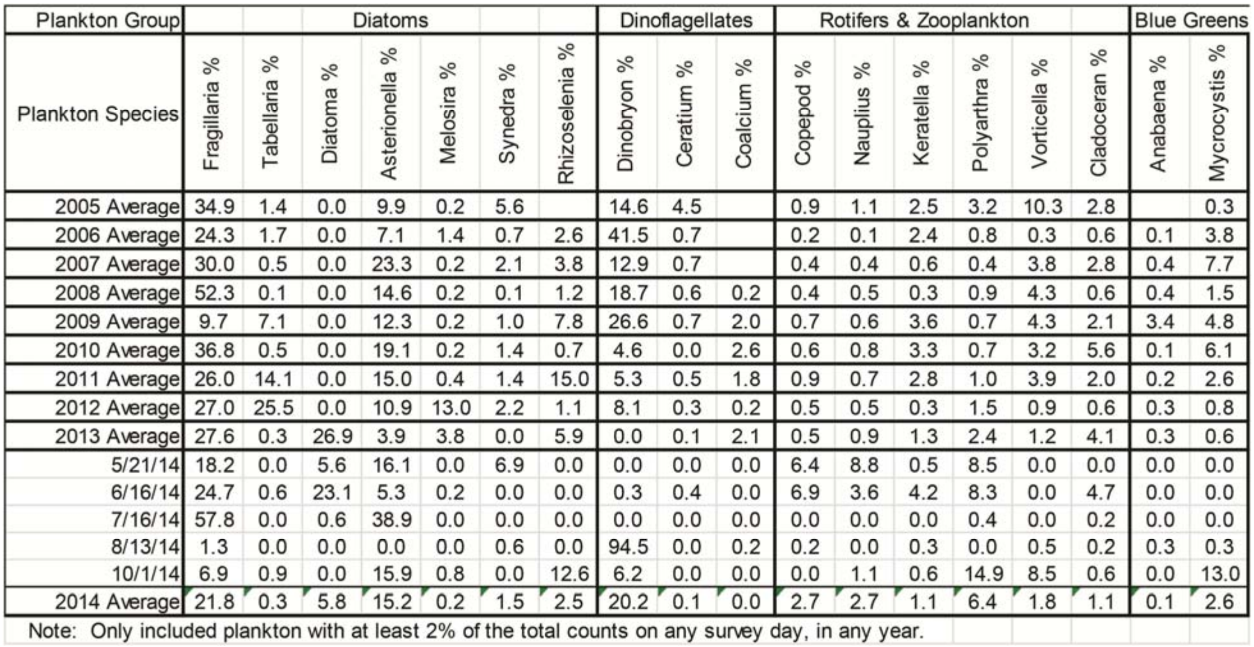
Date Averaged Surface Water Data

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)
5/21/14	2.4	4.4	29.1	15.5	0.7	1097.6	4.1
6/16/14	4.8	1.3	11.1	7.8	0.3	739.0	1.2
7/16/14	2.9	2.6	18.1	4.4	0.7	96.5	3.3
8/13/14	3.1	7.1	14.3	0.4	0.5	251.7	2.3
10/1/14	5.5	1.9	16.1	0.7	0.5	564.3	4.9
Average	**3.7**	**3.5**	**17.7**	**5.8**	**0.5**	**549.8**	**3.2**

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)
5/21/14	---	5.2	29.0	22.4	0.6	1219.0	0.9
6/16/14	---	1.0	15.3	2.4	0.7	1074.8	0.7
7/16/14	---	1.2	9.1	3.1	1.2	1171.1	0.6
8/13/14	---	4.2	5.8	1.8	1.1	1413.3	0.6
10/1/14	---	1.0	9.9	4.5	0.7	1394.6	0.4
Average	**---**	**2.5**	**13.8**	**6.8**	**0.9**	**1254.6**	**0.6**

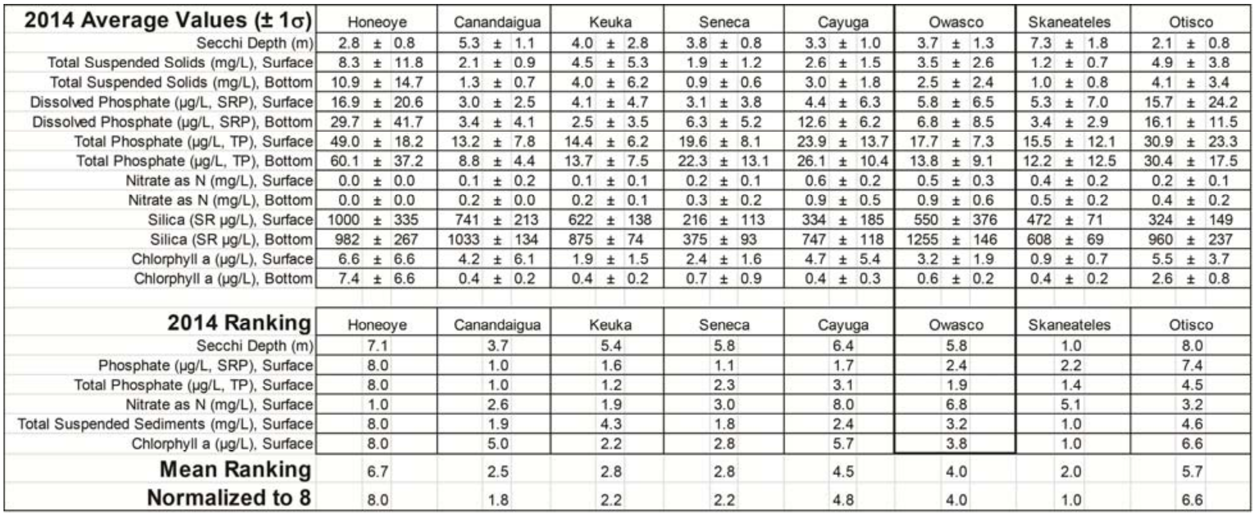
Table 4. Annual Average Plankton Data from 2005 through 2014, and Daily Average Data for 2014.



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
5/21/14	18.2	0.0	5.6	16.1	0.0	6.9	0.0	0.0	0.0	0.0	6.4	8.8	0.5	8.5	0.0	0.0	0.0	0.0
6/16/14	24.7	0.6	23.1	5.3	0.2	0.0	0.0	0.3	0.4	0.0	6.9	3.6	4.2	8.3	0.0	4.7	0.0	0.0
7/16/14	57.8	0.0	0.6	38.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0
8/13/14	1.3	0.0	0.0	0.0	0.0	0.6	0.0	94.5	0.0	0.2	0.2	0.0	0.3	0.0	0.5	0.2	0.3	0.3
10/1/14	6.9	0.9	0.0	15.9	0.8	0.0	12.6	6.2	0.0	0.0	0.0	1.1	0.6	14.9	8.5	0.6	0.0	13.0
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

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

Table 5: Annual Average 2014 Lake Data from the Finger Lake Survey.



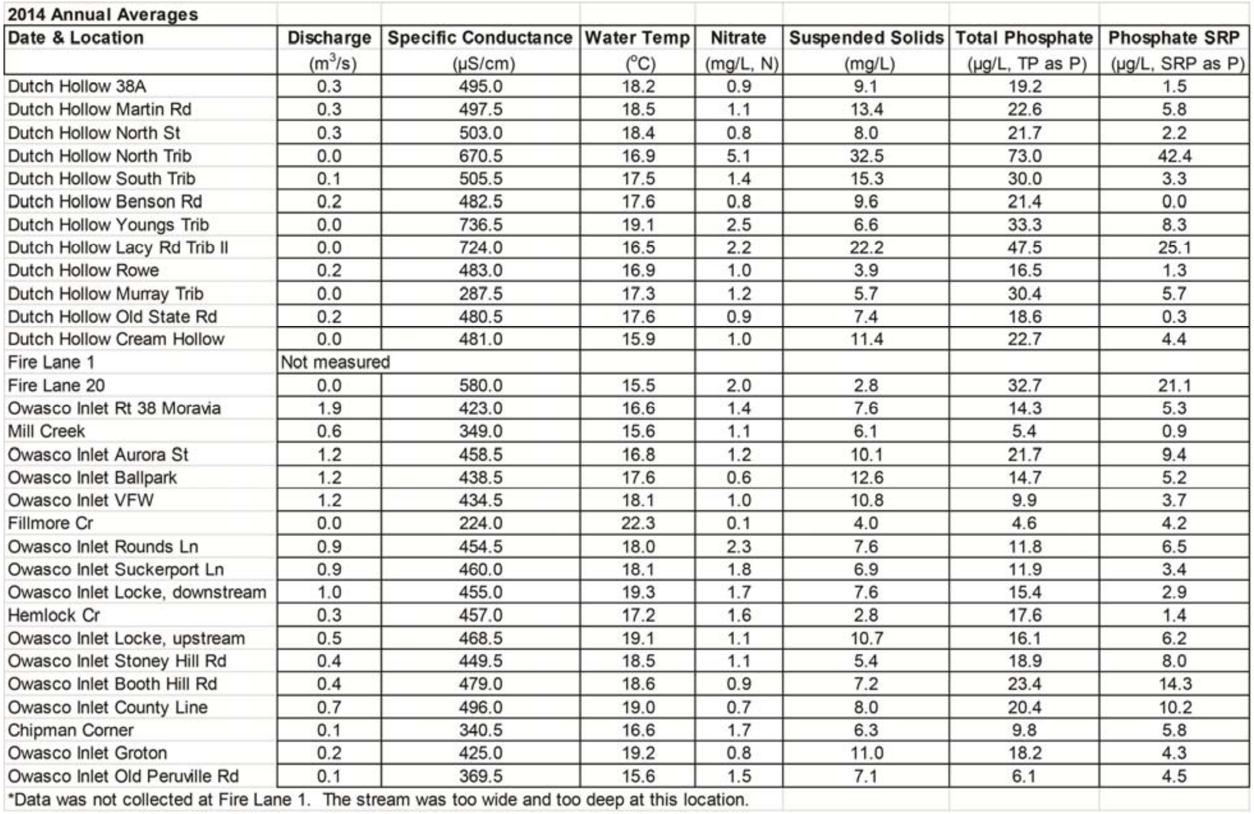
2014 Average Values (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.8 ± 0.8	5.3 ± 1.1	4.0 ± 2.8	3.8 ± 0.8	3.3 ± 1.0	3.7 ± 1.3	7.3 ± 1.8	2.1 ± 0.8
Total Suspended Solids (mg/L), Surface	8.3 ± 11.8	2.1 ± 0.9	4.5 ± 5.3	1.9 ± 1.2	2.6 ± 1.5	3.5 ± 2.6	1.2 ± 0.7	4.9 ± 3.8
Total Suspended Solids (mg/L), Bottom	10.9 ± 14.7	1.3 ± 0.7	4.0 ± 6.2	0.9 ± 0.6	3.0 ± 1.8	2.5 ± 2.4	1.0 ± 0.8	4.1 ± 3.4
Dissolved Phosphate (μg/L, SRP), Surface	16.9 ± 20.6	3.0 ± 2.5	4.1 ± 4.7	3.1 ± 3.8	4.4 ± 6.3	5.8 ± 6.5	5.3 ± 7.0	15.7 ± 24.2
Dissolved Phosphate (μg/L, SRP), Bottom	29.7 ± 41.7	3.4 ± 4.1	2.5 ± 3.5	6.3 ± 5.2	12.6 ± 6.2	6.8 ± 8.5	3.4 ± 2.9	16.1 ± 11.5
Total Phosphate (μg/L, TP), Surface	49.0 ± 18.2	13.2 ± 7.8	14.4 ± 6.2	19.6 ± 8.1	23.9 ± 13.7	17.7 ± 7.3	15.5 ± 12.1	30.9 ± 23.3
Total Phosphate (μg/L, TP), Bottom	60.1 ± 37.2	8.8 ± 4.4	13.7 ± 7.5	22.3 ± 13.1	26.1 ± 10.4	13.8 ± 9.1	12.2 ± 12.5	30.4 ± 17.5
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.2	0.1 ± 0.1	0.2 ± 0.1	0.6 ± 0.2	0.5 ± 0.3	0.4 ± 0.2	0.2 ± 0.1
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.3 ± 0.2	0.9 ± 0.5	0.9 ± 0.6	0.5 ± 0.2	0.4 ± 0.2
Silica (SR μg/L), Surface	1000 ± 335	741 ± 213	622 ± 138	216 ± 113	334 ± 185	550 ± 376	472 ± 71	324 ± 149
Silica (SR μg/L), Bottom	982 ± 267	1033 ± 134	875 ± 74	375 ± 93	747 ± 118	1255 ± 146	608 ± 69	960 ± 237
Chlorphyll a (μg/L), Surface	6.6 ± 6.6	4.2 ± 6.1	1.9 ± 1.5	2.4 ± 1.6	4.7 ± 5.4	3.2 ± 1.9	0.9 ± 0.7	5.5 ± 3.7
Chlorphyll a (μg/L), Bottom	7.4 ± 6.6	0.4 ± 0.2	0.4 ± 0.2	0.7 ± 0.9	0.4 ± 0.3	0.6 ± 0.2	0.4 ± 0.2	2.6 ± 0.8
2014 Ranking	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	7.1	3.7	5.4	5.8	6.4	5.8	1.0	8.0
Phosphate (μg/L, SRP), Surface	8.0	1.0	1.6	1.1	1.7	2.4	2.2	7.4
Total Phosphate (μg/L, TP), Surface	8.0	1.0	1.2	2.3	3.1	1.9	1.4	4.5
Nitrate as N (mg/L), Surface	1.0	2.6	1.9	3.0	8.0	6.8	5.1	3.2
Total Suspended Sediments (mg/L), Surface	8.0	1.9	4.3	1.8	2.4	3.2	1.0	4.6
Chlorphyll a (μg/L), Surface	8.0	5.0	2.2	2.8	5.7	3.8	1.0	6.6
Mean Ranking	6.7	2.5	2.8	2.8	4.5	4.0	2.0	5.7
Normalized to 8	8.0	1.8	2.2	2.2	4.8	4.0	1.0	6.6

Table 6. 2014 Stream Data.

2014 Stream Segment Analysis Data

Date & Location	Discharge (m^3/s)	Specific Conductance (µS/cm)	Water Temp (°C)	Nitrate (mg/L, N)	Suspended Solids (mg/L)	Total Phosphate (µg/L, TP as P)	Phosphate SRP (µg/L, SRP as P)
6/3/2014							
Dutch Hollow 38A	0.3	514	20.2	0.7	9.2	30.9	3.0
Dutch Hollow Martin Rd	0.4	512	20.6	0.9	6.7	33.2	8.7
Dutch Hollow North St	0.4	513	20.2	1.1	3.9	30.3	1.8
Dutch Hollow North Trib	0.0	657	17.1	6.6	28.1	89.4	38.3
Dutch Hollow South Trib	0.1	499	19.3	1.5	3.0	41.7	3.3
Dutch Hollow Benson Rd	0.2	484	19.1	0.9	4.0	31.2	0.0
Dutch Hollow Youngs Trib	0.0	735	20.2	3.7	5.6	42.8	10.8
Dutch Hollow Lacy Rd Trib	0.0	798	16.8	2.4	3.7	34.1	1.9
Dutch Hollow Rowe	0.2	479	17.8	1.2	1.7	23.6	2.6
Dutch Hollow Murray Trib	0.0	331	18.1	1.5	8.9	52.1	5.7
Dutch Hollow Old State Rd	0.2	462	18.5	1.3	3.5	25.8	0.3
Dutch Hollow Cream Hollow	0.1	453	16.6	1.7	8.0	28.2	5.7
7/30/2014							
Dutch Hollow 38A	0.3	476	16.1	1.0	9.0	7.5	0.0
Dutch Hollow Martin Rd	0.3	483	16.4	1.3	20.0	12.0	2.8
Dutch Hollow North St	0.3	493	16.6	0.4	12.2	13.0	2.7
Dutch Hollow North Trib	0.0	684	16.7	3.7	36.8	56.5	46.4
Dutch Hollow South Trib	0.0	512	15.7	1.3	27.6	18.3	3.2
Dutch Hollow Benson Rd	0.1	481	16.1	0.6	15.2	11.6	0.0
Dutch Hollow Youngs Trib	0.0	738	18.0	1.3	7.6	23.7	5.8
Dutch Hollow Lacy Rd Trib II	0.0	650	16.2	2.0	40.6	61.0	48.3
Dutch Hollow Rowe	0.2	487	15.9	0.9	6.2	9.5	0.0
Dutch Hollow Murray Trib	0.0	244	16.4	0.9	2.6	8.8	5.6
Dutch Hollow Old State Rd	0.2	499	16.7	0.5	11.2	11.4	0.3
Dutch Hollow Cream Hollow	0.0	509	15.2	0.2	14.8	17.3	3.1
6/4/2014							
Fire Lane 1	not measured						
Fire Lane 20	not measured						
Owasco Inlet Rt 38 Moravia	2.3	417	16.7	2.2	4.9	16.6	3.4
Mill Creek	0.7	341	15.2	1.5	5.5	8.7	1.5
Owasco Inlet Aurora St	1.3	461	16.7	1.7	6.7	19.5	6.1
Owasco Inlet Ballpark	1.3	440	17.5	0.9	8.0	14.5	7.8
Owasco Inlet VFW	1.3	447	17.8	1.1	6.5	16.4	4.0
Fillmore Cr	0.0	227	21.8	0.3	5.6	6.4	7.9
Owasco Inlet Rounds Ln	1.0	451	18.0	3.4	5.2	13.7	4.4
Owasco Inlet Suckerport Ln	0.9	457	17.7	2.9	4.7	14.7	4.1
Owasco Inlet Locke, downstream	1.0	457	18.1	2.5	5.5	14.5	5.5
Hemlock Cr	0.3	450	16.8	3.0	2.3	26.4	2.7
Owasco Inlet Locke, upstream	0.5	461	19.1	1.6	9.3	24.7	10.4
Owasco Inlet Stoney Hill Rd	0.4	454	18.6	1.7	5.3	29.5	11.6
Owasco Inlet Booth Hill Rd	0.4	479	18.5	1.4	6.9	36.1	24.1
Owasco Inlet County Line	0.7	499	18.7	0.8	8.9	28.3	15.0
Chipman Corner	0.1	291	16.1	2.4	3.9	17.3	9.3
Owasco Inlet Groton	0.2	429	19.9	0.7	10.7	27.4	7.5
Owasco Inlet Old Peruville Rd	0.1	383	14.8	1.8	1.1	11.3	7.9
8/1/2014							
Fire Lane 1	not measured						
File Lane 20	0.0	580	15.5	2.0	2.8	32.7	21.1
Owasco Inlet Rt 38 Moravia	1.6	429	16.5	0.6	10.2	12.0	7.2
Mill Creek	0.5	357	15.9	0.7	6.6	2.2	0.3
Owasco Inlet Aurora St	1.1	456	16.9	0.6	13.4	23.8	12.6
Owasco Inlet Ballpark	1.1	437	17.7	0.4	17.2	14.8	2.5
Owasco Inlet VFW	1.0	422	18.3	0.9	15.0	3.3	3.4
Fillmore Cr	0.0	221	22.8	0.0	2.4	2.7	0.4
Owasco Inlet Rounds Ln	0.9	458	17.9	1.1	10.0	10.0	8.7
Owasco Inlet Suckerport Ln	0.8	463	18.5	0.6	9.2	9.1	2.7
Owasco Inlet Locke, downstream	1.0	453	20.4	1.0	9.6	16.2	0.4
Hemlock Cr	0.2	464	17.6	0.2	3.4	8.8	0.0
Owasco Inlet Locke, upstream	0.5	476	19.0	0.5	12.0	7.5	2.0
Owasco Inlet Stoney Hill Rd	0.4	445	18.4	0.6	5.4	8.2	4.5
Owasco Inlet Booth Hill Rd	0.4	479	18.6	0.4	7.4	10.7	4.4
Owasco Inlet County Line	0.7	493	19.2	0.7	7.0	12.5	5.3
Chipman Corner	0.1	390	17.0	1.0	8.8	2.4	2.4
Owasco Inlet Groton	0.2	421	18.4	0.9	11.2	8.9	1.1
Owasco Inlet Old Peruville Rd	0.1	356	16.4	1.3	13.0	1.0	1.1

Table 6. 2014 Stream Data (continued)



2014 Annual Averages							
Date & Location	Discharge	Specific Conductance	Water Temp	Nitrate	Suspended Solids	Total Phosphate	Phosphate SRP
	(m^3/s)	(µS/cm)	(°C)	(mg/L, N)	(mg/L)	(µg/L, TP as P)	(µg/L, SRP as P)
Dutch Hollow 38A	0.3	495.0	18.2	0.9	9.1	19.2	1.5
Dutch Hollow Martin Rd	0.3	497.5	18.5	1.1	13.4	22.6	5.8
Dutch Hollow North St	0.3	503.0	18.4	0.8	8.0	21.7	2.2
Dutch Hollow North Trib	0.0	670.5	16.9	5.1	32.5	73.0	42.4
Dutch Hollow South Trib	0.1	505.5	17.5	1.4	15.3	30.0	3.3
Dutch Hollow Benson Rd	0.2	482.5	17.6	0.8	9.6	21.4	0.0
Dutch Hollow Youngs Trib	0.0	736.5	19.1	2.5	6.6	33.3	8.3
Dutch Hollow Lacy Rd Trib II	0.0	724.0	16.5	2.2	22.2	47.5	25.1
Dutch Hollow Rowe	0.2	483.0	16.9	1.0	3.9	16.5	1.3
Dutch Hollow Murray Trib	0.0	287.5	17.3	1.2	5.7	30.4	5.7
Dutch Hollow Old State Rd	0.2	480.5	17.6	0.9	7.4	18.6	0.3
Dutch Hollow Cream Hollow	0.0	481.0	15.9	1.0	11.4	22.7	4.4
Fire Lane 1	Not measured						
Fire Lane 20	0.0	580.0	15.5	2.0	2.8	32.7	21.1
Owasco Inlet Rt 38 Moravia	1.9	423.0	16.6	1.4	7.6	14.3	5.3
Mill Creek	0.6	349.0	15.6	1.1	6.1	5.4	0.9
Owasco Inlet Aurora St	1.2	458.5	16.8	1.2	10.1	21.7	9.4
Owasco Inlet Ballpark	1.2	438.5	17.6	0.6	12.6	14.7	5.2
Owasco Inlet VFW	1.2	434.5	18.1	1.0	10.8	9.9	3.7
Fillmore Cr	0.0	224.0	22.3	0.1	4.0	4.6	4.2
Owasco Inlet Rounds Ln	0.9	454.5	18.0	2.3	7.6	11.8	6.5
Owasco Inlet Suckerport Ln	0.9	460.0	18.1	1.8	6.9	11.9	3.4
Owasco Inlet Locke, downstream	1.0	455.0	19.3	1.7	7.6	15.4	2.9
Hemlock Cr	0.3	457.0	17.2	1.6	2.8	17.6	1.4
Owasco Inlet Locke, upstream	0.5	468.5	19.1	1.1	10.7	16.1	6.2
Owasco Inlet Stoney Hill Rd	0.4	449.5	18.5	1.1	5.4	18.9	8.0
Owasco Inlet Booth Hill Rd	0.4	479.0	18.6	0.9	7.2	23.4	14.3
Owasco Inlet County Line	0.7	496.0	19.0	0.7	8.0	20.4	10.2
Chipman Corner	0.1	340.5	16.6	1.7	6.3	9.8	5.8
Owasco Inlet Groton	0.2	425.0	19.2	0.8	11.0	18.2	4.3
Owasco Inlet Old Peruville Rd	0.1	369.5	15.6	1.5	7.1	6.1	4.5

*Data was not collected at Fire Lane 1. The stream was too wide and too deep at this location.