THE 2022 WATER QUALITY MONITORING REPORT, OWASCO LAKE, NY.

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INTRODUCTION

Since the initial Finger Lake Institute (FLI) water quality survey of the eastern Finger Lakes in 2005, Owasco Lake and its watershed has been the focus of ongoing water quality research due to the lake's poor water quality in comparison to neighboring Finger Lakes. The resulting decade+ monitoring program of Owasco Lake and its watershed was designed to:

1. Document spatial and temporal trends in pertinent water quality;
2. Investigate the source and magnitude of nutrients in the watershed, as their inputs promote algal growth and thus degrade water quality;
3. Investigate linkages between the water quality data and the recent rise in cyanobacteria blooms and their associated toxins; and,
4. Promote the development of comprehensive and effective watershed management policies to improve water quality in Owasco Lake.

This decade^{+} effort was supported by numerous sponsors including: the Fred L. Emerson Foundation, Auburn, NY, New York State funds secured by New York State Senator Michael Nozzolio, the Owasco Watershed Lake Association (OWLA), the Town of Fleming, Cayuga County Soil and Water Conservation District, the Finger Lakes – Lake Ontario Watershed Protection Alliance and most notably the Cayuga County Legislature. Additional funds to hire summer research students came from the Provost's Office and the Finger Lakes Institute at Hobart & William Smith Colleges. Thank you all for your support.

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

- The trophic status (productivity level) of Owasco Lake fluctuates above and below the oligotrophic (good water quality) – mesotrophic (intermediate water quality) boundary.
- Phosphorus is the limiting nutrient in Owasco Lake, based on open lake, dissolved nutrient (soluble reactive phosphate and nitrate) concentrations in the lake. Additional inputs of phosphorus stimulate additional algal growth and degrades water quality.
- The lake has experienced late-summer / early fall blooms of cyanobacteria (blue-green algae, BGA). Cyanobacteria are a concern due to their affiliation with impaired / eutrophic (poor water quality) water bodies, their ability to form unsightly, surface water, algal scums. More importantly, some species of cyanobacteria may produce toxins (Harmful Algal Blooms, HABs) that have health implications for humans and other warm-blooded organisms.
- Nutrient and sediment sources include point sources like wastewater treatment facilities and onsite wastewater (septic) systems, and, more significantly, nonpoint sources like

animal and crop farms, lawn fertilizers, soil erosion, stream bank erosion, roadside ditches, drainage tiles, and construction activities.

- Phosphorus loads to the Owasco Inlet from the Moravia Municipal Wastewater Treatment Facility effluent are regulated, and limited to slightly less than 1 kg/day.
- Phosphorus loads to the Owasco Inlet from the Groton Municipal Wastewater Treatment Facility effluent significantly decreased to under 1 kg/day after a 2007 DEC mandated reduction in its effluent phosphorus load.
- Updated regulations to improve water quality and agricultural best management practices in the watershed were recently summarized in the revised Owasco Lake Watershed Rules and Regulations undertaken by the Owasco Lake Watershed Management Council on behalf of the City of Auburn and the Town of Owasco; a collaborative effort by numerous state, county and local groups and other stakeholders within the watershed. (Owasco-Watershed-Rules-and-Regulations)
- Cayuga County Planning and numerous partners completed the State approved EPA Nine Key Elements Plan (9E Plan) for Owasco Lake/Watershed. The Owasco Lake Watershed Management Council will begin the oversight of its implementation. (Owasco 9E Plan)
- Streams and tributaries are the primary source of nutrients and sediments to the lake, especially during "wet" years but also "dry" years.
- Daily nutrient and sediment loads measured near the terminus of Dutch Hollow Brook revealed that over 90% of the loads are delivered during precipitation/runoff events.
- The large nutrient and sediment inputs during 2011, 2014, and 2015 were coincident with and probably "triggered" the onset of the recent cyanobacteria blooms[1]. Even though coincidence does not prove causation, these excessive loads were unique over the past decade and coincident with the first bloom sightings. The huge rainfall events in 2021 preceded a larger number of blooms around the lake the following week.
- Since 2011, estimated annual phosphorus budgets for Owasco Lake initially revealed larger inputs than outputs. A continued net accumulation of phosphorus in the lake, i.e., when nutrient inputs exceed outputs, degrades water clarity and water quality. Since 2016, the balance has turned and estimated inputs have become similar or smaller than outputs through 2020. Despite these reductions in inputs, water quality has not significantly improved in the lake. This balance was reversed in 2021, the last year phosphorus budgets were estimated. The 2021 inputs, that supplied ~50% of the fluvial inputs, were approximately twice the outputs due to a single, very intense, rain event.
- Phosphorus load reductions must radically intensify to significantly improve water quality in Owasco Lake. This effort must span a minimum of five water retention times, i.e., approximately a decade or two, for the lake to naturally cleanse itself of excess phosphorus and improve water quality. Phosphorus stored within the sediments will take longer to flush out.

This report presents the 2022 monitoring results within the Owasco Lake watershed, including water quality analyses of the lake and selected tributaries.

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

Halfman, J.D., 2017. Decade-scale water quality variability in the eastern Finger Lakes, New York. Clear Waters. Fall 2017, v. 47, No. 3, pg. 20-32. http://nywea.org/clearwaters/uploads/Decade-ScaleWater7.pdf

METHODS

A few differences are noteworthy for the 2022 monitoring program from past surveys. Halfman collected and analyzed the lake samples. The Owasco Watershed Lake Association volunteers collected the stream samples and had them analyzed by a commercial laboratory. Halfman also monitored similar water quality parameters in Seneca Lake, but not neighboring Finger Lakes.

Owasco Lake: The lake monitoring program sampled Sites 1 and 2 nineteen times in 2022, weekly from late May through the end of September (Table 1, Fig. 1). These two sites have been sampled since the initial 2005 survey, and were representative of the open water limnology in previous surveys of multiple offshore sites along the length of Owasco Lake.

The lake field methods were similar to the earlier monitoring efforts. A CTD profile, Secchi disk depth, vertical plankton tow (integrate upper 15 m, 80-μm mesh), and surface and bottom water samples were collected at each site. The CTD electronically measures 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 total chlorophyll, 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 cast, and downcast profiles were utilized in these reports. The plankton collected by each tow were preserved in a lugol's (iodine) solution, and enumerated, typically to species level, by Barbara Halfman back in the laboratory under a microscope.

Lake samples were analyzed onsite for temperature (°C), conductivity (specific conductance, μS/cm), dissolved oxygen (mg/L, O_2) and alkalinity (mg/L, $CaCO_3$) using hand-held probes and field titration kits, and aliquots were analyzed back in Halfman's laboratory for total phosphate (TP, μg/L, P), soluble reactive phosphate (SRP, μg/L, P), nitrate/nitrite (NO_x, mg/L, N), chlorophyll-a (μg/L) and total suspended solid (TSS, mg/L) concentrations. Surface and bottom water grab samples were analyzed by FluoroProbe in the lab at FLI to differentiate four different algal groups and yellow substances based on their accessory pigments to distinguish the relative concentrations of: 'green' algae (Chlorophyta and Euglenophyta), 'brown' algae (diatoms: Baccillariophyta, Chyrsophyta, and Dinophyta), 'blue-green' algae (Cyanophyta), and 'red' algae (Cryptophyta).

Table 1. Owasco Lake Site Locations and Water Depths.

Site Name	Latitude	Longitude	Water Depth
Offshore Sites:			
Site 1	42° 52.40' N	76° 31.35' W	34 m
Site 2	42° 49.15' N	76° 30.45' W	52 m
FLI Buoy Site	42° 50.35' N	76° 30.85' W	49 m
Nearshore Sites:			
Martin Pt North	42° 53.64' N	76° 31.59' W	dockside
Martin Pt South	42° 53.31' N	76° 31.48' W	dockside
Burtis Pt	42° 51.89' N	76° 30.96' W	dockside
Fire Lane 20	42° 48.69' N	76° 30.92' W	dockside

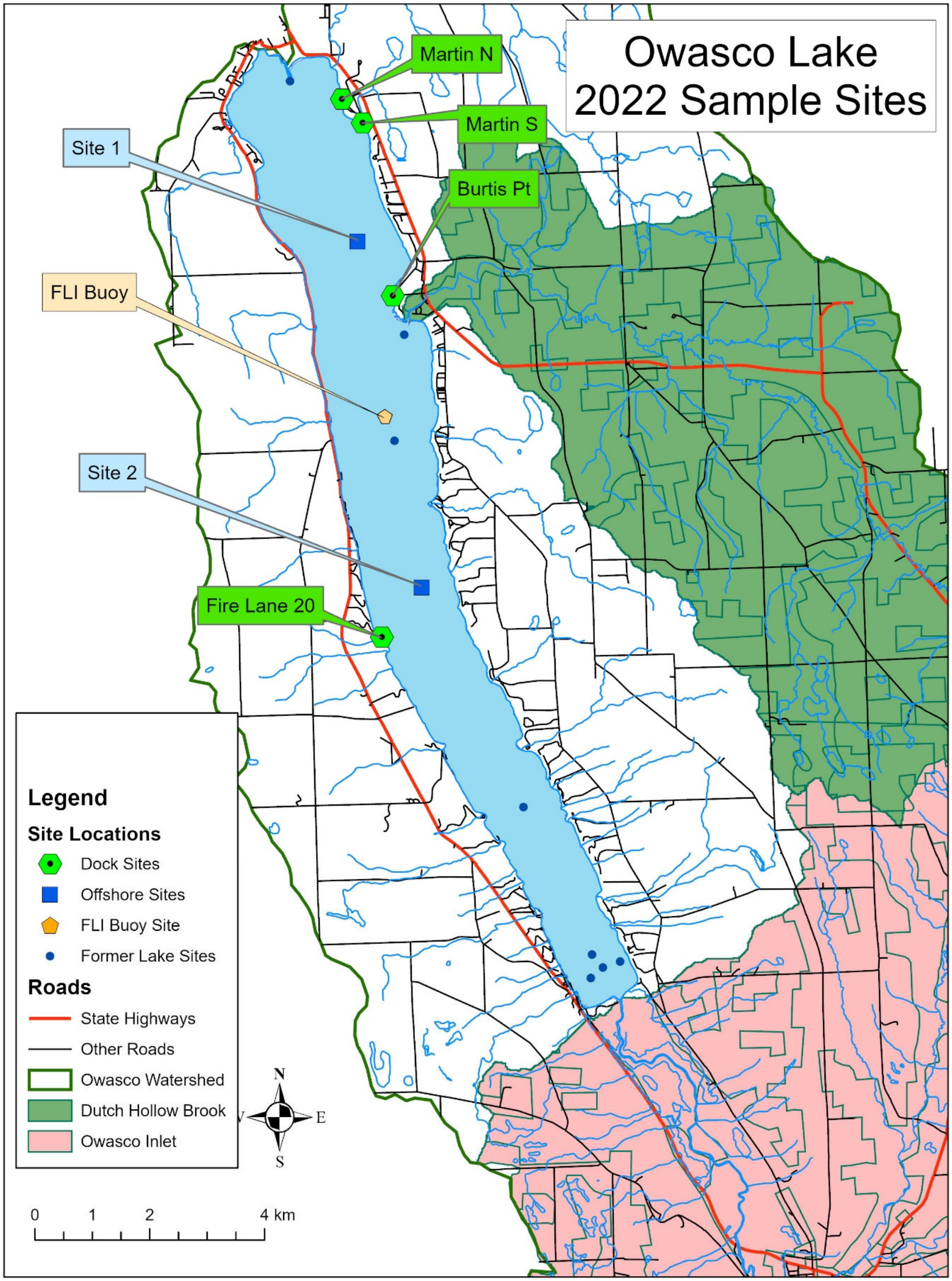

Fig. 1. The 2022 lake, FLI buoy, and dock monitoring sites.

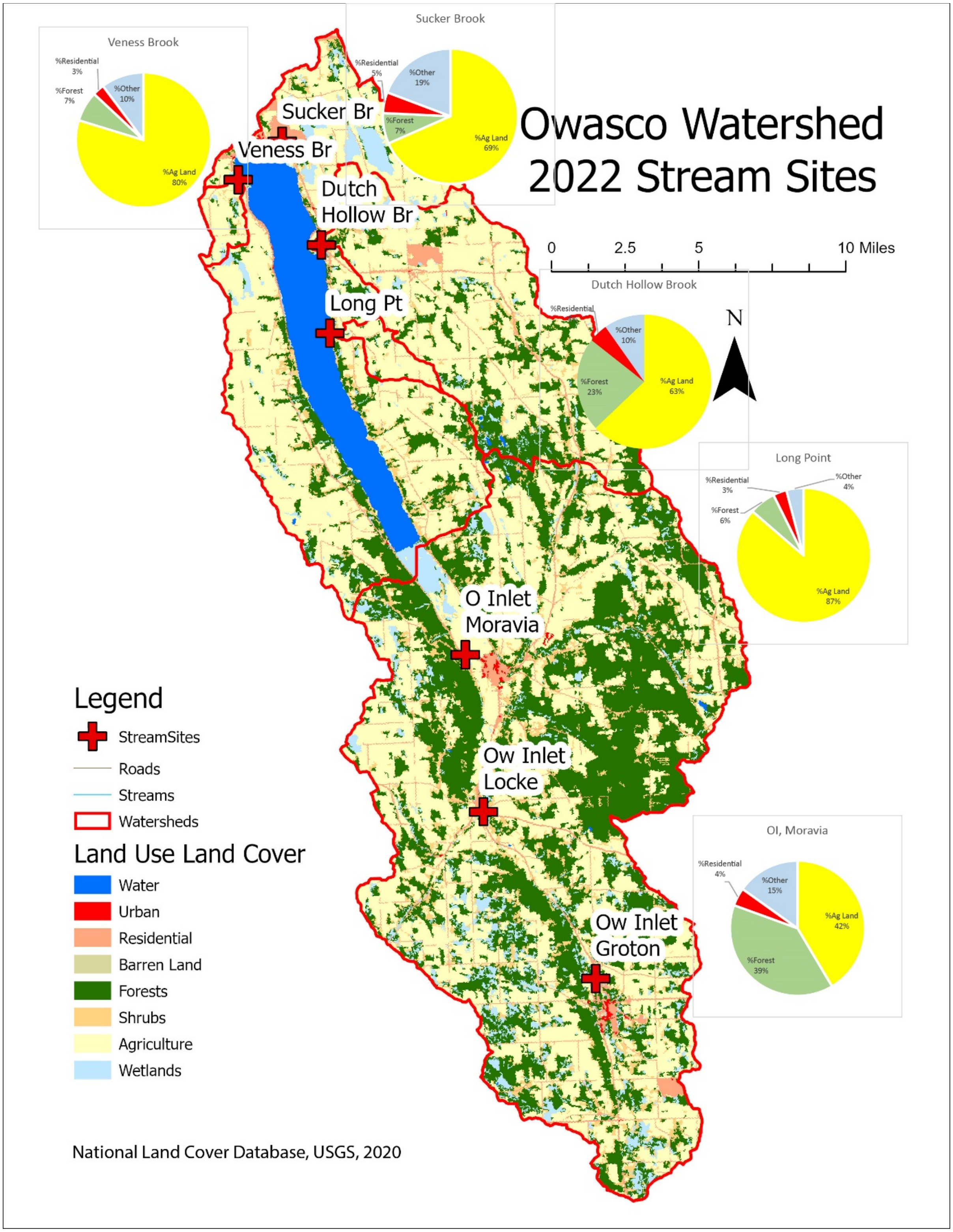

Fig. 1 continued. Stream site locations utilized by the OWLA volunteers, and percent land use – land cover pie charts for each samples stream in the Owasco watershed.

Owasco Streams: The 2022 stream monitoring program sampled seven sites within the watershed, the terminus of Veness Brook, Sucker Brook, Dutch Hollow Brook, Long Point Creek, and the Owasco Inlet at Cayuga St (Moravia, Fig. 1). Two additional sites were sampled upstream along the Owasco Inlet, at Rt 90 St (Locke) and Walpole Rd (Groton). Stream sites were visited twelve times in 2022, twice each month from May through October. The volunteers attempted to sample events, but 2022 was a dry year and lacked significant, basin-wide, events. The selected sites focused on different basin areas and land use - land cover characteristics to investigate their contributions on nutrient and sediment loads to the lake, and expanded on Halfman's previous focus on Dutch Hollow Brook, the Owasco Inlet and two tributaries along the western side of the watershed (Table 2).

Table 2. Owasco Stream Watershed Areas and Land Use - Land Cover (NLCD, 2020)

Stream	Area (km^2)	Urban/Residential %	Forested %	Agricultural %
Veness Brook	5	2.8	7.2	79.7
Sucker Brook	23	5.0	7.3	68.4
Dutch Hollow Brook	78	4.6	22.8	62.9
Long Point Creek	5	3.2	6.3	86.3
Owasco Inlet (Moravia)	305	4.3	39.1	41.5

At each site, a single water velocity was collected, coupled with a detailed streambed profile and HyFi sensor stream levels to estimate stream discharge for each visit. Water samples were also collected and subsequently analyzed by a certified laboratory (UFI) for total phosphate (TP), total dissolved phosphate (TDP), soluble reactive phosphate (SRP), total nitrogen (TN), nitrate/nitrite (NO_x), ammonium (NH_4) and total suspended sediment (TSS) concentrations following EPA/DEC approved methodologies. Unfortunately, the single stream velocity measurement could lead to large errors in the estimated discharge and two HyFi sensors detecting lake levels and not stream stage, thus discharge data and fluxes are not discussed in this report.

Laboratory Analyses: Plankton enumerations identified over 100 individuals to genus (and typically species) level under a microscope and was reported as date averaged relative percentages. Laboratory analyses for the lake nutrient, chlorophyll-a, and total suspended sediment concentrations were determined in Halfman's research lab following standard limnological techniques[2]. Briefly, an aliquot of each water sample was analyzed for total phosphate using a colorimetric analysis by spectrophotometer after digestion of any organic-rich particles in hot (100ºC) persulfate for 1 hour. A known amount of water (~3L) was filtered through pre-weighed, 0.45 μm glass-fiber filters immediately after returning from the field. The weight gain and filtered water volume determined the total suspended sediment concentration. A third known volume (~1L) of lake water was filtered through a Gelman HA 0.45 μm membrane filter. The lake filtrate was stored at 4°C until SRP and NO_x analyses. The filtered residue was kept frozen until chlorophyll-a analysis by spectrophotometer after pigment extraction in 90% acetone. Multiple reagent blanks and standards for each parameter were run during the analysis of each group of samples for a continuous check on data quality. The NO_x triplicate blanks and standards occasionally yielded concerns. 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) and nitrate ±0.1 mg/L.

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[2] Wetzel and Likens, 2000. Limnological Analyses, 3rd Edition. Springer-Verlag, New York.

Stream samples, daily duplicates and field blanks were analyzed using EPA/DEC approved methodologies by Upstate Freshwater Institute in Syracuse, a certified laboratory. Contact OWLA and UFI for specific information.

Owasco Buoy: The last year of a three-year award by the Fred L. Emerson Foundation supported the redeployment of the FLI meteorological and water quality monitoring buoy manufactured by YSI/Xylem at its mid-lake site from 4/13/22 through 10/11/22 (Table 1, Fig. 1). The buoy was again programmed to collect water column profiles with a YSI/Xylem EXO2 water quality sonde every 12 hours (noon and midnight). The sonde detected temperature (°C), conductivity (µS/cm, reported as specific conductance), dissolved oxygen (mg/L & % saturation, by optical sensor), turbidity (NTUs by backscattering), and algal fluorescence (RFUs). The fluorescence sensor measured both total chlorophyll and cyanobacteria phycocyanin concentrations (after specific pigment excitation by different wavelengths of light). WQ data were collected every 1.5 meters down the water column starting at 1 m below the surface. The buoy also contained a standard suite of meteorological sensors that recorded five-minute mean, air temperature, barometric pressure, relative humidity, light intensity, wind speed and wind direction data every 30 minutes. Raw data were periodically transferred to HWS by cellular phone ~1 hour after collection and archived in a database on a user accessible website (http://fli-data.hws.edu/buoy/owasco/). Calibrated data will also be available on this website soon. Leaking pontoon floats prevented collection of water quality data from 5/31 through 6/6 to repair the floats, and from 6/20 through 6/28 due to minimal power and software issues. The meteorological data was interrupted from 5/31 through 6/6 when the buoy was pulled to repair the floats.

Drone Flights & Spectrophotometer Measurements: FL-LOWPA funds supported drone flights and collection of light spectra. Red, Green and Blue (RGB bands) aerial photos were collected by a DJI Mini 2 at during each dock site visit. An Ocean Insight R400 VIS-NIR spectrophotometer measured the spectral signature of the upwelling and down-welling radiation (light) over 350 to 800 nm in 0.5 nm steps at the offshore and dock sites (Figs. 1 & 3).

Fig. 3. The spectrophotometer in the field.

Fig. 4. A weather station, automated camera and water sensors at a dock site.

Dockside Water Quality & Meteorological Monitoring: The last year of funding from the Fred L. Emerson Foundation enabled redeployment of a weather station, water quality sonde, water temperature loggers, and an automated camera at four dock sites in Owasco Lake (Figs. 1 & 4). The equipment was deployed to elucidate the connections of nearshore cyanobacteria blooms, and the bloom's associated precursor and concurrent meteorological and limnological data. The program follows up on promising initial results from previous years[3]. The deployment locations were at the northern and southern sides of Martin Point, Burtis Point, and at the end of Fire Lane 20 (Fig. 1, Table 1).

At each dock, a weather station (Ambient 1002-WS or its replacement model WS-2000 Osprey) recorded air temperature, rainfall, barometric pressure, humidity, light intensity, wind speed and direction at 30-minute intervals. An *ONSET* HOBO U20L-04 logger was strapped to a dock post, initially deployed at a depth of ~1 m to collect lake level and water temperature data at 30-minute intervals. A Brinno TLC-200 automated camera was deployed on the weather station pole 3 to 4 m above the lake's surface to collect images of the lake near the shoreline every 10 minutes from dawn to dusk to log nearshore water quality, i.e., log clear vs. turbid water, and obvious surface cyanobacteria blooms. At this deployment height, the camera's 60° field of view imaged 2 by 3 to 3.5 by 5 meter area of the lake's surface. Finally, an *In-Situ* Aqua Troll 600 water quality sonde with temperature, conductivity, total chlorophyll and cyanobacteria phycocyanin sensors was deployed at each dock except one, where a *YSI/Xylem* EXO2 water quality sonde with temperature, conductivity, dissolved oxygen, turbidity, and total chlorophyll and cyanobacteria phycocyanin fluorescence sensors was deployed instead. The results of this dockside investigation will be discussed in a companion HABs report[4].

RESULTS & DISCUSSION

2022 PRECIPITATION

Previous reports concluded that annual rainfall, its seasonal variability and individual storm events influenced the delivery of nutrients and sediments to the lake, and thus water quality in the lake. On annual time scales, rainfall was proportional to runoff, and its associated nutrient and sediment loads to the lake. On a seasonal scale, runoff is influenced by, for example, changes in soil saturation, water infiltration rates, evapotranspiration rates, and the extent of plant cover on agricultural lands (e.g., spring tillage for planting, harvesting in the fall, winter cover). Thus, numerous variables influence the percentage of rainfall that entered runoff rather than infiltrates into the ground that, in turn, dictates the seasonal delivery of nutrients and sediments by streams to the lake. During the spring and early summer, saturated or nearly saturated soils and less evapotranspiration dominate. Soils become increasingly more unsaturated and evapotranspiration increases in the summer. The fall is typically in between. The percentage of rainfall that enters runoff increases with less infiltration and less evapotranspiration, and more soil erosion results from runoff over land surfaces without vegetation, i.e., unplanted fields. Thus, a spring or "mega" rainstorm typically produces

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[3] The early results were supported by funds from the Finger Lakes - Lake Ontario Watershed Protection Alliance, Seneca Lake Pure Waters Association and the Finger Lakes Institute.

[4] Halfman, et al., 2023. Cyanobacteria on Owasco and Seneca Lakes, the 2022 Update. The 2022 Annual Report to the Fred L. Emerson Foundation, Seneca Lake Pure Waters Association and the Finger Lakes – Lake Ontario Watershed Protection Alliance.

proportionally more runoff, erodes more soil, and increases nutrient and sediment loads to the lake than a typical summer or fall event.

Global Warming is predicted to alter rainfall patterns. Quoting a 2017 government report:

> Heavy precipitation events in most parts of the United States have increased in both intensity and frequency since 1901 (high confidence). There are important regional differences in trends with the largest increases occurring in the northeastern Unites States (high confidence).
>
> Global warming also dictates the opposite extreme, i.e., seasonal droughts. [5]

In the Finger Lakes region, a few examples of increasingly larger and more localized rainfall events were observed over the southern portion of the Skaneateles watershed (2017), over Lodi and the southeastern portion of the Seneca Watershed (2018), and over the northeastern portion of the Owasco Watershed (2021). These examples dumped ~ 10" of rainfall in the immediate, localized area in a one to two-day period. In comparison, previous heavy rainfall events typically dumped up to 2 inches of rain in a one to two-day period.

Rainfall at the Ithaca Airport was below normal (70% of normal) during the 2022, March through October, field season (Fig. 5). The weather bureau defines the climatological normal as the previous 30-year average. Rainfall in 2022 was drier than 2016 and 2019 and nearly as dry as 2020 (Fig. 5). Seasonally, rainfall in the early spring was 86% of "normal", late spring 39% of "normal", summer 83% of "normal", and fall 61% of "normal". Mega sized events were uncommon during 2022.

Rainfall at a weather station in the Owasco Watershed (NY-CY-8 data maintained by CoCoRaHS) was also below a "mean" rainfall spaning 2011 – 2022 (a 30-year climatological "normal" is not available). The slightly different monthly patterns observed at this site from those at the Ithaca Airport most likely reflected the spatial variability in rainfall (Fig. 5a). Seasonally, rainfall in the early spring was 110% of the "mean", late spring 92% of the "mean", summer 59% of the "mean", and fall 74% of the "mean". Again, slightly different patterns were observed at this site compared to the Ithaca Airport. Rainfall totals at the four dock sites were 6.4 to 13.9" through the HABs deployment, and 10.7" of rain was measured at the NY-CY-8 site. Besides the 5" of rain at FL-20 in 2022, two additional "events" dumped 2 or more inches of rain on 9/1 and 9/2 at selected sites. Note, each dock site revealed similar rainfall patterns, however the exact rainfall amounts (daily amounts and seasonal totals) are different at each site. The slightly drier conditions in 2022 suggests that runoff and nutrient loading to Owasco Lake should have decreased in 2022, and water quality in the lake should have improved from previous years.

The maximum daily rainfall in each year suggests larger maximum daily rains in 2022 than many previous years (2012, 2918, 2019, 2020, 2021) at the Ithaca Airport, and larger maximum daily rains in 2022 than many previous years (2012, 2013, 2018, 2019, 2020) at the NY-CY-8

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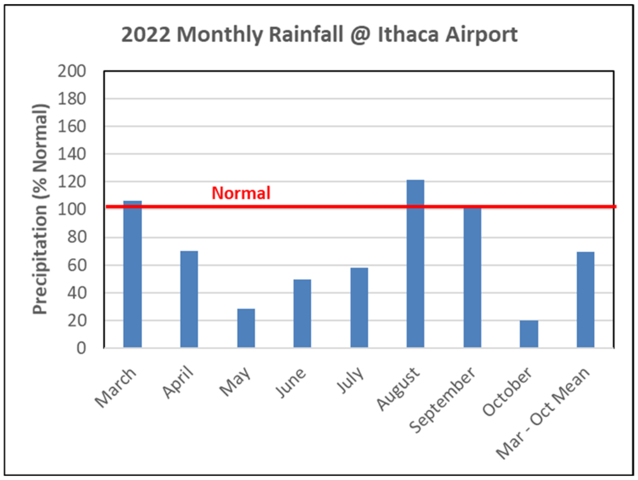
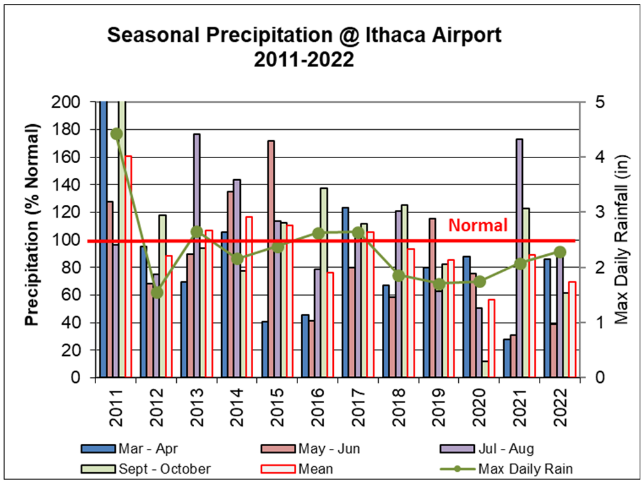
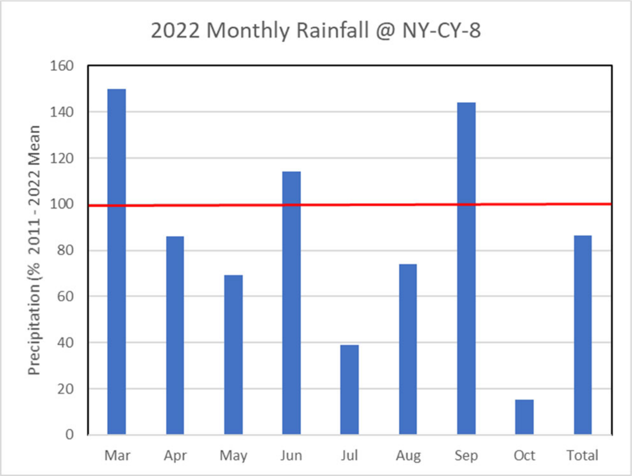
[5] Easterling, D., et al., 2917 Precipitation change in the United States. In: Climate Science Special Report: A Sustained Assessment Activity of the U.S. Global Change Research Program [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA (2017), pp. 301-335.

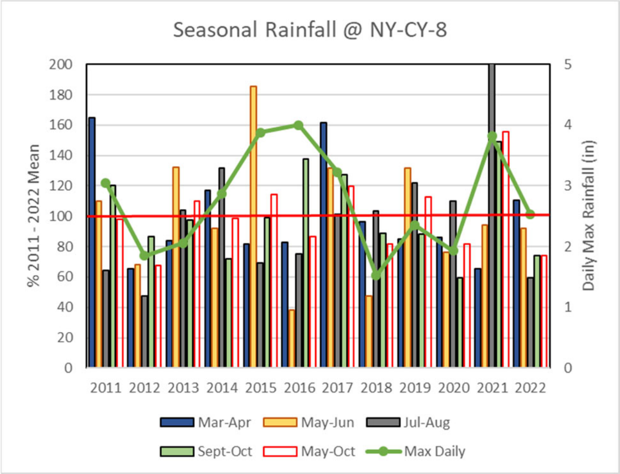
site (Fig. 5b). Slightly different daily maximum and annual total patterns exist between these two sites and highlights the spatial variability in rainfall, that is expected to intensify in the years ahead with global warming. Why is this important? Large rainstorms deliver significantly more nutrients and suspended sediments to the lake, e.g., the fall flood event in 2021 delivered ~50% of the annual nutrient and sediment load to the lake. It suggests that large and typically more localized daily rainfall events, rather than annual total or seasonal total rainfalls, yield a greater impact nutrient and sediment loads to the lake, and water quality in the lake. Its impact on water quality will be emphasized later in this report.

Owasco Lake Levels: Another indicator of weather conditions in 2022 is lake level and groundwater table depths. Records of both are available within the Owasco Watershed. Lake levels in the late summer and early fall were close but then dropped slightly below the rule curve summer elevation of 713 ft (Fig. 6). This past year also experienced small declines in groundwater table depths during late summer/fall-season at the Moravia (CY-7) and Auburn (CY-122) USGS monitoring wells, after experiencing a return to normal levels in 2021, and some of the deepest declines in 2020 (Fig. 6). These records all highlight a return to a slightly drier, less saturated conditions in 2022.









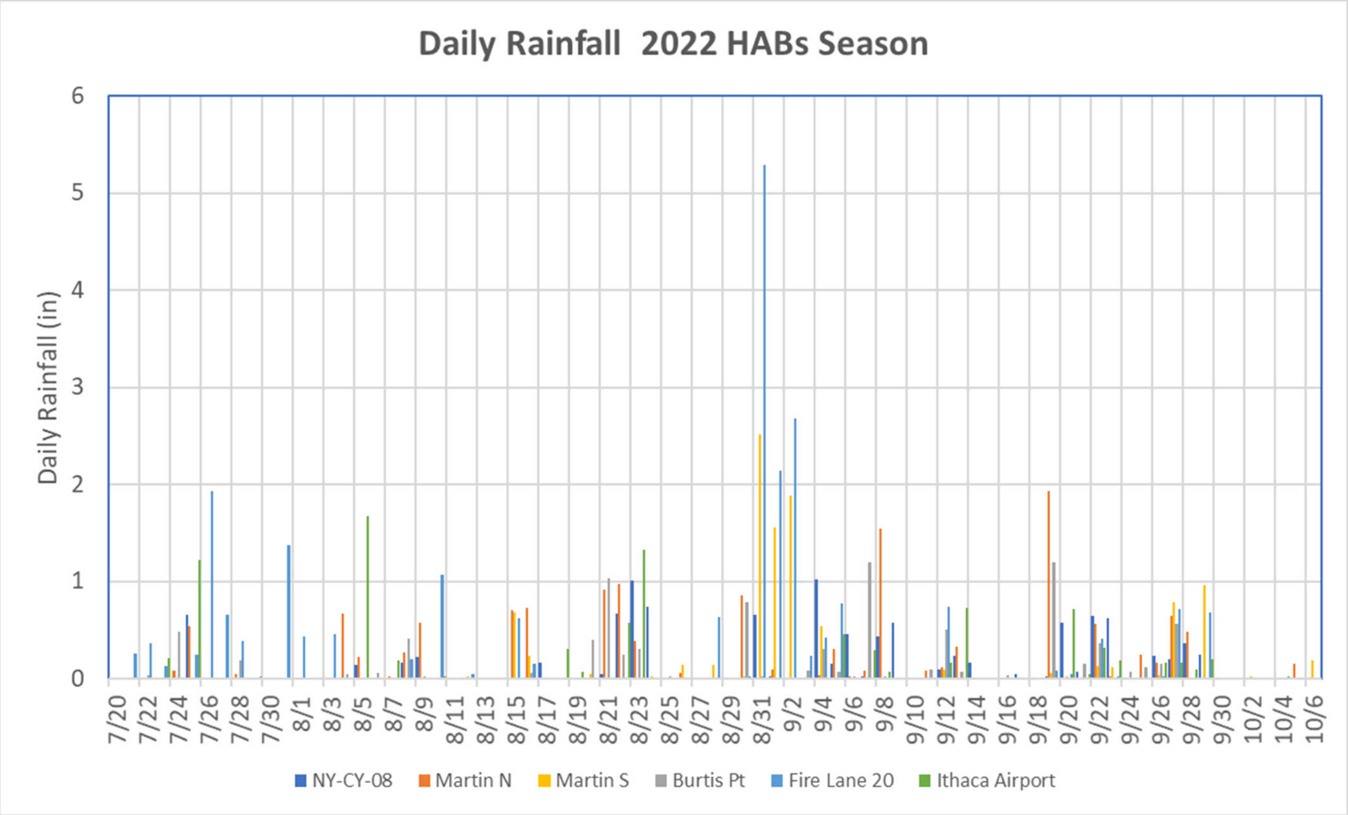


Fig 5a. 2022 Monthly (above left) and 2011 – 2022 seasonal precipitation (above right) compared to normal totals at the Ithaca Airport. 2022 Monthly (middle left) and 2011 – 2022 seasonal precipitation (middle right) compared to normal totals at CoCoRaHS Site NY-CY-8. Daily Maxima are also shown in the seasonal graphs. Daily rainfall at the Ithaca Airport, the 4 dock sites, and NY-CY-08, a CoCoRaHS site during the HABs season (below).

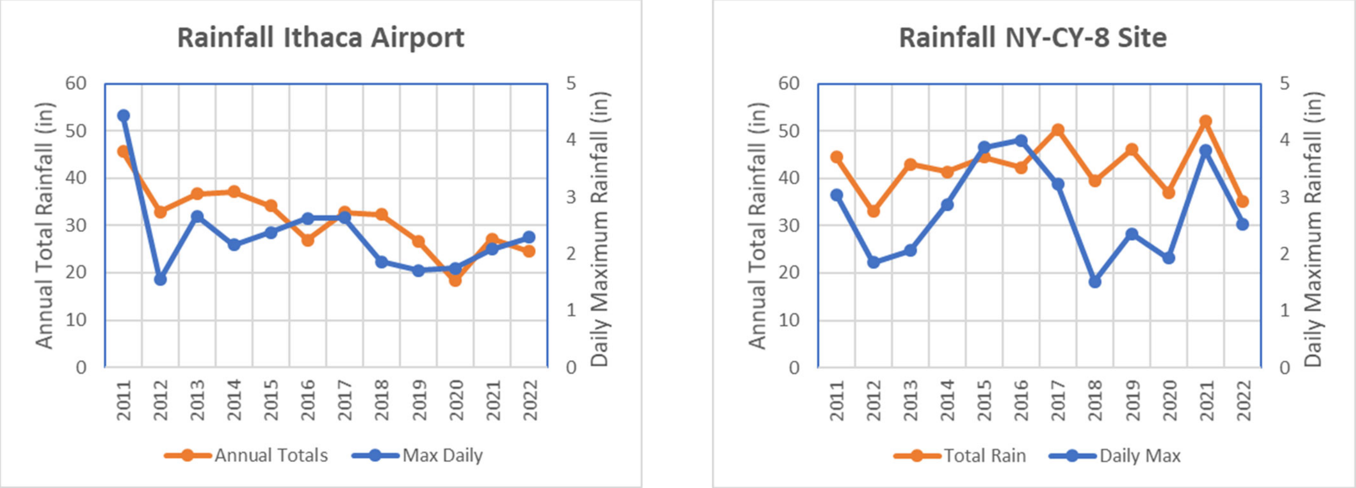


Fig. 5b. Maximum daily rainfall and total annual rainfall at the Ithaca Airport (left) and NY-CY-8 site (right).

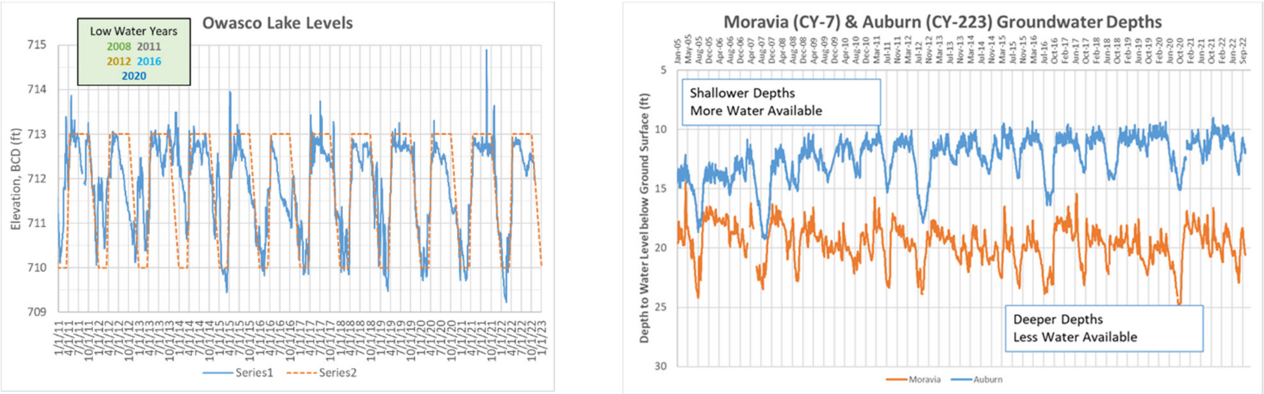


Fig. 6. 2008 through 2022 lake levels for the summer/fall season (left). 2012 through 2022 groundwater water table depths below the ground's surface (right).

LAKE MONITORING

Lake CTD Profiles: The 2022 offshore water temperature profiles detected similar warm surface water temperatures as the past surveys (Figs. 7 & 8). The seasonal stratification, the initiation of less dense and warmer epilimnion (surface water) overlying the denser and uniformly cold hypolimnion (bottom water), was already established by the first cruise (and buoy deployment). The thermocline, the boundary between the surface and bottom waters, was again between 10 and 15 meters for most of the stratified season. The depth of the thermocline deepened near the end of the stratified season, and oscillated up and down by a few meters due to internal seiche activity. Epilimnetic water temperatures ranged from 13ºC (~55 ºF) in late May peaked at 24.3ºC (~76ºF) in early August, and cooled to 17ºC (63ºF) by the last cruise of the survey (10/4). The 2022 temperatures were slightly cooler than 2020, warmer than those recorded in 2014, 2015, 2017, and 2021, and as warm as those recorded in 2016, 2018, and 2019. The past eleven years, when HABs events impacted Owasco Lake, surface water temperatures were collectively warmer than earlier years, as water temperatures in the lake have warmed over this multi-decade monitoring effort. Hypolimnetic water temperatures remained cold, warming slightly from 5.6º to 5.8ºC (~42ºF) through the field season.

The CTD temperature record is consistent with buoy temperatures when both records overlapped in time (Fig. 8). A best-fit, linear interpolation of the CTD surface temperatures revealed a mean warming of 0.2°C/year (0.0006°C/day). Water temperatures deviated above and below the linear trend and were probably influenced by natural climatic variability including the amount of cloud cover, rainfall, wind speed, storm events, and global phenomena like El Nino. For example, 2009, 2016, 2020 and 2022 were slightly warmer, whereas 2013, 2014 and 2021 were slightly cooler than a linear warming trend. The long-term warming however, suggests that Owasco Lake is influenced by Global Warming. Coincidentally, the warmest water, which was detected in 2020, also revealed the largest number of cyanobacteria blooms in Owasco Lake (DEC NYSHABs Data). In support, warmer temperatures can promote faster and more complete bacterial decay of the dead organic matter and release more nutrients for algal uptake. However, blooms counts in other years do not parallel surface water temperatures. Also, Seneca Lake surface water was also warmest on record in 2020, but Seneca experience very few blooms in 2020 compared to previous years, and a return to warm conditions in 2022 did not parallel a return to a large number of blooms. It suggests that warmer water helped promote the recent onslaught of HABs events but were not the sole criteria for blooms events, as calm weather, nutrient availability and other factors are also important.

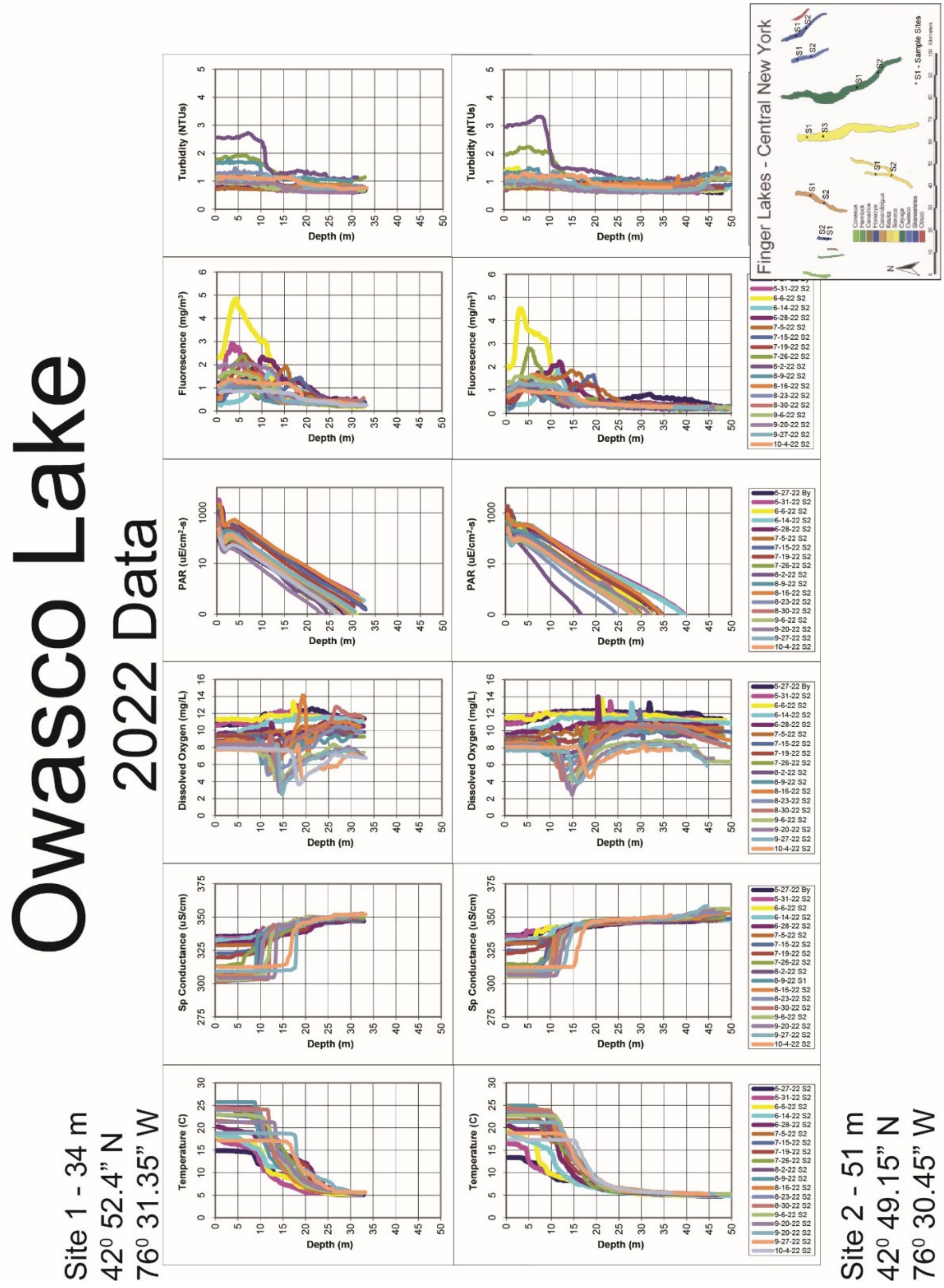


Fig. 7. CTD profiles from Sites 1 & 2 in 2022. The PAR (light) data are plotted on an exponential scale, so that the expected exponential change in light intensity with water depth appears as straight lines.

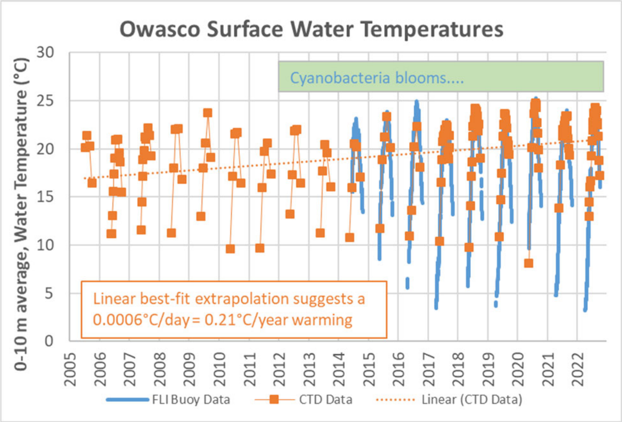


Fig. 8. The available CTD and FLI buoy mean surface water temperatures (1 to 10 m average) since 2005.

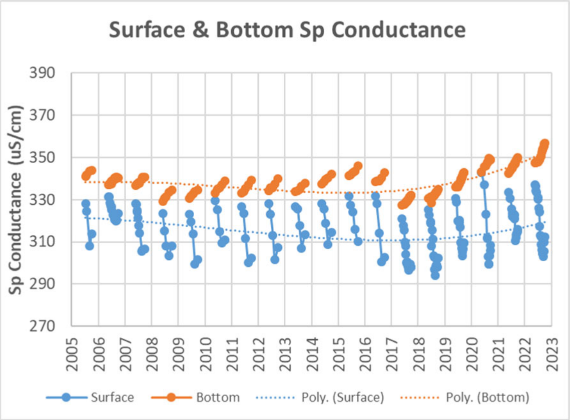


Fig. 9. Mean surface (upper 10 m) and bottom (lowest 10 m) water salinities by CTD since 2005.

Epilimnetic salinity (specific conductance) ranged from 303 to 337 μS/cm in 2022 (~150 ppm TDS). Like previous years, epilimnetic salinity decreased by ~30 μS/cm (~10 ppm TDS, a small amount) from the largest values detected in the late spring to the lowest values in late summer as the epilimnion was progressively diluted by less saline precipitation and stream runoff (Figs. 7 & 9). The early spring, surface water specific conductance was slightly larger than previous years but this difference is very small. The small annual changes in salinity are interpreted to reflect the extent of road salt application during the preceding winter, e.g., larger salinity in 2015 was due to more snowfall and road salt the previous winter. Since 2015, presumably less snow and thus less road salt accumulated in the lake, allowing salinity in the lake to decline with a slight reversal in 2022. It may also reflect the extent of the early spring rainfall, a parameter not investigated here.

The 2022 hypolimnetic specific conductance data ranged from 347 and 357 μS/cm and increased slightly over time (Figs. 7 & 9). These values were similar to or slight larger than those detected in in previous years but this difference is very small. Small annual fluctuations can again reflect the suspected inputs of road salt during the previous winter and dilution by spring rainfalls, i.e., the use of an estimated 10,000 tons of additional road de-icing salt from the larger and more frequent snowfall over the 2014 - 2015 winter probably maintained the slightly larger hypolimnetic salinity in 2014 and 2015 than earlier years, and the larger concentrations carried over into 2016 until the dilution by spring rains in 2017. It can also reflect the date for stratification, as stratification would limit the exchange of dilute rainfall with the bottom waters, and earlier stratification would “trap” larger salinity hypolimnetic waters as it would have less time to be diluted by spring rains.

The epilimnetic dissolved oxygen (DO) concentrations remained between 8 and 12 mg/L, and consistently near or slightly above 100% saturation. The lower concentrations were detected in warmer water. Yet, dissolved oxygen concentrations remained at saturated conditions because DO is less soluble warmer then colder water. In contrast, hypolimnetic DO concentrations were progressively depleted below saturation through the stratified season from over 12 mg/L (100% saturation) to 2 mg/L (~40% saturation) in the upper hypolimnion and just below 7 mg/L (~55% saturation) in the lowest hypolimnion by late summer. These lowest saturation levels exceeded the threshold for respiratory stress in sensitive organisms. Similar declines in saturation were detected in 2015 and 2017 in the Owasco Lake buoy and CTD datasets. The decrease is interpreted to reflect significant hypolimnetic bacterial respiration and decomposition of dead algae in 2022. In comparison, hypolimnetic dissolved oxygen concentrations deplete to anoxic conditions near the end of the stratified season in eutrophic lakes, and barely deplete below saturated conditions in oligotrophic lakes.

Profiles of photosynthetic available radiation (PAR), i.e., light intensity, again decreased exponentially with water depth from a maximum intensity of a few 100 to a few 1,000 $\mu E/cm^2$-s at the surface to 1% of surface light intensities within the lower epilimnion at water depths of 10 to 15 m in 2021 (Fig. 7). The observed decrease in light reflects the preferential and expected exponential absorption and conversion of longer wavelengths of light (infrared, red, orange, yellow) to heat, and scattering of shorter wavelengths of light (ultraviolet, violet, blue) back to the atmosphere. The range in surface intensities reflected the season, the extent of cloud cover, and the turbidity of the water (suspended sediment and/or algal density) on the survey date. The 1% of surface light threshold defines the maximum depth for the photic zone, i.e., water depths above the minimum amount of light required for algae to photosynthesize enough biomass to survive. Thus, algal photosynthesis and growth was again restricted by light to the epilimnion in Owasco Lake. Many profiles revealed a marked decrease in light intensity at 2 or 3 meters. It corresponded to the sensor passing through the shadow of the boat.

Fluorescence, a measure of algal pigment concentrations, revealed peaks in algal abundance within the lower epilimnion at approximately 5 to 10 m below the lake's surface (Fig. 7). Peak concentrations exceeded 5 μg/L (mg/m^3) on 6/6, and were above 3 μg/L on 7/6. The buoy revealed larger algal concentrations at these mid-epilimnetic depths on these dates as well. Algal peak concentrations were lower, between 1 and 2 μg/L, on the other survey dates. Fluorescence measures algal pigment concentrations and not algal populations. Thus, the algal fluorescence peak at depth may reflect some combination of an increase in algal biomass and/or more pigments per cell in the lower light conditions. These peak concentrations and frequency of peaks were larger in 2021 and 2022 than the three previous years. Qualitatively, the lake also looked "greener" most of the early summer during 2021 and 2022 than in the past. The 2021 larger concentrations parallel the increase in winter and spring rainfall, and the mid-summer to fall events, as runoff is the primary source of new nutrients for large algal blooms. Early spring heavy rains were also experienced in 2022, that may have delivered sufficient nutrients to maintain the early summer, open water, algal blooms. However, the field season rainfall totals were low. Alternatively, the maximum daily rainfall was higher in 2021 and 2022 then the three preceding years. It suggests that algal concentrations reflect huge rainfall events, and the associated larger delivery of nutrients and suspended sediments (see subsequent section for more information). Hypolimnetic concentrations were consistently below 1 μg/L, i.e., algal pigments were nearly absent in the dark bottom waters.

The turbidity profiles revealed peak turbidities of 3 NTUs just above the thermocline on one survey date, 8/2, and a peak up to 3 NTUs on 5/31 and 7/26, all above the typical 1 to 2 NTU water column turbidities. Poorly defined benthic nepheloid layers were also detected at the deep site (Fig. 7). The change in benthic turbidities from year to year typically parallel the change in rainfall and wind velocities, as the primary source of bottom-water suspended sediments (turbidity) is runoff events from precipitation and snowmelt, and resuspension events by waves. For example, the poorly defined benthic nepheloid layer in 2020, probably reflected the decreased rainfall (both rainfall seasonal totals and maximum daily events) in 2020 compared to other years. In 2022, the benthic TSS probably reflected late summer and early fall rain events.

The bbe FluoroProbe data revealed similar concentrations of greens, diatoms, and cryptophytes and lesser amounts of cyanobacteria in surface water grabs at the offshore sites in 2022 (Table 3 in appendix, Fig. 10). The date averaged, total algal concentrations ranged from 1.2 µg/L on 7/15 to 31.7 µg/L on 6/6. From 2017 to 2022, the algal population changed from mostly diatoms, greens and cryptophytes, with trace amounts of cyanobacteria in 2017 to increasingly more cyanobacteria by 2020. The concentration of cyanobacteria declined since, and decreased to 2018 concentrations by 2022. Are cyanobacteria declining in the lake? Was 2022 unfavorable for cyanobacteria growth? The number of HABs events detected by the OWLA volunteers declined since a peak in 2020 as well (Fig. 11).

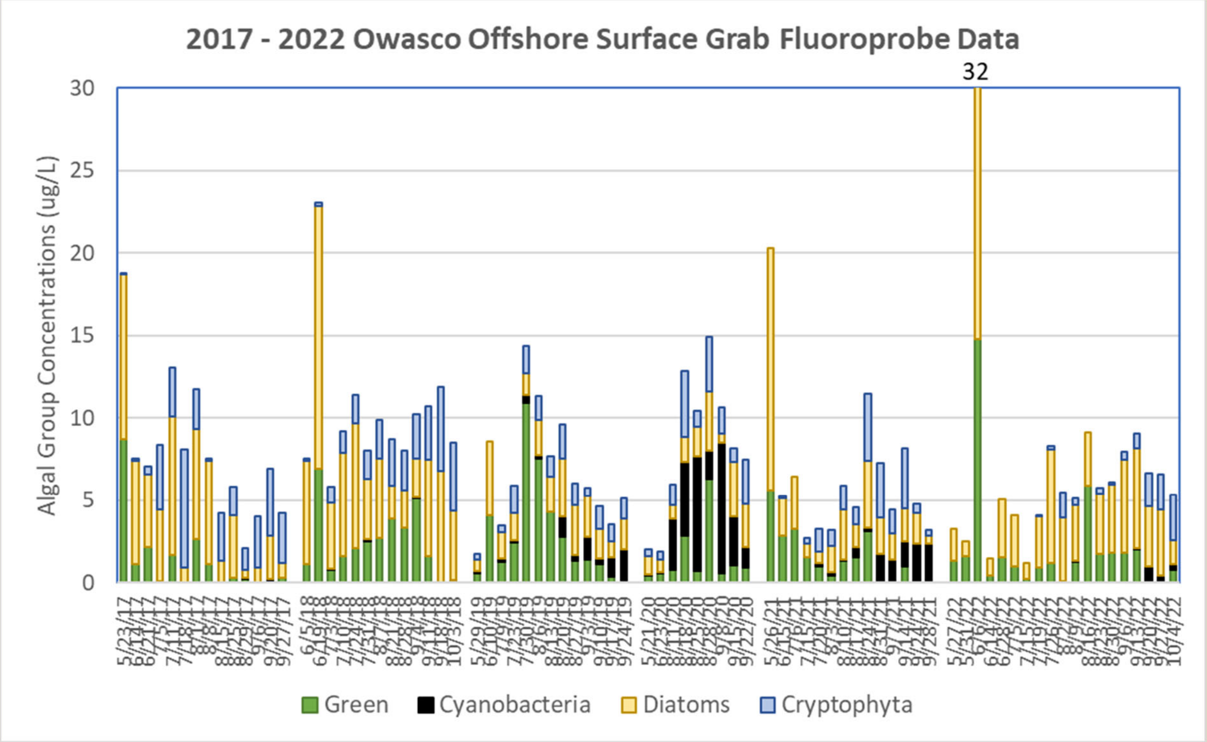


Fig. 10. Offshore, surface grab, date averaged, bbe FluoroProbe data revealing the relative concentrations of the four algal groups from 2017 through 2022.

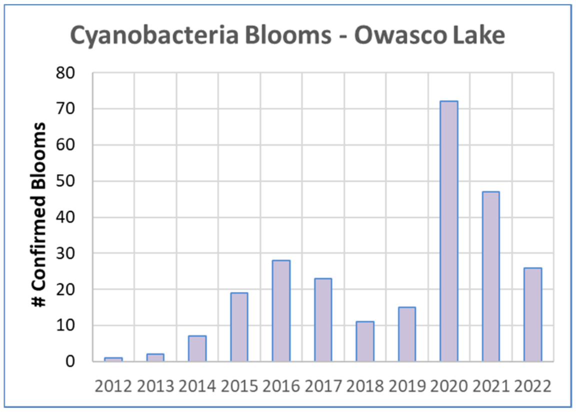


Fig. 11 Number of confirmed cyanobacterial blooms in Owasco Lake from the NYS DEC - HABs mapper web site.

Limnology & Trophic Status: Date averaged mean chlorophyll-a concentrations in the epilimnion ranged from 1.2 to 8.6 μg/L and averaged 3.5 μg/L in 2022 (Table 4 in appendix, Fig. 12). The largest values were detected in June and again in September. The chlorophyll-a concentrations were smaller than CTD total chlorophyll and FluoroProbe fluorescence data because the former only measures the concentration of one algal pigment whereas the fluorescence datasets measured the concentration of all pigments in slightly different units. The 2022 annual mean chlorophyll-a concentration was similar to the two previous years, and just below the DEC's do not exceed potable water body limits of 4 to 6 μg/L[6], but daily mean concentrations on 6/6, 9/6, 9/13 and 9/27 exceeded this limit. A similar 2022 annual mean concentration to the preceding two years is surprising as 2022 was slightly drier than earlier years. However, the largest maximum daily rains were as large in 2021 and especially 2022, than earlier in the record. It suggests that large rainfall events are more important to the water quality in the lake (see subsequent section). The 2021 flood may have added legacy nutrients to the lake that contributed to the larger algal populations in 2022 as well.

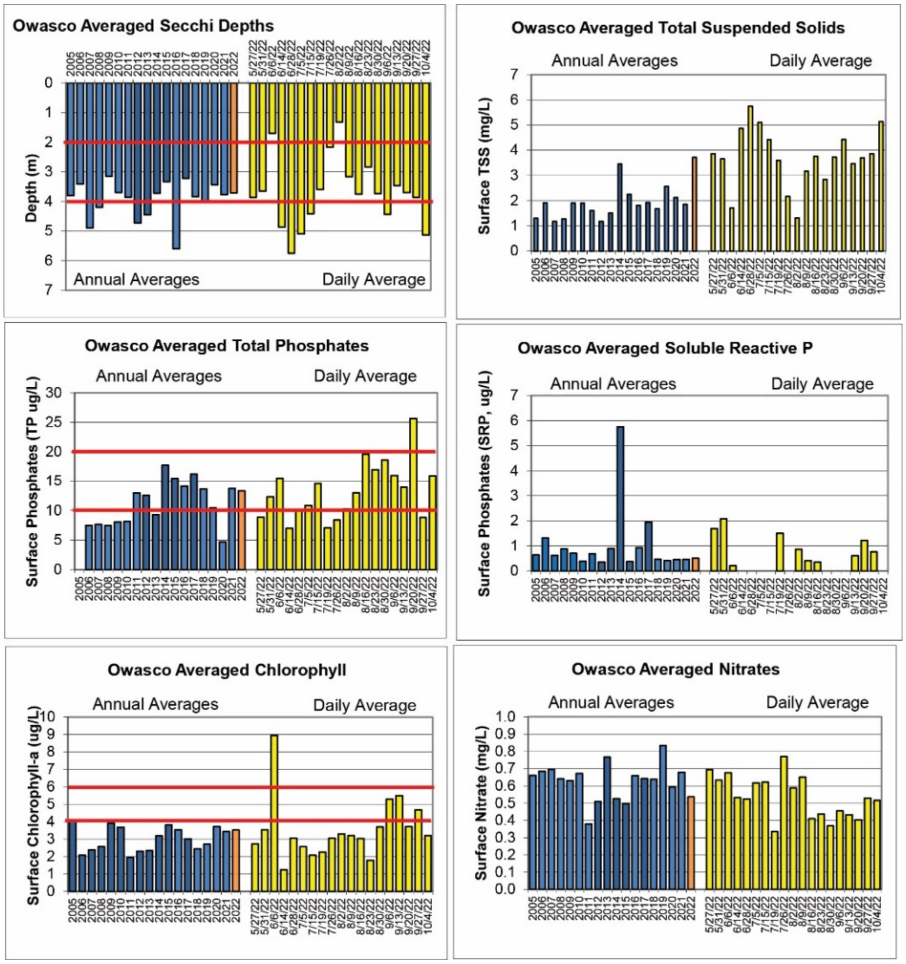


Fig. 12. Annual average surface water concentrations from 2005 (blue) through 2022 (orange), and survey date averaged offshore surface water data during 2022 (yellow). When appropriate, boundaries for oligotrophic, mesotrophic and eutrophic concentrations are marked with red lines.

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

Secchi disk depths ranged from 1.3 to 5.8 meters and averaged 3.7 meters in 2022 (Fig. 12). On two dates, 6/6 and 8/2, depths were shallower than the mesotrophic-eutrophic boundary. Otherwise depths were mostly within the mesotrophic and less often oligotrophic ranges. Annual mean depths gradually deepened from 2009 through 2012, then shallowed to 2017, except for a reversal in 2016. Deeper depths were detected again in 2018 and 2019, but shallowed slightly (0.6 m) in 2020 and slightly deeper depths (0.4 m) in 2021 and 2022. The timing suggests that the major trigger for the decline in water clarity during 2014 and 2015 and again in 2017 was the larger spring rainfalls and/or more intense rainfall events in those years. It also suggests that the "dry" conditions in 2016 and the reduced spring though mid-summer rainfall in 2018 and "normal" rainfall in 2019 allowed the lake to recover. However, shallower Secchi depths in 2020 and slightly deeper depths in 2021 and 2022 are not consistent with rainfall conditions. Perhaps the percentage increase of cyanobacteria in the algal populations, and their ability to float near the surface, obstructed light penetration and Secchi disk depths in 2020, reversing the annual trends. Finally, mid-depth, epilimnion, fluorescence peaks suggest that Secchi depths measure the top of the of the mid-depth epilimnetic fluorescence peak rather than a well-mixed concentration of algae throughout the epilimnion.

The annual average total phosphorus of 13.3 μg/L was below the 20 μg/L TP threshold used by the DEC that designate impaired (eutrophic) water bodies. The impaired waterbody threshold was exceeded only once in 2022 with a maximum date-averaged TP concentration of 25.6 μg/L on 9/20. Since 2006, annual mean TP concentrations have increased from ~8 to over 17 μg/L by 2014 with a slight dip in 2013 (Fig. 12). After another dip in 2015 and 2016, TP increased to 16.2 μg/L in 2017. Since 2017, TP decreased to 4.7 μg/L in 2020 but significantly increased to 13.7 μg/L in 2021 and 13.3 in 2022, most of these fluctuations paralleled maximum daily rainfall trends (see subsequent section).

Annual mean soluble reactive phosphate (SRP) concentrations in 2021 remained very small 0.5 μg/L, similar to 2010, 2012, 2015, 2018, 2019, 2020 and 2021, compared to years with larger SRP concentrations, i.e., 2006 and 2017 (1.9 μg/L), and especially 2014 (5.8 μg/L, Fig. 12). The large 2014 mean was biased by a May sample collected immediately after intense May rains. Interestingly, mean annual SRPs in 2016, a "dry" year, and 2017 a "normal" year were 2nd largest to 2014. Reduced external sources in 2016 and 2020 suggests that decomposition of organics within the lake may provide a critical SRP source. The consistently low SRP concentrations indicates that SRP is the limiting nutrient in the open lake.

Nitrate concentrations ranged from 0.5 to 1.4 mg/L and averaged 0.7, and an order of magnitude (10 times) below the 10 mg/L maximum contaminant level (MCL) established by the EPA.

Total suspended sediments (TSS) concentrations ranged from 1.3 to 5.8 mg/L and averaged 3.7 mg/L. In 2022, the TSS concentrations were highest in the spring and again in August, consistent with the largest fluvial inputs. The total suspended sediment (TSS) annual mean concentrations in 2019 (2.6 mg/L) reversed a declining trend from a peak of 3.5 in 2014, down to 1.7 mg/L in 2018 (Fig. 12). Since 2019, TSS concentrations continued to decrease to 2021, perhaps a reflection of minimal rainfall in 2020, and the input of fluvial sediments as a coherent plume just above the thermocline that decreased a significant surface water expression in 2021. In 2022, TSS concentrations jumped to 3.7 mg/L, perhaps a reflection of rainfall events. The trends, weakly parallel changes in rainfall. Wind driven waves could also increase suspended sediment concentrations during “dry” years. More persistent cyanobacteria in 2019 and 2020 may have increased the TSS concentrations in surface grab samples, as well.

The 2022 trophic status indicators yielded a mixed signal and were similar to those in 2021. Annual mean Secchi depth, TP concentrations and hypolimnetic dissolved oxygen saturation data placed Owasco Lake on the mesotrophic side of the oligotrophic-mesotrophic boundary (Table 5). Nitrogen, measured as NO_x concentrations, and chlorophyll data placed Owasco Lake below the boundary. Thus, the overall trophic status of Owasco Lake in 2022 is just above the oligotrophic-mesotrophic boundary, similar to 2021 and slightly worse than 2020. The fluctuations above and below the boundary over the past decade indicate that the lake is in a delicate balance. Any increase (or decrease) in nutrient loads from one year to the next decreases (or increases) the lake’s water quality. The data also indicate that water quality has not improved (or worsened) in the lake over the past decade, and recently declined in 2021 and 2022. The stagnation and recent decline are discouraging and indicates that remediation efforts over the past decade have not been extensive enough to improve water quality in the lake!

Table 5. Concentration ranges for Oligotrophic (low productivity), Mesotrophic (mid-range productivity), and Eutrophic (high productivity) lakes. The bold entries bracket Owasco’s 2022 annual 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 are noteworthy. First, the mean, surface water, soluble reactive phosphate (SRP) to nitrate (NO_x) ratio in the lake, the two nutrients that typically limit algal growth, averaged 1:1,050 in 2022. The P:N ratio in algae, thus what algae require for growth, is 1:7 (Redfield Ratio). These ratios indicate that phosphate has consistently been (since the start of the FLI monitoring effort) the limiting nutrient in Owasco Lake. The limiting nature of phosphorus is unlikely to change because fluvial sources yield 10 to 100 times more nitrogen than phosphorus, and fluvial sources of NO_x are augmented by additional sources of nitrogen to the lake (e.g., atmospheric deposition of acid rain NO_x) not available to phosphorus. Preliminary mesocosm (nutrient limitation) experiments suggest that ammonium (NH_4^+), the reduced and preferred source of nitrogen for algae, might also limit algal growth.

Second, variability was observed in every parameter from one survey date to the next (Fig. 12). The extent of the variability is best observed in the buoy data (see Fig. 19 and the companion report) and the extreme values depicted by the box and whiskers plots (Fig. 13). It reflects, for example, that algal blooms do not persist the entire summer but are instead episodic and only bloom for a week or so at a time before nutrient limitations and/or grazing by zooplankton and mussels decrease the algal concentrations in an open water bloom.

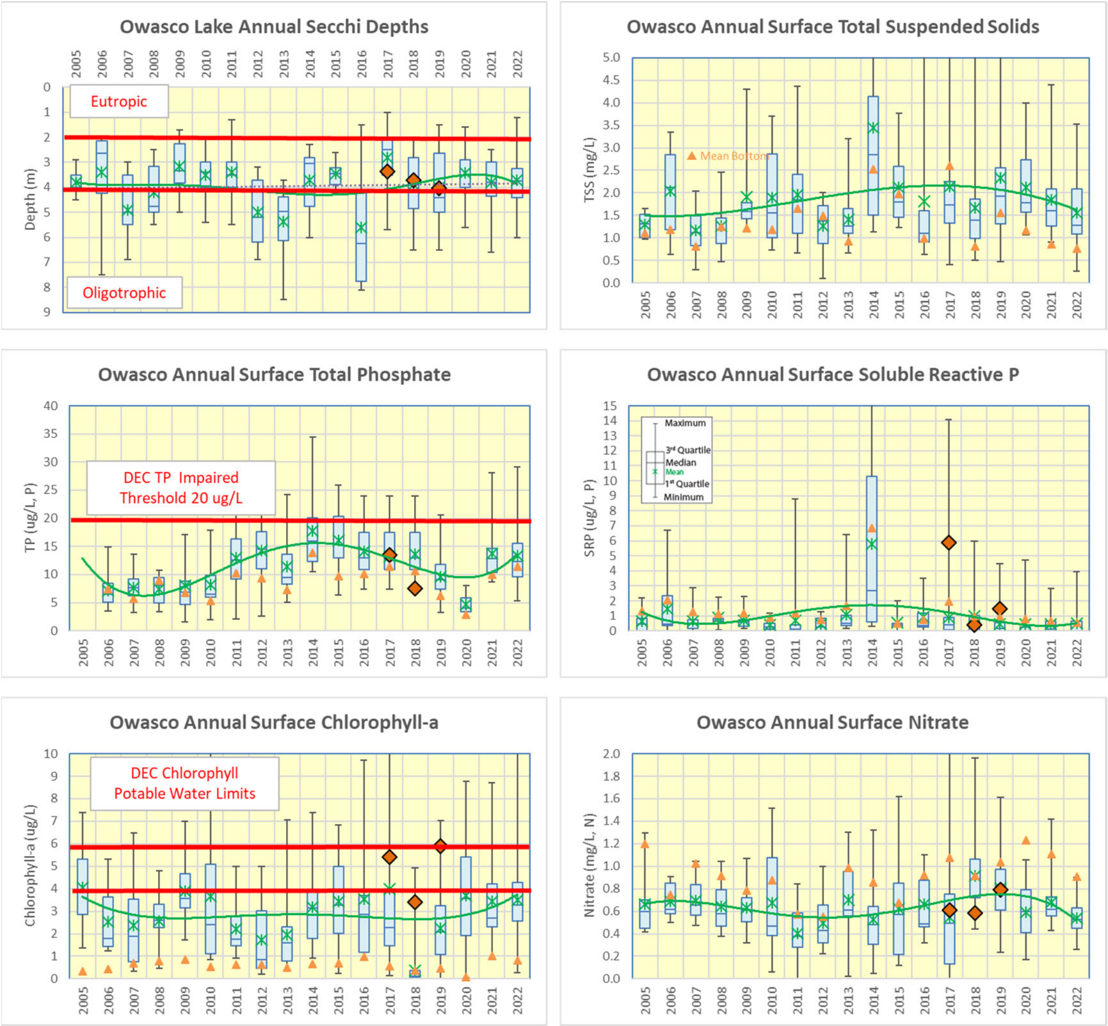


Fig. 13. Box and Whisker plots of the annual nutrient, chlorophyll and Secchi disk data. The annual mean bottom water concentrations (orange triangles) and annual mean DEC C-SLAP data (orange diamonds) are also plotted (TP unavailable since 2019, others since 2020). DEC measured TDP in 2017 instead of SRP, and total chlorophyll instead of chlorophyll-a. Both differences should result in larger DEC than this survey's data.

Third, the dissolved nutrient concentrations revealed slightly larger concentrations in the hypolimnion than the epilimnion. The annual mean surface and bottom water concentrations were 0.3 to 0.5 μg/L for SRP, and 0.6 to 0.9 mg/L for NO_x. respectively. Chlorophyll-a concentrations revealed the expected decrease from the epilimnion to the hypolimnion from 3.7 to 0.8 μg/L. The separation highlights the expected algal uptake of nutrients in the epilimnion and bacterial decomposition of organic materials (e.g., algae) and release of nutrients in the hypolimnion.

Fourth, 2017 through 2019 mean TP (no 2019 data), SRP, total chlorophyll and NO_x surface concentrations determined by the C-SLAP program were similar to the results from this study (Fig. 13). C-SLAP's TP, SRP and NO_x were within or just above the "box" of the box and whisker plots, and total chlorophyll above the "box". Larger concentrations reflected by C-SLAP's chlorophyll and 2017 total dissolved phosphate (TDP) concentrations may reflect the natural day to day variability in these parameters. In addition, total chlorophyll determined by C-SLAP measured more chlorophyll pigments that just chlorophyll-a presented in this report, and C-SLAP's TDP measured both dissolved organic matter and dissolved phosphorus (SRP) in the sample than just the SRP (dissolved phosphorus) presented here.

Sufficient data is now available to investigate the impact of maximum daily rainfalls and/or total annual rainfall on the nutrient and sediment concentrations, thus water quality in the lake. Annual mean Secchi depths, TP, SRP, NO_x, chlorophyll-a, and TSS concentrations from 2011 through 2022 were plotted versus the NY-CY-8 annual daily maximum rainfall and annual total rainfall (Fig. 14). TP and chlorophyll-a concentrations correlated to the maximum daily rainfall and to a lesser degree, if at all, to the total annual rainfall. It suggests that the severity of the daily rainfall events impact water quality in the lake much more than total rainfall accumulations, e.g., a huge event has significantly larger erosive capabilities than numerous gentle drizzles. Interestingly, SRP, TSS and NO_x did not correlate to either rainfall proxy ($r^2 < 0.01$). Potential reasons are numerous and speculative at this time. For example, SRP, the limiting nutrient, should be quickly utilized by algae as soon as it enters the lake, and lake concentrations should remain unchanged. Sediment plumes were observed flowing at depth in the lake along the top of the thermocline, and thus will not be detected by the surface water samples. NO_x is pervasive in the lake (i.e., it is not the limiting nutrient), and stream loads rarely change the lake concentrations. Finally, Secchi depths probably measure the depth to the upper portion of the mid-epilimnetic peak in algae (as revealed by the fluorescence profiles) and not uniformly mixed algal concentrations.

The daily buoy data confirm and improve these daily maximum rainfall correlations for algae (measured as fluorescence) and the depletion of dissolved oxygen (Fig. 15). Larger daily maximum rainfalls parallel larger algal concentrations and smaller dissolved oxygen minima in the lake. It suggests that algal concentrations increase with the extra loading of TP, and the dissolved oxygen concentrations declined as the extra algae were respired by bacteria in the water column. Other drivers will refine these imperfect correlations, however these relationships suggest that the maximum daily rainfalls not only deliver the largest loads to the lake from the watershed but also impact water quality in the lake. Unfortunately, global warming will only heighten the amount and frequency of these maximum daily rainfall events in the future, and continue to degrade water quality in the lake.

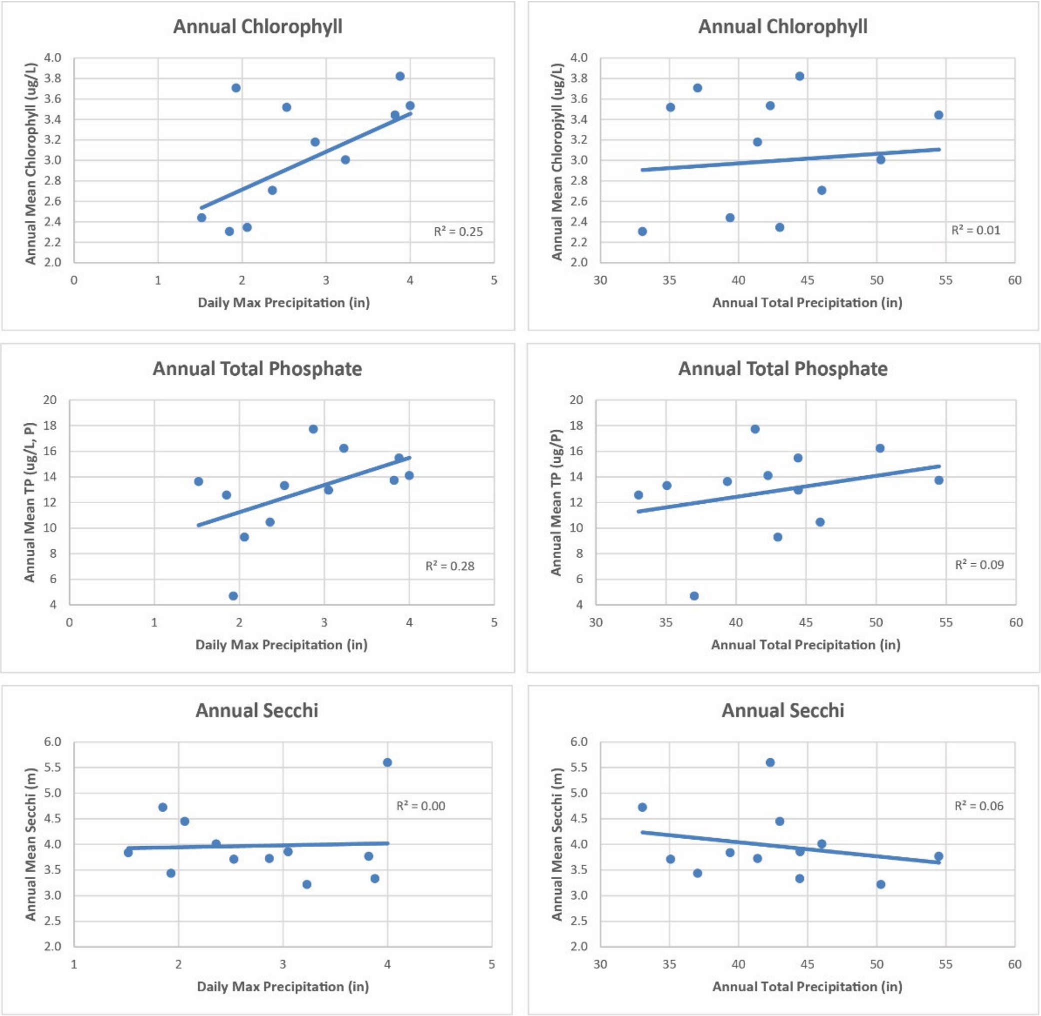
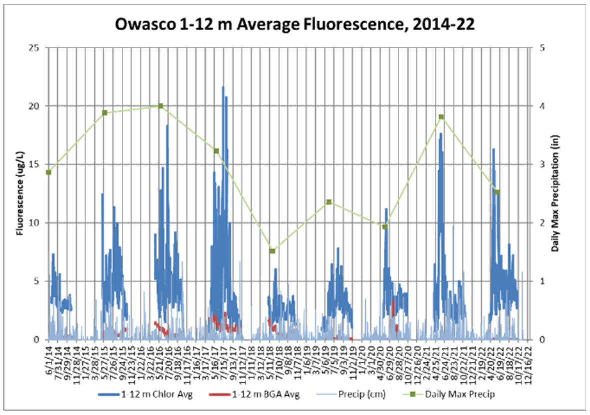
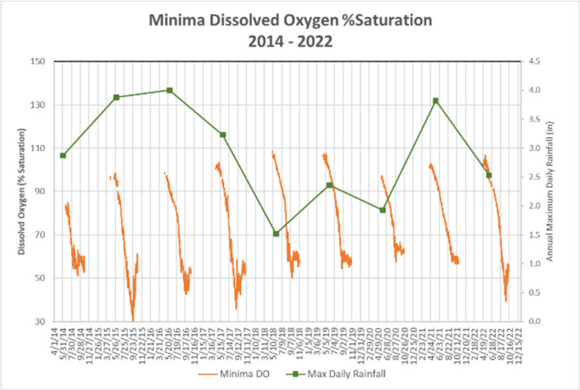


Fig. 14. Mean annual water quality parameters plotted versus maximum annual daily rainfall (left column) and the annual total rainfall (right column) for Chlorophyll (top), TP (middle) and Secchi depths bottom).





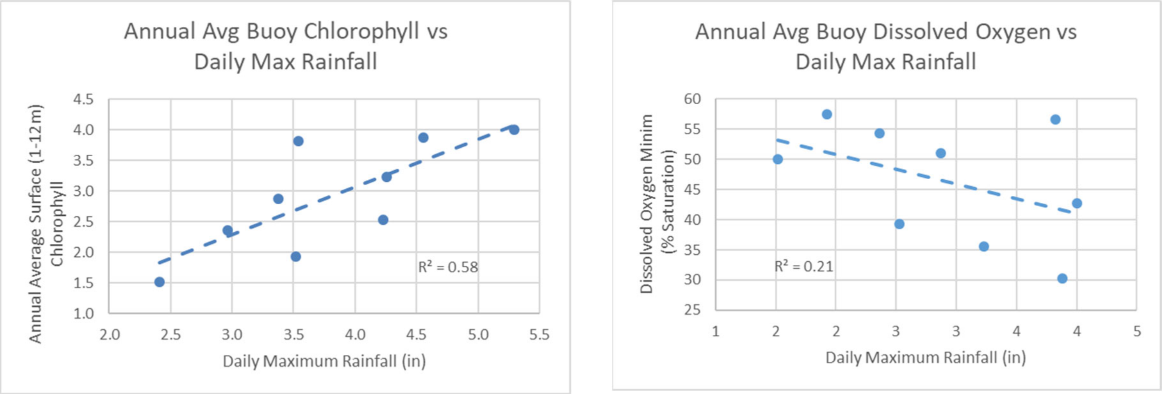


Fig. 15. Mean annual buoy chlorophyll (fluorescence, left) and water column dissolved oxygen minima (%saturation, right) plotted versus maximum annual daily rainfall.

Plankton Data: Like recent years, the phytoplankton (algal) species in Owasco Lake during 2022 were dominated by diatoms in the early part of the field season, primarily *Asterionella*, with smaller numbers of *Fragillaria* and *Diatoma,* and cyanobacteria later in the season, primarily *Mycrocystis* with some *Dolichospermum* (formerly *Anabaena*), and other species (Table 6 in appendix, Fig. 16). Other phytoplankton species detected included a small percentage of *Synedria,* and *Dinobryon*. The relative percentage of green algae also increased in 2022 over previous years from a maximum of 2% to 5% on any survey date. Zooplankton species were dominated by rotifers, namely *Vorticella*, *Keratella* with some cladocerans, like *Copepods*, and *Cercopagis*, the fishhook water flea. Zebra and quagga mussel larvae were also detected in the plankton tows.

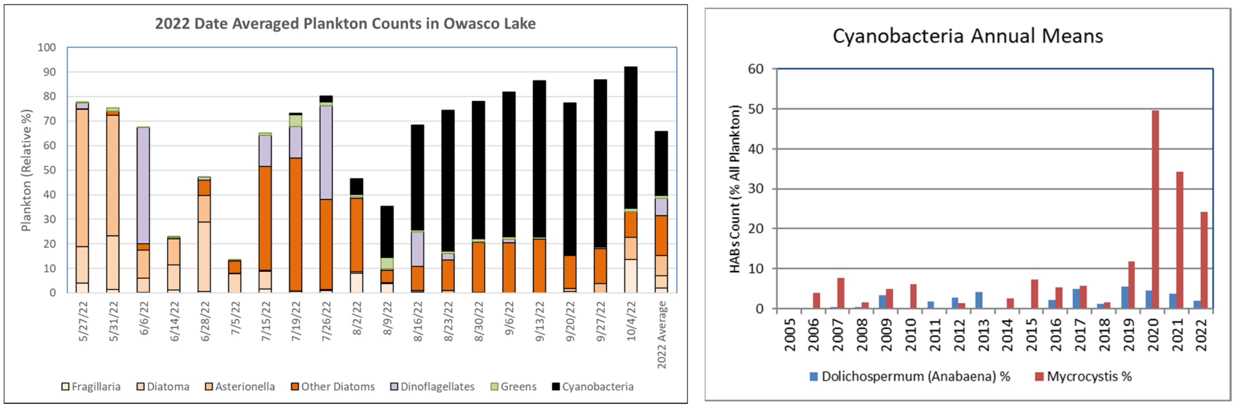


Fig. 16. Date averaged plankton data for 2022 (left). Mean cyanobacteria abundance since 2005 (right).

Cyanobacteria genera, *Microcystis* and to a lesser degree *Dolichosperma*, continued their 2020 dominance into 2022 during the late July through September surveys (Fig. 16). Detection of cyanobacteria in the lake is not new, as they were always detected in the open water of Owasco Lake since the initial FLI surveys in 2005. In fact, cyanobacteria species were documented in neighboring Finger Lakes as long ago as 1914[7]. However, major blooms of cyanobacteria have been increasingly detected along the shoreline in Owasco Lake since 2012[8]. These blooms were

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

restricted to the late summer and/or early fall, with *Microcystis* representing over 40% (up to 85%) of the plankton counts during a late summer surveys in 2007, 2010, 2014, 2015, 2017, 2019, 2020, 2021, and 2022, and *Dolichosperma* making up 30% of the late-summer counts in 2013. Starting in 2020, the offshore dominance of cyanobacteria decreased since a peak in 2020, with a maximum relative percentage of 92% for *Microcystis* during the 8/5/20 survey, a 84% in the 8/3/21 survey, and 68% in the 9/27 survey. This is consistent with the Fluoroprobe results if differences between cell counts (plankton tows) and pigment concentrations (fluorescence data) are considered.

Water Quality Rank: Water quality rank for Owasco Lake was similar in 2022 than previous years, except for 2014 (Table 7 in appendix, Figs. 17). The ranks were based on annual average Secchi disk depths, and surface water concentrations of chlorophyll-a, total and dissolved phosphorus, nitrate and total suspended sediments collected by the May through October, monthly FLI survey. These annual ranks revealed similar trends between lakes as other comparative water quality / trophic state methods like the oligotrophic-eutrophic trophic states (discussed above), and Carlson's Trophic Indices[9] that quantitatively combine chlorophyll-a, total phosphorus and Secchi depth data (Fig. 17). In 2022, water quality in Owasco was more degraded than Seneca Lake, the only other Finger Lake surveyed in 2022.

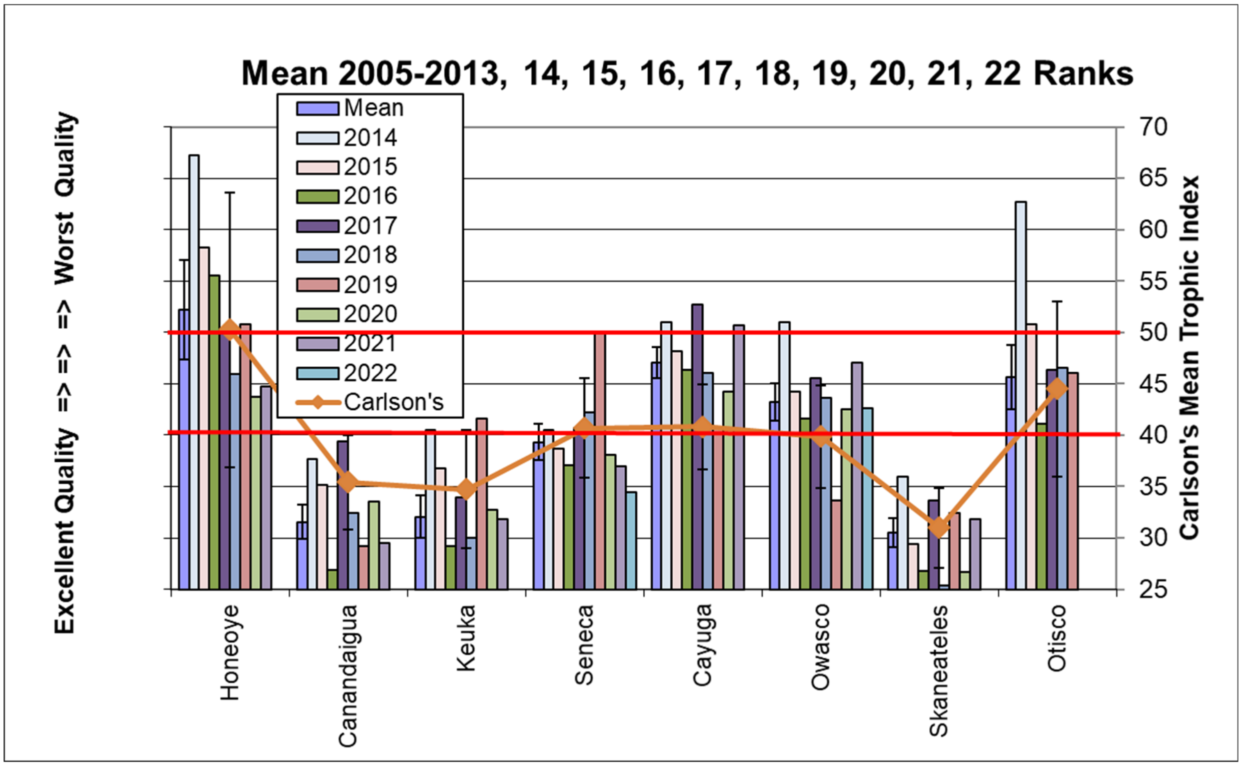

Fig. 17. Water Quality Ranks from 2005 – 2021 for the eight easternmost Finger Lakes, and in 2022 for Seneca & Owasco Lakes. Otisco was excluded from the survey starting in 2020. The leftmost "mean" dark blue bar averaged the 2005 - 2013 ranks for each lake with a 1σ standard deviation error bar. Carlson's mean trophic indices using the mean Secchi depths, total phosphate and chlorophyll concentrations are also shown. The red horizontal lines reflect the oligotrophic-mesotrophic and mesotrophic-eutrophic boundaries for Carlson's trophic indices

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[9] Carlson, R.E. 1977. A trophic state indicator for lakes. Limnology & Oceanography, 22:361-369.

Owasco Lake water quality improved from 2014 through 2019, and declined slightly in 2020, 2021 and 2022. It suggests that the observed change in water quality in these lakes are not only influenced by nutrient loading and rainfall totals but are probably also be influenced by a number of other sometimes competing and always intertwined factors. First and foremost, the degree of water quality protection legislation and its implementation, that protect the lakes from nutrient and sediment loading issues. The trend suggests that the recently adopted BMPs were not sufficient to improve water quality, especially in "normal" rainfall years. Algal populations are also influenced by "top-down" ecological pressures from zebra and quagga mussels, Asian clams and *Cercopagis*, the fishhook water flea.

DRONE FLIGHTS & NEARSHORE SPECTRAL DATA

Drone flights during each visit to the four dock sites unfortunately did not coincide with cyanobacteria blooms in 2022. The preliminary analyses did not reveal major changes in the macrophyte densities at each site.

The relationship between the spectra of light to algal concentrations is complicated. Complete spectra (from 340 to 823 nm at ~0.5 nm intervals) of the upwelling and down-welling light were collected multiple times at the two offshore and four dock sites (Fig. 18). The intent was to determine if the ratio between upwelling and down-welling spectra could resolve algal concentrations. Like earlier years, the 2022 results were still encouraging and revealed potential algal signatures in the near infrared portions of the spectrum where algae reflect/emit the largest up/down ratios of light (wavelength of ~700 nm). A recent workshop at the USHABs conference in Albany, NY, provided an algorithm to differentiate between cyanobacteria and other algae to be investigated in more detail in the coming year. We are still concerned that the reflection of clouds on the water's surface and the lake floor at the dock sites and the reduction in downwelling light by the clouds created an irresolvable impact the spectral results. The offshore sites provided similar results, although backscattering by waves and the reflections of the boat also influenced the spectra results.

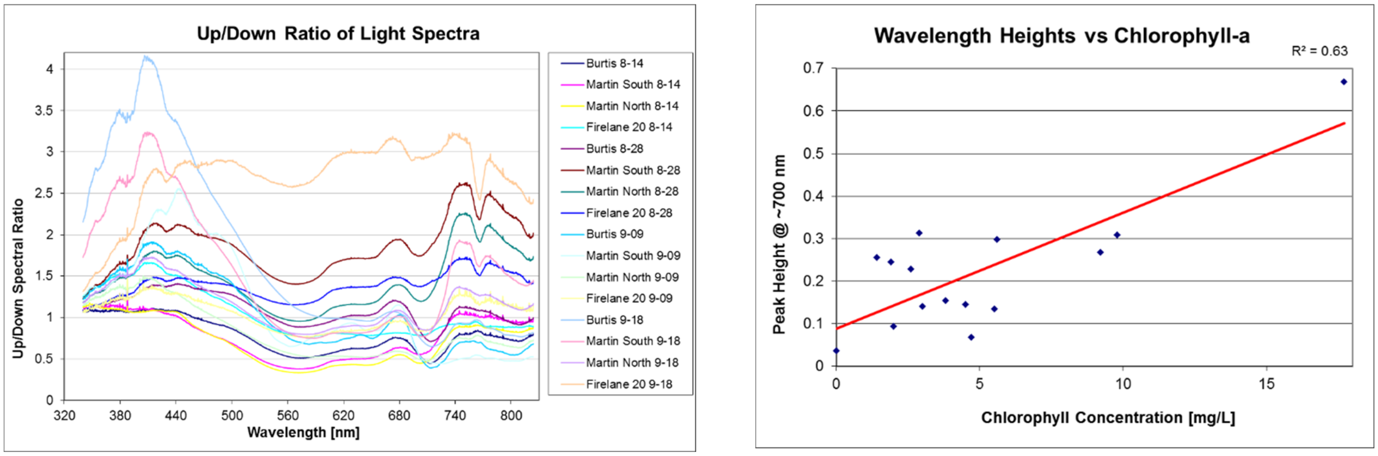

Fig. 18. Ratio of upwelling and down-welling spectra from the dock sites (left). Algal signatures are typically in the near infrared (~700 nm). Peak height at 700 nm for each up/down spectral ratio vs. chlorophyll-a concentration (right) show some promise.

FLI BUOY & DOCKSIDE DATA

The FLI meteorological and water quality monitoring buoy was redeployed in Owasco Lake during the 2022 field season. It revealed higher resolution but otherwise consistent changes in the water column as described in the CTD section (Fig. 19). More information is available in the companion HABs report.

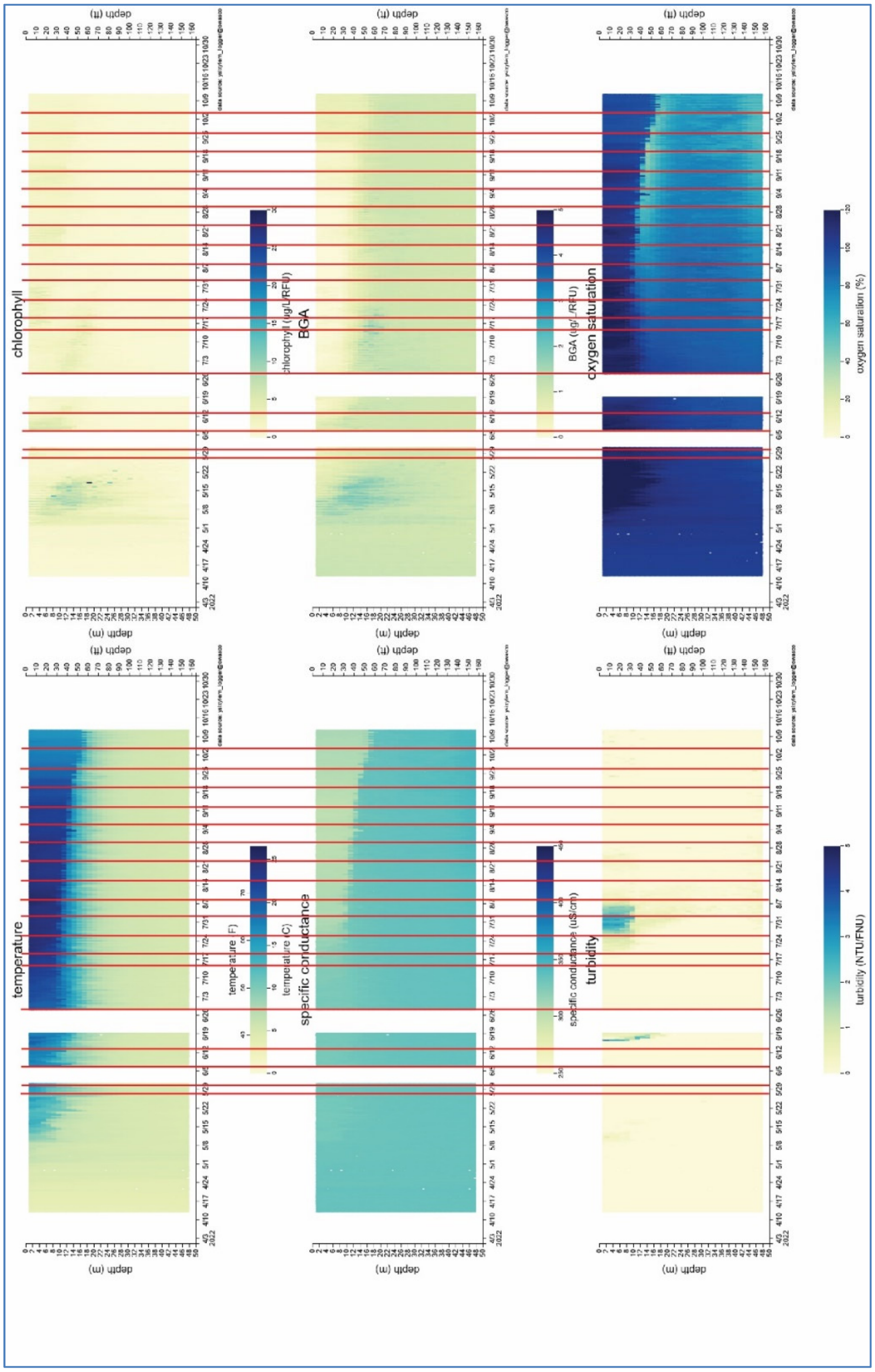

Fig. 19. Buoy water quality data in 2022. The data shown above are raw uncalibrated values. Subsequent calibrations alter the turbidity and chlorophyll data slightly (see companion report). The red lines depict the weekly monitoring cruise dates.

STREAM MONITORING

Stream Discharge: The 2022 stream discharge data collected by the OWLA volunteers are not presented here. Instead, this section focuses on the Moravia, USGS gauge, daily discharge data and the HyFi stream stage data.

The Owasco Inlet (USGS Gauge, 4235299) field-season, mean daily discharge of 4.5 m^3/s in 2022 was smaller than every year since 2009 but 2016, and indicative of a "dry" year (Fig. 20). Similar variability was observed for the Owasco Outlet where the mean 2022 flow of 7.6 m^3/s was smaller than every year since 2009, except 2016 (USGS Gauge, 4235440, Fig. 20). The trends were consistent with annual and seasonal rainfall, lake levels and water table depths. Flow variability during any one year at the Owasco Outlet does not precisely parallel the Inlet because the Outlet has additional mandates on flow besides rainfall that include stabilizing lake levels to the seasonal rating curves, minimizing downstream flooding and other concerns.

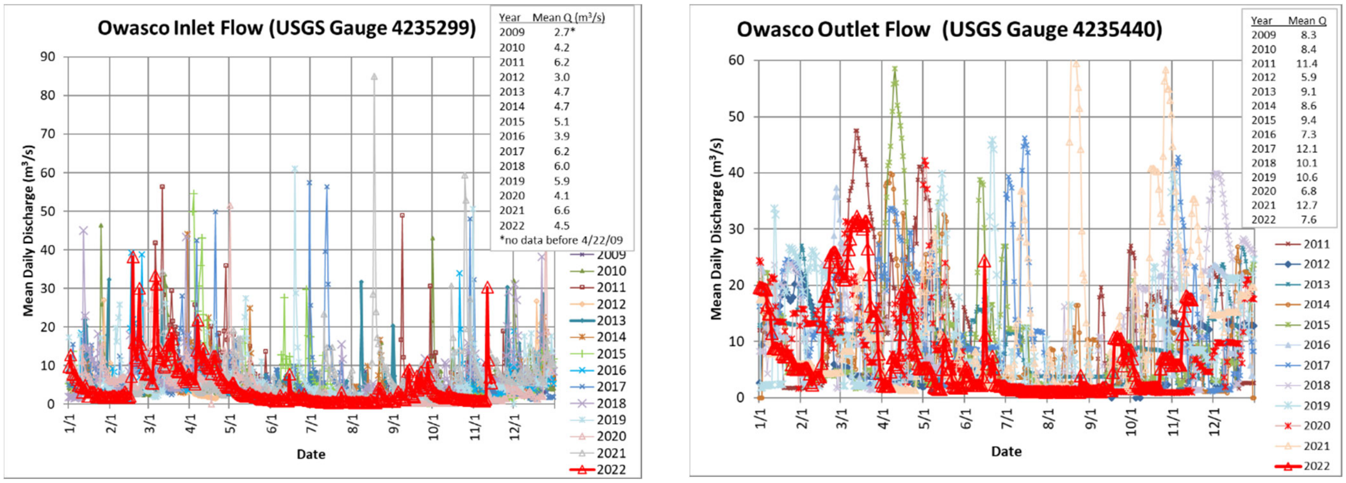

Fig. 20. Stream discharge for the Owasco Inlet near Moravia (left) – USGS Stream Gauge 4235299 and the Owasco Outlet (right) – USGS Stream Gauge 4235440.

Extreme Events: The Owasco Inlet revealed precipitation induced events in its hydrology (Fig. 21). Box and whisker plots of mean daily USGS discharge data for the May – June period at Owasco Inlet revealed larger mean flows in 2011, 2015, 2017 and 2019, and slightly lower mean flows during 2010, 2012, 2013, 2014, 2016, 2018 and 2020 (Fig. 21). The top whisker in the B&W plot, which marks the maximum daily recorded discharge, revealed significantly larger events in 2014, 2015, 2017, 2019 and 2020 than the other years in the record. These events are critical because large events generate exponentially larger impacts on nutrient and sediment loads to the lake.

Seasonal Variability: Seasonally, the largest discharges at the Owasco Inlet in 2022 were during the Spring and Fall seasons (Fig. 22). As events became more frequent in the fall, baseflow was rejuvenated, and the stream maintaining high flows throughout the fall season.

Differences to Earlier Years: The 2022 annual mean discharge was similar to the other small mean discharges detected at the Owasco Inlet (Fig. 23). The annual variability parallel annual changes in precipitation (both seasonal totals and max daily events in each year), lake levels and water table depths.

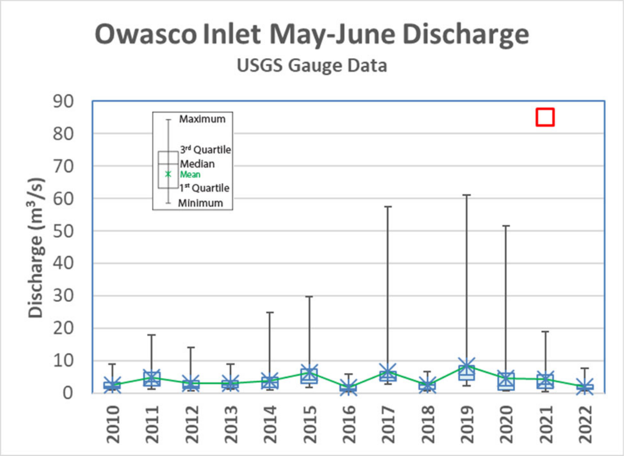

Fig. 21. Box and Whisker plot of daily mean discharge during the May – June season over the past thirteen years for Owasco Inlet near Moravia using the USGS Stream Gauge 4235299 data. Notice the Inlet responds dramatically to rain events, the most serve events were after the May – June time interval. The red square marks the huge August flood event in 2021.

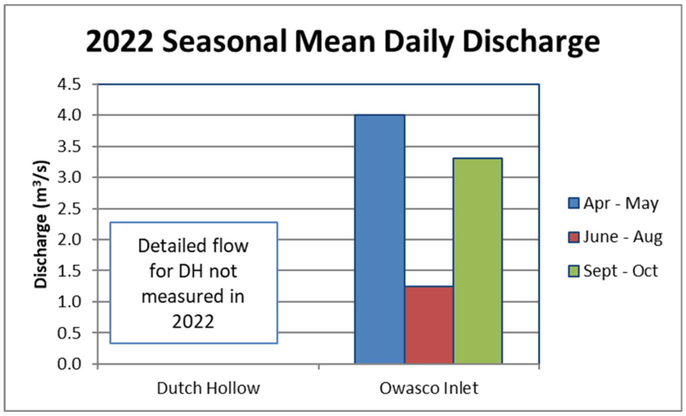

Fig. 22. Seasonal averaged stream discharge for the Owasco Inlet USGS gauge. Dutch Hollow data are not reported here.

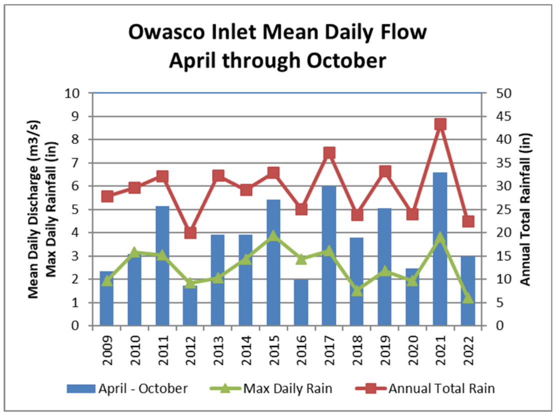

Fig. 23. Field season annual average stream discharge for the Owasco Inlet USGS gauge. Also shown are the field season total precipitation and max daily precipitation using the NY-CY-8 site.

HyFi Data: HyFi stream stage data from the Owasco Inlet (OI) at Groton (Walpole Rd), Locke (Rt 90) and Moravia (Cayuga St), Dutch Hollow Brook and Long Point Creek compared favorably (Fig. 24). The stage time-series revealed "event" peak discharges induced by precipitation events at the same time. The variability in peak heights and return times to baseflow parallels the size of the watershed upstream from the data collection site and rainfall variability between basins. Those sensors monitoring larger watersheds revealed proportionally taller peak stages and longer return to baseflow times, as expected. Two exceptions are noteworthy. Sucker and Veness Brook HyFi data were out of sync with the other watersheds. We believe that these sites measured lake levels and not stream stage, as both time series more closely mimicked the level of Owasco Lake than the neighboring stream stage data. Sucker Brook revealed similar issues in 2021.

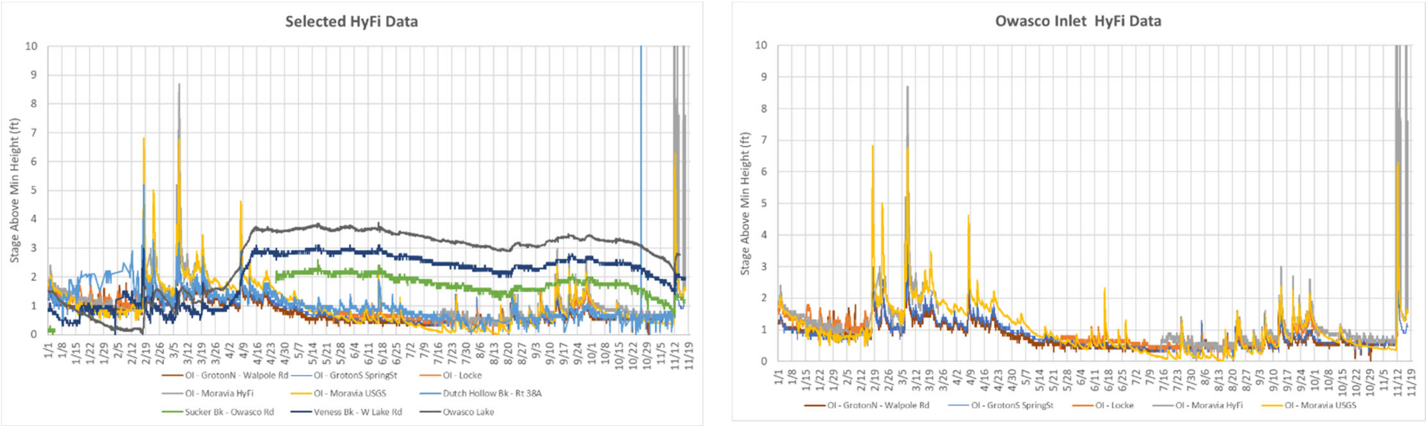

Fig. 24. Comparison of selected HyFi stage data to the stage data at the USGS Gauge in Moravia and the USGS Lake Level data at Auburn. The sensor at Long Point was installed late in the season and not shown here.

A direct comparison of the USGS stage data and the HyFi stage data at the Owasco Inlet Moravia site revealed very similar depth and hydrodynamic responses of the Owasco Inlet but also a persistent offset of a few tenths of a foot (Fig. 24). An earlier HyFi report confirmed a strong correlation between the HyFi and USGS data ($r^2 = 0.94$) with a mean offset of 0.8 ft.[10] The HyFi report indicated that the offset and other small differences were probably due to the separation of the two sites by 0.37 miles, and different stream bed geometries at each site.

Stream Nutrient & TSS Concentration Data: The Owasco Watershed Lake Association volunteers collected grabs samples twice a month at seven sites in the watershed. Upstate Freshwater Institute, a certified lab, analyzed the samples for total phosphate (TP), total dissolved phosphate (TDP), soluble reactive phosphate (SRP), total nitrogen (TN), nitrate/nitrite (NO_x), ammonium (NH_4), and total suspended sediment (TSS) concentrations. The OWLA team planned to collect baseflow and event samples. However, the dry weather prevented systematic collection of event samples.

Total phosphate (TP) concentrations in their 2022 grab samples ranged from 8.1 to 1,402 µg/L, and averaged 99 µg/L (Table 8 in appendix, Fig. 25). The Owasco Inlet at Groton site recorded the largest average TP at 241 µg/L, and the Owasco Inlet at Moravia site the smallest at 36.5 µg/L. The downstream decrease in TP along the Inlet is interpreted to reflect the dilution of TP concentrations by the input of dilute tributaries. A few large TP results in 2022 are interpreted as event samples, as baseflow TP concentrations were typically below 30 µg/L at Dutch Hollow Brook and the Owasco Inlet at Moravia in the past. Total Dissolved Phosphate (TDP) concentrations ranged from 4 to 1,430 µg/ and averaged 53 µg/L in 2022. The Owasco Inlet at Groton site recorded the largest average TDP at 204 µg/L, and the Moravia Owasco Inlet at Moravia site the smallest at 13.2 µg/L(dilution by tributaries). Soluble Reactive Phosphate (SRP) concentrations ranged from 0.9 to 1,433 µg/L and averaged 42.6 µg/L. Again, the Owasco Inlet at Groton site recorded the largest average SRP at 188 µg/L, and the Owasco Inlet at Moravia site recorded the smallest average at 6.4 µg/L (dilution by tributaries). Total Nitrogen (TN) concentrations ranged from 0.04 to 6.0 mg/L and averaged 1.3 mg/L. The Long Point site recorded the largest average at 2.2 mg/L, and the Owasco Inlet at Locke site recorded the smallest average at 0.9 mg/L. Nitrate/Nitrate (NO_x) concentrations ranged from 0.01 to 5.4

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[10] Riley, Joshua, 2021. HyFi and USGS Depth Comparisons. A HyFi report. 20 pgs.

mg/L, and averaged 0.9 mg/L. The Long Point site recorded the largest average NO_x at 2.0 mg/L, and the Sucker Brook site recorded the smallest average at 0.8 mg/L. Ammonium (NH_4) concentrations ranged from 0.07 to 1.2 mg/L, and averaged 0.1 mg/L. The Owasco Inlet at Moravia site recorded the largest average NH_4 at 0.2 mg/L, and the Dutch Hollow Brook site recorded the smallest average at 0.1 mg/L. Finally, Total Suspended Solids (TSS) concentrations ranged from 0.7 to 259 mg/L and averaged TSS 21.3 mg/L. The Sucker Brook site recorded the largest average at 58.9 mg/L, and the Owasco Inlet at Groton site recorded the smallest average at 5.6 mg/L.

The results are similar to, complimented and provided additional insights to the earlier stream data. The 2022 annual average nutrient (TP, SRP, NO_x) and total suspended sediment concentrations at Dutch Hollow Brook and Owasco Inlet at Moravia are similar to earlier results after obvious event samples were excluded from the 2022 average (Fig. 26). The phosphorus and nitrogen concentrations in all samples declined from TP (high), TDS to SRP (low), and TN (high), NO_x and NH_4 (low) as expected. Dutch Hollow Brook had the largest percentage of particulate phosphorus of the phosphorus species, and Groton had the largest contribution by soluble reactive phosphate. It is interpreted to reflect the erosion of soils at Dutch Hollow and input of wastewater effluent at Groton. Nitrate/Nitrate, the oxidized forms of dissolved nitrogen, dominated the nitrogen species, as expected in the oxygenated stream environments, in that, ammonium, that is released by bacterial decomposition of organic material, will quickly oxidize to nitrate in oxygenated waters. Nitrogen concentrations reflected large due to the agricultural LULC dominance in the watershed.

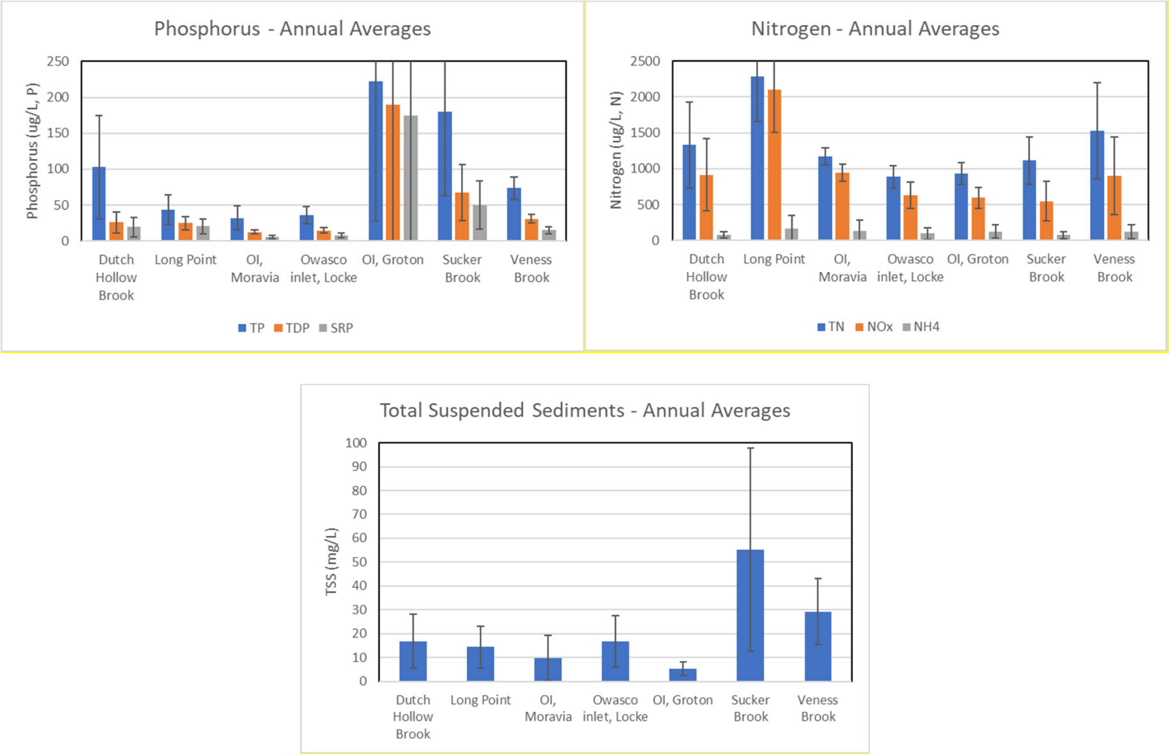

Fig. 25. Site averaged (±1σ error bars) nutrient and suspended sediment concentrations for the stream sites in the watershed.

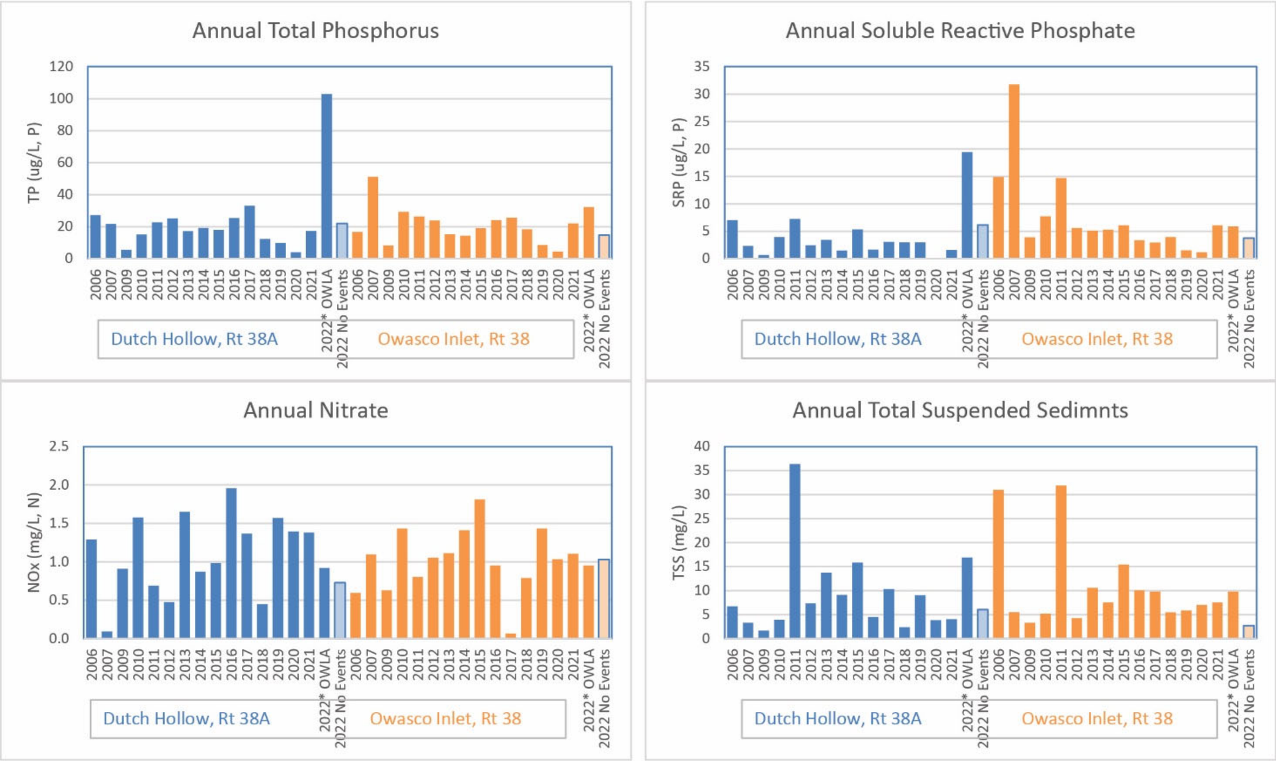

Fig. 26. Mean annual concentrations of total phosphorus, soluble reactive phosphorus, nitrate and total suspended sediments at the Dutch Hollow Brook and Owasco Inlet at Moravia. Two 2022 bars are shown, the left bar included obvious event samples, and the right bar excluded the obvious event samples in the respective basins.

Stream Land Use Land Cover – Nutrient Load Connections: The 2022 stream sites were selected for their diversity in basin size and LULC characteristics to discern which contributes the greatest percentage of nonpoint source nutrients and suspended sediments to the lake (see Table 2, Fig. 1). Unfortunately, the lack of reliable 2022 discharge data prevented the calculation of nutrient and sediment loads to the lake, and dictated another method to discern the LULC to nutrient (TP, TN) and sediment loading connections.

Annual mean TP, TN and TSS concentrations were divided by their respective basin areas to highlight changes in LULC on these parameters (Fig. 27). The normalized values were plotted versus LULC percentages for each basin (Fig. 28). A positive correlation was detected between agricultural LULC and the respective TP, TN and TSS contributions to the lake. A negative correlation was detected between forested LULC and the respective TP, TN and TSS contributions to the lake. The variability in residential+urban landscapes in these basins was too small to discern a relationship between urban land and nutrient and sediment contributions. Clearly more work is required to identify the other factors contributing to these relationships and the observed variability from the best-fit straight line, but the plots indicate that agricultural LULC is the primary nonpoint source of nutrients and sediments to the lake. This is critical because the Owasco watershed is dominated (~50%) by agricultural land. These findings support and should be used to refine the SWAT model predictions used in the 9E Plan for the Owasco Watershed (see next section).

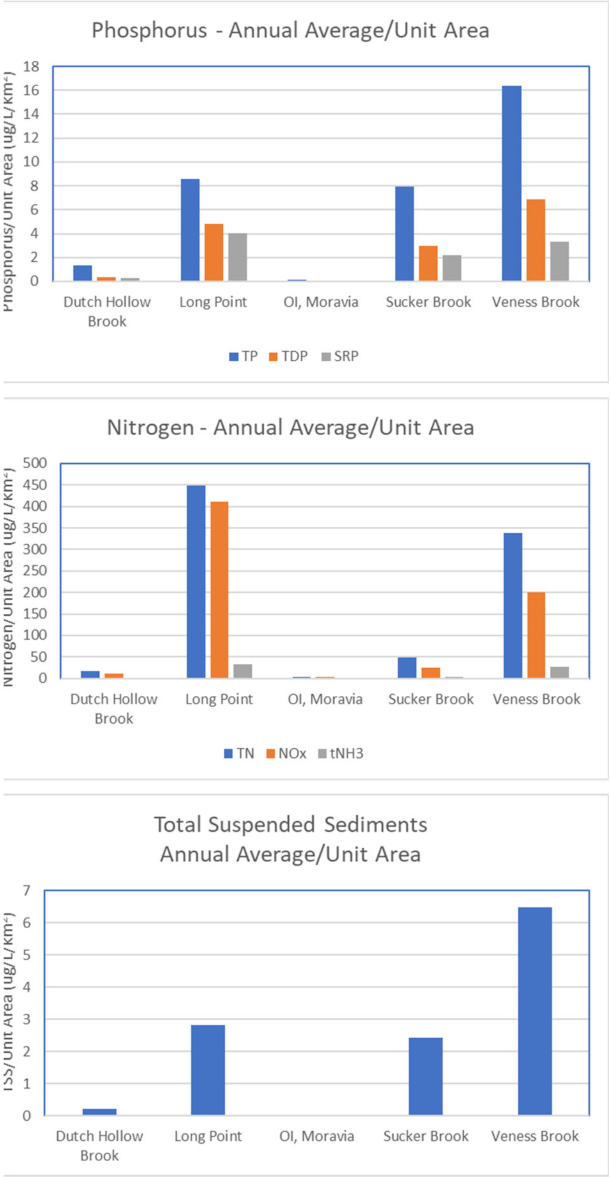

Fig. 27. Site averaged nutrient and sediment concentration per unit basin area for the five terminal stream sites sampled in this survey.

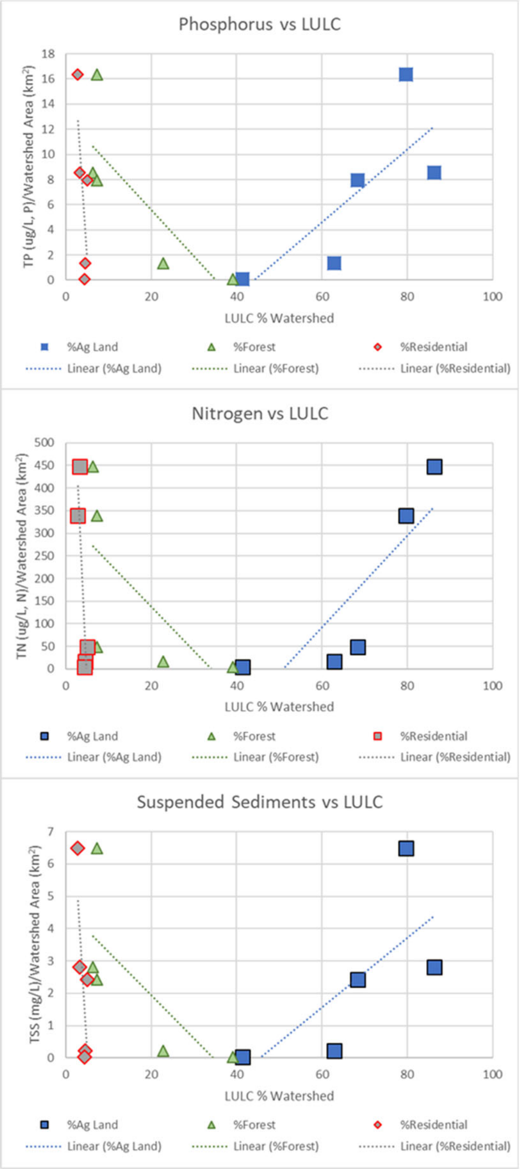

Fig. 28. Annual average nutrient and sediment concentrations / unit basin area versus land use - land cover (LULC) in the basin.

EVENT SAMPLING AT DUTCH HOLLOW BROOK

Detailed event sampling was not preformed in 2022. However, the previous 2011 through 2021 event vs baseflow investigations clearly demonstrated the importance of rainfall events on the delivery of nutrient and sediments to the lake. Events delivered, on average, 90% of the TP (annual range, 70 – 99%), 92% of the SRP (60 – 99%), 98% of the TSS (95 – 99%) and 88% of the NO_x (73 – 99%) loads to the lake compared to base flows (Table 9).

A dependence on maximum daily rainfalls was also observed in the annual mean fluxes of nutrients and sediments from Dutch Hollow Brook (Fig. 29). As observed earlier in the report, weaker or minimal correlations were revealed for total annual rainfall. It suggests that the largest storms deliver the most nutrients and suspended sediments and, in turn, impact water quality, i.e., the concentration of algae, in the lake. More work is required to firm up these relationships as many other factors like, the quality and quantity of numerous remediation practices, impact the results.

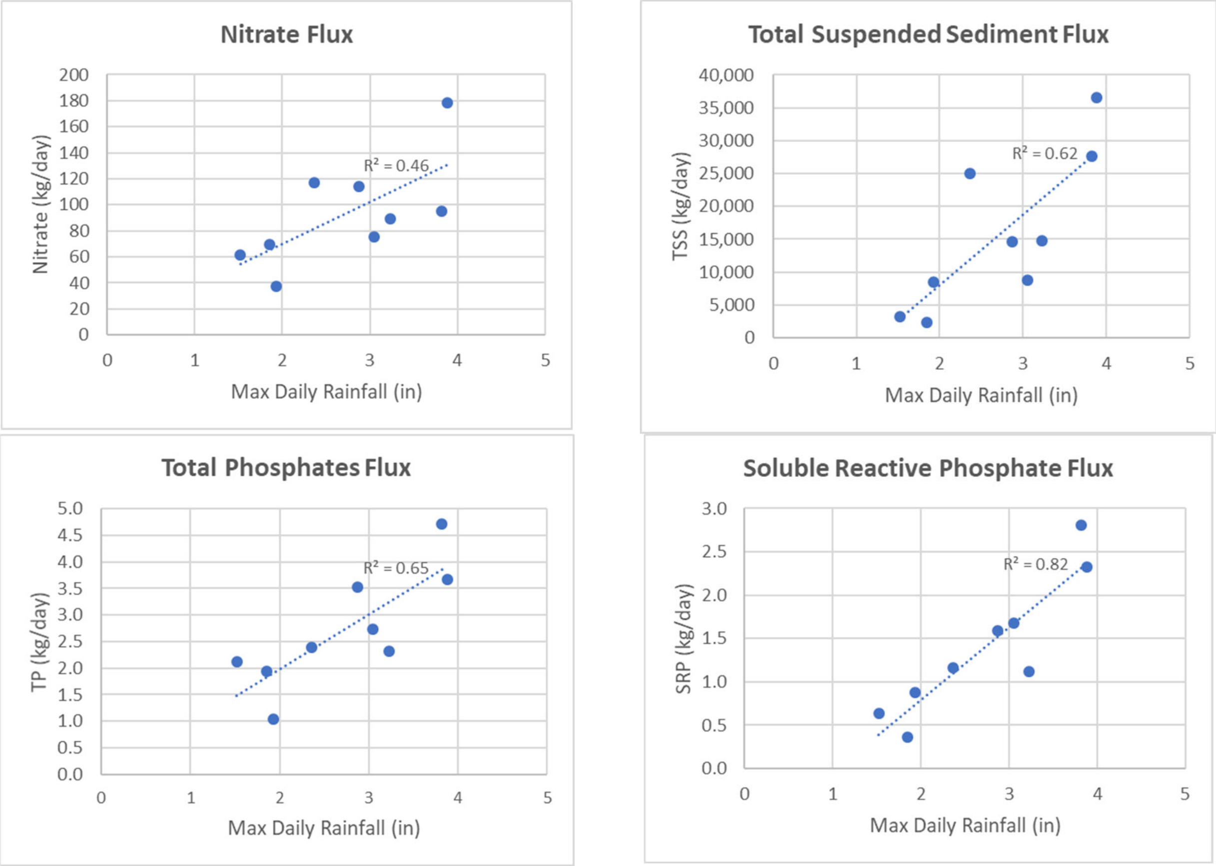

Fig. 29. Annual maximum daily rainfall versus nutrient and sediment fluxes from Dutch Hollow Brook.

Table 9: 2011 – 2021 Autosampler Fluxes at Rt 38A Dutch Hollow Brook.

2011 (6/9-11/4)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	8,700	75	2.7	1.7
Event (kg/day)	24,500	180	6.9	4.5
Baseflow (kg/day)	115	19	0.4	0.1
% by events	99%	84%	90%	96%
2012 (3/20-11/2)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	2,400	69	1.9	0.4
Event (kg/day)	6,850	150	4.0	0.6
Baseflow (kg/day)	190	28	0.9	0.2
% by events	95%	73%	70%	60%
2013 (4/10-10/29)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	7,550	270	4.4	1.3
Event (kg/day)	12,000	370	6.4	1.8
Baseflow (kg/day)	290	100	1.3	0.3
% by events	99%	85%	89%	91%
2014 (4/19-10/28)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	14,600	115	3.5	1.6
Event (kg/day)	36,000	185	6.5	3.2
Baseflow (kg/day)	300	67	1.5	0.5
% by events	99%	65%	74%	81%
2015 (4/19-10/28)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	35,600	180	3.7	2.3
Event (kg/day)	81,500	370	7.7	5.2
Baseflow (kg/day)	185	27	0.5	0.0
% by events	99%	93%	94%	99%
2016 (4/13-10/25)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	7,482	1,323	1.4	0.7
Event (kg/day)	25,844	4,602	4.7	2.3
Baseflow (kg/day)	137	11	0.1	0.0
% by events	99%	99%	97%	99%
2017 (4/25-11/25)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	14,770	84	2.2	1.1
Event (kg/day)	29,195	167	4.2	2.1
Baseflow (kg/day)	176	9	0.3	0.1
% by events	99%	94%	92%	96%
2018 (4/12-11/4)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	3,277	62	2.1	0.6
Event (kg/day)	6,953	110	4.2	1.3
Baseflow (kg/day)	158	21	0.3	0.1
% by events	97%	82%	91%	95%
2019 (4/10-10/29)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	25,018	117	2.4	1.2
Event (kg/day)	34,191	150	3.2	1.6
Baseflow (kg/day)	331	29	0.3	0.1
% by events	99%	93%	97%	98%
2020 (4/29-10/30)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	8,556	38	1.0	0.9
Event (kg/day)	19,557	81	2.2	1.9
Baseflow (kg/day)	175	4	0.1	0.1
% by events	99%	94%	93%	93%
2021* (4/11-11/2)	**TSS**	**NOx**	**TP**	**SRP**
Mean (kg/day)	27,697	95	4.7	2.8
Event (kg/day)	50,352	173	8.1	5.1
Baseflow (kg/day)	170	0	0.6	0
% by events	99.7%	99.8%	95%	99%

*Used the estimated event concentrations

The event *versus* baseflow data from 2011 through 2021 also indicated that base flow grab samples severely underestimated annual fluxes from a stream. For example, the 2021 autosampler estimated a mean sediment flux of 27,700 kg/day, total phosphates 4.7 kg/day, dissolved phosphates 2.8 kg/day, and nitrate 95 kg/day; whereas the grab sampling estimated an annual mean flux of 300 kg/day for sediments, 0.7 kg/day for TP, 0.1 kg/day for SRP, and 70 kg/day for NO_x. The grab sample estimates for TSS, TP and SRP were much smaller because these samples were biased to baseflows. Grab samples were therefore less accurate for detailed flux estimates compared to the daily data collected by the autosampler and data loggers. However, grab samples were essential for stream segment analysis, i.e., the investigation of nutrient and sediment sources from within a watershed.

One facet of nutrient and sediment delivery to the lake is still poorly understood and should be investigated in the future. Data are unavailable to quantify the nutrient and sediment delivery by road-side ditches and drainage tiles draining agricultural fields. The scientific literature indicates that their contributions should be significant but a few examples suggest otherwise. Someone should investigate their contributions in the Owasco watershed to resolve this debate. If they are significant, they pose simple remediation strategies, e.g., deploy phosphorus binding materials at the end of every drain tile, hydroseed and install catch basins periodically along drainage ditches, etc., to reduce their contributions.

PHOSPHORUS BUDGET:

Even though 2022 inputs and outputs were not estimated, the phosphorus budgets presented in earlier reports is repeated here due to its significance on water quality issues in the lake.

Phosphorus loads are critical to the health of and water quality in Owasco Lake because phosphorus limits algal growth and thus impairs water quality and clarity. The recent increase of cyanobacteria blooms, some with life threatening concentrations of toxins, also highlight its importance. Clearly, stream loads dominate the inputs, even in “dry” years. However, the stream inputs are only one part of the equation. A complete budget must include other inputs like municipal wastewater treatment facilities, onsite septic systems, atmospheric loading and lakeshore lawn fertilizers. Outputs must also be calculated to estimate the net change in phosphorus for the lake (Fig. 30). The net change (Inputs – Outputs) is critical because the amount of phosphorus increases in the lake, if inputs exceed outputs. Phosphorus decreases in the lake, if inputs are less than outputs. Finally, phosphorus remains the same, i.e., at equilibrium, when inputs equal outputs. To improve water quality, the inputs of phosphorus must be smaller than outputs for a decade or more (multiple water retention times). A sustained reduction allows phosphorus in the lake to be flushed out the outlet or be buried in the sediments, and increasingly limit algal growth, and improve water quality and clarity.

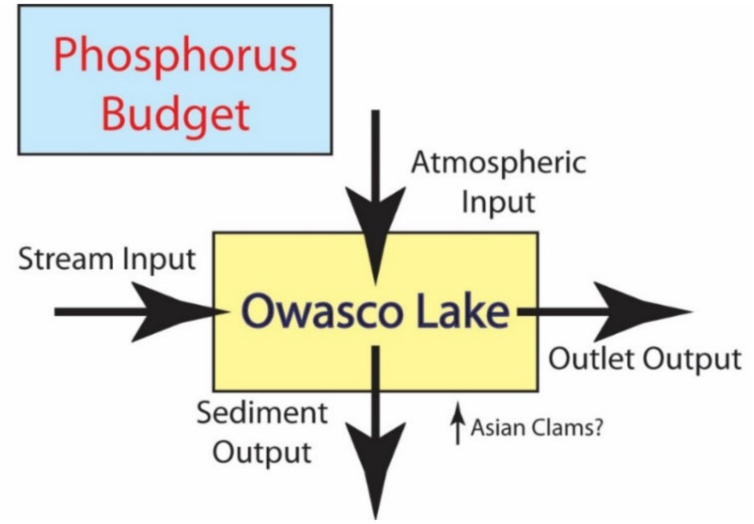

Fig. 30. The Owasco Lake phosphorus budget: Sources and sinks for phosphorus in Owasco Lake. Water quality improves if inputs are less than outputs for a number of years.

The Inputs:

Stream Inputs: The 2011 through 2021detailed 38A autosampler data calculated a mean total phosphate flux from Dutch Hollow Brook. An extrapolation of annual fluxes and surface areas from Dutch Hollow Brook and Owasco Inlet to the entire Owasco watershed, estimated an annual input phosphorus from every remaining stream to the lake. The stream extrapolation incorporates the input from all the 1st and 2nd order (small) tributaries like Veness, Sucker, and Fire Lanes 20 and 26. The estimated fluvial inputs paralleled those predicted by the 9E Plan SWAT model for this watershed.

Other Inputs: Inputs were also tabulated and/or estimated from the Moravia and Groton WWTFs[11], atmosphere and septic systems. The total phosphate contribution to the Owasco Inlet by the Groton Municipal Wastewater Treatment Facility has continued to be significantly smaller since a peak in 2003. The decrease reflects the DEC mandated a phosphorus load limit for the facility's effluent in 2007 (Fig. 31). The load contributed by the Moravia WWTF has been and continued to be very small as well. Since 2010, both facilities averaged ~0.1 to 0.5 kg/day, well within their mandated TP effluent limits (0.95 kg P/day).

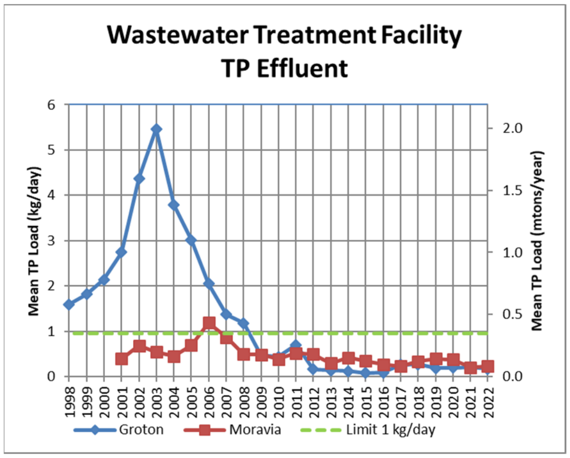

Fig. 31. Phosphorus loads to the Owasco Inlet from the Moravia and Groton wastewater treatment facilities.

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[11] http://cfpub.epa.gov/dmr/facility_search.cfm Groton: NY0025585, Moravia: NY0022756.

The 2011 report estimated atmospheric and septic system inputs at 0.1 metric tons/year and ~1 metric ton/year, respectively, and these loads were used every year of this study. This septic estimate is slightly larger than N. Colas' estimate from septic systems using GIS modeling[12]. Loads from water fowl were estimated at 0.1 mton/year assuming 1,000 geese poop on average 3 times/day, yielding 1.5 g dry poop/dropping at 1% phosphorus content[13], and live on Owasco Lake for the entire year. This load was deemed insignificant and ignored as the estimate exaggerated geese numbers and length of stay. Lawn fertilizers are supposed to be phosphorus free, thus not a source. The contribution from clams/mussels (Asian clams and zebra/quagga mussels) and decaying macrophytes is unclear at this time as mussel and plant lake-floor densities are not well known. The extent mussels redistribute nutrients from the offshore to nearshore locations is also unclear. These should be investigated in the near future as nutrient inputs from lake-floor sediments are speculated to be a significant nutrient source for nearshore cyanobacteria blooms (see companion report). Macrophytes release P taken up from the sediments whereas zebra/quagga mussels redirect P from the open water algae to the nearshore lake floor. The mean input of ~10 mtons of P/year is similar to the 9E Plan's SWAT Model predictions.

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). Phosphorus losses were estimated from annual mean total phosphate concentrations in the lake and annual mean daily discharges out the Owasco Outlet (USGS Owasco Outlet Gauge #04235440), and this loss added to an estimated flux of phosphorus to the sediments. The earlier reports 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 Net Flux: Subtract the annual total outputs from the total inputs to determine an annual Net Flux for Owasco Lake (Figs. 32 & 33). Up to 2016, inputs > outputs. Thus, the lake gained phosphorus and water quality should have declined. A steady rise in chlorphyll-a and Total phosphate concentrations were observed from 2011 through 2015. Since 2016, net P losses or steady state conditions were observed. The recent, multi-year, negative or steady state P fluxes suggests that the current level of remediation efforts in the watershed kept the lake at or near steady state, but were not sufficient enough and/or spanned enough time to significantly improve water quality in the lake. These years were primarily "dry" years with minimal P inputs as well, which also assisted in steady state water quality conditions in the lake. It also indicates that the current level of remediation efforts were insufficient to curtail the larger inputs in 2021, a "normal" and huge event rainfall year. Remember, 2021 and 2022 experienced large "abnormal" events, however these "abnormal" events are becoming the new "normal" in a global warming world. Therefore, the remediation efforts must significantly increase to curtail P loading and improve water quality in the lake into the future.

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[12] Colas, N., 2021. Estimated contributions from Septic Systems. 9E Plan Public Meeting #2, 9/21/21.

[13] Fleming and Fraser, 2001. The impact of water fowl on water quality – a literature review. Ridgetown College, U of Guelph, Ontario, Canada.

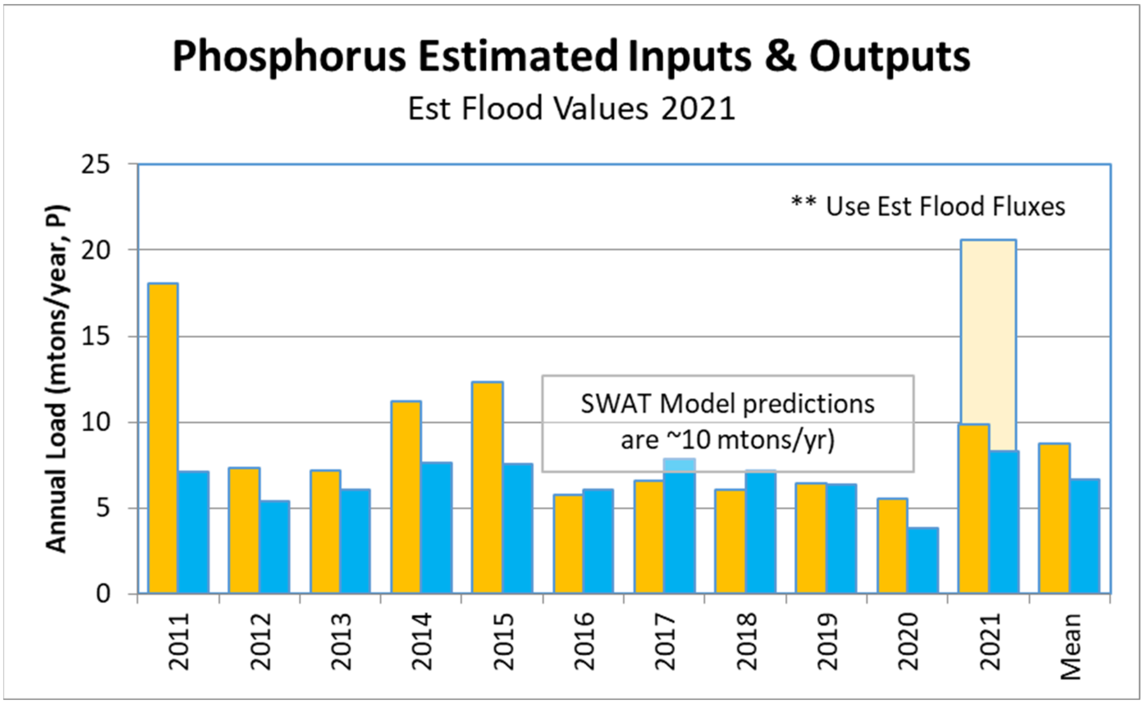

Fig. 32. Estimated annual total phosphorus inputs (orange) and outputs (blue) for Owasco Lake. The 2021 light orange bar included the interpolated flood event data.

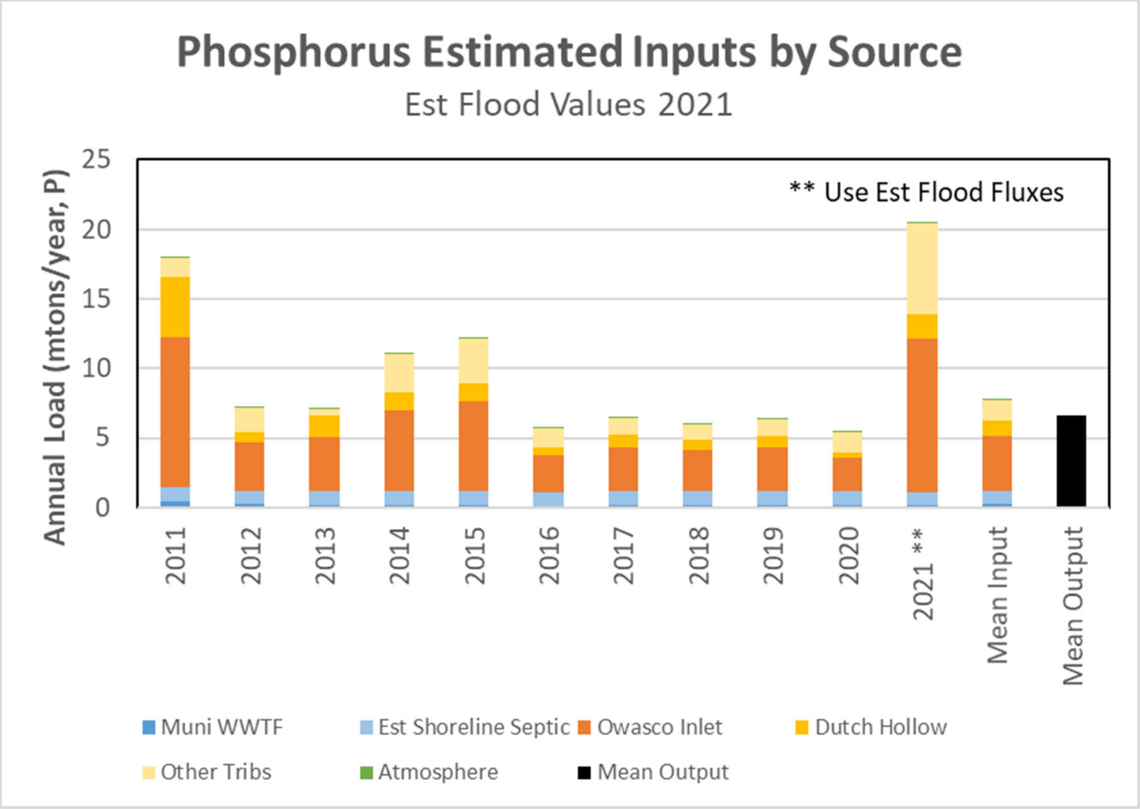

Fig. 33. Estimated annual inputs of phosphorus by source for Owasco Lake. The 2021 light orange bar included the missing flood event data.

Where should more remediation efforts be directed to reduce future P loading? The data indicate that the total contribution from stream sources changed from year to year, but were significantly larger than the relatively constant inputs from other sources (Fig. 33). For example, the annual contribution from the Owasco Inlet, excluding the wastewater treatment facilities (WWTFs), ranged from 3 to 30 metric tons since 2011. The variability reflects changes in precipitation intensity, seasonality, frequency, and totals. In contrast, the two WWTFs contributed from 0.1 to 0.5 metric tons/year over the same time interval. Despite the variability in stream inputs, nonpoint source materials via streams were always the largest contributors of phosphorus to the lake, ranging from 77 to 94% and averaging 84% of the total load. The lowest contribution by streams was in 2020, a very "dry" year, but even in 2020, streams still dominated the source of nutrients and sediments to the lake (77% of total loads). The stream dominance and its associated nonpoint sources clearly pinpoints where additional remediation efforts must be focused to reduce phosphorus loads to the lake.

Other practices should be implemented. Roadside ditches should be hydro-seeded and/or utilize other flow reducing structures to decrease water velocities and the erosion potential of the draining water. Slower water speeds allow for greater deposition of the particles with the attached phosphorus before it enters the stream. This is critical if drain tile effluent enters a roadside ditch as drain tiles more efficiently transport phosphorus from the fields to the ditch. This last statement is open to some interpretation depending on which study is quoted from the literature. We recommend analyzing drainage tile and road ditch effluent from agricultural and forested settings to determine if these sources are, as expected, significant sources.

Buffer strips of vegetation should be established and maintained alongside each stream course and along low-lying portions of each field, because the vegetated strips reduce the runoff velocity and allows particles with attached phosphorus to settle out before entering the stream. Installation of gully plugs, vegetation strips, layers of wood chips 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. These practices also keep topsoil in the fields were farmer need topsoil.

The 9E Plan's SWAT Model predicted that the source for the annual TP load is split between Cultivated Crops (53%), Pasture/Hay Fields (36%), Forested Lands (6%) and Developed Lands (5%)[14]. The reason is simple, agricultural land is the primary land use in the watershed, and more importantly, agricultural land contributes proportionally more nutrients and suspended sediments per acre than any other land use in the watershed (Table 10). Thus, nearly 90% of the loads originates from the agricultural sector. The second largest land use in the watershed is forests, which release significantly less phosphorus per acre of land than the agricultural sector due to its vegetated landscape. Renewed remediation therefore, should specifically target agricultural areas, both animal farms (manure spreading and barnyard runoff) and crop farms (including remediation of drain tile effluent). Additional reductions should focus on other sources like drain-tiles, road-side ditches and construction sites.

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[14] Walter, T., 2021. Findings of the SWAT Model and Recommendations. 9E Plan Public Meeting #2, 9/21/21.

Table 10: Land Use Percentages in the Owasco Watershed.

Region	Agriculture	Forest	Developed
Entire Watershed	55	41	3
Dutch Hollow	64.5	32.8	2.5
Owasco Inlet Headwaters	43.8	50.5	2.8
Mill Creek	46.9	50.7	1.9
Hemlock Creek	56.5	41.2	0.6
Direct Drainage to Lake	69.3	25.4	4.1

In the agricultural sector, the SWAT Model indicated that **significant reductions result** from three remediation practices (Table 11)[15]:

1. Restriction of manure and fertilizer application to the land.
2. Adoption of strict nutrient management planning for all farms
3. Use of winter crops.

When these three remediation strategies were integrated into the SWAT model, it predicted a 60% reduction in phosphorus loads to the lake (Table 11). The different phosphorus reduction percentages in each subwatershed primarily reflected the different land use – land cover percentages in each subwatershed.

Table 11: Percent Phosphorus Reduction from Selected Agricultural Activities.[16]

Subwatershed	Winter Cover Crops	Nutrient Management for All Farms	Restrict Manure & Fertilizer Applications
Dutch Hollow Brook	37.2	27.3	9.6
Owasco Inlet Headwaters	23.7	21.6	19
Mill Creek	55.5	23.8	--
Hemlock Creek	50	17.2	--
Direct Drainage to Lake	33.3	28.7	--

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[15] Walter, T., 2021. Findings of the SWAT Model and Recommendations. 9E Plan Public Meeting #2, 9/21/21.

[16] Walter, T., 2021. Findings of the SWAT Model and Recommendations. 9E Plan Public Meeting #2, 9/21/21.

CONCLUSIONS & RECOMMENDATIONS:

Owasco Lake Water Quality:

- Owasco Lake is a borderline oligotrophic – mesotrophic lake. The improvements in water quality from 2011 through 2013 were lost in 2014 and 2015. Water quality improved again in 2016, 2018, and 2019 with a reversal in 2017, but declined since.
- Based on surface water soluble reactive phosphate and nitrate concentrations, phosphorus is the limiting nutrient for algae growth in Owasco Lake.
- Water quality degradation in 2014, 2015, 2017, 2021 and 2022 is attributed to the heavy rains and, more importantly, intense precipitation events in those years.
- The water quality monitoring buoy provided a more robust view of water quality in the lake by detecting algal blooms, turbidity plumes and other short-term events potentially missed by the weekly or longer interval lake surveys.
- Finally, water quality in the lake has not significantly improved over the past decade. This lack of improvement is disturbing in light of the various remediations practices already implemented in the watershed.

Cyanobacteria Blooms:

- The relative contribution of cyanobacteria to the algal population in the open lake increased in 2019, and dominated the late season assemblages in 2020, but declined to 2018 levels since.
- Details on cyanobacteria blooms are contained in a companion report that also focuses on the limnological and meteorological analysis at a number of dock sites.

Stream Loads & Watershed Phosphorus Budget:

- Earlier daily discharge data for the Owasco Inlet and Dutch Hollow Brook revealed the significant flood events in 2011, 2014, 2015, 2017, 2019 and 2020. However, the worst floods were detected in 2021. For example, the mid-August event dumped up to 10” of rain on the northeast portion of the watershed, 8” more than a typical significant event in the past.
- The excessive nutrient loads during 2012, 2014 and 2015 were coincident with and perhaps triggered the onset of the cyanobacteria blooms in Owasco and many other Finger Lakes. Once these loads triggered the initial blooms, cyanobacteria have typically returned in larger numbers to the same nearshore locations in subsequent years.
- The huge event (flood) in 2021 preceded a large number of HABs events around the lake the following week.
- Earlier stream segment analysis did not identify significant point sources along Dutch Hollow Brook, and indicates that nonpoint sources of nutrients and sediments dominate loads in this watershed.
- Segment analysis before 2007 along the Owasco Inlet highlighted the point source of nutrients from the Groton municipal wastewater treatment facility (MWWTF) and stimulated the establishment of the DEC phosphorus limit mandate for its effluent.
- The previous event *versus* baseflow analysis at Dutch Hollow Brook highlighted the dominance of events and associated runoff of nonpoint sources on the delivery of nutrients and sediments to the lake. It also provided more accurate load estimates than grab samples, especially in those years when surveys were limited to base-flow conditions and/or the summer months.

- The earlier partitioning of phosphorus loads by source, i.e., Owasco Inlet, Dutch Hollow Brook and other streams provided the most phosphorus to the lake, even in very “dry” years. Other smaller sources of P included lakeshore onsite septic systems, municipal wastewater treatment facilities, and the atmosphere.
- Samples should be collected and analyzed from drainage tile and road ditch effluent to quantitatively assess their contributions to the fluvial P-loads to the lake.
- Owasco Inlet and Dutch Hollow Brook were always the largest and 2nd largest fluvial contributors. The stream inputs however, vary from year to year, proportional to the amount, intensity and seasonality of rainfall.
- The 2022 stream nutrient and sediment data normalized by basin area indicated that agricultural landscapes deliver significantly larger concentrations, whereas forested landscapes deliver significantly smaller concentrations of nutrients and sediments to the lake. This analysis confirms and potentially refines the 9E SWAT model results.
- The 9E Watershed Plan’s SWAT model indicates that over 90% of the nutrients entering the lake originate from the agricultural sector. Therefore, P-loading reduction strategies must focus on cover crops, nutrient management and restriction of manure and fertilizer applications.
- Both the Moravia and Groton MWWTFs have done an amazing job maintaining their annual phosphorus loads to a minimum.
- Septic systems contribute a small portion of the phosphorus loads to the lake.
- Contributions of phosphorus from geese and other large waterfowl are insignificant.
- More research is required to assess the impact of zebra/quagga mussels and macrophytes on the nutrient budget and internal nutrient redistributions in the lake.
- Besides continued monitoring of the lake and selected tributaries, additional research should focus on the nutrient and sediment contributions by roadside ditches and drainage tiles. Firm data would then establish their contributions rather than guesswork based on the available literature, and pave the way to the most effective remediations practices, if necessary.

Remediation Strategies:

- The limited improvement in water quality in the lake since 2016 is very discouraging despite the negative to neutral, i.e., promising, P-budgets. Any potential long-term reduction in phosphorus was reversed in 2021, a near “normal” rainfall year by huge rain events. Couple these results with the high confidence prediction of increased intensity and frequency of intense precipitation events due to global warming, indicates a continued aggravation of nonpoint source delivery of nonpoint source phosphorus to the lake. It commands the immediate use of additional and extensive remediation strategies.
- Clearly, implementation of the revised Owasco Lake Watershed Rules and Regulations and reduction strategies outlined in the recently approved 9E Watershed Plan are critical to the health and wellbeing of the lake. The sooner they are followed the sooner the lake might return to its early 20th century oligotrophic state.
- The 2022 stream data and the 9E Plan’s SWAT model indicated that the agricultural sector is the primary source of phosphorus to the lake, and thus must have a major part in the load reduction strategies. Three remediation strategies were recommended by the SWAT Model as they collectively could reduce phosphorus loads by over 60%:
    - Nutrient management plans should be invoked for all farms.
    - Winter cover crops must use used.
    - Manure spreading and fertilizer use must be restricted.

- Other BMPS should be employed along stream banks and in the low lying and other water saturated areas in each field. The BMPs include buffer strips, gully plugs, vegetation strips, barnyard cleanup, and other means to slow down and stop the runoff of nutrients and sediments.
- Roadside ditches, especially those that accept drain tile effluents, should be hydro-seeded, have catch basins installed and/or employ other strategies, to retain the nutrient and sediment load on land before the runoff enters the lake. The ditches and catch basins will require periodic cleaning to be effective.
- Perhaps all human and farm animal wastes in the watershed should be treated at a municipal wastewater treatment facility instead of spreading manure on local fields. This option would be expensive though.
- Additional flood retention basins should be built near the terminus of Owasco Inlet and initiated in the Dutch Hollow Brook watershed.
- Floating wetlands should be anchored just offshore of tributary mouths, as the vegetation would utilize some of the nutrients and thus reduce nutrient loads to the lake as long as the vegetation does not die and decompose in the lake and thus release the sequestered nutrients back into the lake.
- Nutrients in the form of algae and other plant biomass should also be physically removed from the lake, when feasible. For example, macrophytes should be harvested from the nearshore areas in the late summer and disposed outside the watershed. Those macrophytes and attached algae that wash up on the shoreline should be removed before they decompose along the lakeshore. The cyanobacteria blooms themselves should be vacuumed before they disappear (feasible?).
- Owasco Lake is probably too large and the existing phosphorus concentration too small for phosphorus sequestration techniques like Alum and Phoslock (bentonite clay) that remove available phosphorus from the water column and bury it into the sediments. However, phosphorus binding materials should be used in road-side ditches and at drain tile discharge pipes, especially fields used for spreading manure, to reduce phosphorus loads from these sources.
- Bio-manipulation is a poor option because lake-wide recreation, including fishing, is too vital for the economy.
- Finally, the financial burden to install the remediation efforts cannot be placed solely on farmers, lakeshore landowners or other individual groups. Water quality is a watershed-wide issue. Everyone benefits from a cleaner lake. Thus, everyone must support the remediation efforts.

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Table 3. 2022 Date Averaged bbe FluoroProbe Data

Owasco Lake Date Averaged bbe Fluoroprobe Data					
Date	Green	Cyanobacteria	Diatoms	Cryptophyta	Total
Offshore Sites					
27-May	1.3	0.0	1.9	0.0	3.3
31-May	1.6	0.0	0.9	0.0	2.5
6-Jun	14.8	0.0	16.9	0.0	31.7
14-Jun	0.4	0.0	1.0	0.0	1.5
28-Jun	1.5	0.0	3.6	0.0	5.1
5-Jul	1.0	0.0	3.1	0.0	4.1
15-Jul	0.2	0.0	0.9	0.0	1.2
19-Jul	0.9	0.0	3.1	0.1	4.1
26-Jul	1.2	0.0	6.9	0.2	8.3
2-Aug	0.1	0.0	3.9	1.5	5.5
9-Aug	1.3	0.0	3.4	0.4	5.1
16-Aug	5.9	0.0	3.3	0.0	9.1
23-Aug	1.7	0.0	3.7	0.3	5.7
30-Aug	1.8	0.0	4.2	0.2	6.1
6-Sep	1.8	0.0	5.7	0.5	7.9
13-Sep	2.0	0.1	6.1	0.9	9.0
20-Sep	0.0	0.9	3.7	1.9	6.6
27-Sep	0.1	0.4	4.0	2.1	6.6
4-Oct	0.8	0.3	1.5	2.7	5.3
Dock Sites					
20-Jul	0.7	0.0	1.3	0.2	2.2
27-Jul	0.5	0.0	3.6	0.1	4.3
11-Aug	1.1	0.0	1.4	0.7	3.1
24-Aug	0.4	0.4	0.8	1.0	2.6
7-Sep	0.6	0.3	2.3	0.7	3.9
23-Sep	0.0	1.9	0.0	2.3	4.2
24-Sep	0.0	0.2	0.9	3.8	4.9
5-Oct	0.1	0.6	1.2	2.2	4.1
10/5 Bloom	3.4	13.0	2.2	25.7	44.3

Table 4. 2022 Lake Data.

2022 Owasco Lake Site Averaged and Date Averaged Data

Site Averaged Surface Water Data

Site	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
1	3.7	1.7	13.8	0.3	0.6		3.7
Buoy	3.7						
2	3.7	1.4	12.9	0.7	0.5		3.3
Average	**3.7**	**1.5**	**13.3**	**0.5**	**0.5**	**No Data**	**3.5**

Site Averaged Bottom Water Data

Site	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
1	---	0.8	11.5	0.5	0.9		0.8
Buoy							
2	---	0.8	11.4	0.6	0.9		0.8
Average	**---**	**0.8**	**11.4**	**0.6**	**0.9**	**No Data**	**0.8**

Date Averaged Surface Water Data

Date	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
5/27/22	3.9	1.7	8.9	1.7	0.7		2.7
5/31/22	3.7	1.1	12.3	2.1	0.6		3.5
6/6/22	1.7	2.6	15.5	0.2	0.7		8.9
6/14/22	4.9	1.1	7.0	0.0	0.5		1.2
6/28/22	5.8	0.7	10.0	0.0	0.5		3.0
7/5/22	5.1	0.7	10.8	0.0	0.6		2.6
7/15/22	4.4	1.1	14.5	0.0	0.6		2.1
7/19/22	3.6	1.6	7.1	1.5	0.3		2.3
7/26/22	2.2	2.3	8.4	0.0	0.8		3.1
8/2/22	1.3	3.2	10.3	0.9	0.6		3.3
8/9/22	3.2	1.9	13.0	0.4	0.7		3.2
8/16/22	3.8	1.4	19.6	0.4	0.4		3.0
8/23/22	2.8	2.1	17.0	0.0	0.4		1.8
8/30/22	3.7	1.6	18.6	0.0	0.4		3.7
9/6/22	4.4	1.1	16.0	0.0	0.5		5.3
9/13/22	3.5	1.9	14.0	0.6	0.4		5.5
9/20/22	3.7	1.3	25.6	1.2	0.4		3.7
9/27/22	3.9	1.3	8.8	0.8	0.5		4.7
10/4/22	5.1	1.0	15.9	0.0	0.5		3.2
Average	**3.6**	**1.6**	**12.6**	**0.5**	**0.6**	**No Data**	**3.3**

Date Averaged Bottom Water Data

Date	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
5/27/22	---	1.2	9.2	1.5	0.7		1.0
5/31/22	---	1.1	9.3	0.2	0.9		0.8
6/6/22	---	0.6	12.6	1.3	0.9		0.6
6/14/22	---	0.5	6.5	0.1	0.6		0.6
6/28/22	---	0.4	6.0	0.0	0.8		1.1
7/5/22	---	0.8	6.9	0.0	0.7		0.3
7/15/22	---	0.7	8.6	1.1	0.8		0.8
7/19/22	---	0.5	8.6	0.0	0.6		0.6
7/26/22	---	0.8	8.3	0.0	0.8		2.1
8/2/22	---	1.0	19.1	0.4	1.3		0.6
8/9/22	---	0.9	10.3	0.5	1.6		0.8
8/16/22	---	0.8	10.1	2.4	1.1		1.1
8/23/22	---	1.0	19.7	0.0	0.8		0.7
8/30/22	---	0.8	15.7	0.0	1.0		0.6
9/6/22	---	0.9	8.7	0.4	1.1		0.6
9/13/22		0.7	11.4	0.0	1.0		0.8
9/20/22		0.7	15.8	0.1	0.9		0.8
9/27/22		0.6	10.0	2.4	0.8		0.9
10/4/22		0.4	20.9	0.4	0.9		0.5
Average	---	**0.8**	**10.6**	**0.5**	**0.9**	**No Data**	**0.8**

	Surface	**Bottom**
Mean P:N Ratio	1004	1577

Table 6. Annual Average Plankton Data from 2005 through 2022, and Daily Average Data for 2022.

Plankton Group	Diatoms							Dinoflagellates			Greens	Rotifers & Zooplankton					Blue Greens	
Plankton Species	Fragillaria %	Tabellaria %	Diatoma %	Asterionella %	Melosira %	Synedra %	Rhizoselenia %	Dinobryon %	Ceratium %	Coalcium %	Total Greens %	Copepod %	Keratella %	Polyarthra %	Vorticella %	Cladoceran %	Dolichospermum (Anabaena) %	Mycrocystis %
2005 Average	34.9	1.4	0.0	9.9	0.2	5.6		14.6	4.5		100.0	0.9	2.5	3.2	10.3	2.8		0.3
2006 Average	24.3	1.7	0.0	7.1	1.4	0.7	2.6	41.5	0.7		100.0	0.2	2.4	0.8	0.3	0.6	0.1	3.8
2007 Average	30.0	0.5	0.0	23.3	0.2	2.1	3.8	12.9	0.7		96.8	0.4	0.6	0.4	3.8	2.8	0.4	7.7
2008 Average	52.3	0.1	0.0	14.6	0.2	0.1	1.2	18.7	0.6	0.2	100.0	0.4	0.3	0.9	4.3	0.6	0.4	1.5
2009 Average	9.7	7.1	0.0	12.3	0.2	1.0	7.8	26.6	0.7	2.0	100.0	0.7	3.6	0.7	4.3	2.1	3.4	4.8
2010 Average	36.8	0.5	0.0	19.1	0.2	1.4	0.7	4.6	0.0	2.6	100.0	0.6	3.3	0.7	3.2	5.6	0.1	6.1
2011 Average	26.0	14.1	0.0	15.0	0.4	1.4	15.0	5.3	0.5	1.8	0.0	0.9	2.8	1.0	3.9	2.0	0.2	2.6
2012 Average	27.0	25.5	0.0	10.9	13.0	2.2	1.1	8.1	0.3	0.2	0.0	0.5	0.3	1.5	0.9	0.6	0.3	0.8
2013 Average	27.6	0.3	26.9	3.9	3.8	0.0	5.9	0.0	0.1	2.1	0.0	0.5	1.3	2.4	1.2	4.1	0.3	0.6
2014 Average	21.8	0.3	5.8	15.2	0.2	1.5	2.5	20.2	0.1	0.0	0.0	2.7	1.1	6.4	1.8	1.1	0.1	2.6
2015 Average	28.6	7.5	1.0	20.2	0.3	0.8	3.9	3.7	0.1	0.1	0.0	0.7	1.8	3.5	0.8	3.1	0.1	7.3
2016 Average	11.5	2.8	6.7	13.7	1.2	0.3	0.2	11.7	0.0	0.1	0.3	0.7	4.0	5.0	1.7	1.5	2.1	5.3
2017 Average	11.8	0.1	0.1	6.4	1.5	0.0	11.1	5.4	0.3	0.5	4.1	0.6	2.0	2.7	4.0	2.3	4.9	5.6
2018 Average	1.2	0.1	6.9	24.7	0.0	33.1	0.1	0.5	0.0	0.1	0.5	0.2	2.0	0.4	0.4	0.2	1.2	1.5
2019 Average	41.6	0.0	1.7	12.7	0.2	0.1	0.5	0.5	0.2	0.9	0.5	5.4	1.8	1.5	4.4	0.3	5.5	11.8
2020 Average	4.1	0.0	7.2	17.8	0.1	0.3	0.0	2.8	0.0	0.0	2.3	0.4	3.3	0.0	5.1	0.3	4.4	49.6
2021 Average	11.8	0.0	11.9	1.7	0.4	1.8	0.0	0.7	0.2	0.0	3.0	1.2	7.0	0.6	4.8	1.7	3.8	34.3
5/27/22	4.1	0.0	14.8	55.9	0.0	0.3	0.0	2.3	0.0	0.0	0.3	6.8	0.0	0.0	0.0	0.0	0.0	0.0
5/31/22	1.4	0.0	21.7	49.3	0.0	1.4	0.0	0.0	0.0	0.0	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0
6/6/22	0.2	0.0	5.8	11.3	0.5	2.2	0.0	47.3	0.0	0.0	0.2	2.8	0.2	1.6	0.0	0.0	0.0	0.0
6/14/22	1.1	0.0	10.2	10.8	0.6	0.0	0.0	0.0	0.0	0.0	0.3	29.0	3.4	8.5	0.0	0.0	0.0	0.0
6/28/22	0.6	0.0	28.3	10.9	0.0	6.2	0.0	1.2	0.0	0.0	0.2	0.3	2.8	1.6	0.0	0.0	0.0	0.0
7/5/22	0.0	0.0	7.8	0.3	0.0	5.0	0.0	0.3	0.0	0.0	0.3	0.0	7.8	0.0	0.0	0.5	0.0	0.0
7/15/22	1.7	0.0	7.1	0.4	0.0	42.0	0.2	12.6	0.0	0.0	1.0	0.3	7.7	0.0	0.0	0.5	0.0	0.0
7/19/22	0.5	0.0	0.3	0.0	0.0	53.6	0.6	12.9	0.0	0.0	4.9	0.0	10.5	1.0	0.0	2.0	0.0	0.5
7/26/22	1.1	0.0	0.0	0.3	0.0	36.5	0.3	38.2	0.0	0.0	1.6	0.3	8.1	0.3	0.0	2.9	1.6	0.8
8/2/22	8.1	0.0	0.0	0.5	0.2	29.7	0.0	0.6	0.0	0.0	1.0	0.3	23.1	0.7	7.1	2.2	1.7	4.9
8/9/22	3.8	0.0	0.0	0.3	0.0	5.1	0.0	0.2	0.0	0.3	4.6	0.3	14.2	1.1	7.5	5.6	9.0	12.0
8/16/22	0.4	0.0	0.0	0.5	0.0	9.8	0.0	13.9	0.0	0.2	0.7	0.3	11.4	0.6	2.9	1.1	10.5	32.3
8/23/22	0.0	0.0	0.0	1.0	0.0	12.4	0.0	2.7	0.0	0.0	1.0	0.3	8.8	1.6	0.0	1.0	9.7	47.7
8/30/22	0.0	0.0	0.0	0.3	0.0	20.4	0.0	0.3	0.0	0.0	1.1	0.0	3.3	1.7	0.0	1.7	2.4	53.6
9/6/22	0.0	0.0	0.0	0.0	0.0	20.5	0.0	1.4	0.0	0.0	1.0	1.0	1.6	2.0	0.7	0.0	0.0	58.9
9/13/22	0.0	0.0	0.0	0.0	0.0	21.1	0.7	0.7	0.0	0.0	0.3	0.0	0.7	0.7	0.7	0.3	2.0	61.5
9/20/22	0.7	0.0	0.0	1.2	0.0	13.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.6	0.3	61.8
9/27/22	0.0	0.0	0.0	3.8	0.0	14.1	0.0	0.8	0.0	0.0	0.0	0.4	0.0	1.5	1.1	0.8	0.0	68.0
10/4/22	13.6	0.0	0.0	9.1	0.0	10.5	0.0	0.0	0.0	0.0	1.3	0.7	0.0	0.0	1.0	0.3	0.0	57.6
2022 Average	2.0	0.0	5.1	8.2	0.1	16.0	0.1	7.1	0.0	0.0	1.1	2.3	5.5	1.3	1.1	1.0	2.0	24.2

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

Table 7: Annual Average 2022 Limnological Data from the monthly Finger Lake Survey.

2022 Average Values (± 1s)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	Not Sampled	Not Sampled	Not Sampled	4.7 ± 1.2	Not Sampled	3.7 ± 1.2	Not Sampled	Not Sampled
Total Suspended Solids (mg/L), Surface				1.2 ± 0.4		1.5 ± 0.6		
Total Suspended Solids (mg/L), Bottom				0.7 ± 0.1		0.8 ± 0.2		
Total Phosphate (µg/L, TP), Surface				13.1 ± 3.2		13.3 ± 4.9		
Total Phosphate (µg/L, TP), Bottom				13.7 ± 2.8		11.4 ± 4.6		
Dissolved Phosphate (µg/L, SRP), Surface				0.3 ± 0.3		0.5 ± 0.7		
Dissolved Phosphate (µg/L, SRP), Bottom				3.3 ± 2.5		0.6 ± 0.8		
Nitrate as N (mg/L), Surface				0.1 ± 0.0		0.5 ± 0.1		
Nitrate as N (mg/L), Bottom				0.2 ± 0.0		0.9 ± 0.2		
Silica (SR µg/L), Surface	Not Measured							
Silica (SR µg/L), Bottom	Not Measured							
Chlorphyll a (µg/L), Surface				3.6 ± 2.9		3.5 ± 1.7		
Chlorphyll a (µg/L), Bottom				1.3 ± 0.6		0.8 ± 0.4		

Table 8. 2022 Stream Data collected by OWLA Volunteers and Analyzed by UFI.

Station Name	**Sampling Date**	**Total Phosphate**	**Total Dissolvd Phosphate**	**Souble Reactive Phosphate**	**Total Nitrogen**	**Nitrate/Nitrite**	**Ammonium**	**Total Suspended Solids**
		(µgP/L)	**(µgP/L)**	**(µgP/L)**	**(mgN/L)**	**(mgN/L)**	**(mgN/L)**	**mgDW/L**
Dutch Hollow Brook	5/5/22	10.4	6.9	2.3	2	1.3	0.0	2.2
	5/20/22	14.3	9.4	3.9	1.3	1.0	0.0	5.5
	6/1/22	22.2	13.9	7.3	1.3	0.8	0.1	12.5
	6/16/22	387.9	63.7	46.3	4	3.7	0.1	
	7/11/22	387.9	11.6	4.1	1	0.4	0.0	
	7/20/22	18.3	11.3	4.5	0.6	0.2	0.0	6.6
	8/3/22	13.9	9.3	4.8	0	0.1	0.0	1
	8/23/22	184.5	101.2	91.6	3	1.4	0.3	42.6
	9/8/22	109.3	40.0	28.5	1	0	0.0	66.8
	9/21/022	67.0	34.4	19.0	1.9	1.4	0.1	11.7
	10/5/22	8.1	4.3	1.3	0.4	0.3	0.0	2.7
	10/19/22	9.5	5.9		0.1	0.1	0.2	
Long Point	5/5/22	10.3	5.9	3.3	3	2.5	0.0	1.3
	5/20/22	11.1	11.1	5.3	2	2.0	<LOD	15.8
	6/1/22	18.8	16.7	14.2	2.255	1.9	0.1	4.4
	6/16/22	105.0	51.4	37.7	6	5.4	0.0	36
	7/11/22	105.0	16.7	13.6	2	2.3	0.1	<LOD
	7/20/22	20.6	19.1	14.4	2.1	1.7	0.0	2.1
	8/3/22	20.0	19.2	14.9	1.6	1.4	0.0	1.1
	8/23/22	94.08	67.82	76.50	2.61	1.37	0.19	25.00
	9/8/22	91.1	45.7	35.2	2	2	0.0	51.3
	9/21/022	24.2	18.8	16.0	1.3	1.0	0.0	2.0
	10/5/22	12.7	12.4	10.5	1.6	1.6	0.0	5.1
	10/19/22	10.5	11.3	6.3	1.3	0.0	1.2	
Owasco Inlet, Cayuga St, Moravia	5/5/22	15.1	7.1	2.7	1	1.3	0.0	4.2
	5/20/22	9.4	7.9	2.0	1	1.1	<LOD	2.3
	6/1/22	21.6	11.2	6.7	1.597	1.2	0.1	6.1
	6/16/22	102.6	28.5	16.6	1.3	1.0		69.3
	7/11/22	105.1	15.2	5.3	1	0.9	0.1	2.5
	7/20/22	16.7	10.3	5.1	1.2	0.9	0.0	2.4
	8/3/22	14.8	8.5	0.9	1	0.7	0.0	0.7
	8/23/22	39.5	18.3	11.5	1	0.6	0.0	16.6
	9/8/22	24.3	16.1	8.7	1	1	0.0	4.3
	9/21/022	16.2	10.6	4.9	1.1	0.8	0.0	1.7
	10/5/22	8.7	9.4	4.0	1	1	0.0	1.5
	10/19/22	13.0	9.0	2.2	1.1	0.0	1.0	6.2
Owasco Inlet, Rt 90, Locke	5/5/22	16.4	8.3	2.8	1	1.2	0.0	4.6
	5/20/22	13.2	8.1	2.1	1	0.9	0.0	3.5
	6/1/22	34.6	17.4	12.7	1.175	0.9	0.1	13.3
	6/16/22	82.9	25.7	20.2	1	1.1		81
	7/11/22	82.9	27.5	4.2	1	0.3	0.0	7.6
	7/20/22	27.4	12.0	5.8	0.8	0.4	0.0	8.0
	8/3/22	27.3	10.6	3.9	0	0.2	0.0	12.6
	8/23/22	31.0	22.5	21.1	1	0.6	0.0	30.7
	9/8/22	39.5	20.2	13.3	1	1	0.0	16.8
	9/21/022	33.8	11.6	4.2	0.8	0.6	0.2	16.2
	10/5/22	12.0	6.4	4.1	0.9	0.8	0.0	4.9
	10/19/22	35.3	8.8	2.0	0.5	0.0	0.5	1.4
Owasco Inlet, Walpole Rd, Groton	5/5/22	40.4	29.9	21.3	1	1.1	0.1	4.6
	5/20/22	26.0	17.0	10.4	1	0.9	0.0	3.9
	6/1/22	40.5	30.0	21.6	1.168	0.8	0.1	3.9
	6/16/22	325.8	299.1	235.0	2	0.8	0.5	21
	7/11/22	325.8	46.9	18.4	1	0.5	0.1	3.0
	7/20/22	142.9	101.8	98.3	0.9	0.4	0.0	7.1
	8/3/22	185.5	181.3	161.4	1	0.4	0.0	3
	8/23/22	85.3	66.2	51.2	1	0.7	0.1	8.8
	9/8/22	1402.8	1430.6	1422.2	1	1	0.1	3.6
	9/21/022	41.9	35.2	26.6	0.7	0.4	0.1	1.3
	10/5/22	26.6	19.4	15.5	0.7	0.5	0.0	0.9
	10/19/22	23.4	13.7	16.5	0.5	0.0	0.6	1.0
Sucker Brook	5/5/22	20.8	12.7	3.3	0.5	0.1	0.0	4.0
	5/20/22	27.5	20.4	8.7	1	0.3	0.0	1.4
	6/1/22	54.0	41.9	26.8	1.126	0.4	0.0	4.4
	6/16/22	627.8	268.0	210.2	2	1.9	0.1	259
	7/11/22	627.8	49.7	24.8	1	0.2	0.1	2.3
	7/20/22	66.2	50.6	35.0	1.2	0.3	0.0	60.9
	8/3/22	77.9	60.2	47.5	1	0.4	0.0	2.7
	8/23/22	98.7	49.6	32.7	1	0.4	0.0	134.8
	9/8/22	417.5	179.3	172.0	2.1	1.6	0.0	166.0
	9/21/022	87.6	50.2	32.3	1.1	0.4	0.1	12.4
	10/5/22	37.8	12.0	7.3	0.7	0.2	0.0	14.4
	10/19/22	17.3	12.7	2.4	0.0	0.5	0.4	1.2
Veness Brook	5/5/22	51.9	25.5	13.9	1	0.6	0.0	19.8
	6/1/22	119.4	45.6	29.9	1.486	0.8	0.1	80.2
	6/16/22	101.7	38.3	26.0	5	3.6		34
	7/11/22	100.8	41.3	4.6	0.7	0.0	0.1	10.0
	7/20/22	53.8	24.7	7.3	0.7	0.0	0.0	10.4
	8/3/22	50.8	19.9	3.5	1	<LOD	0.0	4.6
	8/23/22	55.8	37.9	21.6	1	0.3	0.1	28.8
	9/8/22	115.4	44.2	28.3	2	1	0.0	82.4
	9/21/022	74.7	34.4	13.3	1.4	0.6	0.1	10.2
	10/5/22	59.2	14.2	10.0	1	1	0.0	31.1
	10/19/22	25.4	12.7	6.2	0.5		0.7	9.1
Annual Averages		**TP**	**TDP**	**SRP**	**TN**	**NOx**	**tNH3**	**TSS**
		(µgP/L)	**(µgP/L)**	**(µgP/L)**	**(mgN/L)**	**(mgN/L)**	**(mgN/L)**	**mgDW/L**
Dutch Hollow Brook		121.6	30.2	21.2	1.5	1.1	0.1	18.6
Long Point		46.3	25.3	23.1	2.2	2.0	0.1	15.4
Owasco Inlet, Cayuga St, Moravia		34.2	13.2	6.4	1.2	0.9	0.2	11.0
Owasco Inlet, Rt 90, Locke		36.5	15.7	8.4	0.9	0.7	0.1	18.2
Owasco Inlet, Walpole Rd, Groton		241.1	204.3	188.0	1.0	0.6	0.1	5.6
Sucker Brook		193.5	72.4	55.4	1.2	0.5	0.1	58.9
Veness Brook		74.2	32.4	15.1	1.5	0.8	0.1	28.2