OWASCO LAKE, NEW YORK:
WATER QUALITY & NUTRIENT SOURCES, 2013 FINDINGS.

John D. Halfman, Alison Cole (WS'14), Genevieve Moralez (WS'15), Tyler Goldstoff (H'15)
Department of Geoscience & Environmental Studies Program
Finger Lakes Institute
Hobart and William Smith Colleges
Geneva, NY 14456
Halfman@hws.edu

12/30/2013

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 a focus for additional research due to the lake's poor water quality in comparison to the 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 effective and comprehensive 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 just 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 some (not all) blue green species 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 agricultural activities (both 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, especially during major precipitation/runoff events.
- Efforts are being made to reduce the inputs of nutrients to the lake. A DEC mandated reduction in phosphorus in the Groton Wastewater Treatment Facility effluent has reduced nutrient loading down the Owasco Inlet. The adoption of 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 and 2012 surveys added two new initiatives: expand the summer season sampling to the early spring through late fall to investigate seasonal fluctuations in nutrient loading; and, initiate an event *versus* base flow analysis of nutrient and sediment loading at Dutch Hollow Brook. The results to date include:

- 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 phosphorus budget for Owasco Lake estimated an input of over 16 metric tons of phosphorus per year, a loss of 4.4 metric tons of phosphorus per year, and a net, inputs minus outputs, gain of roughly 12 metric tons of phosphorus to the lake. The excess phosphorus stimulated additional algal growth and a decline in water quality/clarity.
- In comparison, the 2012 phosphorus budget estimated an input of only 2.6 metric tons, a loss of 4.4 metric tons, and a net loss of 1.8 metric tons of phosphorus that stimulated a slight improvement in water quality.
- The difference between 2011 and 2012 was significantly more in rainfall, thus more runoff, in 2011 than 2012. 2011 was one of the wettest and 2012 was one of the driest years on record.
- The negative phosphorus budget in 2012 indicates that water quality / clarity in the lake can improve but only if nutrient sources are mitigated during the wet years.

Here, we report on our 2013 results that continued and expanded on the 2011 and 2012 research. Specifically, the 2013 effort continued the spring through fall monitoring of water quality in the lake and major streams; continued the investigation of nutrient and sediment sources in the Dutch Hollow Brook and Owasco Inlet; continued the event *versus* base flow analysis of Dutch Hollow Brook; and, initiated a similar event *versus* base flow analysis of Owasco Inlet to substantiate and build on the 2011 eye-opening results. This study was made possible through the continued support by the Cayuga County Legislature.

METHODS

The sample sites and field/laboratory methods used in 2013 were similar to the 2011 and 2012 programs.

Owasco Lake: The 2013 lake survey sampled Sites 1 and 2, the same sites utilized since the 2005 survey, on a monthly basis (Table 1, Fig. 1). These two sites are representative of the open water limnology in Owasco Lake. The specific 2013 survey dates were: 4/14, 5/5, 5/28, 6/25, 7/23, 8/16, 10/1, 10/21.

The field and laboratory methods were identical to our earlier lake research. A CTD water quality profile, secchi disk depth, horizontal and vertical plankton tows (80-μm mesh), and surface and bottom water samples were collected at each site. The CTD electronically gathers water column profiles of temperature (°C), conductivity (reported as specific conductance, μS/cm, a measurement proportional to salinity), dissolved oxygen (mg/L), pH, turbidity (NTUs), photosynthetic active radiation intensities (PAR, $\mu E/cm^2$-s), and fluorescence (a measure of

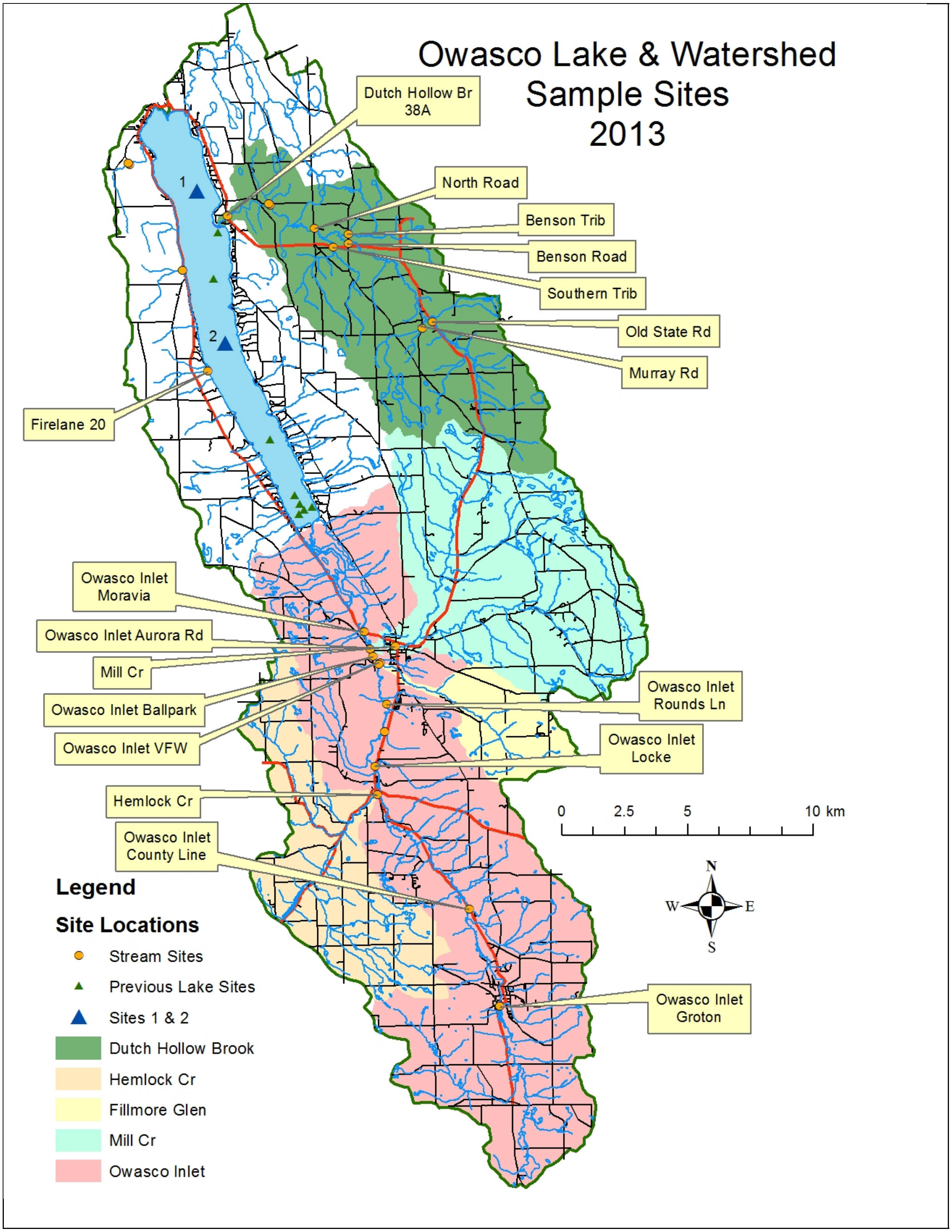


Fig. 1. The 2013 lake and stream sites. Dutch Hollow Brook drains the second largest portion (77 km^2), and the Owasco Inlet drains the largest portion (299 km^2) of the Owasco watershed. The Ballpark (Owasco Inlet) site was added in 2013 at the expense of sampling Fillmore Creek.

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 sediment (mg/L) concentrations. 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 Streams: The 2013 stream monitoring focused on Dutch Hollow Brook and Owasco Inlet and continued sampling a small tributary at the very end of Fire Lane 20. The sites were sampled monthly: 4/20, 5/15, 6/4, 7/3, 7/24, 8/20, and 9/28 for onsite analyses and collection of water samples for nutrient and sediment analyses in the laboratory. Dutch Hollow Brook and Owasco Inlet have been continually studied since 2005 to investigate the source of nutrients and sediments entering the lake, because these two watersheds delivered more nutrients and sediments to a lake than the other tributaries. The reason, these watersheds are the two largest watersheds in the basin, and both drain critical examples of point and nonpoint sources of nutrients and sediments, e.g., municipal wastewater treatment facilities and agricultural areas. Dutch Hollow Brook drains the 2nd largest subwatershed area (77 km^2) in the Owasco watershed (523 km^2) and drains an agriculturally-rich landscape (64% agricultural, 33% forested) of both crop agronomy and animal husbandry. The Owasco Inlet drains the largest portion (299 km^2) of the Owasco watershed, includes a mixture of agricultural (46%) and forested (49%) landscapes, and contains two municipal wastewater treatment facilities.

Dutch Hollow Brook was sampled at seven sites in 2013 (Figs. 1 & 2). Progressing upstream, four sites were sequentially located at Rt 38A, North St, Benson Rd, and near Old State Rd. Three unnamed tributaries in the tributary were also sampled. The South tributary joined Dutch Hollow between the North St and the Benson Rd site. It drains the agriculturally-rich land to the south. Benson tributary joined Dutch Hollow between the South tributary confluence and the Benson Rd site. It drains another large agricultural area to the northeast. Finally, the tributary at Murray Rd joins Dutch Hollow just downstream of the Old State Rd site. It drains forested land.

Owasco Inlet was sampled at ten sites in 2013 (Figs. 1 & 2). Proceeding upstream, eight sites were sequentially located 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 downstream of the Fillmore Cr. confluence, at Rounds Ln, just south of Locke, at the County Line, and just upstream of Groton (near Spring St). This site selection bracketed two municipal wastewater treatment facilities. Two major tributaries, Mill and Hemlock Creeks, were also sampled just upstream of their confluence with Owasco Inlet. Hemlock Creek is smaller and more agricultural (47 km^2, 57% forested, 41% agricultural) than Mill Creek (77 km^2, 51% forested, 47% agricultural). Fillmore Creek was discontinued from the monitoring program in 2013 to add the Ballpark site, and enable further refinement of nutrient and sediment sources between the Locke and Rt 38 Sites.

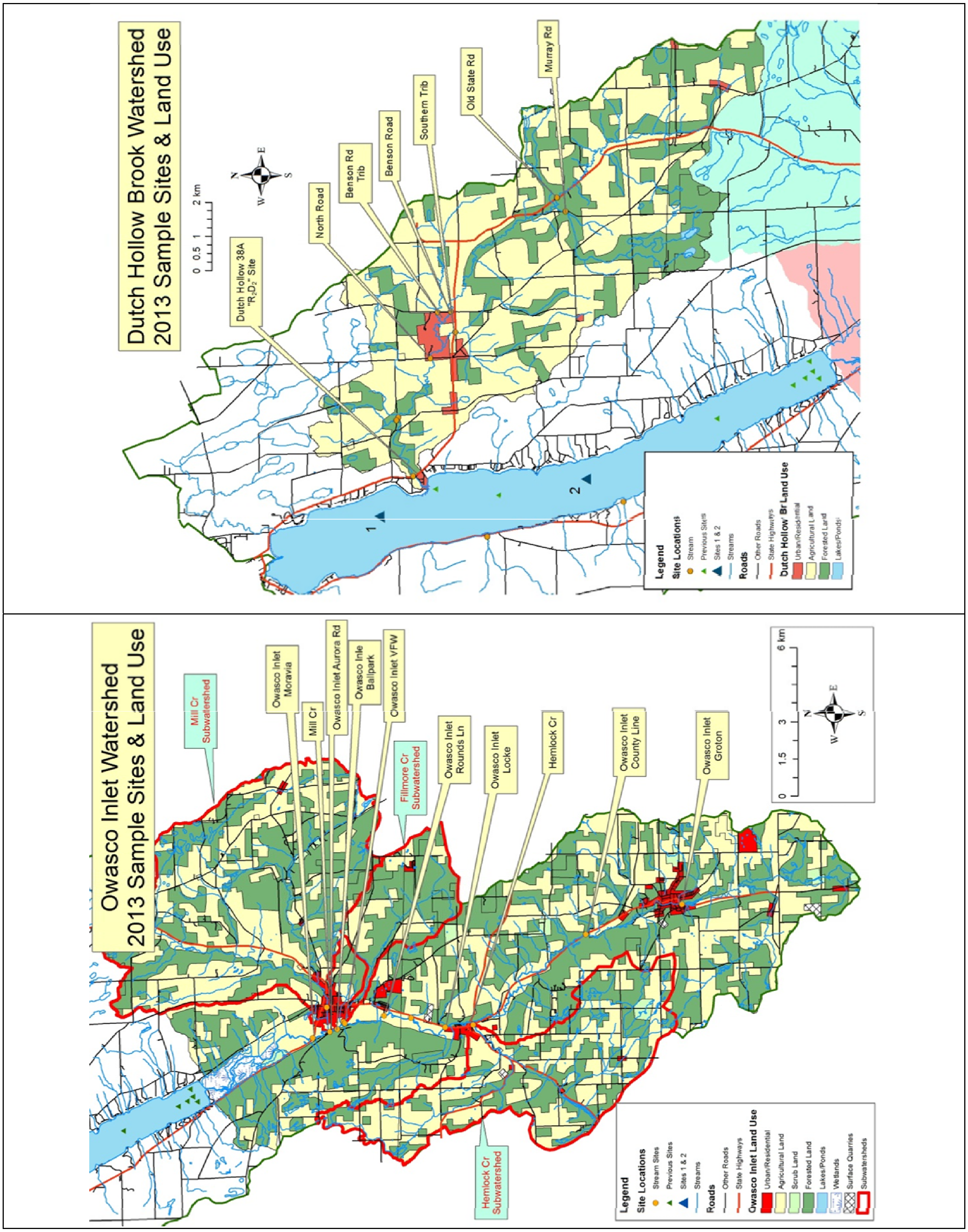


Fig. 2. 2013 site locations and land use along Dutch Hollow Brook and Owasco Inlet watersheds.

The tributary at Fire Lane 20 is typical of numerous 1st or 2nd order (small) tributaries along the east and west shores of the lake.

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 site. 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). Fluxes are critical to delineate the quantity of a substance that is transported by the stream per unit time.

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. 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.

Event and base flow states augment the delivery of point and non-point sources in different ways. Events primarily deliver non-point source materials to the lake, like nutrients and sediments that are removed from the landscape by the runoff of water. Stream concentrations of these non-point source materials increase significantly (10 to 1,000 fold) above base flow concentrations during an event. Event loads dominate the total loading of these materials, especially in an agriculturally rich watershed. Typical non-point source materials include agricultural and lawn soils, fertilizers, herbicides and pesticides, and concentrated animal feedlot (CAFO) wastes from farm lots and manure spread on fields. In contrast, base flow samples highlight point source inputs, e.g., effluent from wastewater treatment facilities and industrial plants, because smaller base flows cannot dilute inputs from the point source to the same degree as significantly larger event flows. It also highlights nitrates transported by groundwater flow.

A Teledyne ISCO automated water sampler and *In Situ* Aqua Troll 200 data loggers were installed at the Rt 38A site in Dutch Hollow Brook from 4/10 to 10/29 to investigate the impact of event and base flows on the delivery of nutrients and sediments to the lake. Another automated sampler was deployed at the most downstream site (Rt 38) on Owasco Inlet from 6/11 through 7/9 for a preliminary investigation of event *versus* base flow variability. It was deployed for only a month due to budget limitations. The reduced agricultural land use, the wastewater treatment facilities, and the larger watershed in the Owasco Inlet watershed suggested a difference response than Dutch Hollow Brook.

At both sites, the sampler was programmed to collect 1-L of water every eight hours (Fig. 3a). This frequency collected both event and base flow samples in previous years. Weekly servicing brought the water samples back to the laboratory for analysis and also enabled weekly measurement of stream discharge. As in 2012, every 8-hr event sample but only daily base flow (4 am) samples were analyzed in 2013, because event concentrations and fluxes revealed quick and substantial sample to sample changes where base flow concentrations revealed minimal sample to sample changes in in prior years. The data loggers deployed in Dutch Hollow recorded stream stage (height), temperature and specific conductance every hour to identify runoff events and enable the estimation of stream discharge at this site. Events were also differentiated from base flow by total suspended sediment concentrations. The hourly 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. Discharge data for the Owasco Inlet samples utilized the USGS Gauge Station data (#4235299), located just upstream of the Rt 38 site. Over the 202 day (605 8-hr samples) deployment in 2013, one sample was lost due to a broken bottle.

Fig. 3a. Servicing "R$_2$D$_2$" 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 measured 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 2013 water temperature profiles were similar to previous surveys and typical for any spring through fall transition (Fig. 4). The first two profiles, 4/14 and 5/5, revealed nearly isothermal conditions, i.e., uniform temperatures throughout the water column at ~ 5 and 7° C, respectively. When the lake is isothermal, the entire water column mixes (i.e., spring or fall overturn), and homogenizes any concentration differences that developed in nutrients, dissolved oxygen and other parameters during the summer (or winter) stratified seasons. Subsequent profiles revealed the establishment of summer season stratification, an increasingly less dense and warmer epilimnion (surface water) over a denser and uniformly cold hypolimnion (bottom water). Epilimnetic temperatures ranged from 15°C in late-May to almost 27° C in in June, and cooled to 15° C by the end of the survey (10/21). Hypolimnetic temperatures remained a uniform 6 to 7° C through the survey. Since 2009 through 2013, the epilimnion and hypolimnion were slightly warmer (by 1 to 2° C) than pre-2009 temperatures and perhaps related to global warming, annual climatic variability or the timing of the sample dates.

Epilimnetic conductivity data ranged from ~300 to 335 μS/cm. Like previous years, epilimnetic salinity in 2013 decreased from the largest detected values in the early spring (~335 μS/cm) through the summer and fall (~20 μS/cm) as the epilimnion was progressively diluted by less saline precipitation. The measured 2013 early spring conductivities and the stratified season decrease in conductivity was slightly less than those detected in 2011, but more typical of earlier 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 below 340 μS/cm and remained relatively uniform over time and depth except for a slight, ~5 μS/cm, increase near the lake floor in the fall (Fig. 4). The source of the dissolved ions to the lake was most likely from the natural weathering of soils, tills and bedrock, other biogeochemical reactions, and human sources like road salt, brought to the lake by runoff and/or groundwater flow.

The 2013 epilimnetic dissolved oxygen (DO) concentrations decreased from 11 to ~8 mg/L from the spring to late summer, responding to the increase in surface water temperatures as they remained at or near 100% saturation (Fig. 4). However, hypolimnetic DO concentrations were progressively depleted below saturations to just below 5 mg/L (~40% 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 bacterial respiration and decomposition of dead algae. It was less severe in 2013 than earlier.

The primary source of oxygen is diffusion from the atmosphere at the lake’s surface. Within the lake, DO concentrations also respond to three primary forcing functions: water temperature, colder water dissolves more oxygen than warmer water; photosynthesis, photosynthesis adds oxygen primarily to the saturated epilimnion with excess oxygen slowly diffusing back the atmosphere; and, respiration, respiration by organisms and especially bacterial consumes oxygen and its removal impacts the isolated hypolimnion, initially just below the thermocline and/or near the lake floor. If decomposition is intense enough, e.g., in a eutrophic lake, the depletion turns the entire hypolimnion anoxic because the bottom waters are isolated from the atmosphere and photosynthesis in the epilimnion where any sources of new oxygen enter the lake. Because DO concentrations respond to temperature and biologic activity, DO concentrations are occasionally reported as “percent saturation”, the percentage of the actual DO concentration to the theoretical

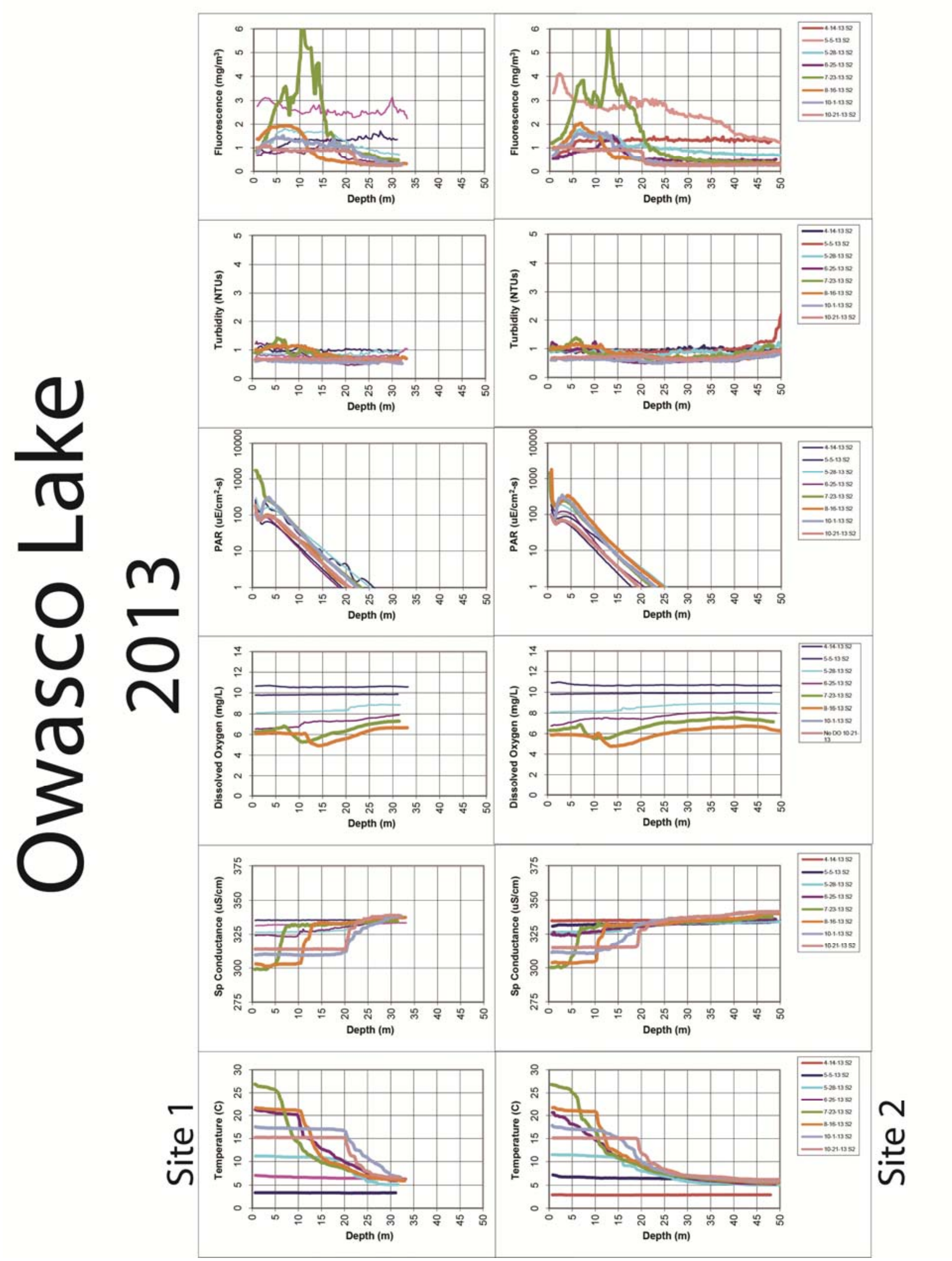


Fig. 4. Owasco 2013 CTD profiles from Sites 1 & 2. The PAR (light) data are plotted on an exponential scale, so that exponential changes with water depth appear as straight lines.

saturated concentration at the water's temperature. Thus, super saturation indicates more photosynthesis than respiration, whereas under saturation indicates more respiration than photosynthesis.

Photosynthetic available radiation (PAR), or light intensity profiles in 2013 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 algal peaks within the epilimnion approximately 5 to 15 m below the lake's surface (Fig. 4). Peak concentrations approached 7 μg/L (mg/m^3), but were more typically between 1 and 2 μg/L in 2013. The 2013 data were similar to profiles from previous years, except for 2011 when larger algal concentrations were detected. Hypolimnetic concentrations were consistently below 1 μg/L, except when the lake was isothermal and the water column mixing uniformly distributed the algae throughout the entire water column during the early spring.

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 2013 summer concentrations were similar to those collected in previous years, but larger than those detected in 2012. The benthic nepheloid layer was not well developed in 2013. The profiles are consistent with algal, fluvial and wave-action, resuspension-event, sources.

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 of roughly 1 mg/L were an order of magnitude (10 times) below the 10 mg/L MCL established by the EPA (Table 2 in appendix, Fig. 5). Neither was the lake impaired, as the annual mean total phosphate concentration was 10.8 μg/L, below the 20 μg/L total phosphate (TP) threshold established for impaired water bodies by the DEC. The 5/5 TP concentration was the only exception with a TP date-averaged lake concentrations of 22.2 μg/L. Surface chlorophyll-a concentrations ranged from 0.8 to 5.5 μg/L, and averaged 2.0 μg/L, slightly lower than previous years. Secchi disk depths ranged from 3.7 to 7.8, averaged 5.4 meters, slightly deeper than previous years.

Annual mean total phosphate concentrations increased from 2005 to 2011 (8 to 13 μg/L) and decreased to 10.8 μg/L since then (Fig. 5). Dissolved phosphate concentrations were larger in 2006, 2011 and 2013 than other years. Chlorophyll-a and total suspended sediment (TSS) 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). Secchi disk depths were deeper in 2007 (4.9 m) and 2008 (4.2 m) and again in 2012 (4.7 m) and deepest in 2013 (5.4 m) compared to the other years (3 to 4 m, Fig. 5). These trends were consistent with increased algal productivity from 2008 through 2010 that subsequently declined through 2013. The data suggest slightly better water quality in the lake before and after 2010 and 2011. However, do not over interpret these annual average trends because the change in the annual averages from year to year was smaller and within the scatter of the individual data from any year. The these trends could also reflect sampling an intense late-summer bloom in one year but not the next, and/or result from the expanded spring, summer and fall sampling performed during the past three years instead of the earlier summer only data.

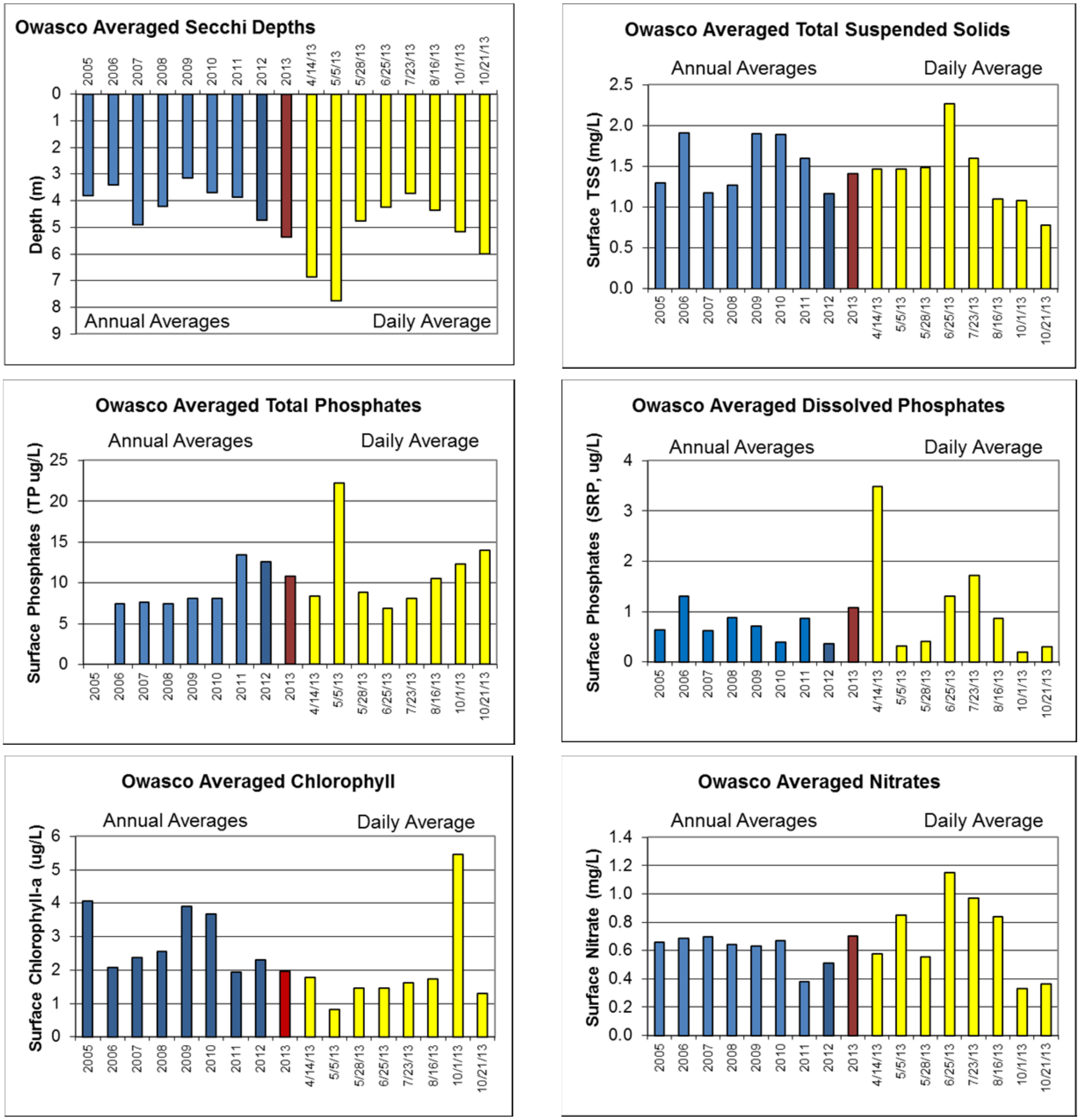


Fig. 5. 2013 annual average surface water data (blue bars, dark red for 2013), and daily average surface water data from each 2013 survey date (yellow bars).

The trophic status of Owasco Lake improved slightly in 2013. The 2013 annual average Secchi disk depth and nitrate concentrations combine to place Owasco Lake just below the oligotrophic/mesotrophic trophic boundary (Table 3, Fig. 5). The annual mean TP concentrations and hypolimnetic dissolved oxygen concentrations placed Owasco Lake in the mesotrophic range. Algae concentrations remained near the threshold between an oligotrophic and mesotrophic lake. Thus, the trophic status of Owasco Lake remains borderline oligotrophic-mesotrophic but since 2011 has been moving ever so slightly towards an oligotrophic system.

Table 3. Concentration ranges for Oligotrophic (low productivity), Mesotrophic (mid-range productivity), and Eutrophic (high productivity) lakes. The bold entries highlight Owasco Lake's 2013 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 still noteworthy. First, the dissolved phosphate to nitrate ratio in the lake, the two nutrients that could limit algal growth, averaged 1:2,275 and was never lower than 1:650 in 2013. 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). Second, some variability was observed in every parameter from one survey date to the next (Fig. 5). It highlights that algal blooms do not last the entire summer but are instead episodic and last for a week or two at a time. It suggests that the lake should be monitored on a daily or weekly basis to detect these shorter time-frame events. Third, dissolved nutrient concentrations revealed a small increase and chlorophyll-a concentrations a small decrease between the epilimnion and hypolimnion, e.g., annual mean surface and bottom water concentrations for soluble reactive phosphate were 1.1 and 1,7 μg/L, nitrate 0.7 and 0.9 mg/L, silica 830 and 1,300 μg/L, and chlorophyll-a 2.0 and 0.7 μg/L, respectively, and reflected the seasonal progression of algal uptake of nutrients and their growth in the epilimnion, and algal decomposition and release of those nutrients back to the water by bacteria in the hypolimnion. These observations have persisted throughout the Owasco lake research.

Plankton Data: The phytoplankton (algal) species in Owasco Lake during 2013 were dominated by diatoms, primarily *Flagillaria* and *Asterionella*, with smaller numbers of *Melosira*, *Tabellaria* and *Synedra* (Table 4 in appendix, Fig. 6). Like previous years, *Asterionella* and *Fragillaria* dominated in the spring, and *Fragillaria* and *Asterionella* dominated in the fall. In the past, *Tabellaria* occasionally dominated the algae population (e.g., 2012). Other phytoplankton species included the dinoflagellate *Dinobryon*, with a few *Ceratium* and *Coalcium*. Zooplankton species were dominated by rotifers, namely *Keratella*, *Polyarthra* and *Vorticella* with some cladocerans, like *Cercopagis*, the spiny water flea. Zebra and quagga mussel larvae were also detected in the plankton tows.

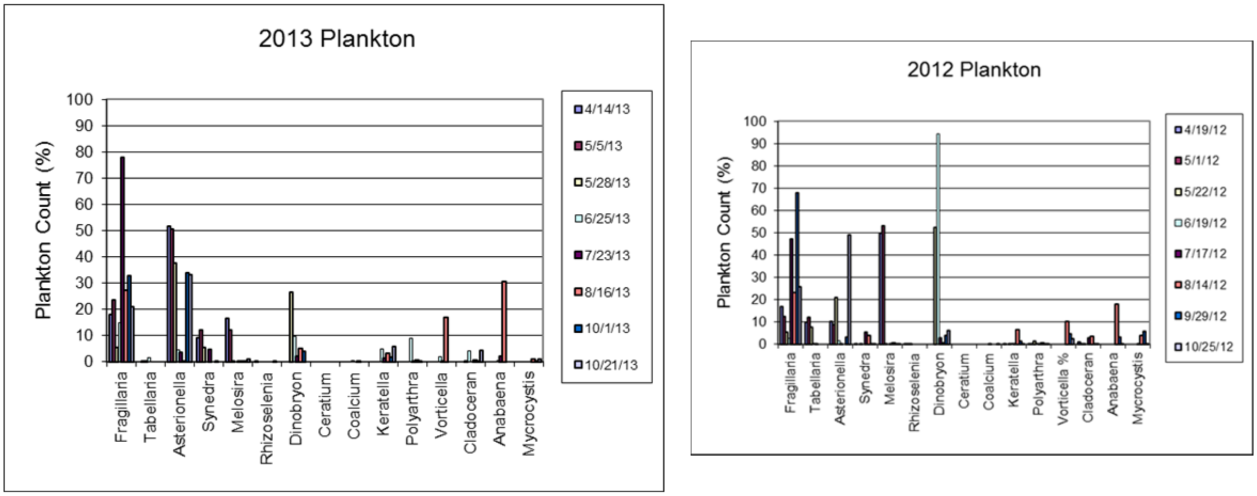


Fig. 6. Date averaged plankton data for 2013 and 2012.

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. 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. It disrupts 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. Unfortunately, only detailed and expensive analyses differentiate between toxic and nontoxic forms of blue green algae. It suggests that Owasco Lake needs a daily monitoring tool, like the meteorological and limnological monitoring buoy previously deployed by UFI, as modern technology can detect the presence of blue green from other algae and thus provide a means to warn users and when samples should be analyzed to protect water supplies, boaters, swimmers and other users of the lake.

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 and depth. Changes in these parameters with season and depth in Owasco Lake were still in between those detected in Skaneateles and Otisco (Fig. 7). The biologically related CTD parameters, fluorescence, dissolved oxygen, and PAR (light penetration), revealed the borderline oligotrophic-mesotrophic state of Owasco Lake, and Owasco Lake is in between the oligotrophic Skaneateles and borderline eutrophic Otisco. It indicates that smaller lakes (Otisco) become eutrophic more easily than larger lakes (Skaneateles). It also highlighted the significant effort, both in time and money, to reduce nutrient loading to Skaneateles Lake from its watershed. Thus, Skaneateles remained oligotrophic, and as a consequence, is one of a handful of surface water supplies in the US that delivers drinking water without filtration.

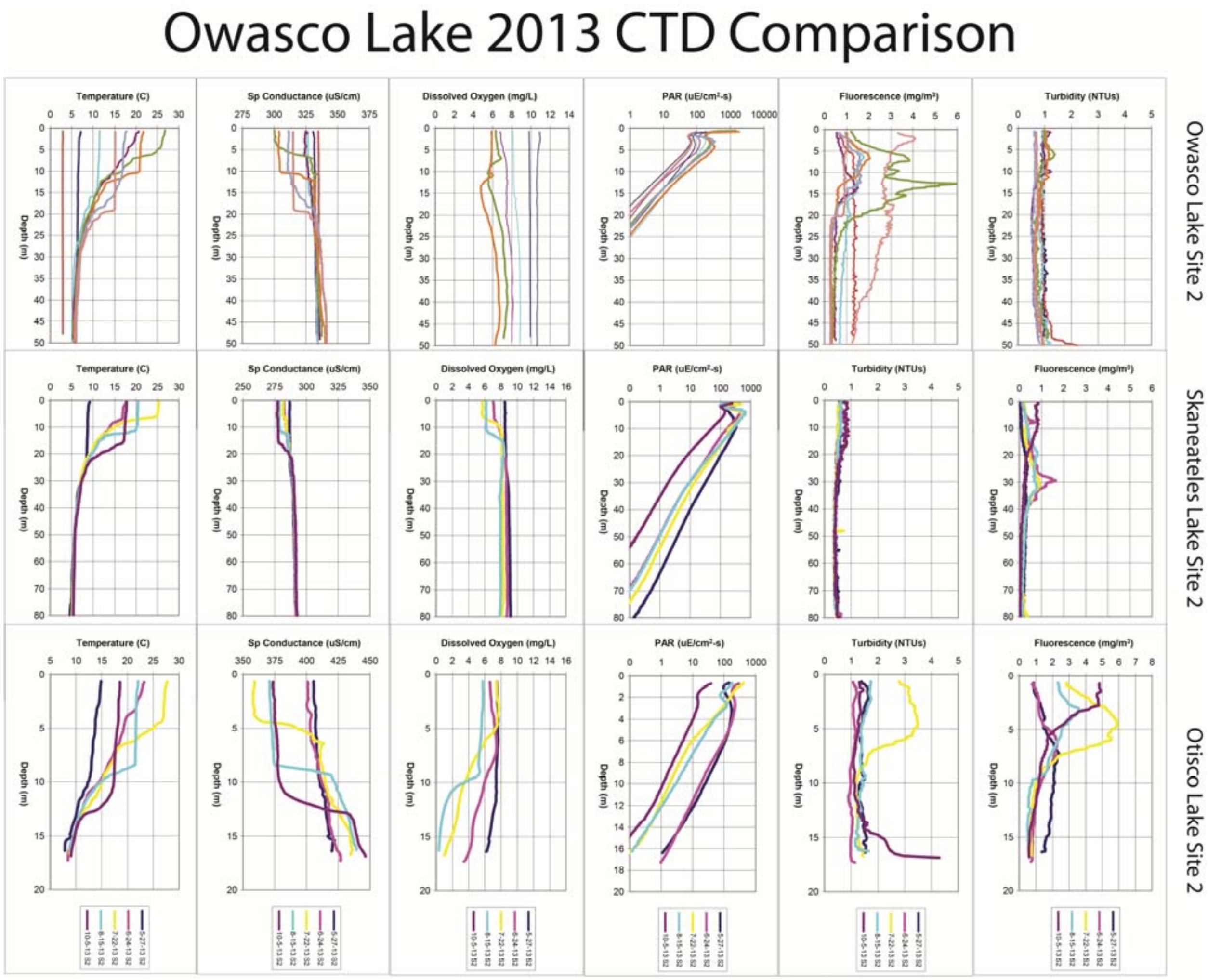


Fig. 7. 2013 CTD Profiles from Owasco (top), Skaneateles (middle) and Otisco (bottom) Lakes. The PAR (light) data are plotted on an exponential scale, so that exponential changes with water depth appear as straight lines.

Finger Lake Water Quality Ranks: The 2013 water quality rankings still place Owasco Lake as one of the worst lakes of the eight easternmost Finger Lakes (Table 5 in appendix, Figs. 8 & 9). These 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. Owasco has a similar ranking as Seneca but slightly better that Honeoye, Otisco and Cayuga. Honeoye retained the worst rank in the survey. Canandaigua, Keuka and Skaneateles Lakes revealed the best water quality ranks. Interestingly, water quality in Owasco and a few other lakes improved from 2011 to 2013.

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 effort appeared to work in Canandaigua and Keuka Lakes, as water quality had improved since 2005 until 2011 (a wet year) and generally improved since 2011. A previous Owasco Lake report highlighted that the percentage of agricultural land and changes in precipitation from year to year in each watershed influences these ranks. 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.

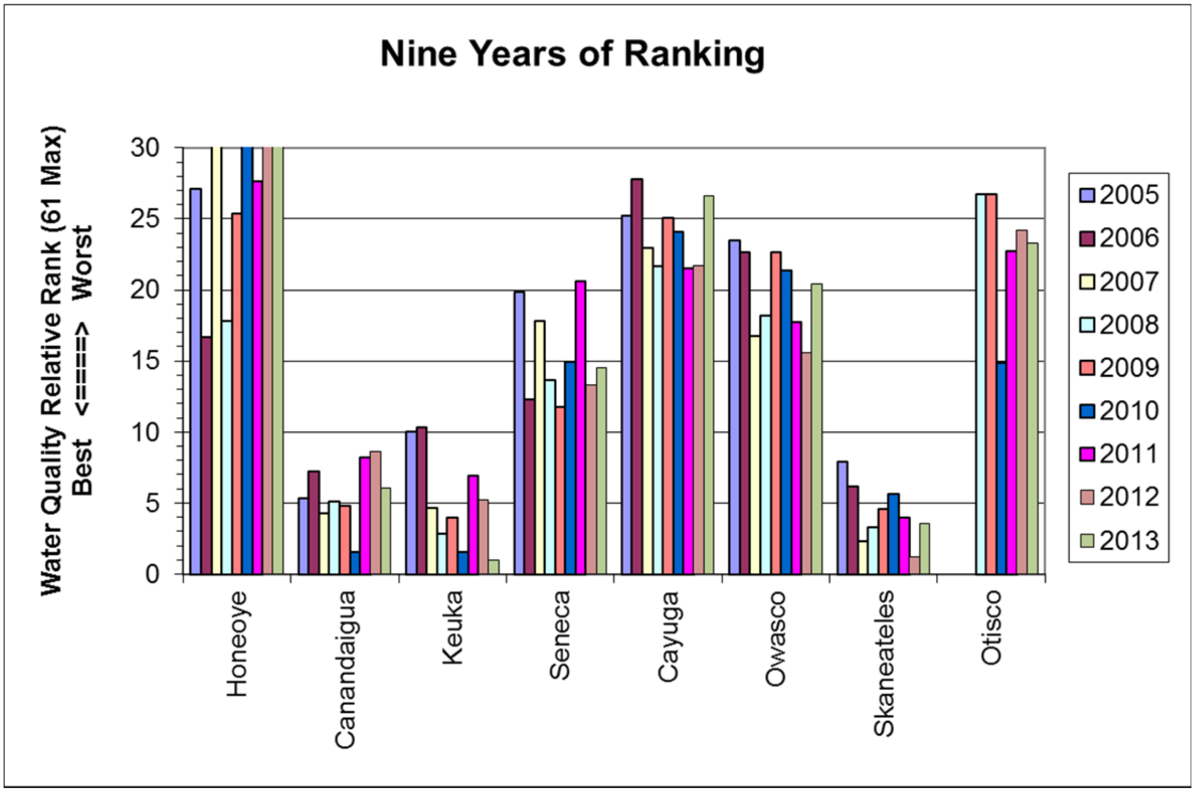


Fig. 8. Annual Water Quality Ranks for the eight easternmost Finger Lakes.

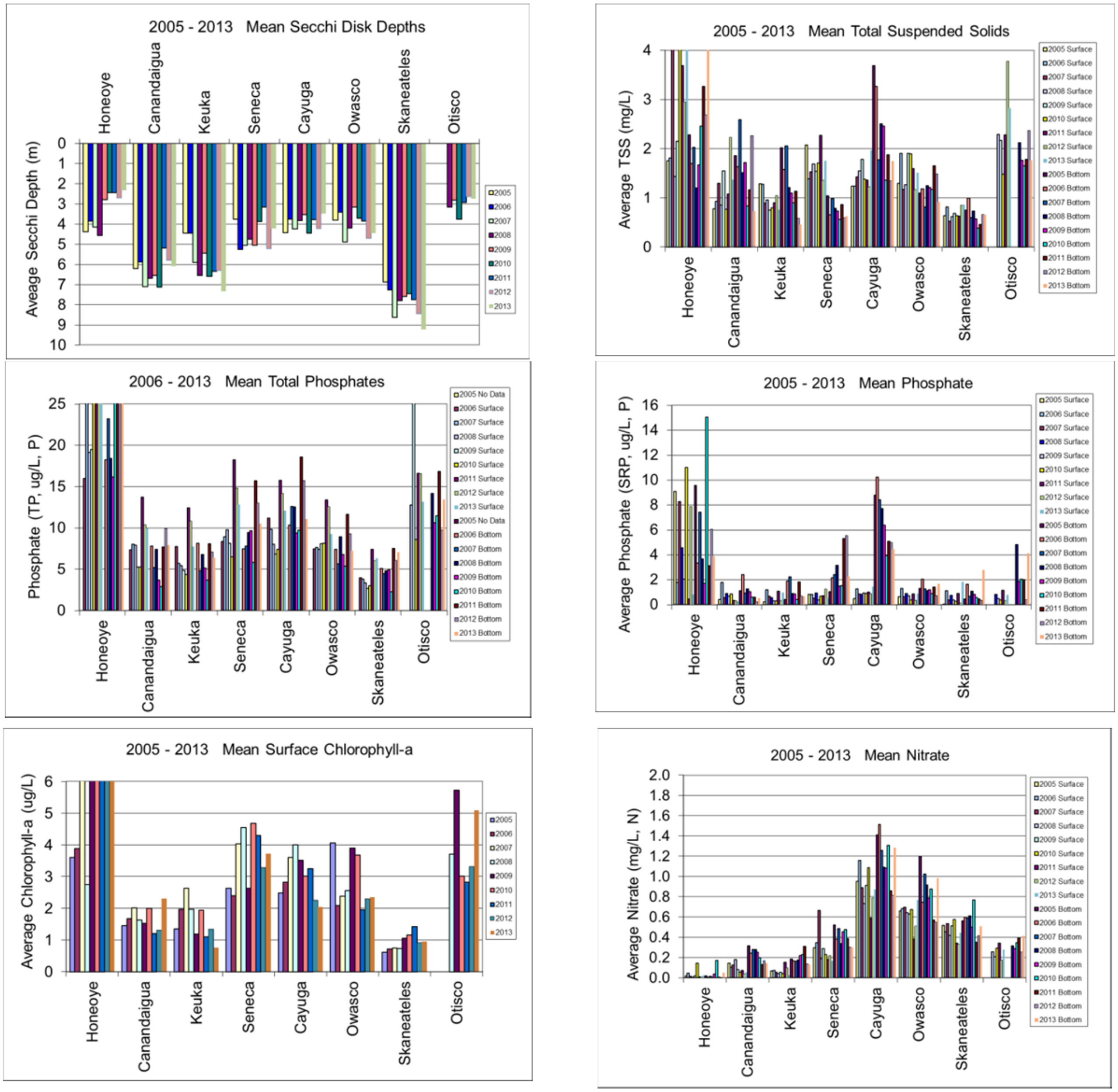


Fig. 9. Annual mean limnological data from selected Finger Lakes. The values for Owasco Lake only utilized data from the 5-month, summer-season, Finger Lakes survey.

STREAM RESULTS & DISCUSSION

Stream Discharge: Measured stream discharge in 2013 ranged from nearly dry (0.01) conditions at Fire Lane 20 during the summer to 5.0 m^3/s on Owasco Inlet at Moravia during the spring. None of the streams were completely dry. Discharge was not measured on 4/20 along the Owasco Inlet due to dangerously high flows. Instead, a discharge of 10 m^3/s was used for the Rt 38 site using the value reported by the USGS Moravia Gauge Station at the time of sample collection. Flows for sites upstream of the Owasco Inlet on 4/20 were proportionally estimated using each site's 2013 mean annual discharge.

The discharges in 2013 were in between those detected in 2011, a wet year, and 2012, a dry year (Table 6 in appendix, Figs. 10 & 11). 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 2013 (Fig. 12, $r^2 = 0.96$). The annual mean discharge of Owasco Inlet (299 km^2), Dutch Hollow Brook (77 km^2), Hemlock (47 km^2) and Mill Creeks (78 km^2) were 3.7, 0.9, 0.3 and 1.0 m^3/s, respectively (Fig. 12).

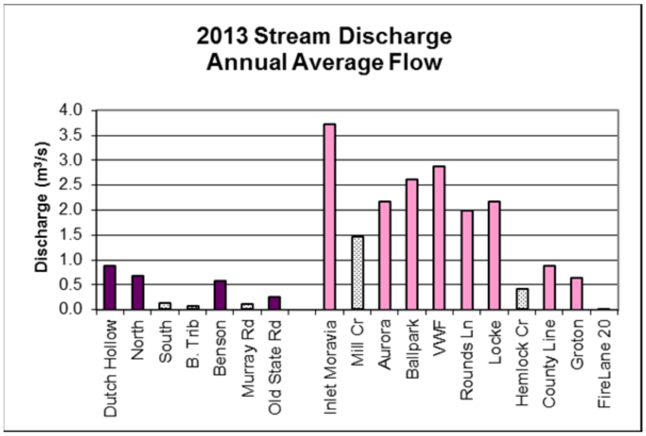


Fig. 10. 2013 annual average stream discharge at each stream site. Dutch Hollow sites are in purple, Owasco Inlet sites in pink. Firelane 20 is in blue. Tributary sites are stippled. Sites are arranged, left to right, from downstream to upstream.

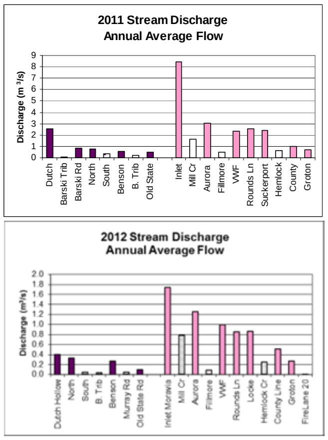


Fig. 11. 2011 (above) & 2012 (below) annual average stream discharge at each stream site.

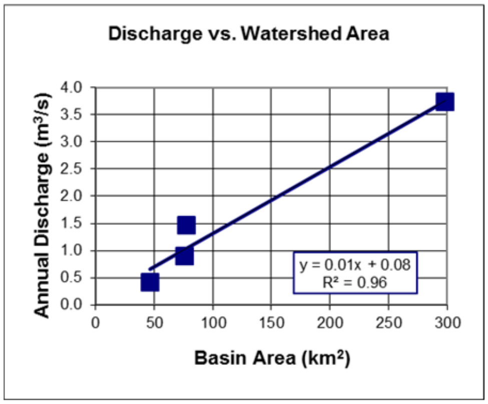


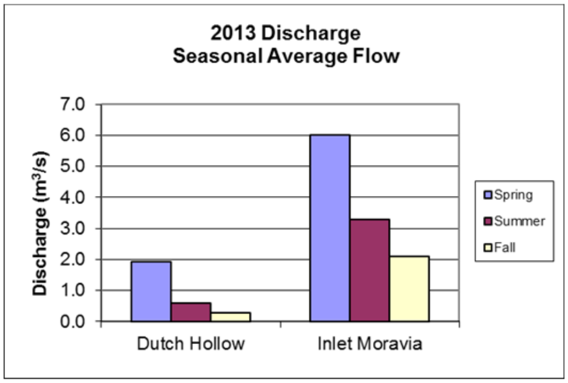
Fig. 12. 2013 Discharge vs. Basin Size.

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 discharges at South tributary, Benson tributary and Benson Rd sites was similar to the discharge at North St.

Within Owasco Inlet, tributary inputs typically accounted for the observed downstream increases in discharge as well. For example, the sum of the mean discharge at Country Line and Hemlock Creek was close to the discharge at Locke, the remaining downstream increase was perhaps supported by contributions from other smaller creeks flowing into the Inlet along this segment. 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.

The Locke through Aurora segment was a notable exception, however. The mean annual stream discharge decreased from Locke to Rounds Ln and again from VWF downstream to the Aurora site. Approximately 0.7 m^3/s of water was lost in 2013 along this stream segment, presumably to the ground. Similar water losses along this stream segment were reported in 2011 and 2012 although the exact location of the loss changed from year to year. A portion of the loss probably resulted from groundwater withdrawals at the municipal well field that supplies ~0.2 m^3/s to Moravia (Eileen O'Connor, personal communication, 2011). The remainder probably recharged the aquifer under the Owasco Flats. It suggests that this this segment of the stream intercepts unique glacial geology at the head of the Owasco Flats and is a major water source to the aquifer under the wetland.

Seasonal Variability: The largest discharges of 2013 were detected in the spring (Fig. 13). The seasonal change in flow from spring to summer paralleled the seasonal decrease in precipitation and increase in evapotranspiration (Fig. 14). However the fall mean discharge was smaller than the summer, unlike previous years. The unexpected summer to fall trend in 2013 reflected larger than normal rainfalls in the summer months.



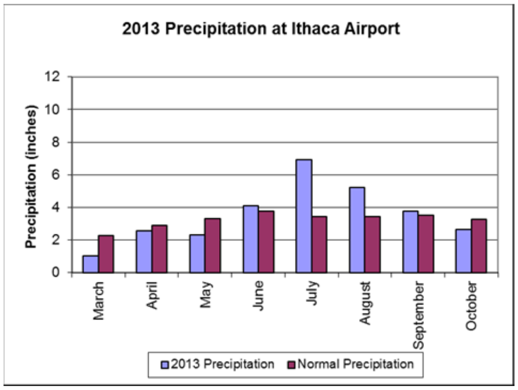


Fig. 13. Seasonal averaged stream discharge for the Rts. 38A and 38 sites, the terminal sites on Dutch Hollow Brook and Owasco Inlet, respectively.

Fig 14. Monthly 2013 and "normal" precipitation totals for the Ithaca Airport.

Differences to Earlier Years: The 2011 annual average discharge at the end of Owasco Inlet and Dutch Hollow Brook was approximately 5 times larger than those measured in 2012, but only twice as large than those measured in 2013 (Fig. 15). These differences can be explained by changes in precipitation. The 2013 precipitation total during the March through October field-season was 3.2 inches larger than normal. However, the 2013 excess was not even close to the 9.4 inch above normal field season precipitation in 2011 (a wet year). In contrast, 2012 was 3.2 inches below normal during the field season, thus a relatively dry year (Fig. 16). It designates 2013 as the "in between" year, 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.

The Owasco Inlet USGS Gauge data also revealed an in between mean annual discharge of 4.6 m^3/s in 2013 compared to 5.7 and 3.0 m^3/s in 2011 and 2012, respectively (Fig. 17). Similar annual variability was observed for the Owasco Outlet (USGS Gauge, 4235440). Mean annual outflows were 8.26, 8.40, 11.38, 8.40 and 8.26 m^3/s for 2009 through 2013, respectively. Clearly, 2013 was an "in between" and perhaps a more normal year for Owasco Lake and its watershed.

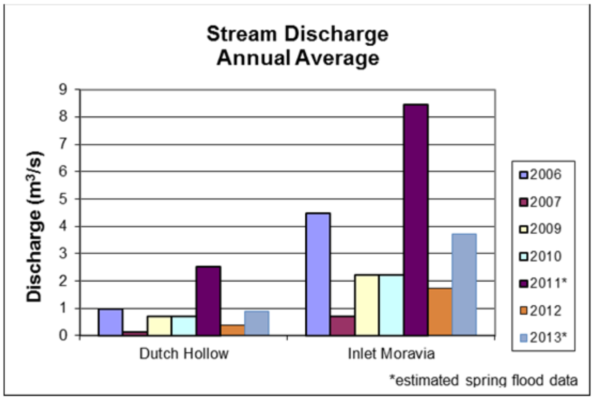


Fig. 15. Annual average stream discharge for the Rts. 38A and 38 sites. Stream data were not collected in 2008.

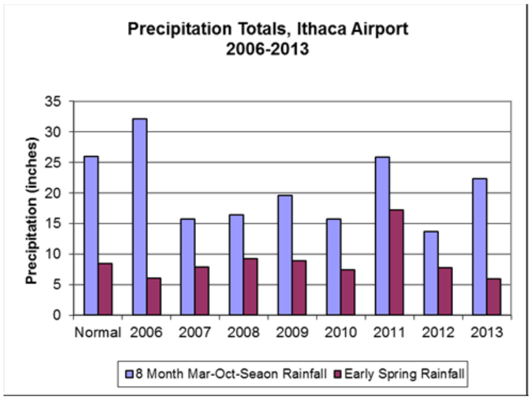


Fig. 16. Annual precipitation totals during the 8-month, March – October, field season at the Ithaca Airport.

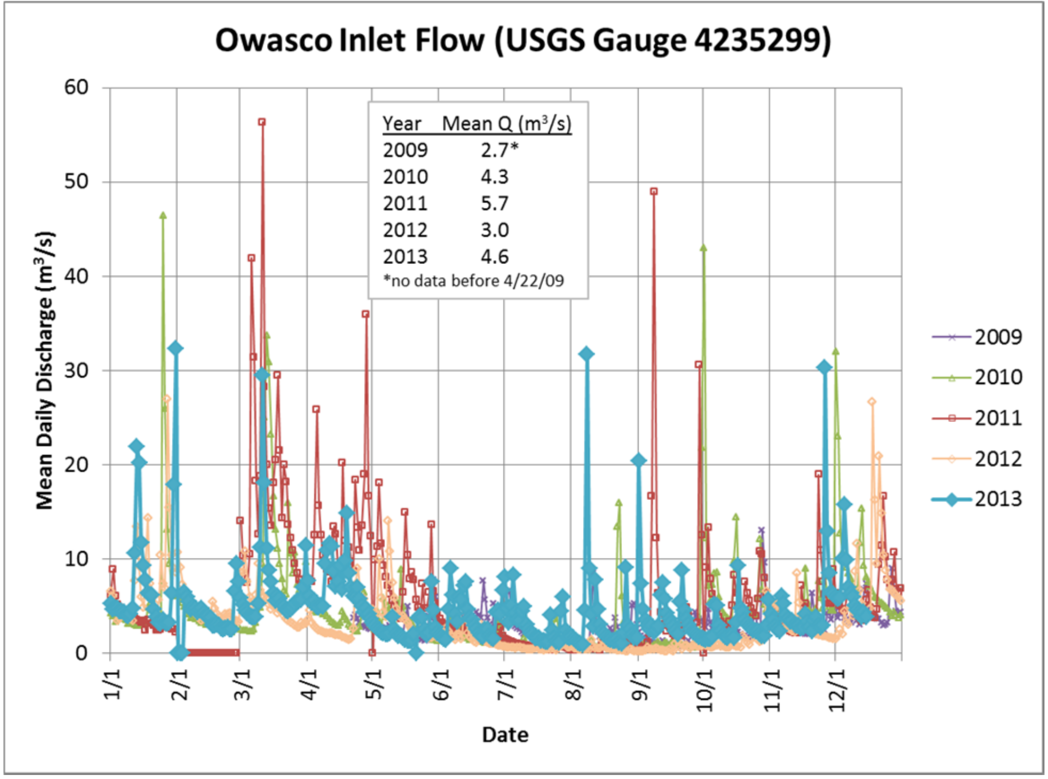


Fig. 17. Annual average stream discharge for the Owasco Inlet near Moravia – USGS Stream Gauge 4235299.

Stream Concentration Data: 2013 individual total phosphate (TP) concentrations ranged from 6 to 35 μg/L, and averaged 16 μg/L in Dutch Hollow Brook, and ranged from 4 to 35 μg/L, and averaged 19 μg/L in Owasco Inlet (Table 6 in appendix, Fig. 18). Within Dutch Hollow Brook watershed, 38A, North and Benson tributary sites revealed the largest annual mean TP concentrations of ~18 μg/L, whereas the South tributary and Old State Rd sites revealed the smallest mean TP concentrations (~13 μg/L). These differences were small in comparison to those detected in 2011. One difference was especially noteworthy. Benson tributary was only a few μg/L larger than neighboring sites in comparison to much larger increases in 2011 and earlier years, i.e., increases of 25 μg/L. Thus, it suggests that recent remediation efforts upstream of this site decreased nutrient loading from this segment of the watershed.

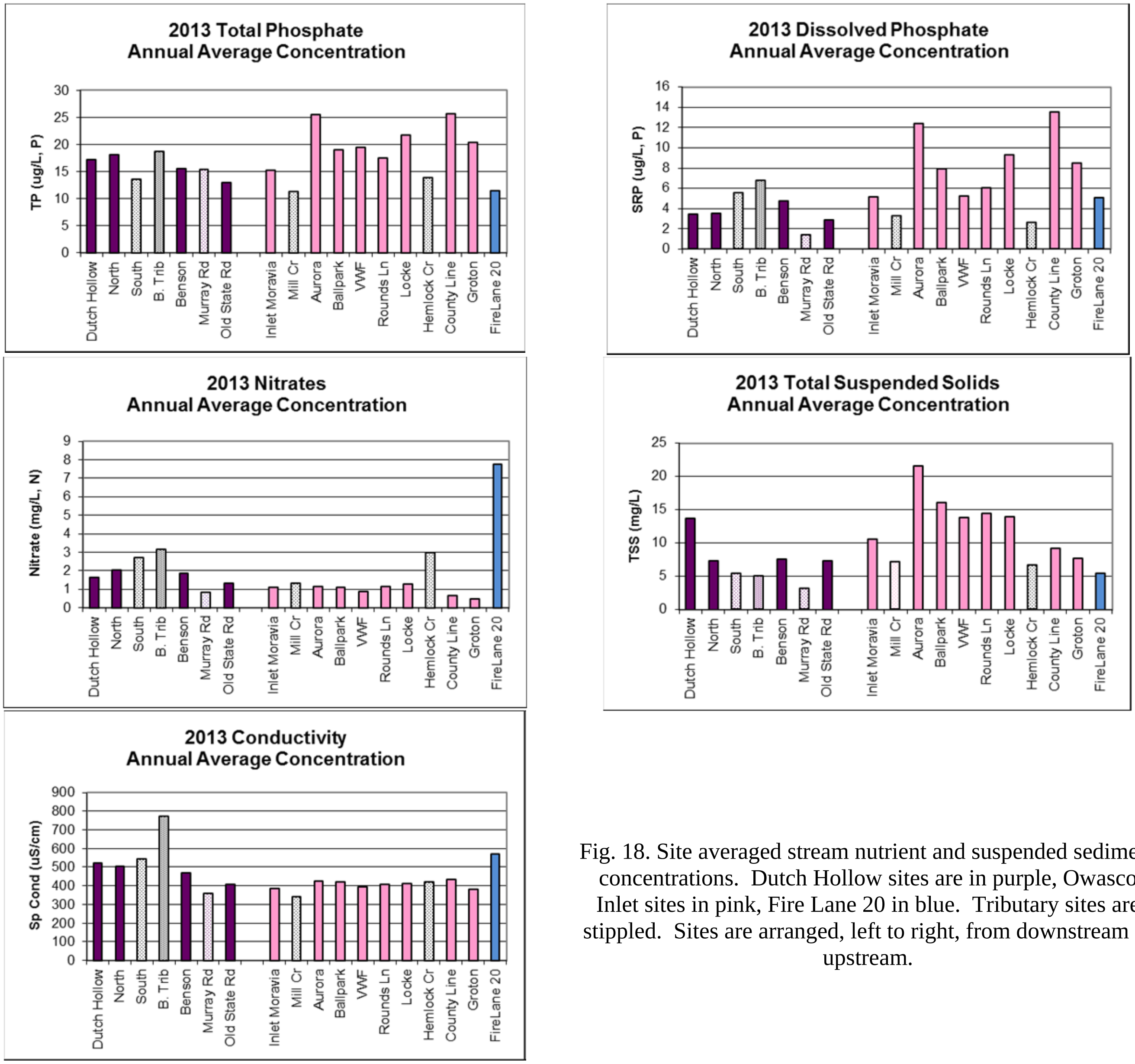


Fig. 18. Site averaged stream nutrient and suspended sediment concentrations. Dutch Hollow sites are in purple, Owasco Inlet sites in pink, Fire Lane 20 in blue. Tributary sites are stippled. Sites are arranged, left to right, from downstream to upstream.

Total suspended sediment concentrations were uniform along Dutch Hollow Brook, except for a notable increase from North St to Rt 38A, and lower concentrations at the Murray Rd. Perhaps the incised stream channel and eroded stream banks provided a source of easily eroded nutrient-free sediments between North St and 38A. The 2012 dry year and slower flows may have also deposited some of its sediment load along this segment, only to have the sediment resuspended and transported downstream in the more normal and faster flows of 2013.

Elevated dissolved phosphate (SRP), nitrate and specific conductance (salinity) concentrations were detected at Benson tributary compared to the other sites. It indicates that Benson tributary was still impacted by the larger percentage of agricultural land upstream of the site. Like the total phosphate results, however the observed impact was smaller in 2013 than previous years. It also suggests remediation efforts are working upstream of this site. The Murray Rd site revealed the smallest or near smallest dissolved and total phosphate, nitrate, suspended sediment concentrations and lowest salinities in the watershed, probably reflecting the more forested landscapes upstream of the site.

Concentrations measured at Owasco Inlet were similar to Dutch Hollow Brook. Along Owasco Inlet, mean annual TP and SRP concentrations increased from Groton to County Line, and from VWF/Ballpark to Aurora, especially late in the summer during low flow conditions. These two segments bracketed the Moravia and Groton wastewater treatment facilities, respectively. The smallest TP and SRP concentrations were detected at Mill and Hemlock Creeks (TP of 11 & 13 μg/L, respectively) and were similar to previous years. The lower concentrations in Mill contributed to the observed dilution of/decrease in TP and SRP from Aurora to Rt 38.

Mean annual total suspended sediment (TSS) and nitrate concentrations revealed different trends. TSS concentrations increased down Owasco Inlet, especially between the County Line and Locke sites and the Aurora and Ballpark sites. Perhaps stream bank erosion along the incised and poorly armored meanders between the VFW and Aurora sites and also along the County Line to Locke segment were a source of sediments. TSS then decreased farther downstream between the Aurora to Rt 38 sites, diluted by the less turbid Mill Creek. Elsewhere, TSS concentrations were smallest at the two tributaries, Mill and Hemlock Creeks. Nitrates were largest at Hemlock Creek, perhaps reflecting the agriculturally rich, and thus nitrate-rich groundwater in the watershed; the other sites revealed similar nitrate concentrations.

Fire Lane 20 was first sampled in 2012, and was sampled again in 2013. It revealed large salinities and the largest nitrate concentrations compared to any other site in the 2013 survey. TP, SRP and TSS concentrations were mid-range or relatively small. The larger nitrate concentrations are presumably due to the agricultural and manure-spreading activities upstream and the solubility of nitrate compared to phosphorus. Because similar trends were observed in 2012, it reduces the chance that these trends were due to the 2012 dry, summertime, conditions and the lack of seasonally small summer concentrations as speculated last year.

Stream Fluxes: Owasco Inlet revealed significantly larger fluxes of nutrients and sediments than Dutch Hollow Brook (TP 5.0 vs. 2.0 kg/day; SRP 1.0 vs. 0.5 kg/day; TSS 6,300 vs. 2,400 kg/day; N 300 vs. 130 kg/day, respectively, Fig. 19). The similar concentrations of nutrients and sediments combined with the significantly larger discharge down the larger Owasco Inlet resulted in its larger fluxes to the lake. Thus, fluxes in the Owasco Lake watershed are sensitive to discharge and basin size.

At the small end of the spectrum, fluxes at the Murray Rd and Fire Lane 20 sites were very small, smaller than the other sites in the survey, even though some of the largest concentrations were detected at the Fire Lane 20 site. The small fluxes paralleled the smallest discharges at both sites, augmented by the small concentrations at the Murray Rd site. It follows that smaller watersheds with smaller discharges delivered the smallest fluxes and larger watersheds with larger discharges delivered the largest fluxes, especially those streams that drain forested land cover. However, Owasco Lake has over 40 tributaries like Fire Lane 20 along its shores. If these tributaries have similar total phosphate loads as Fire Lane 20, then the total phosphate load by all these small tributaries would be 0.8 kg/day, and approximately 50% of the 2.0 kg/day load from Dutch Hollow Brook.

No one part of Dutch Hollow Brook provided significantly more nutrients than any other segment, except the segment between North St and Rt 38A (Fig. 19). 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. For example, the Benson tributary revealed the largest concentrations of phosphates. However, its relatively small flux of phosphates was due to its relatively small discharge. Thus, no 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, including agricultural land, animal feedlot operations, golf courses, suburban homes and other non-point sources of nutrients. The implications are noteworthy. 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.

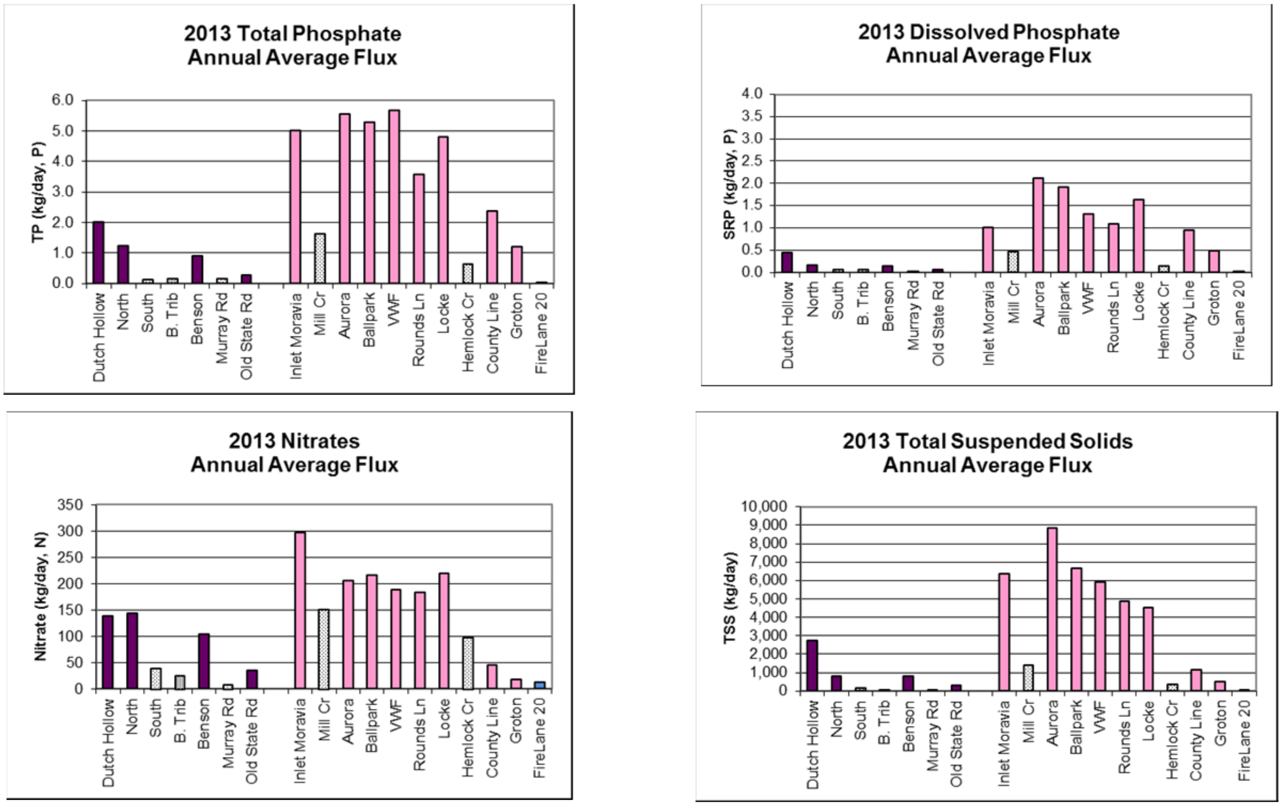


Fig. 19. Site averaged nutrient and sediment fluxes. Dutch Hollow sites are in purple, Owasco Inlet sites in pink, and tributary sites are stippled. Sites are arranged downstream to upstream.

The observed increase in phosphate and suspended sediments form North St to Rt 38A is an exception. The annual average flux of suspended sediments tripled (from 820 to 2,700 kg/day), TP and SRP nearly doubled (1.3 to 2.0 kg/day, and 0.2 to 0.45 kg/day, respectively) along this segment. In contract, nitrates were unchanged between the North St and Rt 38A sites. It suggests that stream bank erosion may have been critical in 2013, adding to agricultural inputs along this segment of stream as this North St to 38A increase was smaller or absent in 2011 and 2012. As mentioned earlier, perhaps the low flow in 2012 built up a supply of sediments and sediment-bound phosphate along this segment of the stream. A return to larger flows in 2013 then remobilized and transported these phosphate-rich sediments. The hypothesis suggests a stream bank erosion focus for future research.

In contrast, the phosphate and sediment fluxes along the Owasco Inlet increased predominately along two segments, from Groton to County Line (TP 1.0, SRP 0.5, & TSS 600 kg/day) and again from County Line to Locke (TP 1.8, SRP 0.6, & TSS by 4,000 kg/day; Fig. 19). Nitrates also increased but by a less noticeable amount. The Groton to County Line increase is attributed to the addition of the phosphate-rich effluent by the Groton wastewater treatment facility. However, the increase in phosphate was smaller than detected in previous years and indicates that remediation efforts by the Groton Facility have worked! In 2013, this segment provided less than 20% 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 accomplishments.

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 data from the recently established Ballpark site refutes this hypothesis. It appears that phosphate increased the most between the VWF and Ballpark sites and not between Ballpark and Aurora where the Moravia WWTF is located. It suggests that sediment-bound phosphates were eroded from the poorly armored, meandering stream segment upstream of the Moravia WWTF, and the facility did not noticeably impacting water quality.

The largest increase in TP, SRP and TSS along Owasco Inlet was between the Locke and County Line sites. The source is unknown at this time but perhaps could be stream bank erosion along this segment. Thus stream bank erosion provides an interesting question for future research at a number of locations in the Owasco Lake watershed.

In summary, the stream segment analyses detected non-point sources in the Dutch Hollow Brook watershed and perhaps the rejuvenation of sediment deposited in 2012 dry year along the meandering and incised North St 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 in 2013 but their contribution to the total load was significantly smaller than earlier years. The Moravia WWTF did not appear to add significant loads to the Inlet in 2013. Additional unidentified non-point sources are also important in this watershed, especially between the Locke and County Line sites. Its source may be stream bank erosion along this segment of the Inlet, and poses a question for additional study.

Seasonal and Longer-Term Variability: Nutrient fluxes were larger in the spring than in the summer but larger in the summer than the fall in 2013 (Fig. 20). It reflects the parallel change in precipitation, evapotranspiration and ground saturation. Differences to earlier years are also attributed to differences in precipitation. For example, the larger precipitation during the summer of 2013 compared to normal is consistent with the larger fluxes observed in the summer of 2013 compared to earlier years. It again indicated the importance of precipitation and stream discharge on many of these parameters.

The 2013 annual fluxes were near those reported in earlier years, and in between those in 2011 and 2012 (Fig. 21). The difference between the past three years can be attributed to differences in the amount of rainfall. It follows that 2013 was the "in between" year, 2011 was the "wet" year, and 2012 was the "dry" year. The 2006 fluxes were 2nd largest in the record, and 2006 was another wet year. Fluxes however were not always a function of precipitation. The similarity of the 2012 fluxes to some of the earlier years can be attributed to the lack of spring and fall data in the earlier years. Precipitation alone predicts proportionally larger fluxes than were measured in 2013. However, the bulk of the increase in precipitation in 2013 happened during the summer months, when evapotranspiration is larger, runoff is reduced by thicker vegetation along the stream banks, and other factors combined to decrease the 2013 fluxes.

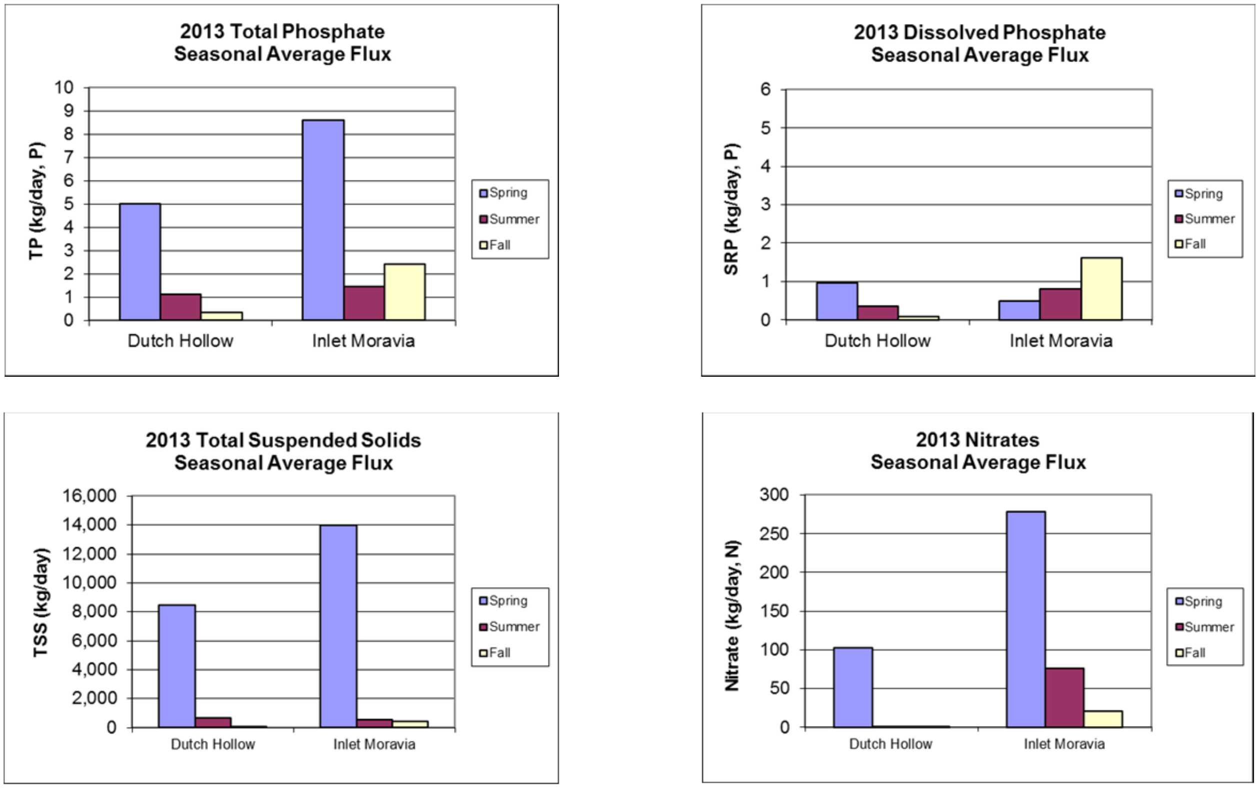


Fig. 20. Selected 2013 seasonal average concentrations (left) and fluxes (right).

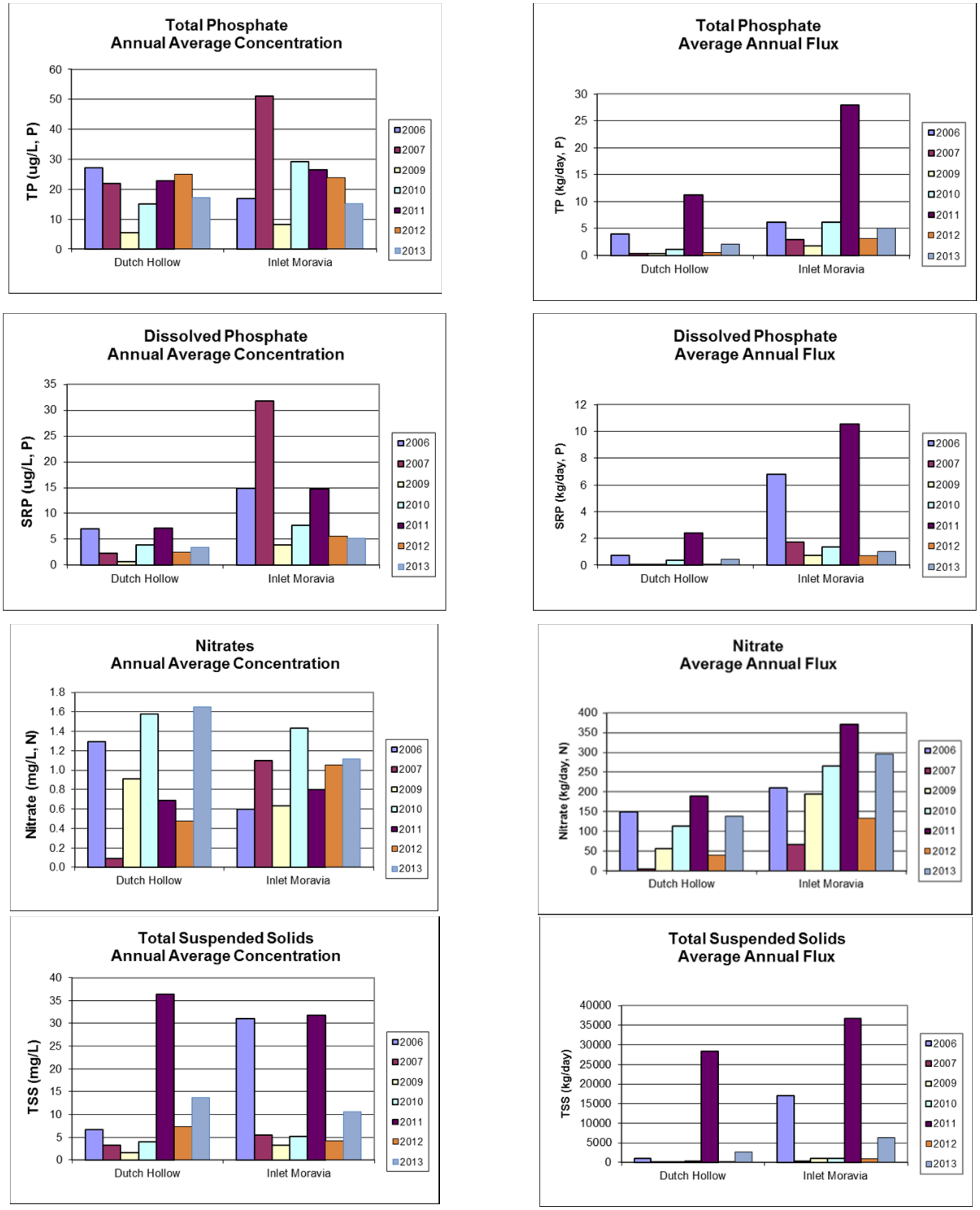


Fig. 21. Annual average concentrations (left) and fluxes (right).

EVENT SAMPLING AT DUTCH HOLLOW BROOK

Detailed Sampling of Dutch Hollow Brook: The data logger stage data revealed textbook responses to precipitation events over the past three years (Fig. 22). Stream stage rapidly increased during rainstorms and peaked just after the bulk of the rain event. Larger precipitation events induced taller and longer duration peaks in stage. Once the rain stopped and the bulk of the runoff passed, the stage slowly declined back to base flow conditions. The slow decline reflected the reduction of runoff induced flow and a slower decline in the precipitation induced near-surface groundwater flow, because surface water moves faster than groundwater. In all three years, each increase in stage through the 2011 to 2013 field seasons corresponded to a precipitation event. The increase in stage for each 2013 event was from 5 to more than 60 cm, similar to the increases observed in 2011, 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. The ground is more saturated during the spring, directing more rainfall to surface runoff than infiltration into the ground, and evapotranspiration is smaller in the early spring season.

Similar seasonal and day to day changes in stage, conductivity and temperature detected in 2013 were also detected in previous years (Figs. 23 – 26).

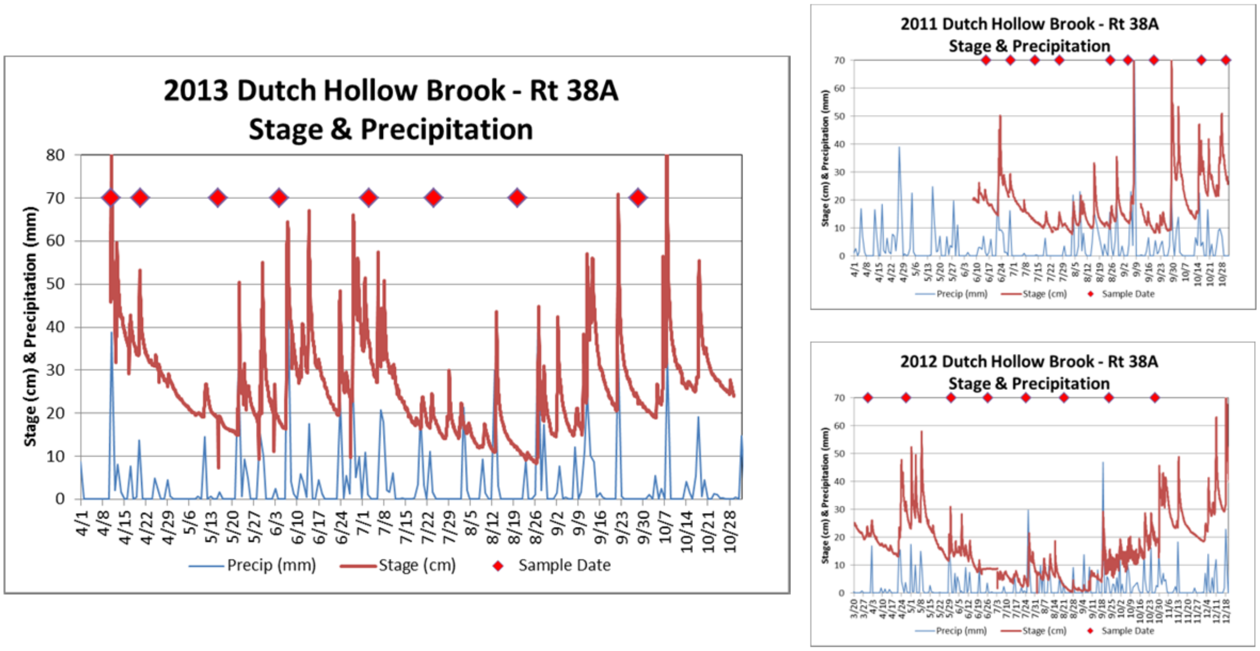


Fig. 22. Dutch Hollow Brook 2013 data logger stage, precipitation and sample dates, left; the 2011 and 2012 data, right. Precipitation data was from NY-CY-8, a station within the watershed, and part of the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS).

Detailed "Event vs Base Flow" Results: Like the previous two years, nutrients and sediments revealed significant responses to precipitation events throughout the 2013 deployment (Fig. 27). Total suspended sediments (TSS) increased dramatically from base flow concentrations of 5 to 20 mg/L to an average event flow concentration of 235 mg/L, and rose to a maximum of 1,250 mg/L during a 33 mm precipitation event on 10/7. 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 transport significantly more soil particles to and has a greater impact on water quality in the stream. The 2013 peak TSS concentrations were between those measured in 2011 and 2012, and the difference parallels the difference in rainfall between these three years.

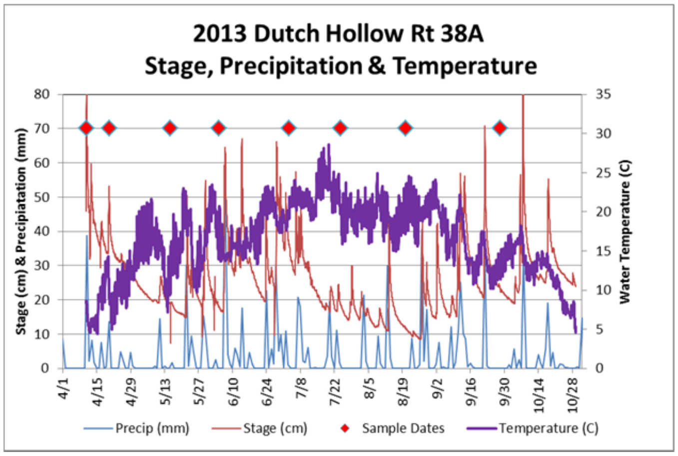


Fig. 23. Data logger water temperature data. The seasonal cold to warm to cold cycle prevails.

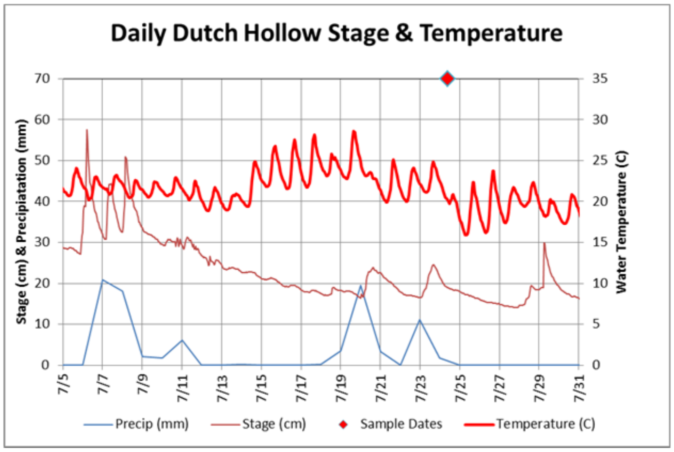


Fig. 24. Daily warm (day) to cold (night) fluctuations in water temperature.

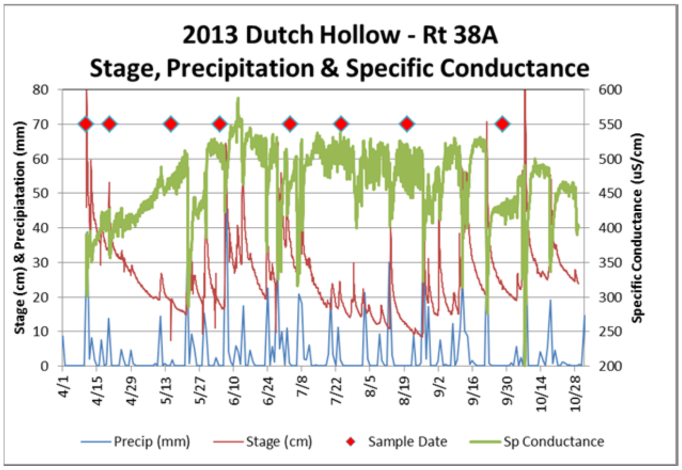


Fig. 25. Data logger salinity data. Stream salinity decreased during events, the groundwater inputs diluted by the rainfall.

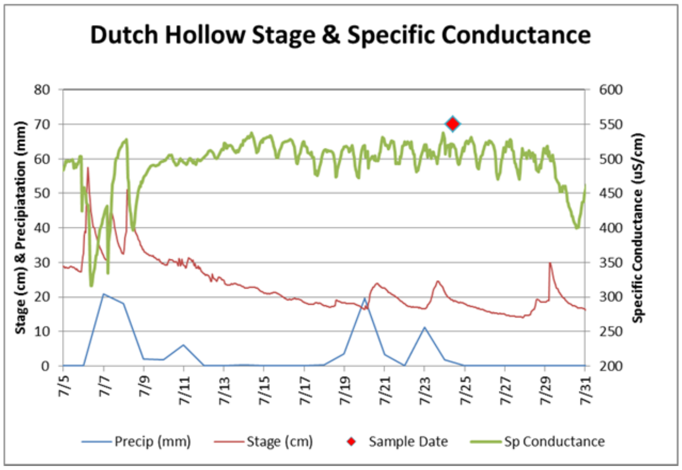


Fig. 26. Daily fluctuations in water salinity.

The event/base flow results suggest remediation practices to reduce TSS impairments. 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 season, 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 60 and 15 μg/L to events means of 125 and 35 μg/L, with maximum event concentrations near 235 μg/L for TP and 90 μg/L for SRP. The number of events and event concentrations in 2013 were in between those detected in 2011 and 2012. Again, the event loads and "in between" nature of 2013 suggest a direct linkage to and the importance of precipitation induced runoff events for phosphorus loading to the lake. Thus, the remediation steps to reduce phosphate loading would be similar to remediating suspended sediment, i.e., reduce the movement of soil particles from runoff events in the Owasco watershed.

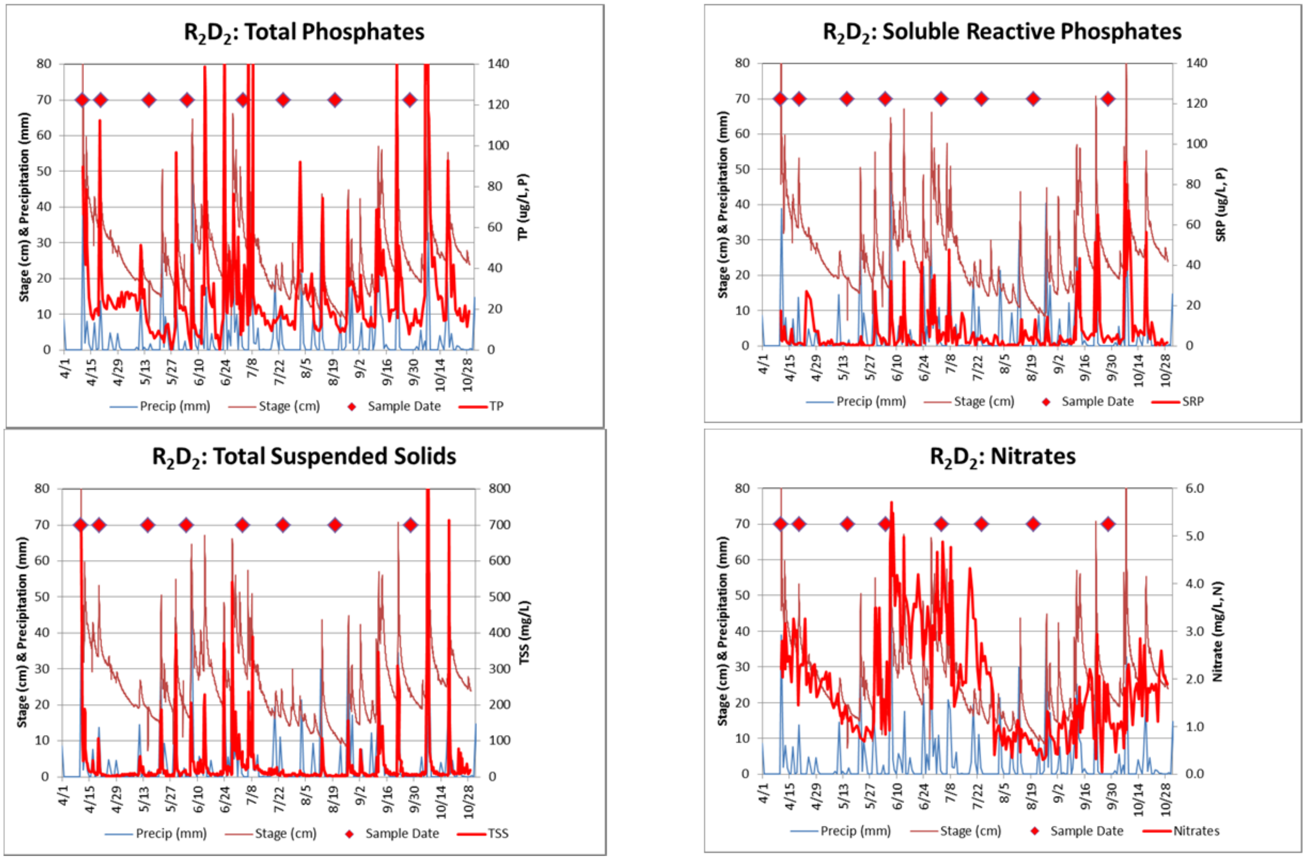


Fig. 27. Autosampler nutrient and suspended sediment concentrations.

Nitrates, once again, revealed a slightly different response to events. The largest nitrate concentrations were still stimulated by events with mean event concentrations of 7.2 and base flow concentrations of 4.9 mg/L. The event to base flow change in nitrate concentrations was however not as dramatic as 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. Nitrates are water soluble and not bound to particles, thus they can enter a stream by runoff and groundwater routes. In contrast, groundwater does not transport TP, SRP and TSS.

Event versus Base Flow Fluxes: To calculate fluxes, a discharge must be determined for each sample. This study used the best-fit linear relationship between the weekly discharge measurements and stage data at Rt 38A along Dutch Hollow Brook to estimate hourly discharge data (Fig. 28, $r^2 = 0.87$). The similarity between the estimated Dutch Hollow discharge and the USGS Owasco Inlet discharge suggests that this was a good estimate. Any differences between watersheds were attributed to differences in precipitation within each watershed.

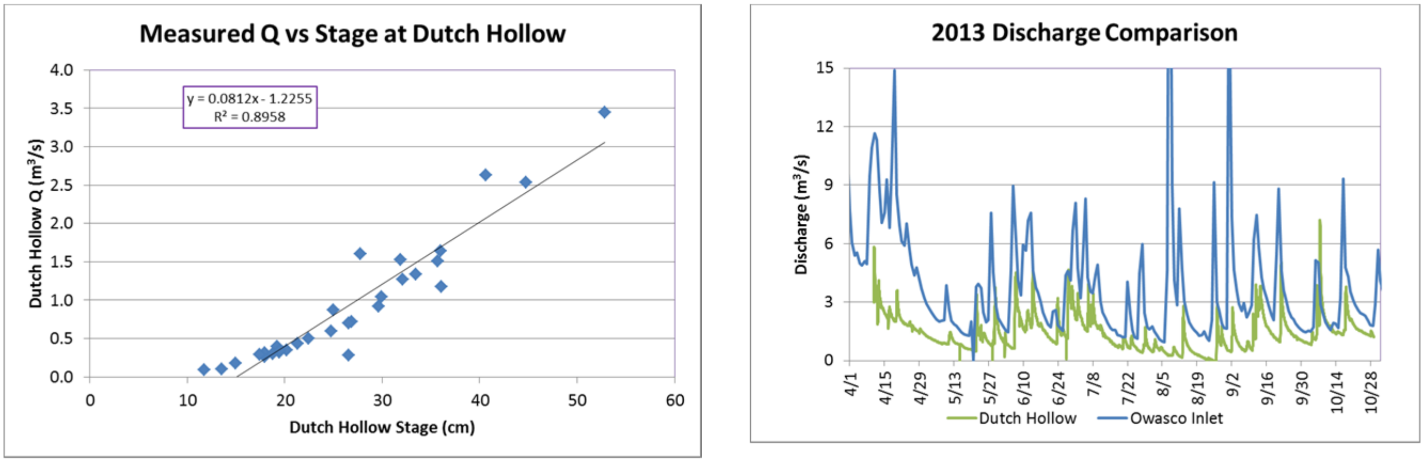


Fig. 28. Estimation of Dutch Hollow Brook 8-hour autosampler discharges from Dutch Hollow Brook stage, weekly discharge measurements, and daily USGS discharge data from Owasco Inlet (Station ID 04235299)

The fluxes of TSS, TP, SRP and nitrates were clearly event dependent over the past three years (Table 7, Fig. 29). In 2013, TSS, TP and SRP event fluxes averaged 12,000, 6.4 and 1.8 kg/day, respectively. TSS, TP and SRP base flow fluxes were much smaller, only 290, 1.3 and 0.3 kg/day, respectively. During the entire 2013 field season, Dutch Hollow provided 1,499,400 kg of sediment to the lake during events, and only 22,400 kg during base flow conditions. In a similar light, the 2013 events delivered 790 kg of TP and 230 kg of SRP to the lake compared to base flow contributions of 100 kg of TP and 25 kg of SRP over the course of the study. Annual changes were observed. The 2013 event fluxes were in between those in 2011 and 2012. The dominance of 2011 is somewhat surprising because the autosampler was deployed for three fewer months in 2011 than the following years. Rainfall ruled these fluxes.

In conclusion, all three 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 improve water quality in the lake (Table 7).

Table 7: 2011 – 2013 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%

All three years of event *versus* base flow data also clearly indicated that grab samples underestimate fluxes down a stream. For example, the 2013 autosampler estimated a mean flux of sediments of 7,550 kg/day, total phosphates 4.4 kg/day, dissolved phosphates 1.3 kg/day, and nitrates 270 kg/day; whereas the grab sampling estimated an annual mean flux of 2,725 kg/day for sediments, 2.0 kg/day for total phosphates, 0.5 kg/day for dissolved phosphates, and 140 kg/day for nitrates. Monthly grab samples yielded smaller fluxes because they were biased to base flows. Grab samples are essential and reliable tools however for stream segment analysis and the investigation of nutrient and sediment sources.

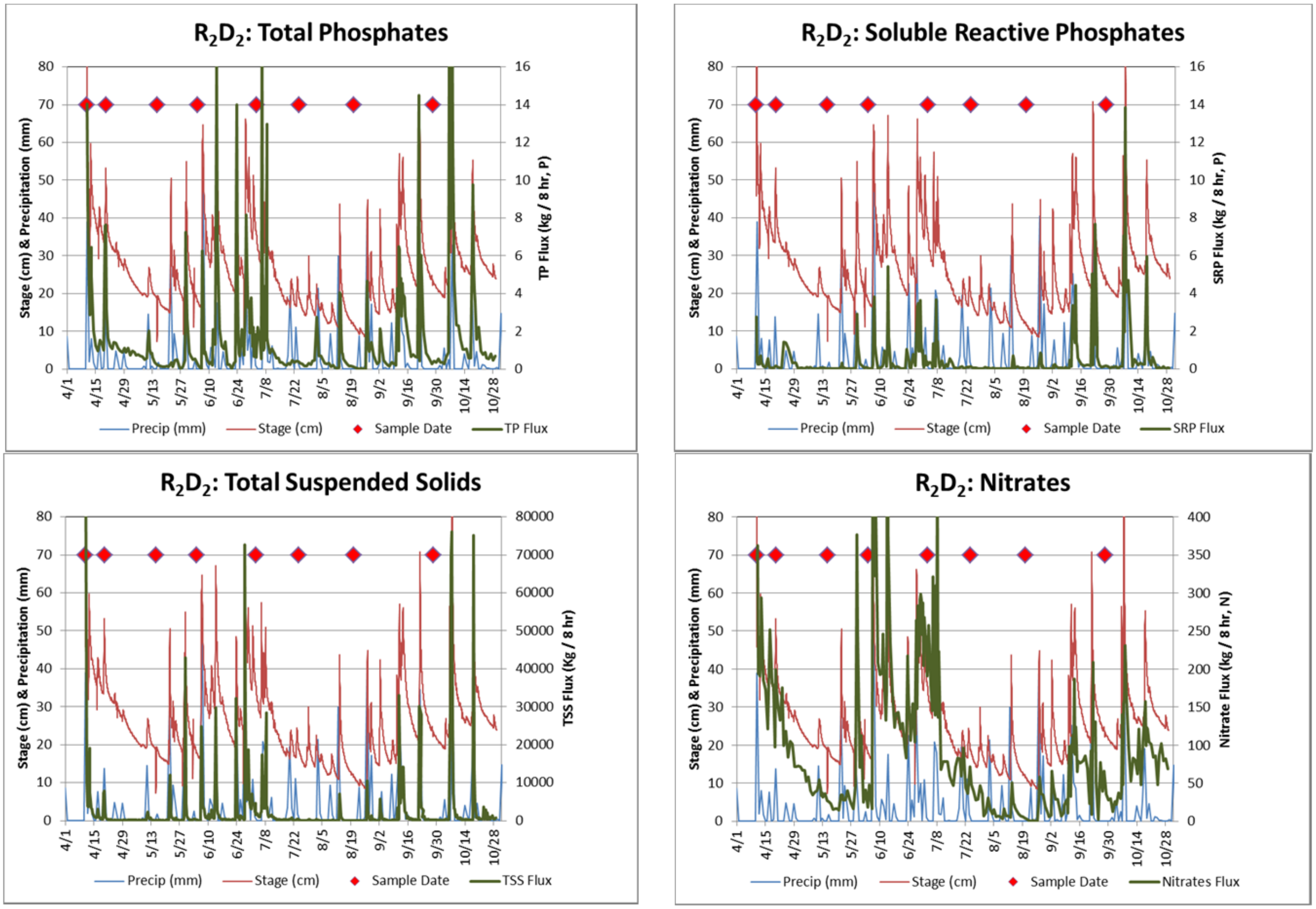


Fig. 29. Autosampler nutrient and suspended sediment fluxes.

A *MONTH-LONG* DETAILED ANALYSIS OF OWASCO INLET:

An autosampler was deployed at the Rt 38 site in Moravia for a preliminary event *versus* base flow analysis of Owasco Inlet and comparison to Dutch Hollow Brook. Both watersheds revealed discharge events during the month long deployment (Fig. 30). These events, for the most part, were time synchronous (e.g., 6/12, 6/14, 6/24, 6/28, 7/2 and 7/6). The change in discharge for each event was typically proportionally larger in the larger Owasco Inlet watershed (298 km^2 vs. 77 km^2, respectively). However, a few events were not observed in both watersheds on the same day (e.g., 6/29, 7/7, 7/9, 7/10), and the discharge was not always proportional between watersheds as well (e.g., 7/2, 7/6, 7/8). These discrepancies were most notably near the end of the one month study.

The occasional differences in the discharge event timing and magnitude can be explained, in part, by changes in precipitation in each watershed (Fig. 30). Rainfall was averaged from the CoCoRaHS sites within and near each watershed. For example, on 6/29 more rain fell over Owasco Inlet than Dutch Hollow, and an event was only observed in the Owasco Inlet. Yet, the relationship was even less clear on other days. For example, equal amounts of rain fell on 7/2 and 7/6 but yielded different stream responses. Perhaps the mean rainfall for each watershed recorded at two or three stations does not faithfully correspond to the total amount of rain in each watershed. This hypothesis was confirmed by Radar derived, 6-hour summaries of rainfall accumulations that revealed non-uniform precipitation accumulations over the entire Owasco watershed, especially during the summer when isolated or frontal lines of convective thunderstorms dominate the precipitation (Fig. 31). Thus, the occasional variability in the stream response was probably induced by the non-uniform precipitation over the entire watershed.

Finally, the total rainfall over the month long study at the CoCoRaHS sites was much larger over Dutch Hollow Brook than the Owasco Inlet watershed, over 6.5 inches compared to 3.7 inches respectively. In comparison, the monthly rainfall at the Ithaca Airport for July was 6.94 inches.

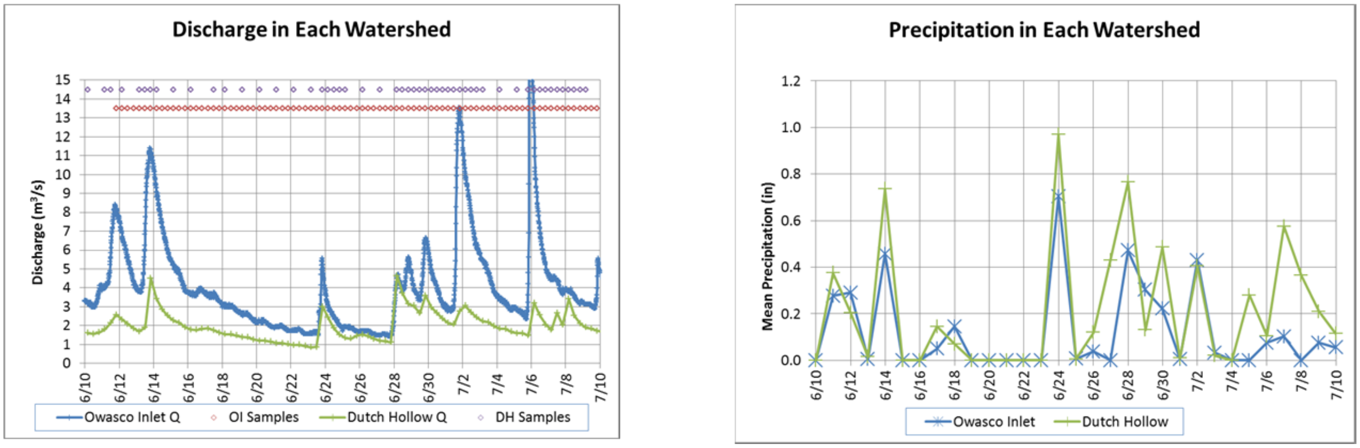


Fig. 30. Dutch Hollow Brook and Owasco Inlet discharge data, left.
Mean daily precipitation for CoCoRaHS stations within or near each watershed, right.

Owasco Inlet total suspended sediment and total phosphate concentrations revealed event signatures (Fig. 32, Table 8). Interestingly, Dutch Hollow Brook revealed larger event TSS concentrations than the Owasco Inlet, 540 mg/L compared to 380 mg/L, but smaller base flow concentrations by 10 mg/L. The largest TP event concentrations were also detected in Dutch Hollow Brook, 200 µg/L, compared to 60 µg/L in Owasco Inlet. Base flow concentrations were smaller in Dutch Hollow by a few µg/L. The differences are probably due to the larger precipitation totals and the larger percentage of agricultural land in the Dutch Hollow Brook watershed. Thus more rain running over a more erodible landscape in Dutch Hollow compared to Owasco Inlet delivered similar to larger concentrations of sediments and phosphates to the lake.

Table 8. Owasco Inlet vs Dutch Hollow Brook Detailed Study.

	Mean Discharge	Mean TSS Conc	Mean TP Conc	Mean TSS Flux	Mean TP Flux
	(m^3/s)	(mg/L)	(ug/L, P)	(tons/day)	(kg/day)
Owasco Inlet	4.12	50.5	17.3	26.02	7.7
Dutch Hollow	1.99	57.2	41.3	13.92	9.6
Comparison only from 6/11 through 7/9					

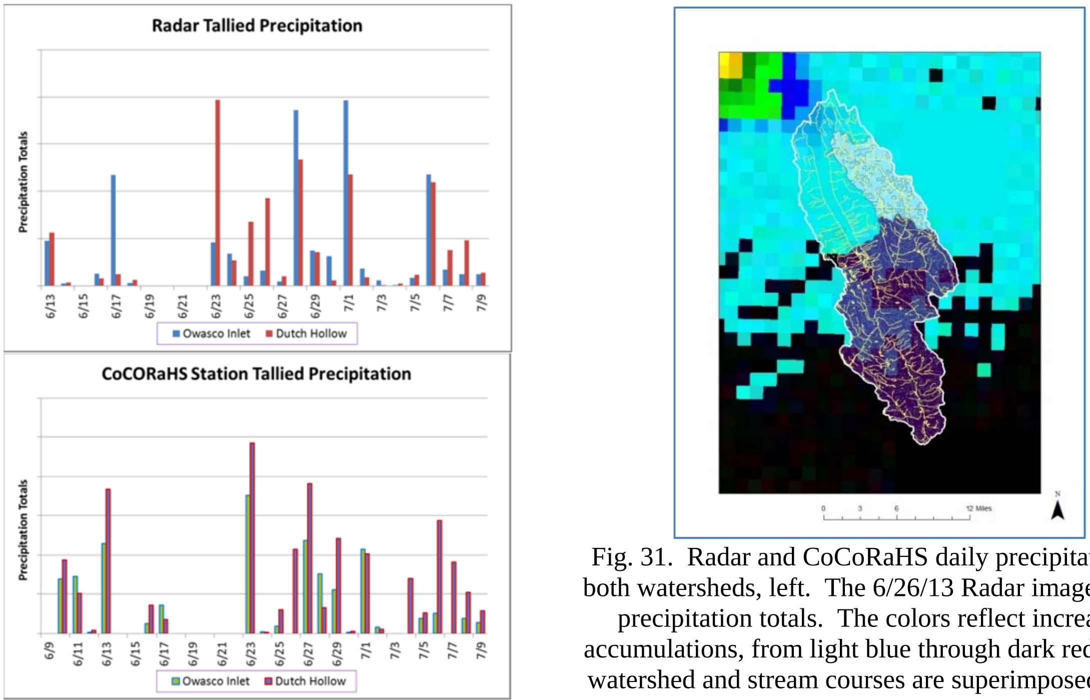
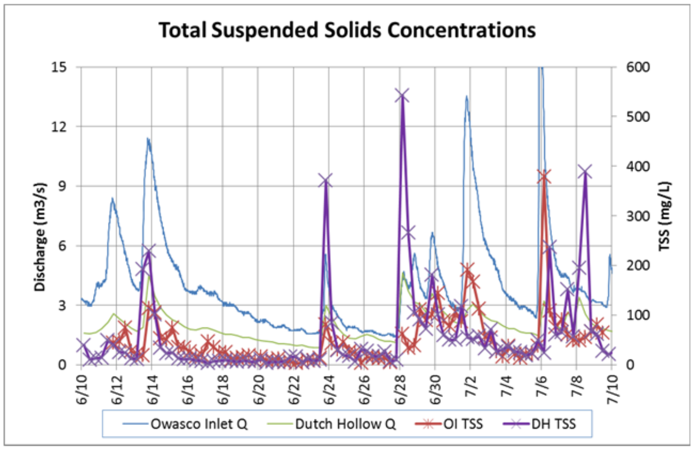
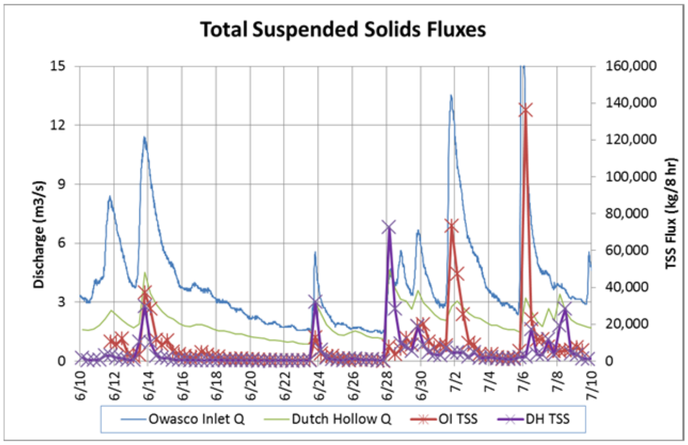


Fig. 31. Radar and CoCoRaHS daily precipitation for both watersheds, left. The 6/26/13 Radar image of 6-hr precipitation totals. The colors reflect increasing accumulations, from light blue through dark red. Lake, watershed and stream courses are superimposed on the radar image.

Owasco Inlet fluxes of suspended sediment and total phosphate also revealed event signatures (Fig. 32, Table 8). This is expected as both the concentration and discharge increased during the events compared to base flow, and fluxes equal the concentration times discharge. Neither stream consistently revealed larger individual suspended sediment event fluxes during this study. Dutch Hollow revealed larger event fluxes on, e.g., 6/24, and 6/28, and Owasco Inlet revealed larger event fluxes on, e.g., 6/14, 7/2, and 7/6. The event and mean daily fluxes of phosphates were typically larger at Dutch Hollow Brook than the Owasco Inlet as well. This is surprising because the larger Owasco Inlet watershed should consistently deliver larger fluxes. In support, total loads from each watershed indicated that the Owasco Inlet delivered much more sediment, over 26 tons/day or 729 tons of sediment over the month-long study period, compared to just under 14 tons/day or 390 tons of sediment from Dutch Hollow Brook over the month-long study period.





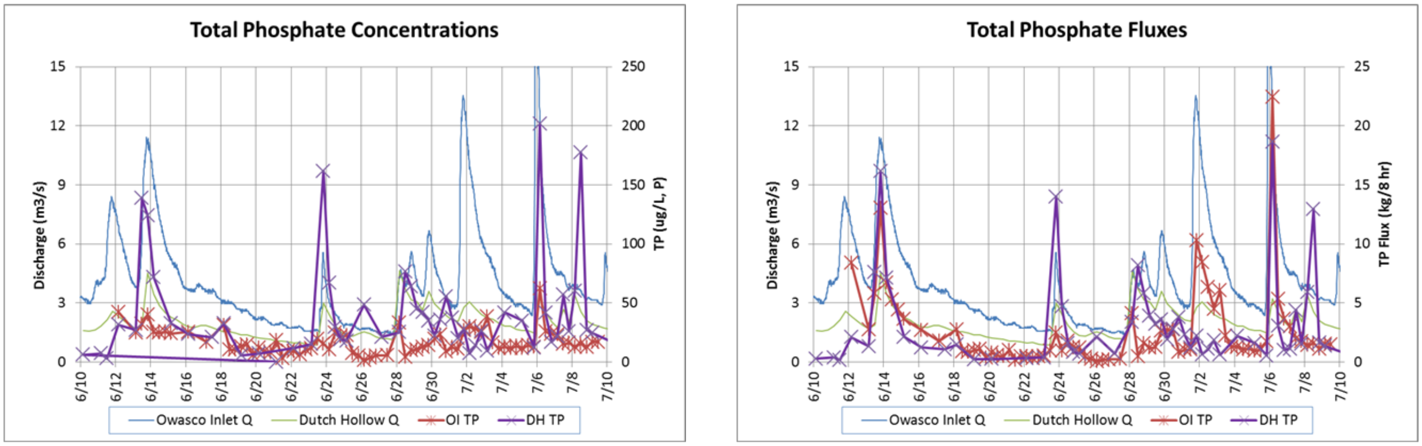


Fig. 32. Dutch Hollow Brook and Owasco Inlet suspended sediment and total phosphate concentrations data, left. Suspended sediment and total phosphate flux data, right.

.

DATA LOGGER DEPLOYMENT AT BENSON TRIBUTARY, DUTCH HOLLOW CREEK WATERSHED:

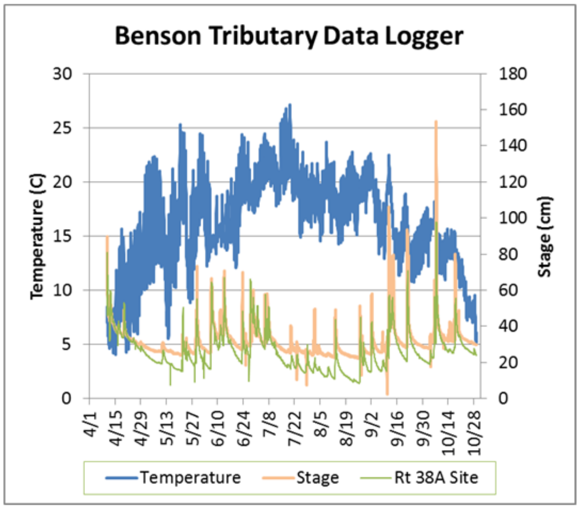


Fig. 33. Data logger stage and temperature data from the Benson tributary site along with stage data for the Rt 38A site in the Dutch Hollow Watershed.

A *In Situ* Aqua Troll 200 data logger was also deployed at the Benson Tributary site over the field season (Fig. 33). Stage data revealed well defined events. The height difference from base flow to peak flow was 10 to 20 cm larger, and duration of the event was a few hours shorter than the stage response at the downstream Rt 38A site. The differences reflected the relative size of the watershed upstream from the two data loggers. The seasonal temperature record was similar, but the day to day and week to week fluctuations were larger at the Benson tributary site. The smaller concentration of trees and other shade vegetation upstream of the Benson site probably influenced the temperature record. Finally, stream salinity decreased during precipitation events (not shown). The decrease in salinity during each event is larger at the tributary site presumably due to the higher base flow salinities which in turn reflected greater evapotranspiration at this site compared to Rt 38A.

PHOSPHATE BUDGET:

Phosphorus is 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. However, the stream inputs are only one part of the equation. A complete budget must also include potential inputs like atmospheric loading, and lakeshore lawns and septic systems. Outputs must be calculated as well to determine the net change in phosphorus in the lake (Fig. 34). The primary outputs include the outflow of phosphorus-rich materials through the Owasco Outlet and their burial into the sediments.

The net change is critical because 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 if 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), as the sustained reduction would limit algal growth, allow existing phosphorus to leave by the outlet or be buried in the sediments, and ultimately improve water clarity.

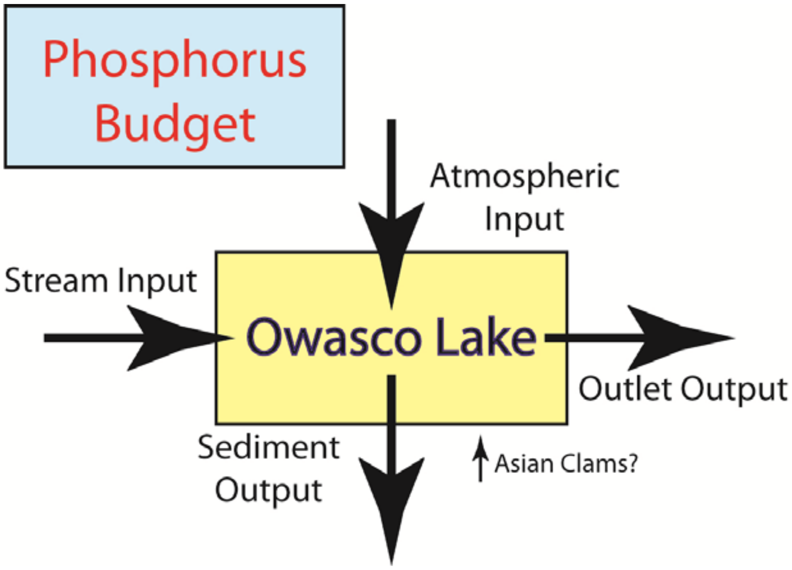


Fig. 34. The Owasco Lake phosphorus budget: Sources and sinks for phosphorus in Owasco Lake. Water quality improves if **inputs are less than outputs**, for a number of years.

The Inputs: The autosampler estimated a mean total phosphate flux of 4.4 kg/day from Dutch Hollow Brook in 2013. Owasco Inlet delivered 5.0 kg/day based on the available 2013 stream grab data. A proportional extrapolation of Dutch Hollow, Mill Creek, Hemlock and Owasco Inlet to the entire Owasco Lake watershed, using fluxes and surface areas, estimated an input of 3.1 metric tons of phosphorus in 2013. The 2013 estimate was larger than those estimated in 2007 and 2012 (1.5 metric tons) but similar to the 2006 estimate and smaller than the 2011 estimates of 5 and 15.4 metric tons, respectively. But remember, 2006 and 2011 were relatively wet years and 2007 and 2012 were dry. The 2006 and 2007 data were also artificially low because they were based on summer grab samples only. It follows that 2013 should be somewhere in between. Assuming loads were strictly proportional to rainfall, it would predict larger 2013 annual loads, loads proportionally closer to the 15 tons/year estimated in 2011. However the above normal rainfall was in the summer during 2013 when precipitation/runoff ratios are reduced and evapotranspiration is larger, and inducing smaller loads than predicted.

The 2013 estimate of 3.1 metric tons did not include event samples down the Owasco Inlet. Assuming the two-fold increase between the grab and event estimates observed at Dutch Hollow Brook, then the Owasco Inlet load should be closer to 11 kg/day. The increase in TP and TSS loads from the summer grabs to the one month event study at Owasco Inlet revealed much larger differences. Events supplied 4.4 and 25 times more TP and TSS than the grab samples. Assuming only the two-fold increase, streams may have added 7.2 tons (or more) of phosphorus to the lake in 2013. 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 2013 estimated influx of phosphorus was 3.1 metric tons/year assuming the grab sample data and is 8.4 metric tons/year assuming the estimated event loads.

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 3.1 metric tons of phosphorus was lost out the Outlet in 2013 assuming an 2013 annual mean total phosphate concentration in the lake of 11.4 μg/L, and a 2013 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 2013 estimated efflux was 5.9 metric tons/year.

The Net Flux: Owasco Lake either lost approximately 2.8 metric tons of phosphorus assuming grab sample data or gained approximately 3.5 metric tons of phosphorus assuming the event loads in 2013. If the 2013 budget was a loss and it persists for a number of years, water quality in the lake should improve over time. However, the net flux was probably near zero or a net gain to the lake, and indicates that more must be accomplished to reduce phosphorus loading to the lake in a more normal, “in between” years like 2013.

In conclusion, a phosphorus mass balance is difficult to estimate because some of the inputs and outputs are tenuous at this time. The largest uncertainties were in the sediment efflux and the septic system estimates. The available 2013 data however suggest that phosphorus inputs were similar to or slightly larger than outputs. The estimates would be more precise if both Dutch Hollow Brook and Owasco Inlet had event/base flow analyses through the year.

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 data indicate that the wastewater treatment facilities are doing a good job at nutrient abatement, and now it is time to focus on nutrient reduction from agricultural and other non-point sources. However the financial burden to install these remediation practices cannot be dumped on the farmer. Water quality is a watershed-wide issue. Everyone benefits from a cleaner lake. Thus everyone should help support the remediation effort. The data also indicate if the reductions occur over a number of years, the net flux of phosphorus is negative thus out of the lake, and water quality will improve.

CONCLUSIONS & RECOMMENDATIONS:

This report confirms and expands on earlier findings.

- As previously observed, Owasco Lake is a borderline oligotrophic – mesotrophic lake. Small improvements in water quality are evident since 2011.
- The monthly monitoring program misses week-long algal blooms and other events in the lake. It suggests that daily monitoring tool, like a water quality buoy, is in order for Owasco Lake. A buoy would also provide daily information on the abundance of blue green algae.
- Segment analysis highlights the importance of non-point sources throughout the Dutch Hollow Brook watershed, and both point and non-point sources in Owasco Inlet watershed.
- It revealed significant reductions in the Groton wastewater treatment facility point source from near 90% to 20% of the total Owasco Inlet load, and no impact by the Moravia WWTF in 2013.
- The source of the nutrients and sediments from the County Line to Locke segment in the Owasco Inlet and from the North St to Rt 38A segment in the Dutch Hollow watershed is unclear at this time and should be investigated in the future.
- The event *versus* base flow analysis at Dutch Hollow Brook highlighted the dominance of events and runoff of non-point sources on the delivery of phosphates and sediments to the lake. It also provided more accurate load estimates than monthly or bi-weekly grab samples, especially those limited to the summer months. Loads and differences between event and base flow loads in 2013 were in between those estimated in 2011 and 2012, and consistent with the change in rainfall between these three years.
- Event signatures were also observed in the preliminary, month-long investigation at the Owasco Inlet. The fluxes of phosphates and sediments were similar or smaller than those down Dutch Hollow. This result was surprising and perhaps skewed by twice as much rainfall during the month-long deployment and more agricultural land in the Dutch Hollow watershed.
- The 2013 phosphate budget for Owasco Lake indicate that the inputs were nearly the same or slightly larger than outputs. The 2013 estimate was in between the positive balance in 2011 and the negative balance in 2012, and consistent with precipitation totals between these three years.
- Streams were the primary source of nutrients and sediments to the lake in all three years of the detailed study, even in the 2012 “dry” year. More should be done to reduce the fluvial nutrient and sediment loads.
- BMPs should be installed, where necessary, to reduce nutrient and sediment loading from agriculturally-rich watersheds, while at the same time monitoring downstream of BMPs and other remediation projects to assess their effectiveness. The critical areas to install BMPs are the low lying and other wetter areas of each field.
- The financial burden to install the BMPs 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.

ACKNOWLEDGEMENTS

The 2013 research was supported by Cayuga County Legislature. 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, former Cayuga County Council Chair Steven Cuddeback, Bill Graney, Mike Didio, Gary Searing, Ed Wagner, Eileen O-Connor, Bruce Natale, Steve Lynch, Anthony DeCaro, Katie Jakaub, Charlie Green, Ron Podolak, Judy Wright, Doug Kierst, Marion Balyszak, Lisa Cleckner, Todd Walter and David Eckhardt. Hopefully, I didn't forget to acknowledge someone, and my apologies to those I omitted.

Table 2. 2013 Lake Data.

2013 Owasco Lake Site Averaged and Date Averaged Data

Site Averaged Surface Water Data

Site	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
1	5.4	1.6	12.2	1.4	0.6	817.8	2.2
2	5.3	1.2	10.6	0.8	0.8	845.2	1.7
Average	**5.4**	**1.4**	**11.4**	**1.1**	**0.7**	**831.5**	**2.0**

Site Averaged Bottom Water Data

Site	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
1	---	1.1	11.3	1.6	0.9	1251.2	0.8
2	---	1.1	10.3	1.5	0.8	1417.1	0.6
Average	**---**	**1.1**	**10.8**	**1.6**	**0.9**	**1334.2**	**0.7**

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)
4/14/13	6.9	1.5	8.4	3.5	0.6	1212.1	1.8
5/5/13	7.8	1.5	22.2	0.3	0.8	1141.8	0.8
5/28/13	4.8	1.5	8.8	0.4	0.6	1054.1	1.5
6/25/13	4.3	2.3	6.9	1.3	1.1	1050.3	1.5
7/23/13	3.7	1.6	8.1	1.7	1.0	319.6	1.6
8/16/13	4.4	1.1	10.5	0.9	0.8	519.5	1.7
10/1/13	5.2	1.1	12.3	0.2	0.3	720.5	5.5
10/21/13	6.0	0.8	14.0	0.3	0.4	634.4	1.3
Average	**5.4**	**1.4**	**11.4**	**1.1**	**0.7**	**831.5**	**2.0**

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)
4/14/13	---	1.7	10.8	1.6	0.9	1334.2	0.7
5/5/13	---	1.7	8.5	3.1	0.7	1261.8	1.5
5/28/13	---	1.4	26.1	0.5	0.9	1177.4	1.1
6/25/13	---	0.6	7.7	1.2	0.7	899.0	0.7
7/23/13	---	1.0	4.7	4.1	1.1	1353.6	0.3
8/16/13	---	0.8	5.3	1.4	1.2	1408.5	0.9
10/1/13	---	0.9	5.9	1.2	1.0	1492.4	0.5
10/21/13	---	0.9	12.6	0.5	0.9	1660.9	0.1
Average	**---**	**1.1**	**10.2**	**1.7**	**0.9**	**1323.5**	**0.7**

Table 4. Annual Average Plankton Data from 2005 through 2013, and Daily Average Data for 2013.

Plankton Group	Diatoms						Dinoflagellates			Rotifers			Zooplankton	Blue Greens	
Plankton Name	Fragillaria %	Tabellaria %	Asterionella %	Melosira %	Synedra %	Rhizoselenia %	Dinobryon %	Ceratium %	Coalcium %	Keratella %	Polyarthra %	Vorticella %	Cladoceran %	Anabaena %	Mycrocystis %
2005 Average	34.9	1.4	9.9	0.2	5.6		14.6	4.5		2.5	3.2	10.3	2.8		0.3
2006 Average	24.3	1.7	7.1	1.4	0.7	2.6	41.5	0.7		2.4	0.8	0.3	0.6	0.1	3.8
2007 Average	30.0	0.5	23.3	0.2	2.1	3.8	12.9	0.7		0.6	0.4	3.8	2.8	0.4	7.7
2008 Average	52.3	0.1	14.6	0.2	0.1	1.2	18.7	0.6	0.2	0.3	0.9	4.3	0.6	0.4	1.5
2009 Average	9.7	7.1	12.3	0.2	1.0	7.8	26.6	0.7	2.0	3.6	0.7	4.3	2.1	3.4	4.8
2010 Average	36.8	0.5	19.1	0.2	1.4	0.7	4.6	0.0	2.6	3.3	0.7	3.2	5.6	0.1	6.1
2011 Average	26.0	14.1	15.0	0.4	1.4	15.0	5.3	0.5	1.8	2.8	1.0	3.9	2.0	0.2	2.6
2012 Average	27.0	25.5	10.9	13.0	2.2	1.1	8.1	0.3	0.2	0.3	1.5	0.9	0.6	0.3	0.8
4/14/13	13.1	38.3		50.0						0.5	0.6		0.2		1.2
5/5/13	19.2	33.4	0.6	53.1						0.0	0.3	0.3	0.3		
5/28/13	10.3	33.8		0.4			0.3			0.3					
6/25/13	14.5	24.8	1.0	0.0				0.4		0.1	0.7		0.1		
7/23/13	6.0	28.0	4.6	0.2		1.1	35.6			0.3	1.1		0.1		
8/16/13	40.8	32.3	2.7	0.5			0.3		0.2	1.0	6.2		2.6		
10/1/13	71.2	2.5	18.3	0.1	0.1		4.2	0.3	0.3		0.4	0.5	0.8		0.4
10/21/13	41.0	11.1	38.4	0.1	4.3		0.2	0.1	0.1	0.2		1.8	0.3	0.3	
2013 Average	27.0	25.5	10.9	13.0	2.2	1.1	8.1	0.3	0.2	0.3	1.5	0.9	0.6	0.3	0.8

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

Table 5: Annual Average 2013 Lake Data from the Finger Lake Survey.

2013 Average Values (± 1σ)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	2.3 ± 1.2	6.1 ± 2.2	7.3 ± 0.9	4.2 ± 1.1	3.5 ± 0.7	4.5 ± 0.5	9.2 ± 3.1	2.7 ± 0.9
Total Suspended Solids (mg/L), Surface	5.5 ± 4.0	1.4 ± 1.1	0.8 ± 0.3	1.8 ± 0.5	2.0 ± 0.5	1.5 ± 0.6	0.9 ± 0.3	2.8 ± 1.2
Total Suspended Solids (mg/L), Bottom	4.3 ± 2.3	0.7 ± 0.5	0.5 ± 0.4	0.6 ± 0.4	1.7 ± 1.7	0.9 ± 0.3	0.7 ± 0.4	1.8 ± 0.7
Dissolved Phosphate (µg/L, SRP), Surface	0.8 ± 0.8	0.3 ± 0.2	1.0 ± 1.6	0.5 ± 0.9	1.4 ± 1.3	0.9 ± 0.7	1.8 ± 3.6	0.8 ± 0.5
Dissolved Phosphate (µg/L, SRP), Bottom	3.9 ± 4.2	0.5 ± 0.3	0.7 ± 0.9	2.3 ± 2.2	4.4 ± 5.1	1.7 ± 1.4	2.8 ± 4.2	4.1 ± 5.8
Total Phosphate (µg/L, TP), Surface	32.4 ± 23.8	9.9 ± 4.4	7.7 ± 4.4	12.8 ± 4.2	12.1 ± 3.1	9.3 ± 2.8	6.4 ± 4.5	13.2 ± 7.0
Total Phosphate (µg/L, TP), Bottom	33.3 ± 17.8	7.9 ± 5.8	6.4 ± 4.1	10.5 ± 5.9	11.1 ± 4.4	7.3 ± 3.2	7.1 ± 4.1	13.5 ± 9.8
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.9 ± 0.3	0.8 ± 0.4	0.4 ± 0.1	0.3 ± 0.1
Nitrate as N (mg/L), Bottom	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	1.3 ± 0.2	1.0 ± 0.2	0.5 ± 0.1	0.4 ± 0.2
Silica (SR µg/L), Surface	1106 ± 707	747 ± 256	583 ± 124	232 ± 87	390 ± 179	733 ± 308	478 ± 57	345 ± 208
Silica (SR µg/L), Bottom	1200 ± 791	1242 ± 191	1017 ± 191	394 ± 135	879 ± 150	1363 ± 294	725 ± 90	919 ± 487
Chlorphyll a (µg/L), Surface	21.7 ± 24.0	2.3 ± 1.8	0.8 ± 0.6	3.7 ± 3.1	2.0 ± 1.8	2.3 ± 2.0	0.9 ± 0.9	5.1 ± 2.6
Chlorphyll a (µg/L), Bottom	11.3 ± 7.6	0.6 ± 0.4	0.7 ± 0.6	1.5 ± 1.4	0.4 ± 0.1	0.5 ± 0.3	0.3 ± 0.1	1.3 ± 1.0
2013 Ranking	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	8.0	4.2	2.9	6.1	6.8	5.8	1.0	7.6
Phosphate (µg/L, SRP), Surface	3.5	1.0	4.2	2.2	6.3	3.9	8.0	3.3
Total Phosphate (µg/L, TP), Surface	8.0	2.0	1.4	2.7	2.5	1.8	1.0	2.8
Nitrate as N (mg/L), Surface	1.0	1.3	1.0	2.2	8.0	7.1	4.5	3.1
Total Suspended Sediments (mg/L), Surface	8.0	1.9	1.0	2.5	2.8	2.1	1.1	4.1
Chlorphyll a (µg/L), Surface	8.0	1.5	1.0	2.0	1.4	1.5	1.1	2.4
Mean Ranking	6.1	2.0	1.9	2.9	4.7	3.7	2.8	3.9
Normalized to 8	8.0	1.1	1.0	2.7	5.6	4.0	2.4	4.3

Table 6. 2013 Stream Data.

Date & Location	Discharge	Specific Conductance	Water Temp	Nitrate	Suspended Solids	Total Phosphate	Phosphate SRP
	(m^3/s)	(µS/cm)	(^{o}C)	(mg/L, N)	(mg/L)	(µg/L, TP as P)	(µg/L, SRP as P)
4/20/2013*							
Dutch Hollow 38A	3.4	418	8.2	1.1	56.2	32.6	6.4
Dutch Hollow North St	2.2	400	7.6	1.8	20.6	22.9	1.3
Dutch Hollow South Trib	0.6	465	7.5	3.5	18.4	11.0	3.3
Dutch Hollow Youngs	0.2	686	7.9	3.6	13.6	26.4	8.6
Dutch Hollow Benson Rd	2.1	394	7.4	1.9	24.3	22.2	1.4
Dutch Hollow Murray Rd	0.4	206	6.9	0.6	5.5	14.9	1.0
Dutch Hollow Old State Rd	0.9	232	7.1	1.5	22.5	12.8	1.3
Owasco Inlet 38 Moravia	10.0	276	8.3	1.2	47.8	27.3	1.0
Owasco Inlet Mill Cr	3.9	232	8.4	1.0	20.5	14.5	2.4
Owasco Inlet Aurora St	5.9	286	9.2	1.0	107.7	34.3	4.5
Owasco Inlet Ball Park	7.0	na	na	0.8	53.5	23.6	4.6
Oweasco Inlet VWF	7.7	312	8.7	0.7	40.9	22.8	3.3
Owasco Inley Rounds Lane	5.3	319	8.7	0.9	58.5	23.5	2.4
Owasco Inlet Locke	5.9	317	8.3	1.1	40.4	23.1	1.7
Owasco Inlet Hemlock	1.1	327	8.4	1.7	17.7	27.3	3.1
Owasco Inlet County Line	2.4	339	9.2	0.7	25.0	38.6	5.2
Owasco Inlet Groton	1.7	292	9.1	0.2	10.6	22.2	3.2
Firelane 20	na	598	8.0	5.9	10.0	10.6	1.5
5/15/2013							
Dutch Hollow 38A	0.4	535	9.7	1.0	5.5	10.0	0.6
Dutch Hollow North St	0.3	510	9.4	1.5	1.7	6.2	0.5
Dutch Hollow South Trib	0.0	543	8.5	2.0	1.1	7.8	6.9
Dutch Hollow Youngs	0.0	757	8.9	2.9	2.3	10.0	4.7
Dutch Hollow Benson Rd	0.2	486	9.0	1.2	2.2	7.6	2.8
Dutch Hollow Murray Rd	0.0	291	8.7	1.3	1.7	6.0	0.5
Dutch Hollow Old State Rd	0.1	463	9.7	1.1	2.8	7.6	0.7
Owasco Inlet 38 Moravia	2.0	417	10.4	1.1	3.7	12.8	3.5
Owasco Inlet Mill Cr	0.7	331	10.8	1.3	7.8	4.1	0.9
Owasco Inlet Aurora St	1.5	437	11.1	0.9	3.9	13.5	3.2
Owasco Inlet Ball Park	1.4	417	11.5	1.7	3.0	6.9	2.7
Oweasco Inlet VWF	1.2	412	11.7	0.9	3.9	7.8	0.7
Owasco Inley Rounds Lane	1.2	427	12.8	1.6	5.3	12.1	1.3
Owasco Inlet Locke	1.1	432	13.3	1.6	3.1	10.7	2.9
Owasco Inlet Hemlock	0.3	414	14.0	3.0	1.6	9.0	1.0
Owasco Inlet County Line	0.3	471	13.7	0.9	4.4	18.9	8.0
Owasco Inlet Groton	0.2	403	14.0	0.8	4.7	9.7	3.2
Firelane 20	0.0	591	12.2	6.2	1.0	7.1	1.8
6/4/2013							
Dutch Hollow 38A	0.3	553	14.7	1.3	1.7	12.5	1.6
Dutch Hollow North St	0.3	523	14.7	1.4	2.9	21.0	3.1
Dutch Hollow South Trib	0.0	549	13.3	2.0	0.4	14.6	7.6
Dutch Hollow Youngs	0.0	779	16.4	1.2	4.7	17.9	1.1
Dutch Hollow Benson Rd	0.2	473	15.3	3.5	1.8	18.7	8.0
Dutch Hollow Murray Rd	0.0	288	14.7	0.4	0.8	6.6	1.4
Dutch Hollow Old State Rd	0.1	457	14.4	0.8	1.5	27.2	1.1
Owasco Inlet 38 Moravia	1.6	409	16.1	1.3	2.1	18.7	3.2
Owasco Inlet Mill Cr	1.0	376	14.7	1.3	-2.7	12.5	1.1
Owasco Inlet Aurora St	0.9	459	16.0	1.3	6.7	22.0	9.7
Owasco Inlet Ball Park	1.1	425	17.8	1.2	2.5	21.8	5.8
Oweasco Inlet VWF	0.9	440	17.5	1.2	7.3	16.2	7.4
Owasco Inley Rounds Lane	0.9	436	19.0	1.2	4.2	14.7	6.4
Owasco Inlet Locke	0.8	441	18.5	1.6	5.3	20.6	7.3
Owasco Inlet Hemlock	0.2	422	18.6	3.2	1.4	12.5	1.4
Owasco Inlet County Line	0.3	499	19.4	0.8	8.6	27.1	23.5
Owasco Inlet Groton	0.1	397	19.6	0.4	10.5	22.2	12.6
Firelane 20	0.0	605	14.2	3.5	3.0	16.1	9.3
7/3/2013							
Dutch Hollow 38A	1.2	513	19.9	4.5	16.7	26.3	9.2
Dutch Hollow North St	1.2	486	19.6	4.4	14.3	26.4	5.5
Dutch Hollow South Trib	0.1	530	19.4	5.3	7.5	16.2	10.1
Dutch Hollow Youngs	0.1	741	21.0	5.2	3.7	23.3	10.2
Dutch Hollow Benson Rd	0.9	418	17.6	3.0	15.4	13.9	3.9
Dutch Hollow Murray Rd	0.2	224	21.4	1.8	7.0	23.8	2.2
Dutch Hollow Old State Rd	0.3	418	19.5	2.9	15.0	15.3	2.8
Owasco Inlet 38 Moravia	5.0	390	20.2				
Owasco Inlet Mill Cr	2.1	302	19.7	1.2	8.4	15.1	5.6
Owasco Inlet Aurora St	2.4	380	21.2	1.1	25.6	34.1	21.2
Owasco Inlet Ball Park	3.8	380	22.4	0.7	29.2	44.2	18.6
Oweasco Inlet VWF	3.5	389	21.9	0.8	24.3	46.3	12.4
Owasco Inley Rounds Lane	2.4	331	22.8	1.2	25.8	39.1	21.2
Owasco Inlet Locke	3.0	391	23.5	0.9	27.3	42.8	14.6
Owasco Inlet Hemlock	0.5	411	22.7	3.8	5.3	16.0	7.6
Owasco Inlet County Line	1.2	381	24.1	0.2	19.0	42.8	28.4
Owasco Inlet Groton	0.8	321	23.6	0.1	8.8	38.1	15.8
Firelane 20	0.1	603	20.5	9.4	8.3	14.3	4.8

Table 6. 2013 Stream Data (continued)

7/24/2013							
Dutch Hollow 38A	0.3	540	20.0	1.8	12.3	13.6	2.6
Dutch Hollow North St	0.2	534	19.5	2.9	2.7	18.0	11.5
Dutch Hollow South Trib	0.0	565	17.9	2.1	1.7	15.0	1.1
Dutch Hollow Youngs	0.1	804	17.9	5.2	4.8	35.4	9.3
Dutch Hollow Benson Rd	0.2	490	18.8	1.7	4.0	12.8	13.0
Dutch Hollow Murray Rd	0.0	318	17.2	0.7	3.0	28.0	1.1
Dutch Hollow Old State Rd	0.1	468	18.1	1.6	3.0	11.6	3.1
Owasco Inlet 38 Moravia	3.2	389	18.9	1.1	4.6	6.2	7.0
Owasco Inlet Mill Cr	0.7	360	17.6	2.1	10.7	11.9	2.0
Owasco Inlet Aurora St	2.1	397	19.2	1.1	2.3	40.5	25.4
Owasco Inlet Ball Park	2.0	388	19.4	1.4	16.8	12.3	13.0
Oweasco Inlet VWF	3.6	332	19.4	0.3	16.9	14.6	3.9
Owasco Inley Rounds Lane	1.6	404	20.1	1.1	2.6	4.8	5.0
Owasco Inlet Locke	2.2	408	19.9	1.3	15.6	31.3	24.0
Owasco Inlet Hemlock	0.2	469	17.9	3.4	18.7	11.3	2.2
Owasco Inlet County Line	0.7	395	20.4	0.4	3.0	13.8	14.0
Owasco Inlet Groton	1.0	341	20.7	0.3	14.5	16.0	16.9
Firelane 20	0.0	574	16.9	11.7	3.3	16.8	4.8
8/20/2013							
Dutch Hollow 38A	0.1	517	19.7	0.4	1.7	11.0	0.0
Dutch Hollow North St	0.1	521	19.6	0.8	6.7	20.0	2.0
Dutch Hollow South Trib	0.0	584	18.4	1.3	7.6	20.7	3.1
Dutch Hollow Youngs	0.0	832	20.3	3.5	4.0	6.8	6.8
Dutch Hollow Benson Rd	0.1	513	19.7	0.6	4.8	22.8	1.7
Dutch Hollow Murray Rd	0.0	387	19.7	0.3	0.9	13.1	2.0
Dutch Hollow Old State Rd	0.0	514	20.6	0.5	4.3	7.1	1.3
Owasco Inlet 38 Moravia	1.8	442	9.7	0.8	3.5	11.8	2.0
Owasco Inlet Mill Cr	0.4	359	19.7	1.2	1.7	8.8	1.7
Owasco Inlet Aurora St	1.2	464	19.9	1.0	3.5	14.3	8.3
Owasco Inlet Ball Park	1.5	444	20.5	1.0	4.8	12.1	2.1
Oweasco Inlet VWF	1.5	444	21.1	1.0	2.5	12.8	1.5
Owasco Inley Rounds Lane	1.0	445	21.7	0.8	3.1	16.2	0.9
Owasco Inlet Locke	1.0	444	20.6	1.0	3.7	9.0	3.1
Owasco Inlet Hemlock	0.2	437	20.8	2.4	1.5	13.1	0.0
Owasco Inlet County Line	0.8	476	20.9	0.9	3.2	19.2	5.1
Owasco Inlet Groton	0.4	415	20.3	0.9	2.6	14.1	1.3
Firelane 20	0.0	583	18.6	10.6	6.8	5.0	4.7
9/28/2013							
Dutch Hollow 38A	0.5	571	12.4	1.5	2.2	14.2	3.8
Dutch Hollow North St	0.5	554	12.4	1.5	2.3	11.6	0.8
Dutch Hollow South Trib	0.1	576	12.4	2.9	1.3	10.2	6.3
Dutch Hollow Youngs	0.0	799	14.2	0.3	1.8	11.1	6.5
Dutch Hollow Benson Rd	0.5	513	12.3	1.2	0.7	10.7	2.3
Dutch Hollow Murray Rd	0.0	304	12.6	1.2	3.0	16.9	8.1
Dutch Hollow Old State Rd	0.3	482	13.3	0.8	2.6	9.3	10.0
Owasco Inlet 38 Moravia	2.4	420	13.9	1.2	1.6	14.7	14.1
Owasco Inlet Mill Cr	1.3	549	13.7	1.0	1.1	12.2	9.1
Owasco Inlet Aurora St	1.2	465	14.1	1.6	1.7	19.8	14.5
Owasco Inlet Ball Park	1.4	441	14.3	1.0	2.4	12.2	8.3
Oweasco Inlet VWF	1.7	491	14.8	1.2	1.2	15.6	7.3
Owasco Inley Rounds Lane	1.4	461	15.2	1.2	1.6	11.8	5.1
Owasco Inlet Locke	1.2	461	15.1	1.5	2.2	14.2	11.5
Owasco Inlet Hemlock	0.4	479	15.9	3.1	0.5	7.4	3.2
Owasco Inlet County Line	0.5	494	15.4	0.8	1.7	19.3	10.6
Owasco Inlet Groton	0.3	427	14.5	0.6	2.0	20.2	6.2
Firelane 20	0.0	613	14.0	7.1	6.1	10.2	8.5
2013 Annual Averages							
Date & Location	**Discharge**	**Specific Conductance**	**Water Temp**	**Nitrate**	**Suspended Solids**	**Total Phosphate**	**Phosphate SRP**
	(m^3/s)	(µS/cm)	(^oC)	(mg/L, N)	(mg/L)	(µg/L, TP as P)	(µg/L, SRP as P)
Dutch Hollow 38A	0.9	521.0	14.9	1.7	13.8	17.2	3.5
Dutch Hollow North St	0.7	504.0	14.7	2.0	7.3	18.0	3.5
Dutch Hollow South Trib	0.1	544.6	13.9	2.7	5.4	13.6	5.5
Dutch Hollow Youngs	0.1	771.1	15.2	3.1	5.0	18.7	6.8
Dutch Hollow Benson Rd	0.6	469.6	14.3	1.9	7.6	15.5	4.7
Dutch Hollow Murray Rd	0.1	288.3	14.5	0.9	3.1	15.6	2.3
Dutch Hollow Old State Rd	0.3	433.4	14.7	1.3	7.4	13.0	2.9
Owasco Inlet 38 Moravia	3.7	391.9	13.9	1.1	10.6	15.3	5.1
Owasco Inlet Mill Cr	1.5	358.4	14.9	1.3	6.8	11.3	3.3
Owasco Inlet Aurora St	2.2	412.6	15.8	1.2	21.6	25.5	12.4
Owasco Inlet Ball Park	2.6	415.8	17.7	1.1	16.0	19.0	7.9
Oweasco Inlet VWF	2.9	402.9	16.4	0.9	13.9	19.4	5.2
Owasco Inley Rounds Lane	2.0	403.3	17.2	1.1	14.4	17.5	6.0
Owasco Inlet Locke	2.2	413.4	17.0	1.3	13.9	21.7	9.3
Owasco Inlet Hemlock	0.4	422.7	16.9	3.0	6.7	13.8	2.6
Owasco Inlet County Line	0.9	436.4	17.6	0.6	9.3	25.7	13.5
Owasco Inlet Groton	0.6	370.9	17.4	0.5	7.7	20.4	8.5
Firelane 20	0.0	595.3	14.9	7.8	5.5	11.4	5.1

*Discharge was not measured on 4/20 along Owasco Inlet due to high flows. Instead they were proportionally estimated from the USGS station at Moravia.