THE 2021 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 monitoring program of Owasco Lake and its watershed was designed to:

1. Document spatial and temporal trends in pertinent water quality / water clarity / limnological parameters;
2. Investigate the source and magnitude of nutrients in the watershed, as their inputs 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 have always been regulated, 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 phosphorus loads in its effluent.
- A 2007 DEC mandated phosphorus limit of the Groton municipal wastewater treatment facility effluent that enters the Owasco Inlet is also less than 1 kg/day.
- 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. (see: Owasco-Watershed-Rules-and-Regulations)
- Cayuga County Planning and numerous partners will complete the EPA Nine Key Elements Plan (9E Plan) for Owasco Lake/Watershed soon.
- 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, typically in the spring season, and more spread out through the field season in 2021.
- 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 events in 2021 triggered significant blooms around the lake.
- 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, will continue to degrade water clarity and water quality. Since 2016, the balance has turned and 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, when the inputs were estimated to be twice the outputs.
- 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 2021 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

The 2021 lake and stream sample sites and field/laboratory methods were similar to the 2005 – 2020 programs.

Owasco Lake: The 2021 lake monitoring program sampled Sites 1 and 2 fifteen times, monthly in May and June, every two weeks in July, and then weekly from August through the end of September (Table 1, Fig. 1). These two sites have been sampled since the initial 2005 survey, and have been deemed representative of the open water limnology in previous surveys of Owasco Lake of multiple offshore sites along the length of the 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 downcast, and downcast profiles are 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.

Water 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 the laboratory for total phosphate (TP, μg/L, P), soluble reactive phosphate (SRP, μg/L, P), nitrate (NO_x, mg/L, N), chlorophyll-a (μg/L) and total suspended solid (TSS, mg/L) concentrations. Surface (each cruise) and bottom (monthly) water grab samples were analyzed by FluoroProbe in the lab 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

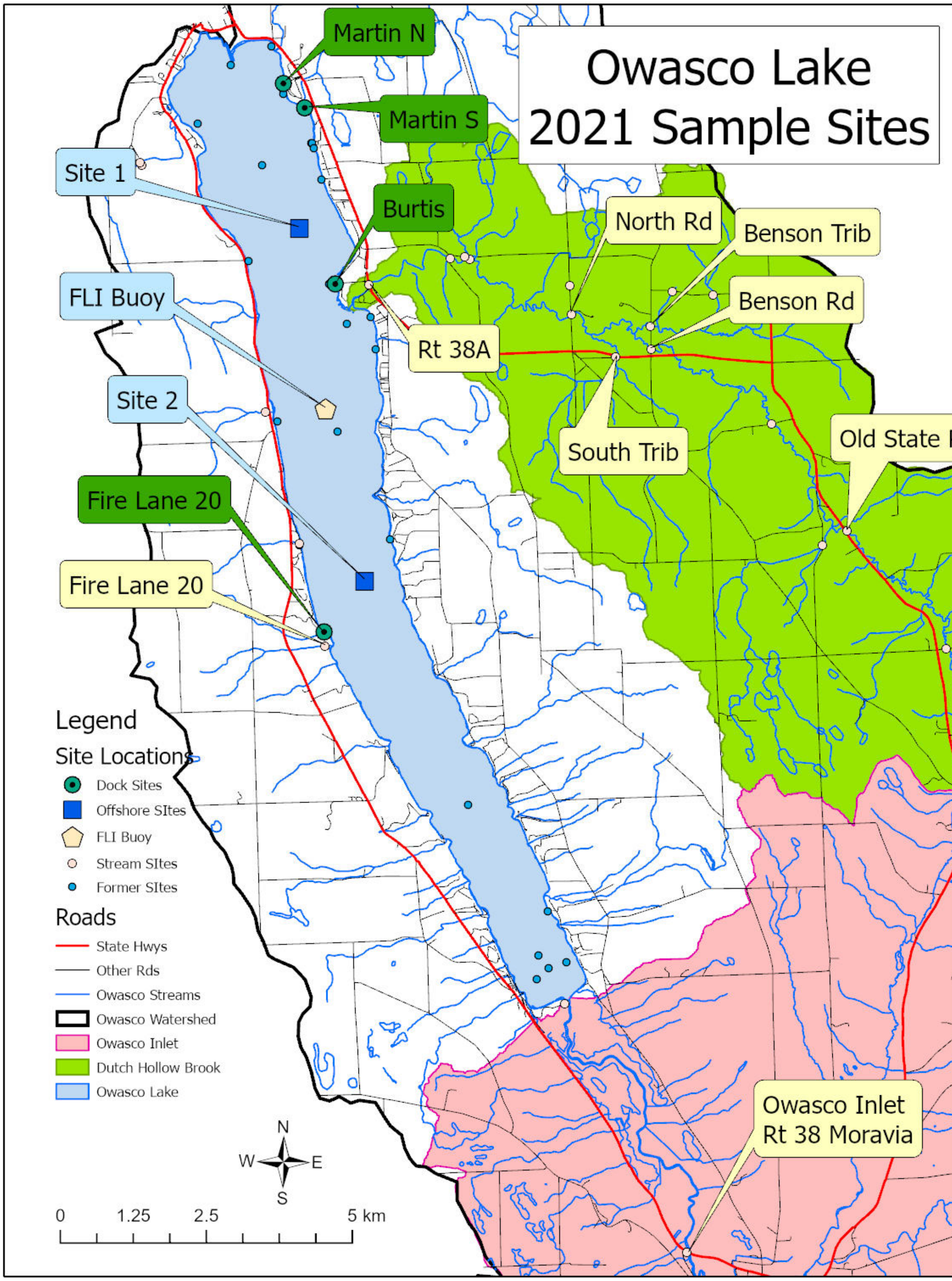

Fig. 1. The lake (blue), FLI buoy (yellow pentagon), dock (green) and stream (yellow circles) monitoring sites.

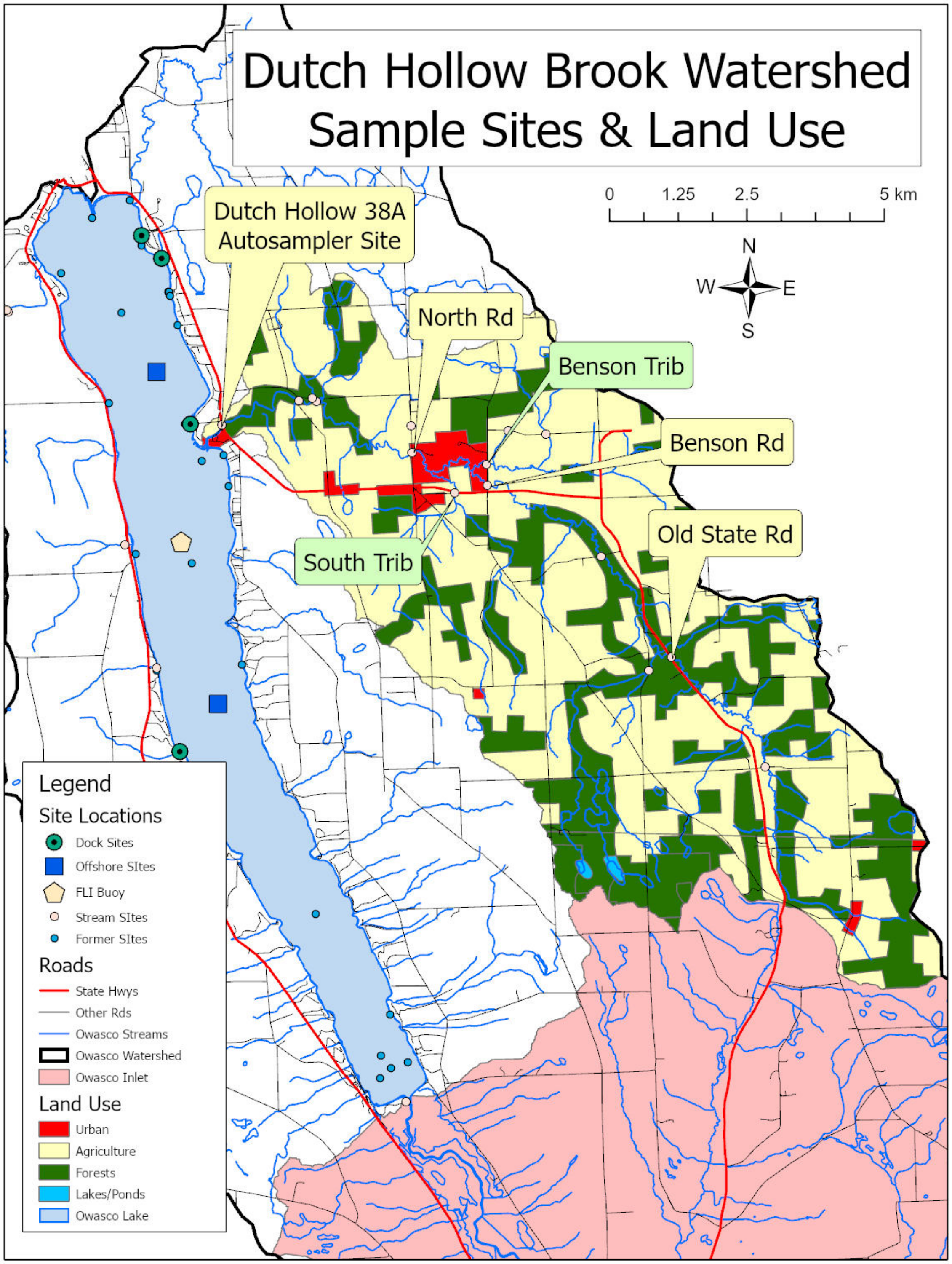

Fig. 1 continued. Site locations and land use within Dutch Hollow Brook watershed.

Owasco Streams: The 2021 stream monitoring program sampled six sites within the Dutch Hollow Brook watershed, the terminus of Owasco Inlet, and the terminus of two small tributaries entering the western side of the lake that cross Fire Lanes 20 and 26 (Fig. 1). Stream sites were visited four times in 2021. Dutch Hollow Brook was sampled at four sites along its main course, the terminus at Rt 38A, and sequentially upstream at North Rd, Benson Rd, and near Old State Rd, and at two unnamed tributaries in the watershed referred to in this report as the South and Benson tributaries. The South tributary was sampled at Rt 38A just east of the Owasco town center. The Benson tributary was sampled along Benson Rd just north of the Benson Rd site. Owasco Inlet was sampled at one site just south of the Owasco Flats and just north of Moravia where the Inlet crosses Rt 38. Two small tributaries that enter along the western edge of the lake at the ends of Fire Lanes 20 and 26 were also sampled. The selected sites duplicated those sampled in recent years.

At each site, stream discharge, water temperature, conductivity, dissolved oxygen, and alkalinity were measured onsite using hand-held probes or field titration kits. Water samples were also collected and subsequently analyzed back in the laboratory for total phosphate (TP), soluble reactive phosphate (SRP), nitrate (NO_x) and total suspended sediment (TSS) concentrations. Stream discharge (the volume of water per unit time flowing past a site) was calculated from measured stream width, depth and water velocity data (using a 30 m tape, wading rod and HACH FH950 portable velocity flow meter with electromagnetic sensor). Both velocity and stream depth were measured at ten (or five) equally distributed segments aligned perpendicular to stream flow. The velocity was measured at ~60% of the stream depth and assumed the average velocity for each segment. Ten segments were utilized when the stream was wide (>10 m) or more accuracy was necessary, e.g., Dutch Hollow Brook at both 38A and North Rd. The published USGS gauge flow measured at Moravia (USGS Gauge 4235299) was used for the Owasco Inlet discharge in 2021 at the time and date for each site visit. Stream discharge (water volume per unit time, e.g., m^3/s) is necessary to calculate the flux (loading) of nutrients and suspended sediments, because flux of a substance (its mass/time, e.g., kg/day) equals stream discharge (volume water/time, e.g., m^3/s) times its concentration (mass/volume water, μg/L).

Runoff/Event Flow versus Baseflow Variability: A Teledyne ISCO 6712, full size, automated water sampler, and two pairs of *ONSET* HOBO U20L-04 data loggers were deployed at the Rt 38A site in Dutch Hollow Brook from 4/11 to 11/2 (205 days) to investigate the impact of event *versus* baseflow variability on nutrient and sediment loads to the lake (Figs. 2a & 2b). The autosampler was programmed to collect 1-L of water daily (4 am). This periodicity successfully collected both event and baseflow samples in previous years. At each site, stream discharge was measured and the autosampler was serviced weekly to bi-monthly. Each water sample was analyzed for total suspended sediment (TSS) and nutrient (TP, SRP and NO_x) concentrations.

Floods hampered the event vs baseflow effort in 2021. Flood waters uprooted and flooded the autosampler on 8/18, flooded a replacement sampler on 10/14 (even though the sampler was deployed on higher ground), and as a consequence prevented sample collection from 8/13 – 9/14, and 10/14 – 11/2. The uprooted autosampler was found by a lakeshore resident floating in the lake a few miles south of the Dutch Hollow mouth. Unfortunately, the electronics in both autosamplers were destroyed by the flood waters. Not all was lost. Suspended sediment and nutrient fluxes were estimated for the missing event samples in 2021 based on a best-fit, linear interpolation of increases in discharge above the preceding baseflow and the associated flux of

TSS, N, TP and SRP for every event since 2016 (116 measured events). Events were defined as any increase in discharge at or above 0.75 m^3/s from the preceding day's baseflow.

Fig. 2a. Servicing "R_2D_2" the Teledyne ISCO automated water sampler located at the Rt 38A site. It collected 1-liter of water daily (4 am).

Fig. 2b. An ONSET HOBO U20L-004 data logger. Each pair of data loggers measured hourly water and air pressure to calculate hourly stream stage (height), and air and water temperatures.

One logger in each pair was deployed in air and the other deployed underwater on the stream bed attached to a 135-lb anchor with an attached chain wrapped around a large rock as previous deployments to a fence post driven into the stream bed were uprooted by large floods. The paired air/water deployment accounted for changes in atmospheric pressure to isolate changes in water level by these unvented pressure transducers. The configuration also provided air and water temperature measurements at the site. Deploying two pairs of loggers hedged against losing a single pair of loggers to a flood, vandalism or any other unfortunate issues. The duplication was again useful in 2021 because the 8/18 flood dislodged both loggers from the stream bed and one air logger was lost (it was attached to the autosampler stand). Fortuitously, data from the HyFi deployment at the same site successfully supplied the missing stage data. An excellent fit between the pre-flood logger and the temperature sensitive HyFi stage data encouraged the extrapolation.

The data loggers were programmed to record hourly pressure and temperature data. The stage data and stream discharge measurements from the weekly to bi-monthly site visits established a rating curve for 2021, the relationship between stream stage (height) and stream discharge. The rating curve was then used to estimate a stream discharge for every ISCO water sample and thus a reliable calculation of a flux for each nutrient and suspended sediment concentrations.

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 nutrient, chlorophyll-a (only lake samples), 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. An additional sample water (~1L for stream, and ~3L for lake samples) was filtered through pre-weighed, 0.45 μm glass-fiber filters

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

immediately after returning from the field. The stream filtrate was stored at 4°C until soluble reactive phosphate (SRP) and nitrate (NO_x) colorimetric analyses by spectrophotometer. The filter and residue were dried at 80°C for at least 24 hours. The weight gain and filtered water volume determined the total suspended sediment concentration. After each lake survey, a known volume (~1L) of lake water was also 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.

Owasco Buoy: The second 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 4/18 through 11/2/21 (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 fluorescence (RFUs). The fluorescence sensor measured both total chlorophyll and cyanobacteria phycocyanin concentrations (after specific pigment excitation by different wavelengths of light). 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 recording 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. Minimal solar power and other issues prevented collection of water quality data on 9/29. The meteorological data collection was not interrupted.

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 (Fig. 3).

Dockside Water Quality & Meteorological Monitoring: Funding from the Fred L. Emerson Foundation enabled deployment of a weather station, water quality sonde, water temperature loggers, and an automated camera at four dock sites in Owasco Lake (Fig. 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).

[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.

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, originally 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 sondes 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 was deployed instead. The results of this dockside investigation will be discussed in a companion HABs report[4].

Fig. 3. The spectrophotometer in the field.

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

[4] Halfman, et al., 2022. Cyanobacteria on Owasco and Seneca Lakes, the 2021 Update. The 2021 Annual Report to the Fred L. Emerson Foundation, Seneca Lake Pure Waters Association and the Finger Lakes – Lake Ontario Watershed Protection Alliance.

RESULTS & DISCUSSION

2021 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, especially rain events in the spring season. 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). 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 rainstorm typically produces proportionally more runoff, erodes more soil, and increases nutrient and sediment loads to the lake than a 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). [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 this past summer 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 slightly (90%) below normal during the 2021, March through October, field season (Fig. 5). Normal as defined by the weather bureau. Rainfall in 2021 returned to "normal" from drier conditions in 2016, 2019 and especially 2020 (Fig. 5). The 2021 return to more normal field-season rainfalls suggest that runoff and nutrient loading to Owasco Lake should have increased, and water quality in the lake should have declined from previous years.

Seasonally, rainfall in the spring was 30% of "normal", summer 117% above "normal", and fall 123% above "normal". The majority (57%) of the "summer season" precipitation, however arrived during the 8/18 flood event which dumped 3.8" of rain at Ithaca but dumped much more

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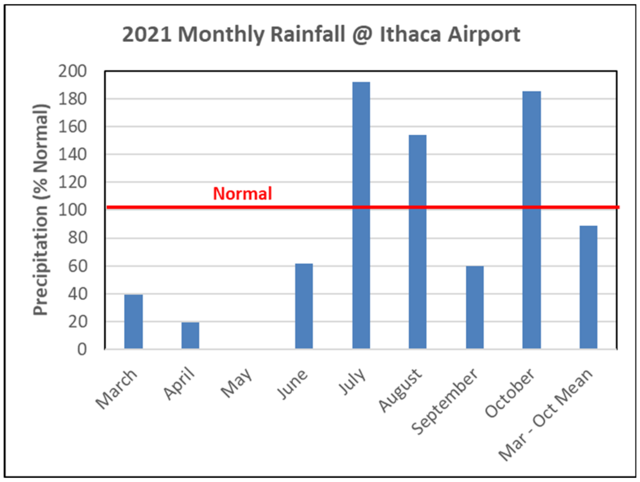
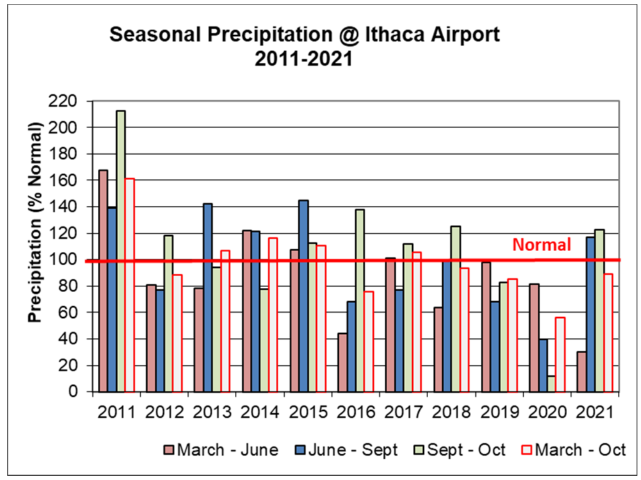
[5] Easterling, D., et al., 2917 Precipitation change in the United States. In: Climate Science Special Report: A Sustained Assessment Activity of the U.S. Global Change Research Program [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change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

rain in the northeastern Owasco Watershed. The four dock sites measured 6.0 to 10.4" of rain (± 2.0"), and 8.4" of rain was measured at the NY-CY-8 CoCoRaHS site in the Dutch Hollow Watershed. Four additional localized "events" dumped 2 or more inches of rain on 7/1, 9/13, 9/23, 10/3, 10/18 and again on 10/24 at these sites. It highlights the increased occurrence of more intense and more localized rainstorms due to global warming. The recorded rainfall at these sites also depict variability between sites (Fig. 5). The increased intensities of these events should significantly increase phosphorus loads to the lake.





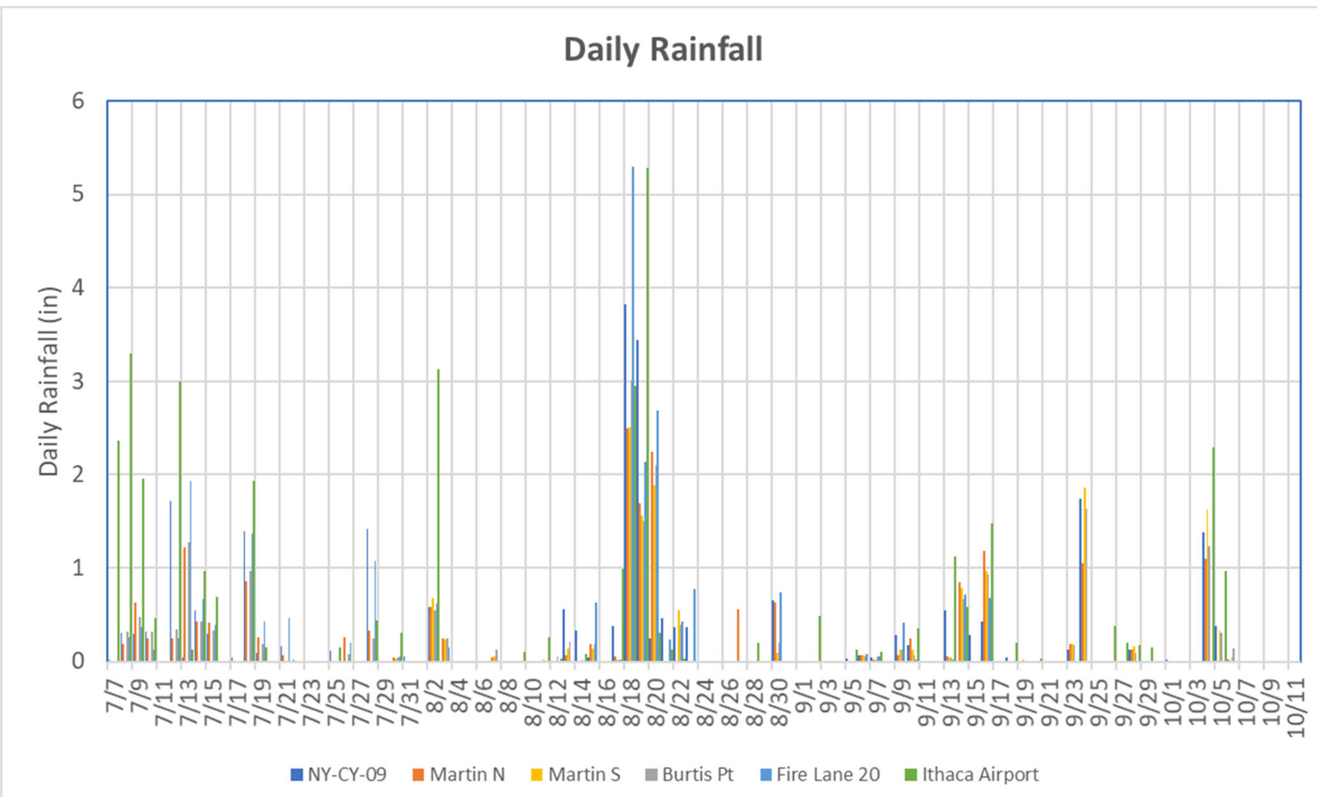
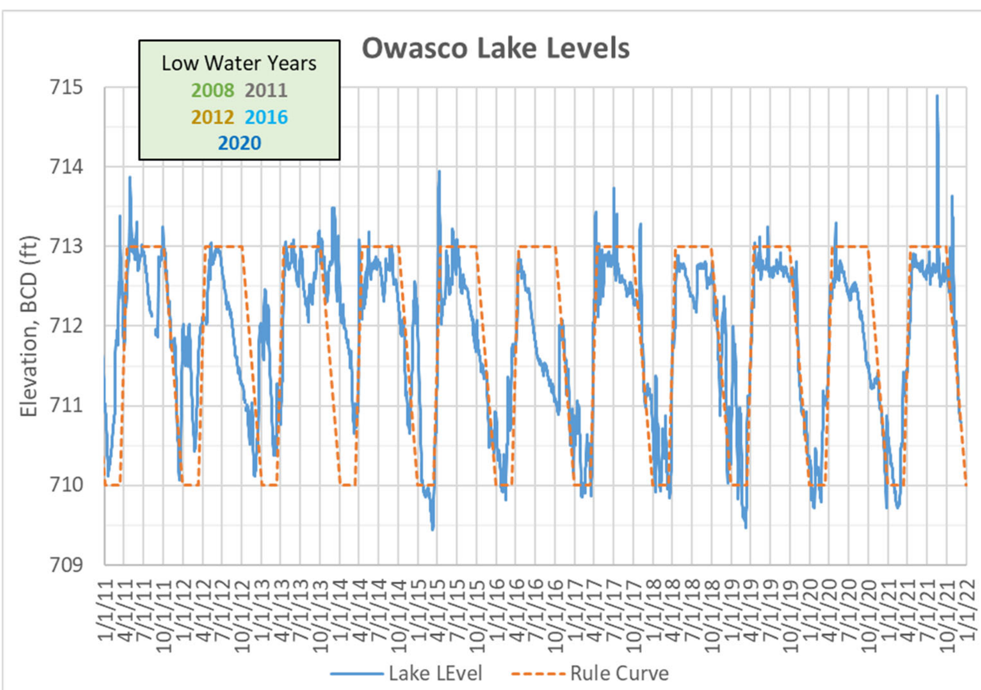


Fig 5. 2021 Monthly (above left) and 2011 – 2021 spring, summer, fall, and field season precipitation (above right) compared to normal totals at the Ithaca Airport. Daily rainfall variability between the Ithaca Airport, the 4 dock sites, and NY-CY-08, a CoCoRaHS site in the Dutch Hollow Watershed (below).

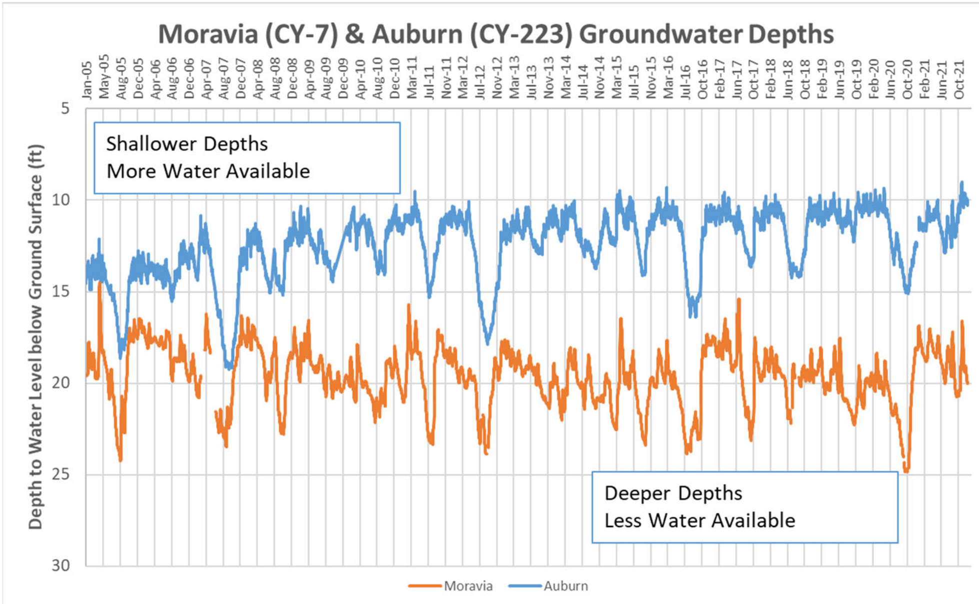
Owasco Lake Levels: Another indicator of wet conditions in 2021 is lake level and groundwater table depths. Records of both are available within the Owasco Watershed. Lake levels in the late summer and early fall were close and occasionally exceeded the rule curve summer elevation of 713 ft (Fig. 6). Lake levels rose ~2 feet during the 8/18 flood event, and as a result, many homeowner docks were submerged or floated away. This past year experienced minimal declines in groundwater table depths during summer/fall-season at the Moravia (CY-7) and Auburn (CY-122) USGS monitoring wells, after experiencing some of the deepest declines in 2020 (Fig. 6). These records all highlight a return to wetter, more saturated conditions in 2021.

We openly speculated that low lake levels in 2020 contributed to the large number of HABs events recorded by the DEC. The DEC record of HABs sightings for Owasco Lake starting in 2012, a low lake level year, and the number of sightings each year peaked in 2016, the lowest recorded lake level since 2008 (Fig. 6). Lower lake levels may have exposed nutrient rich sediments to increased wave action and erosion, and the steady lake level decline through the summer might have allowed more macrophytes to be washed ashore and left to rot along the shoreline. Both processes could provide more nutrients to the lake and support more blooms along the shoreline. Unfortunately, significantly fewer blooms were observed at Seneca Lake in 2020 despite similar precipitation, lake level and water table conditions.

In contrast, the 2021 floods preceded notable HABs events and algal blooms in 2021[6]. It suggests that the associated nutrient runoff was significant, stimulated HABs events immediately following the events, and may have contributed to the second largest number of recorded HABS sightings in Owasco Lake during 2021. Thus, both abnormally low and high lake levels appear to contribute to more HABs events.



[6] Halfman, et al., 2022. Cyanobacteria on Owasco and Seneca Lakes, the 2021 Update. The 2021 Annual Report to the Fred L. Emerson Foundation, Seneca Lake Pure Waters Association and the Finger Lakes – Lake Ontario Watershed Protection Alliance



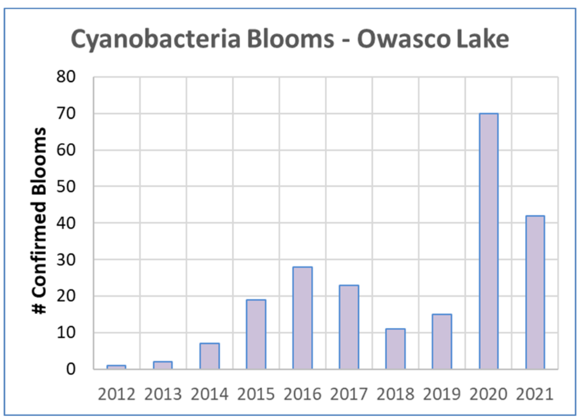


Fig. 6. 2008 through 2021 lake levels for the summer/fall season (above). 2012 through 2021 groundwater water table depths below the ground's surface (middle). Number of confirmed cyanobacterial blooms in Owasco Lake tabulated by the DEC NYS-HABs web site (left).

LAKE MONITORING

Lake CTD Profiles: The 2021 offshore water temperature profiles detected similar warm surface water temperatures as the past seven years (Fig. 7). 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. 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 seasonally, 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 23.5ºC (~74ºF) in early August, and cooled to 19ºC (66ºF) by the last cruise of the survey (9/28). These temperatures were not as warm as those recorded in 2020 with a peak temperature of 25°C, but the 2021 surface water temperatures were as warm or warmer than those recorded since 2015. The past seven years, when HABs events impacted Owasco Lake, surface water temperatures were collectively warmer than earlier years. Hypolimnetic water temperatures remained cold, warming from 5.5º 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, mean wind speed and global phenomena like El Nino. For example, 2009, 2016 and 2020 were slightly warmer, whereas 2013 and 2014 were slightly cooler than the linear trend. The long-term warming however, suggests that Owasco Lake is influenced by Global Warming. Speculatively, the warmest water, which was detected in 2020, was coincident with the largest number of cyanobacteria blooms in Owasco Lake. Warmer temperatures can promote faster and more complete bacterial decay of the dead organic matter and release more nutrients for algal uptake. However, Seneca Lake surface water was also warmest on record in 2020 but Seneca experience very few blooms in 2020 compared to previous years.

Epilimnetic salinity (specific conductance) ranged from 300 to 335 μS/cm in 2021 (~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 (Fig. 7). The early spring, surface water specific conductance was nearly similar to previous years. 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. The salinities in 2020 was slightly larger than previous years. It may have reflected decreased rainfall in 2020 and less dilution of the previous winter's salt input than earlier years. The salinity declined slightly in 2021, probably reflecting the increased precipitation.

The 2021 hypolimnetic specific conductance data were between 340 and 350 μS/cm and increased slightly over time (Fig. 9). These values were similar to those detected in 2020 and slightly larger than those detected in previous years. 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.

The epilimnetic dissolved oxygen (DO) concentrations remained between 8 and 12 mg/L, and near or lightly above 100% saturation. In contrast, hypolimnetic DO concentrations were progressively depleted below saturation through the stratified season from over 13 mg/L (100% saturation) to 6 mg/L (~60% saturation) in the upper hypolimnion and just below 8 mg/L (~60% saturation) in the lowest hypolimnion by late summer. These lowest saturation levels approached the threshold for respiratory stress in sensitive organisms. The decrease is interpreted to reflect hypolimnetic bacterial respiration and decomposition of dead algae. The hypolimnetic depletion was similar to previous years.

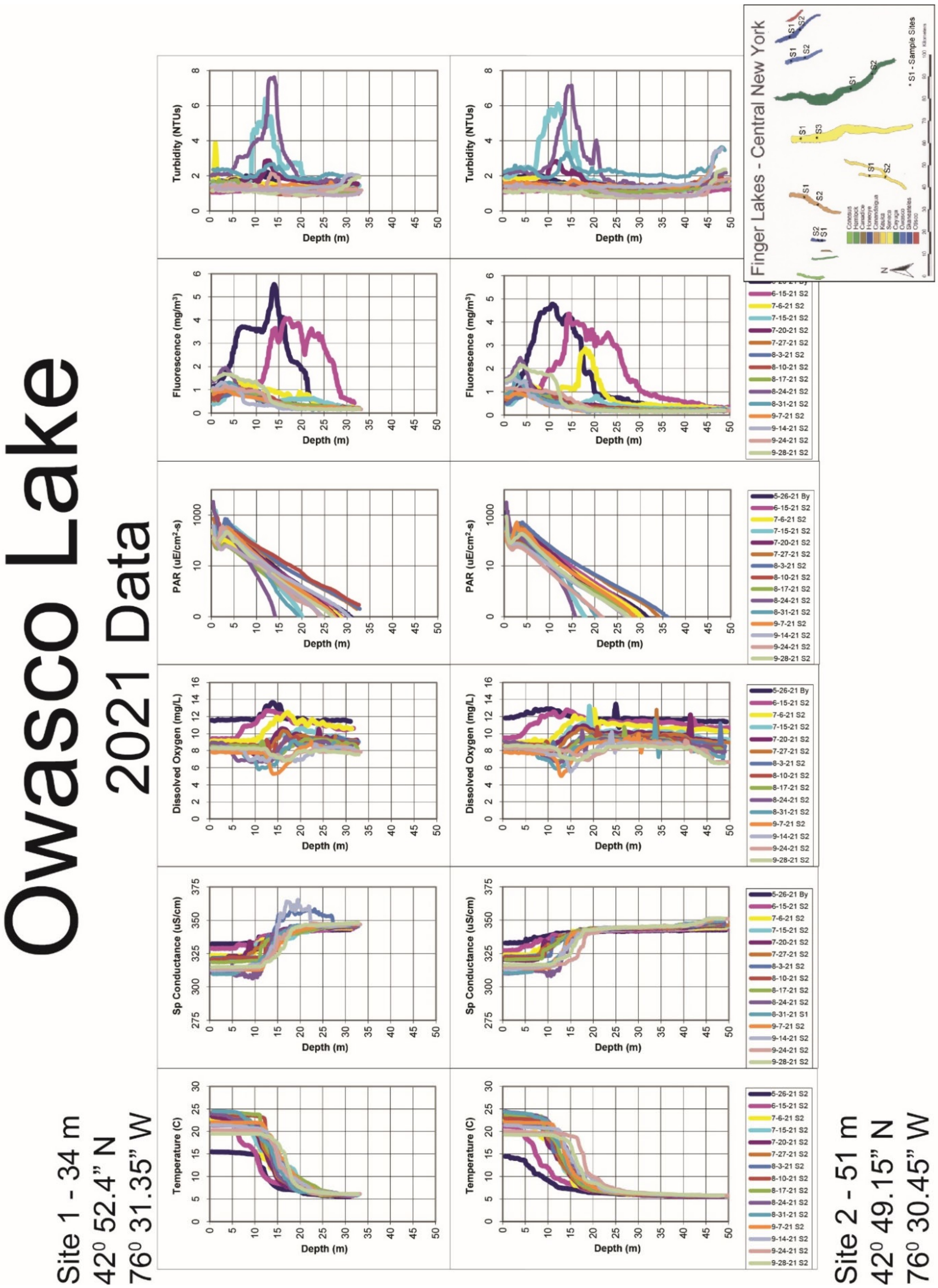


Fig. 7. CTD profiles from Sites 1 & 2 in 2021. The PAR (light) data are plotted on an exponential scale, so that the expected exponential change in light intensity with water depth appears as straight lines.

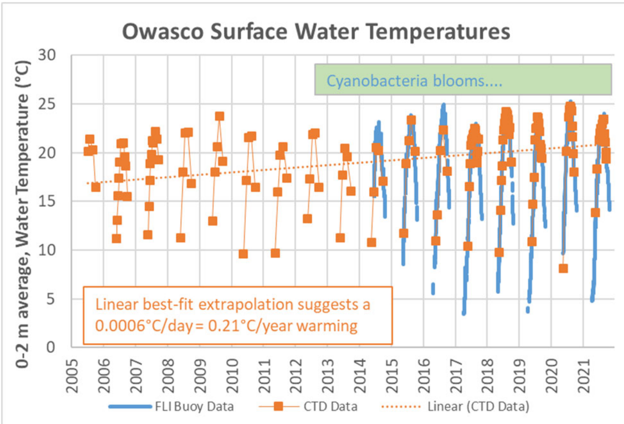


Fig. 8. The available CTD and FLI buoy mean surface water temperatures (1 to 10 m average) since 2005.

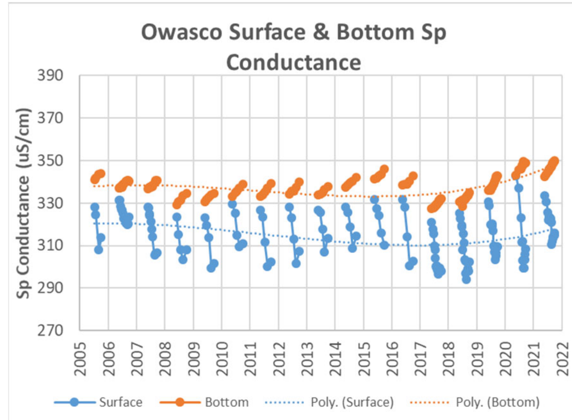


Fig. 9. Mean surface (upper 10 m) and bottom (lower 10 m) water salinities by CTD since 2005.

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 restricted by light to the epilimnion in Owasco Lake. Many of the 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 an occasional peak in algal abundance within the lower epilimnion at approximately 15 to 20 m below the lake's surface (Fig. 7). Peak concentrations exceeded 5 μg/L (mg/m^3) on 5/28, and were above 4 μg/L on 6/15 and above 2 μg/L on 7/6. Algal 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 peak at depth may reflect some combination of an increase in algal biomass or more pigments per cell in the lower light conditions. These peak concentrations and frequency of peaks were larger in 2021 than earlier years. The larger concentrations parallel the increase in winter and spring rainfall, and in 2021 the mid-summer to fall events, as runoff is the primary source of new nutrients for large algal blooms. 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 7 NTUs just above the thermocline on two survey dates, 7/15 and 8/24, and peaks up to 3 NTUs on 5/26, 7/20, 8/31 above the typical 1 to 2 NTU water column turbidities. The largest peaks followed flood events during the field season and probably reflected turbid water injected into the lake just above and along the thermocline by the Owasco Inlet and other streams along the lake as noted in whole lake surveys in previous years. 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 in 2020 compared to earlier years. In 2021, it probably reflected turbid water from the flood events.

The bbe FluoroProbe data revealed similar concentrations of green, diatoms, cryptophyte and cyanobacteria in surface water grabs at the offshore sites in 2021 (Table 2 in appendix, Fig. 10). The date averaged, total algal concentrations ranged from 2.7 μg/L on 7/15 to 20.3 μg/L on 5/26. From 2017 to 2021, the algal population changed from mostly diatoms and cryptophytes with lesser amounts of green algae and trace amounts of cyanobacteria in 2017 to similar amounts of all four algal groups in 2020, and equal numbers of each algal group except slightly less cyanobacteria in 2021. The increased presence in 2020 may reflect decreased rainfall in 2020. In support, larger relative percentages of cyanobacteria compared to other algal groups were detected in the algal populations in neighboring oligotrophic lakes like Skaneateles, Keuka and Canandaigua, compared to mesotrophic and eutrophic Finger Lakes like Honeoye, Seneca and Cayuga. It suggests that cyanobacteria may dominate algal populations in nutrient starved habitats.

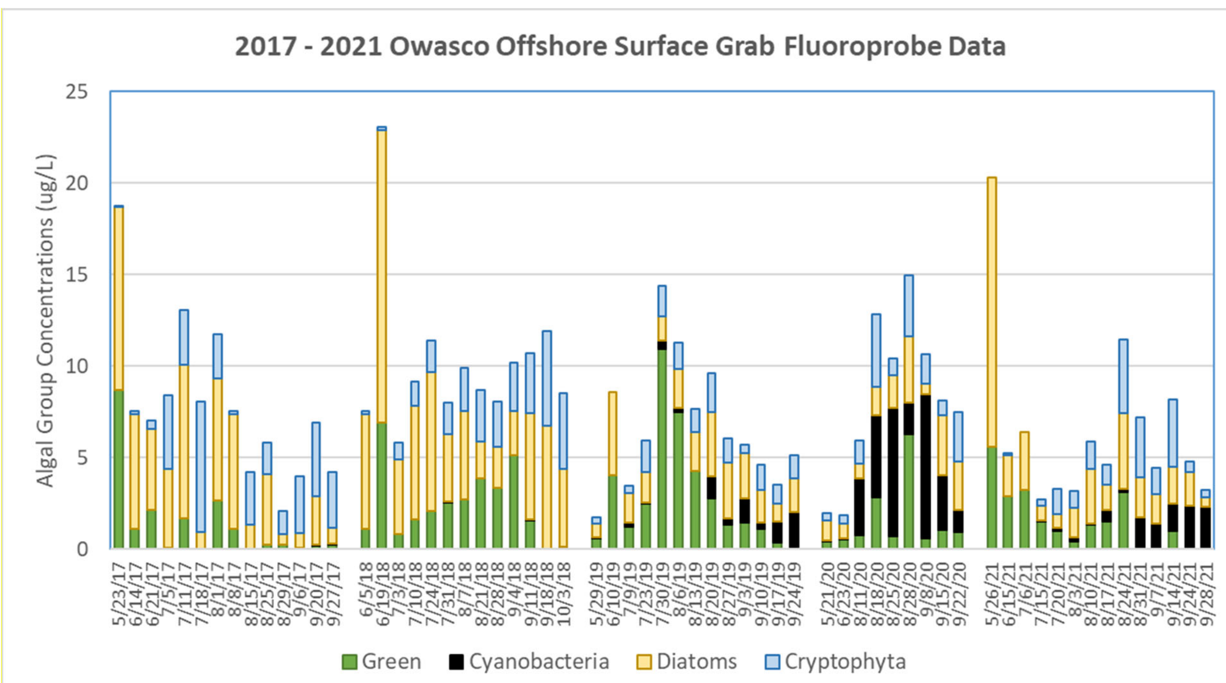


Fig. 10. Offshore, surface grab, date averaged, bbe FluoroProbe data revealing the relative concentrations of the four algal groups from 2017 through 2021.

Limnology & Trophic Status: Date averaged mean chlorophyll-a concentrations in the epilimnion ranged from 1.6 to 6.4 μg/L and averaged 3.4 μg/L in 2021 (Table 3 in appendix, Fig. 11). The largest values were detected during May and August. 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 other fluorescence datasets measured the concentration of all pigments. The chlorophyll-a annual mean concentration was slightly smaller in 2021 compared to the two previous years, and below the DEC's do not exceed potable water body limits of 4 to 6 μg/L[7], but mean concentrations on 8/24 and 9/14 exceeded this limit. This slight decrease in the 2021 annual mean concentration is surprising as 2021 was wetter than earlier years. Perhaps the increased presence of cyanobacteria and their surface floating tendencies compared to other algal groups might have artificially increased the chlorophyll-a concentrations in the surface grab samples in 2019 and 2020 compared to other years. Alternatively, flood sediments injected just above the thermocline in 2021 (see CTD and Buoy profiles) may have provided nutrients for the observed algal peaks just above the thermocline, and a smaller impact on surface waters.

Secchi disk depths ranged from 2.6 to 6.2 meters and averaged 3.8 meters in 2021 (Fig. 11). 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 in 2020 only to become slight deeper in 2021. 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 are not consistent with rainfall conditions. Perhaps the proportional cyanobacteria increase 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. TSS and chlorophyll-a trends, and lower light intensities measured by the CTD were consistent with this hypothesis. The inconsistent 2021 average may reflect fewer but more intense rainfall events in 2021 than earlier years that injected turbid water just above the thermocline in the lake, decreasing a significant surface water expression and detection of suspended sediments by the surface samples.

The lake was not impaired due to phosphorus, as the annual mean total phosphate (TP) concentration ranged from 9 to 19.4 μg/L. The annual average of 13.7 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 never exceeded on any sample date in 2021 with a maximum date-averaged TP concentration of 19.4 μg/L on 6/15. Since 2006, annual mean TP concentrations have increased from ~8 to over 17 μg/L by 2014 with a slight dip in 2013 (Fig. 11). 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, fluctuations that parallel rainfall trends.

Annual mean soluble reactive phosphate (SRP) concentrations in 2021 remained very small 0.5 μg/L, similar to 2010, 2012, 2015, 2018, 2019 and 2020, compared to years with significantly larger SRP concentrations, i.e., 2006 and 2017 (1.9 μg/L), and especially 2014 (5.8 μg/L, Fig. 11). The large 2014 mean was biased by a 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.

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

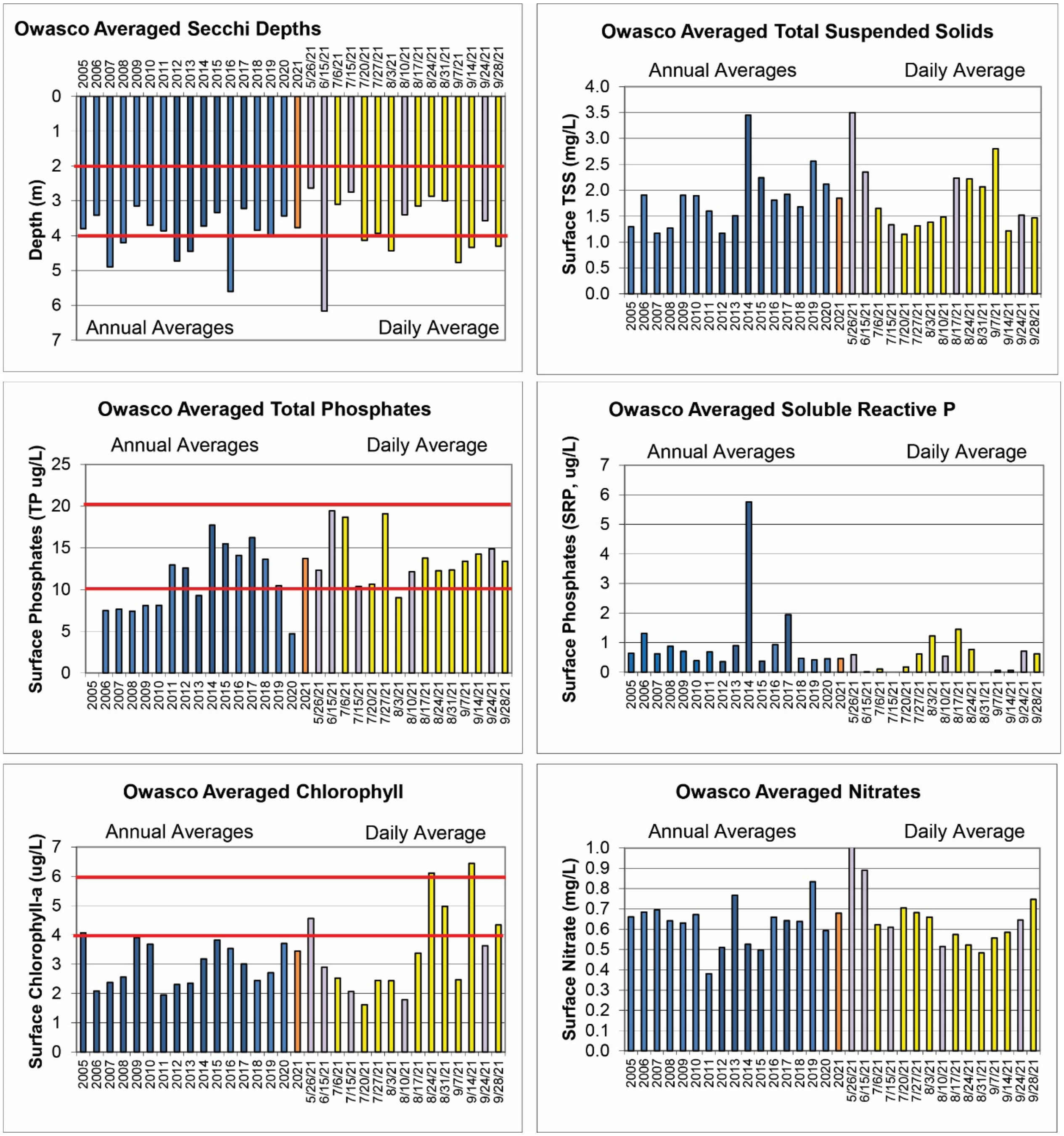


Fig. 11. Annual average surface water concentrations from 2005 (blue) to 2021 (orange), and survey date averaged offshore surface water data during 2021 (yellow). The Finger Lake water quality rank calculations used the dates marked in purple. When appropriate, boundaries for oligotrophic, mesotrophic and eutrophic concentrations are marked with red lines.

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 1.2 to 3.5 mg/L and averaged 1.8 mg/L. In 2021, the TSS concentrations were highest in the spring and 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 since a peak of 3.5 in 2014, down to 1.7 mg/L in 2018 (Fig. 11). Since 2019, TSS concentrations continued to decrease into 2021, perhaps a reflection of minimal rainfall in 2020, and the input of fluvial sediments just above the thermocline decreasing a significant surface water expression in 2021. Overall, 2014 revealed the worst water turbidity for the lake. The trends, for the most part, parallel changes in rainfall. Wind driven waves could also increase suspended sediment concentrations during "dry" years. Alternatively, more persistent cyanobacteria in 2019 and 2020 may have increased the TSS concentrations in surface grab samples.

The 2021 trophic status indicators yielded a mixed and slightly worse signal. Annual mean Secchi depth, TP concentrations and hypolimnetic dissolved oxygen saturation data placed Owasco Lake just above the oligotrophic-mesotrophic trophic boundary (Table 4). Nitrogen, measured by NO_x concentrations, and chlorophyll data placed Owasco Lake below the boundary. Thus, the overall trophic status of Owasco Lake in 2021 is just above the oligotrophic-mesotrophic boundary, 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 indicate that water quality has not improved (or worsened) in the lake over the past decade, and recently declined. The stagnation and recent decline is discouraging and indicates that remediation efforts over the past decade have not been extensive enough to improve water quality in the lake!

Table 4. Concentration ranges for Oligotrophic (low productivity), Mesotrophic (mid-range productivity), and Eutrophic (high productivity) lakes. The bold entries bracket Owasco's 2021 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 1:8,000 in 2021. The P:N ratio required by algae 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 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. 11). The extent of the variability is best observed in the buoy data (next section) and the extreme values depicted by the box and whiskers plots (Fig. 12). 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. For example, the largest 2021 algal blooms occurred for a few days just after the rain events in May, August and October.

Third, the dissolved nutrient concentrations revealed slightly larger concentrations in the hypolimnion than the epilimnion. The annual mean surface and bottom water concentrations were 0.5 to 0.8 μg/L for SRP, and 0.7 to 1.1 mg/L for NO_x. Chlorophyll-a concentrations revealed the expected decrease from the epilimnion to the hypolimnion of 3.4 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.

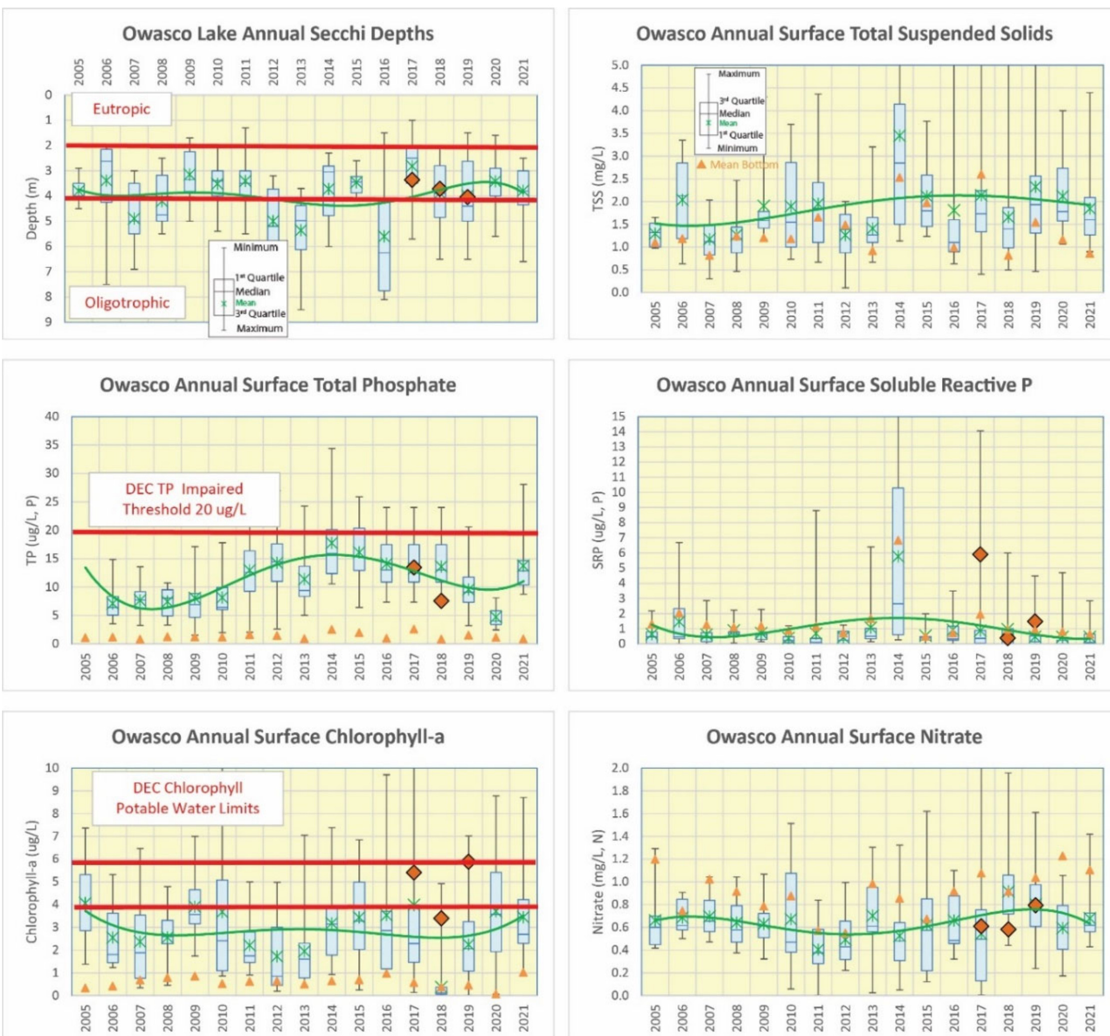
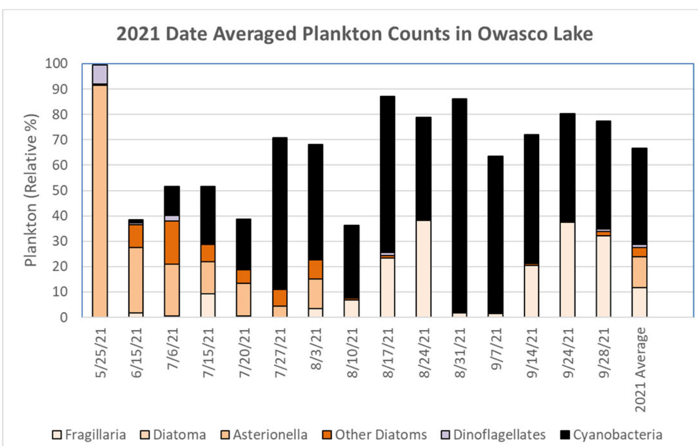


Fig. 12. Box and Whisker plots of the annual nutrient, chlorophyll and Secchi disk data. The annual mean bottom water concentrations (orange triangles) and annual mean DEC C-SLAP data (orange diamonds) are also plotted. DEC measured TDP in 2017 instead of SRP, and total chlorophyll instead of chlorophyll-a. Both differences should result in larger DEC than this survey's data. TP data in 2019, and all 2020 and 2021 C-SLAP data were unavailable.

Finally, 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. 12). 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.

Plankton Data: Like recent years, the phytoplankton (algal) species in Owasco Lake during 2021 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 5 in appendix, Fig. 13). The overall diversity decreased in 2021 from earlier years. Other phytoplankton species detected included a small percentage of *Synedria,* and *Dinobryon*. The relative percentage of green algae also increased in 2021 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.



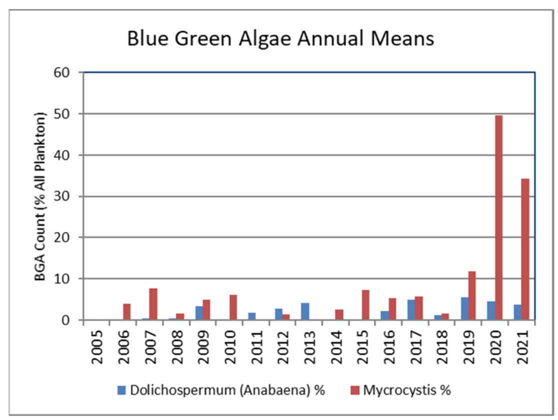


Fig. 13. Date averaged plankton data for 2021 (left) and the mean annual abundance of cyanobacteria species since 2005 (right).

Cyanobacteria genera, *Microcystis* and to a lesser degree *Dolichosperma*, continued their 2020 dominance into 2021 during the late July through September surveys (Fig. 13). Detection of cyanobacteria in the lake is not new, and they were always detected in the open water of Owasco Lake since the initial FLI surveys in 2005. In fact, cyanobacteria species were detected in a neighboring Finger Lake as long ago as 1914[8]. However, major blooms of cyanobacteria have been increasingly detected along the shoreline in Owasco Lake since 2012[9]. The largest BGA populations were 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 and 2021, and *Dolichosperma* making up 30% of the late-summer

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

counts in 2013. Starting in 2020, the offshore dominance of cyanobacteria increased over previous years, with a maximum relative percentage of 92% for *Microcystis* during the 8/5/20 survey and 84% in the 8/3/21 survey. This is consistent with the Fluoroprobe results.

Finger Lake Water Quality Ranks: The 2021 Finger Lake water quality rank for Owasco Lake was slightly worse in 2021 compared to previous years, except for 2014 (Table 6 in appendix, Figs. 14 & 15). 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. Please note: Selecting monthly dates from the more numerous sample dates on Owasco Lake resulted in slightly larger means for the Finger Lake Survey than all of the survey dates on the lake. 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[10] that quantitatively combine chlorophyll-a, total phosphorus and Secchi depth data (Fig. 14). In 2021, water quality in Owasco ranked poorer than Canandaigua, Keuka, Seneca and Skaneateles Lakes, and better than Cayuga and Honeoye Lakes.

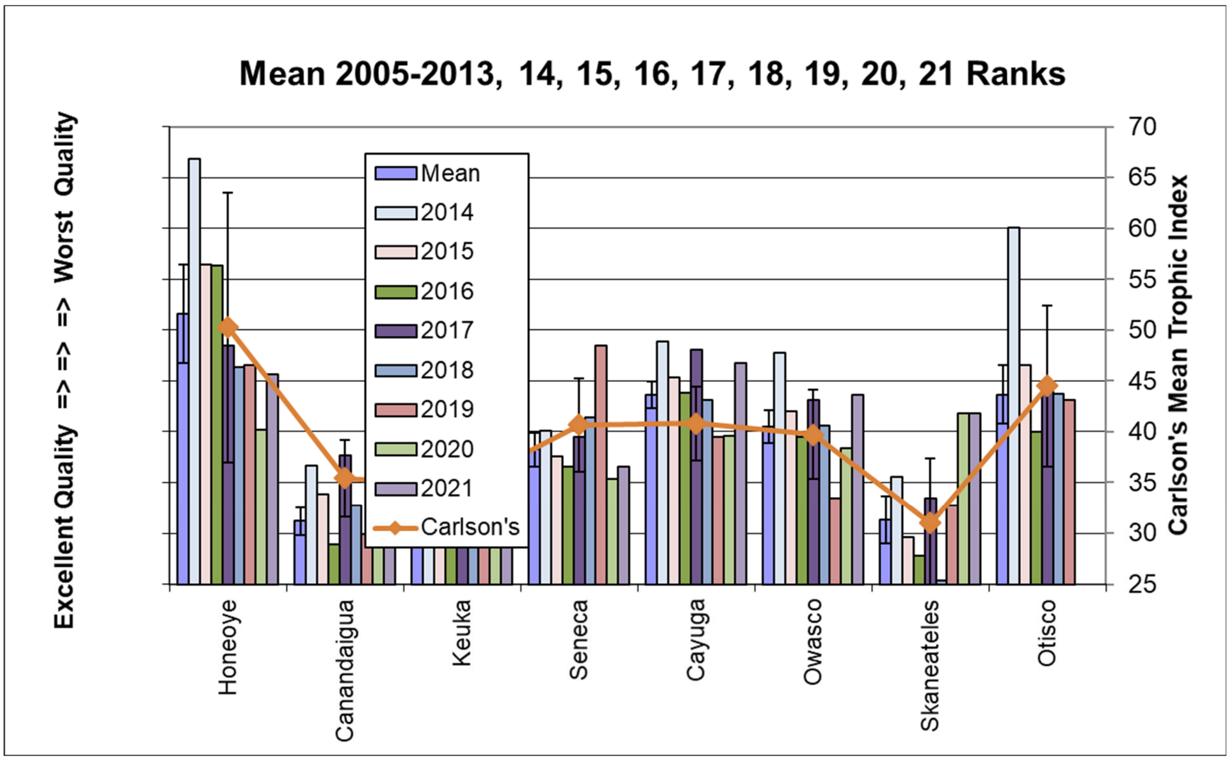


Fig. 14. Annual Water Quality Ranks from 2005 – 2021 for the eight easternmost Finger Lakes. Otisco was excluded from the survey in 2020 and 2021 due to COVID issues. The "mean" dark blue bar averaged the 2005 - 2013 ranks for each lake with a 1σ standard deviation error bar. Carlson's mean trophic indices using the mean Secchi depths, total phosphate and chlorophyll concentrations are also shown.

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

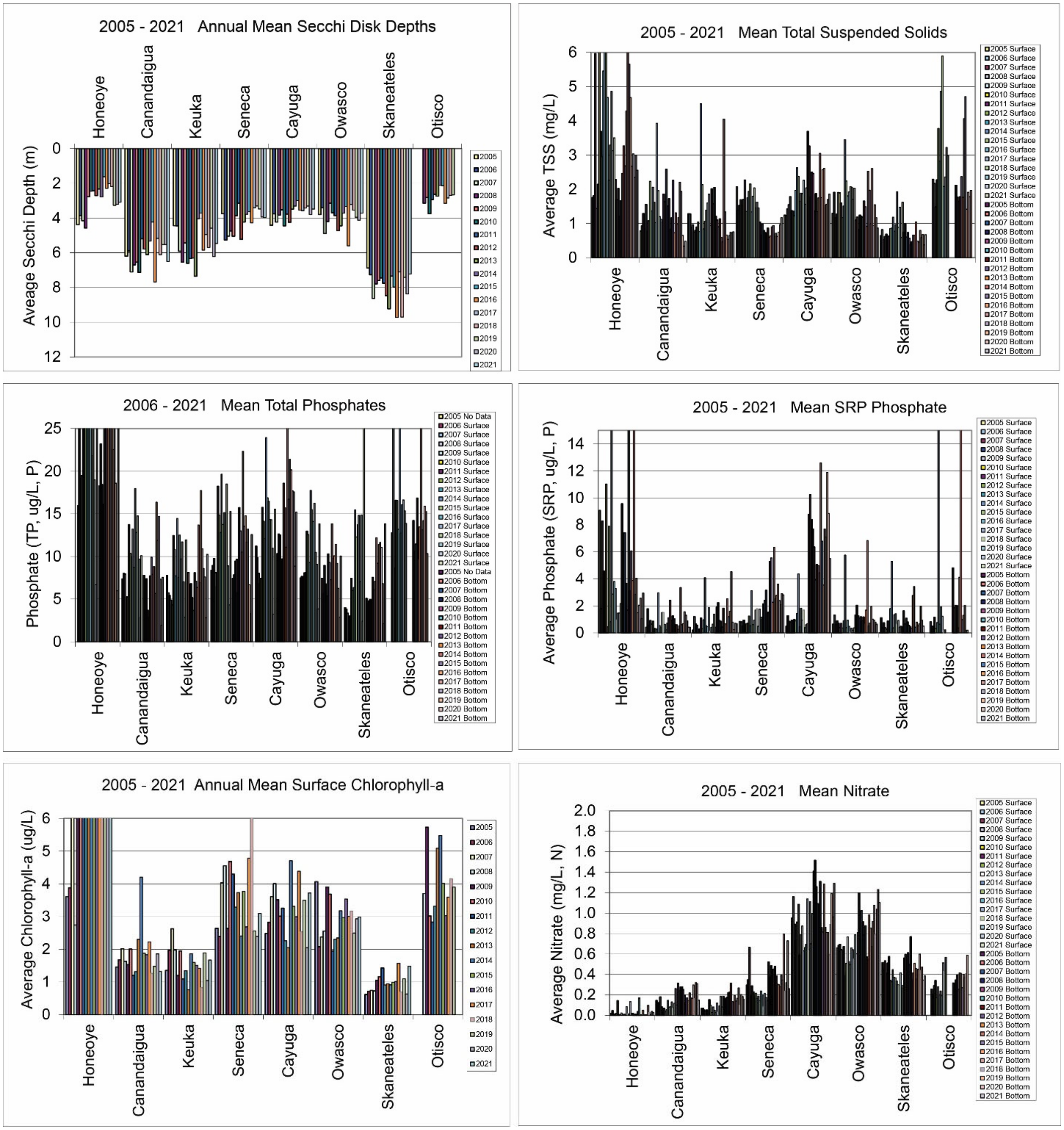


Fig. 15. 2005 – 2021 annual mean limnological data based on monthly surveys on the eight eastern Finger Lakes.

Owasco Lake water quality improved from 2014 through 2019, and declined slightly in 2020 and declined even more in 2021. 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. Finally, a change in offshore algal populations to a larger representation of cyanobacteria in 2020 and 2021 could have arbitrarily increased the chlorophyll-a and TSS data, worsening Owasco's annual rank compared to earlier years.

DRONE FLIGHTS & NEARSHORE SPECTRAL DATA

Drone flights during each visit to the four dock sites unfortunately did not coincide with cyanobacteria blooms in 2021. These images also did not reveal major changes in the macrophyte densities at each site. We plan to continue our periodic drone flights to map the distribution and concentration of nearshore macrophytes, attached algae and cyanobacteria blooms in the years ahead.

The relationship between the spectra of light to algal concentrations became more 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. 16). The intent was to determine if the ratio between upwelling and down-welling spectra could resolve algal concentrations. Like earlier years, the 2021 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). However, 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 impacted the spectral results. The offshore sites provided similar results although backscattering by waves and the reflections of the boat also influenced the spectra results. More work must be done next summer to improve the spectroscopic techniques and confirm the influence of clouds on the spectral signatures.

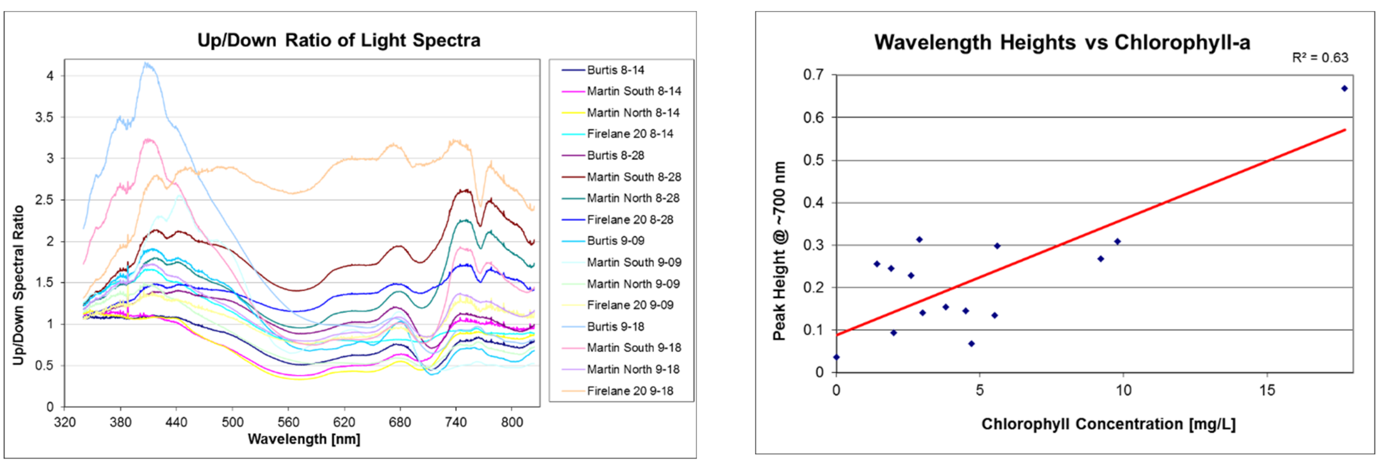


Fig. 16. Ratio of upwelling and down-welling spectra from the dock sites (left). Algal signatures are typically in the near infrared (~700 nm). Peak height at 700 nm for each up/down spectral ratio vs. chlorophyll-a concentration (right).

FLI BUOY & DOCKSIDE DATA

The FLI meteorological and water quality monitoring buoy was redeployed in Owasco Lake during the 2021 field season. It revealed higher resolution but otherwise consistent changes in the water column as described in the CTD section (Fig. 17). More information is available in the companion HABs report.

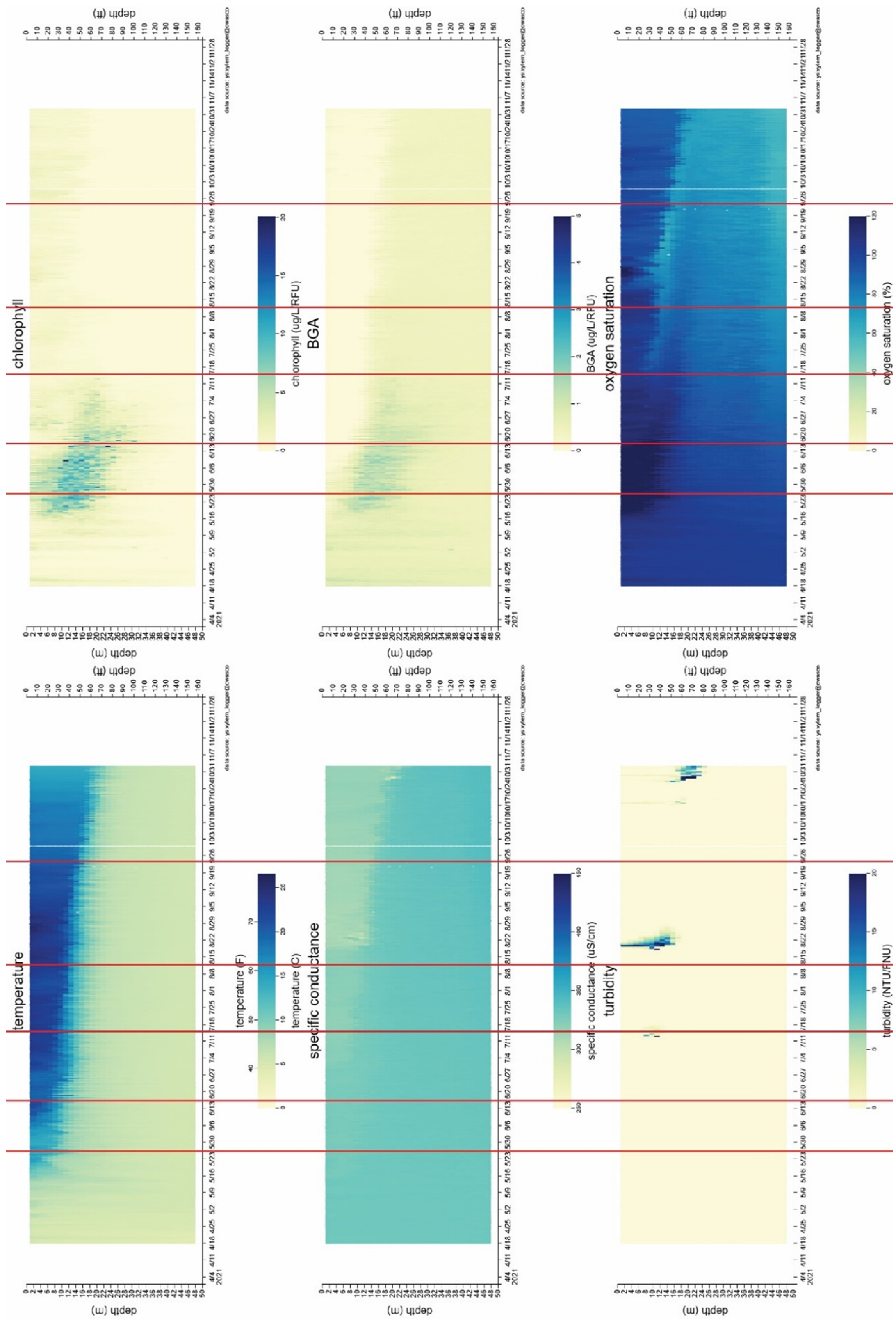


Fig. 17. Buoy water quality data in 2021. The data shown above are raw uncalibrated values. Subsequent calibrations altered the turbidity and chlorophyll data slightly (see companion report). The red lines depict the monthly monitoring cruise dates. The lower epilimnetic spikes in turbidity occurred just after the 7/12, 8/18, 10/14 and 10/27 rainfall events.

STREAM MONITORING

Stream Discharge: The 2021 stream discharge data from the 4 survey dates ranged from nearly dry conditions, 0.01 m^3/s in the small tributaries at Fire Lane 20 & 26 on 5/4, 5/21, and 6/7 to 8.1 m^3/s in Owasco Inlet at Moravia on 5/7 (Table 7 in appendix, Fig. 18). These flows were similar to than those detected in past "normal" rainfall years, and relates to the near "normal" rainfall in 2021. Flows were largest after rain events especially on saturated ground.

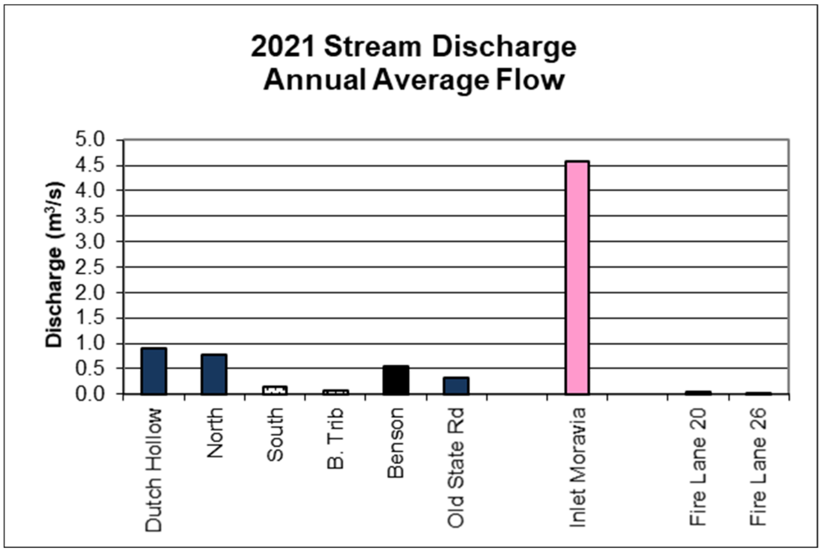


Fig. 18. Annual average stream discharge at each stream site in the Dutch Hollow Brook (purple), Owasco Inlet (pink), Fire Lane 20 and 26 watersheds. Tributary sites along Dutch Hollow Brook are stippled. Sites along Dutch Hollow Brook are arranged from downstream (left) to upstream (right).

Within Dutch Hollow Brook, mean annual discharge at each site typically equaled or was slightly larger than the sum of the discharges at the next upstream site and any measured tributaries entering along the segment between sites (Fig. 18). For example, the sum of the mean annual discharge at North Rd was similar to the sum of the discharges at South, Benson tributary, and Benson Rd sites. Mean annual discharge was slightly smaller at North Rd than 38A this year like previous "normal" years, whereas the opposite was typically true during "dry" years. It suggests that surface runoff and groundwater inputs contributed to and increased stream discharge from North Rd down to Rt 38A during "wet" and "normal" years. Whereas, proportionally more stream water is lost to evapotranspiration by plants, and/or infiltration into the permeable sand and gravel aquifer at the Dutch Hollow Brook delta, during "dry" years. The change in water table depths over the past decade support this conclusion.

Discharge for the Owasco Inlet at Moravia (USGS Gauge, 4235299) was again proportionally larger than Dutch Hollow Brook because the Owasco Inlet drains a significantly larger watershed than Dutch Hollow Brook (299 vs. 77 km^2). Discharge was proportionally smaller at the two Fire Lane sites due to their smaller watersheds (< 10 km^2).

HyFi data from the Owasco Inlet (OI) at Groton, Locke and Moravia, a tributary to OI at Groton, Dutch Hollow Brook, Sucker Brook and Veness Brook compared favorably (Fig. 19). All of dataset revealed similar 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 taller peak stage values and a longer return to baseflow times, as expected. A few exceptions are noteworthy. The Dutch Hollow Brook data experienced daily temperature sensitive noise that decreased the stage readings during the daylight hours (Brandon Wong, personal communication, 2021), and Sucker Brook was out of sync with the other watersheds. Perhaps the Sucker Brook site measured lake levels and not stream stage at the Owasco Lake Rd site, as its stage closely mimicked that of Owasco Lake.

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 most noticeable after the 8/18 flood event (Fig. 19). A HyFi report confirmed a strong correlation between the HyFi and USGS data ($r^2 = 0.94$) with a mean offset of 0.8 ft.[11] The author if the HyFi report suspected that the offset and other small differences were due to the separation of the two sites by 0.37 miles, and different stream bed geometries at each site.

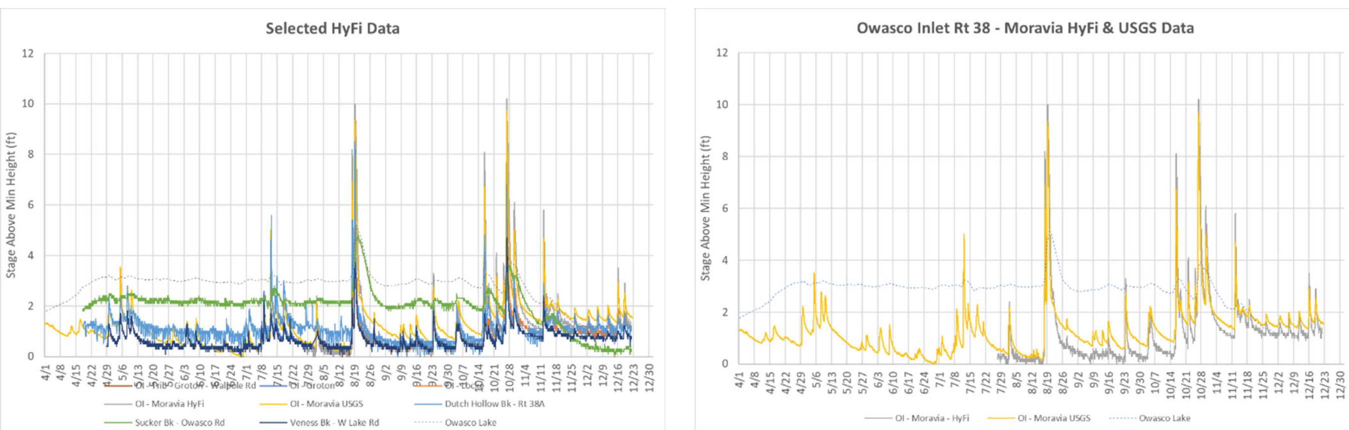


Fig. 19. Comparison of selected HyFi stage data to the stage data at the USGS Gauge in Moravia and the USGS Lake Level data at Auburn.

Seasonal Variability: Seasonally, the largest discharges in 2021 were associated with the events detected throughout the field season at Dutch Hollow and the Owasco Inlet based on the data logger estimated discharge for Dutch Hollow Brook at the Rt 38A site and the USGS gauge for Owasco (Fig. 20). The seasonal change at Dutch Hollow Brook was smaller than previous years. The spring typically has the largest discharges, and baseflow typically declines throughout the field season. The streams experienced larger events in 2021, and these large events were detected throughout the field season compared to earlier years. As a result, baseflow was periodically rejuvenated by these events, maintaining higher baseflows throughout the 2021 season.

Differences to Earlier Years: The 2021 annual mean discharge was similar to the other large mean discharges detected at Dutch Hollow Brook, except for the 2011 anomalously large discharge (Fig. 21). At the Owasco Inlet, the 2021 discharge was larger than every year on record since 2011. These differences parallel annual changes in precipitation, lake levels and water table depths.

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

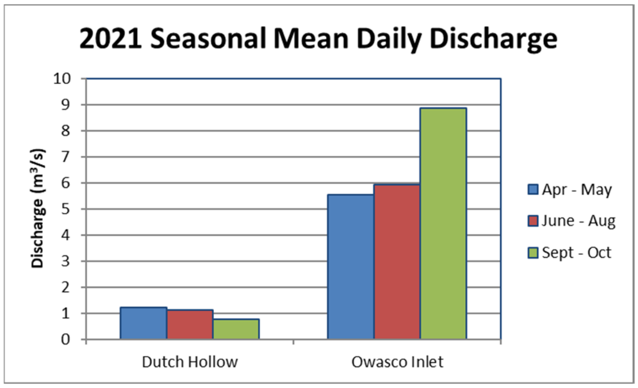


Fig. 20. Seasonal averaged stream discharge for the Rts. 38A and 38 sites, the terminal sites on Dutch Hollow Brook and Owasco Inlet, respectively, based on the estimated Dutch Hollow data logger and USGS daily Owasco Inlet discharge data.

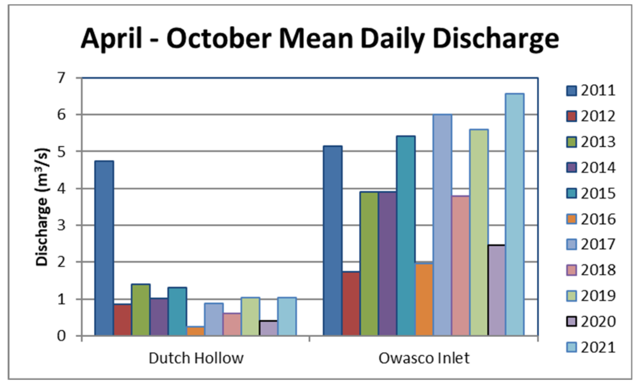


Fig. 21. Field season annual average stream discharge for the Rts. 38A and 38 sites based on the estimated Dutch Hollow Brook data logger and USGS daily Owasco Inlet discharge data.

An Owasco Inlet (USGS Gauge, 4235299) field-season, mean daily discharge of 6.6 m^3/s in 2021 was larger than every year since 2009, and again indicative of an "event-rich" year (Fig. 22). Similar variability was observed for the Owasco Outlet where the mean 2021 flow of 12.7 m^3/s was larger than every year since 2009 (USGS Gauge, 4235440, Fig. 22). 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 curve levels, minimizing downstream flooding and other concerns.

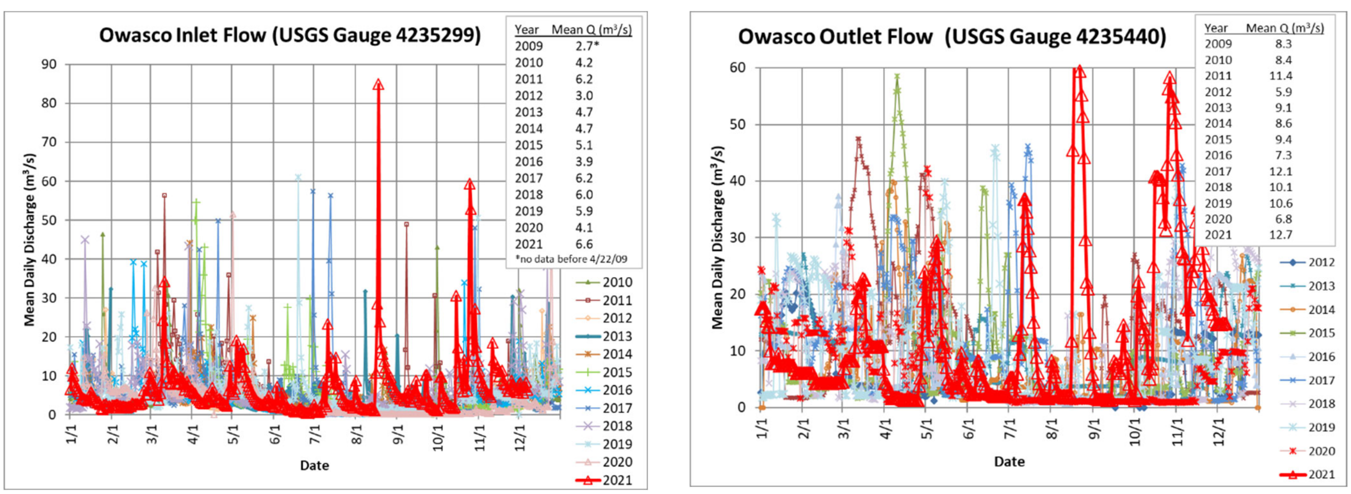
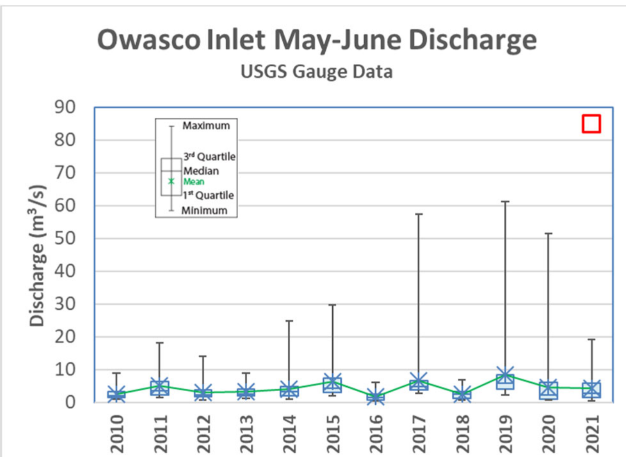


Fig. 22. Stream discharge for the Owasco Inlet near Moravia (left) – USGS Stream Gauge 4235299 and the Owasco Outlet (right) – USGS Stream Gauge 4235440.

Extreme Events: Both the Owasco Inlet and Dutch Hollow Brook revealed extreme precipitation induced events in their hydrology (Fig. 23). 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. 23). 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. A similar pattern is observed at Dutch Hollow Brook if the event during early July is included in the Dutch Hollow record (2017* Fig. 23). These events are critical because large events generate exponentially larger impacts on nutrient and sediment loads to the lake.

At first glance, this past summer (2021) was an apparent anomaly, as the upper whisker is small despite the extra-large flood events in 2021 that dislodged the data logger and autosampler deployment at Rt. 38A. However, the 2021 floods were not included in the Box & Whisker plots as they occurred after the May to June 2021 time period. Rain on August 18 yielded the largest runoff event signature in the watershed (53 m^3/s at Dutch Hollow and 85 m^3/s at Owasco Inlet on 8/19). More intense rainfall events are a predicted outcome of Global Warming.



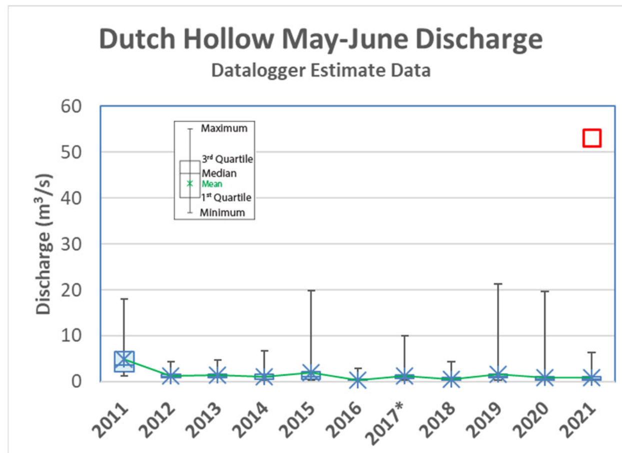
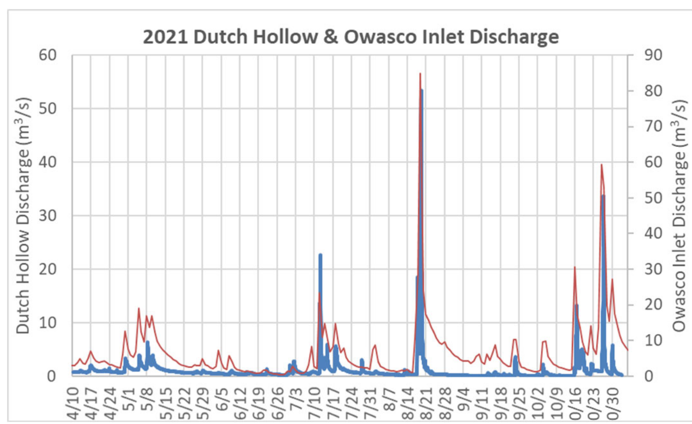


Fig. 23. Box and Whisker plots of daily mean discharge during the May – June season over the past nine years for Owasco Inlet (above left) near Moravia using the USGS Stream Gauge 4235299 data and Dutch Hollow Brook (above right) using the Rt 38A data logger data. Discharge vs time at Dutch Hollow Brook and the Owasco Inlet (right). Notice both streams respond dramatically to rain events, the most serve events were after the May – June time interval. The red square marks the huge August flood event.



Stream Nutrient & TSS Concentration Data: Total phosphate (TP) concentrations in the 2021 grab samples ranged from 8.2 to 33 μg/L, and averaged 8.2 μg/L at Rt 38A in Dutch Hollow Brook, ranged from 15.7 to 28.4 μg/L, and averaged 15.7 μg/L at Rt 38 in Owasco Inlet, and ranged from 9.8 to 20.2 μg/L, and averaged 15.1 μg/L at the two Fire Lane sites (Table 7 in appendix, Fig. 24).

Along Dutch Hollow Brook, the Benson tributary site revealed the largest annual mean TP, SRP, NO_x, and specific conductance (salinity) values than the other sites in 2021 (Fig 24). For example, the TP annual mean concentration was 24 μg/L at the Benson tributary site. The next largest concentration was 19 μg/L at the Old State Rd site, and the other sites in this basin were below 17.5 μg/L. It suggests that runoff from agricultural crop and animal sources impacted the

Benson tributary in 2021. Its downstream impact was diluted by larger stream volumes downstream. It appears that the 2015 and 2016 reduction of nutrients, suspended sediment concentrations and salinity at the Benson tributary site compared to other sites in the basin and a subsequent return to larger values in 2017 were due to decreased rainfall in 2016 and not due to other causes as previously speculated, as the decline was not duplicated in 2020 and 2021 (Fig. 25). The South tributary that drains agriculturally rich land to the south also revealed larger SRP and NO_x.

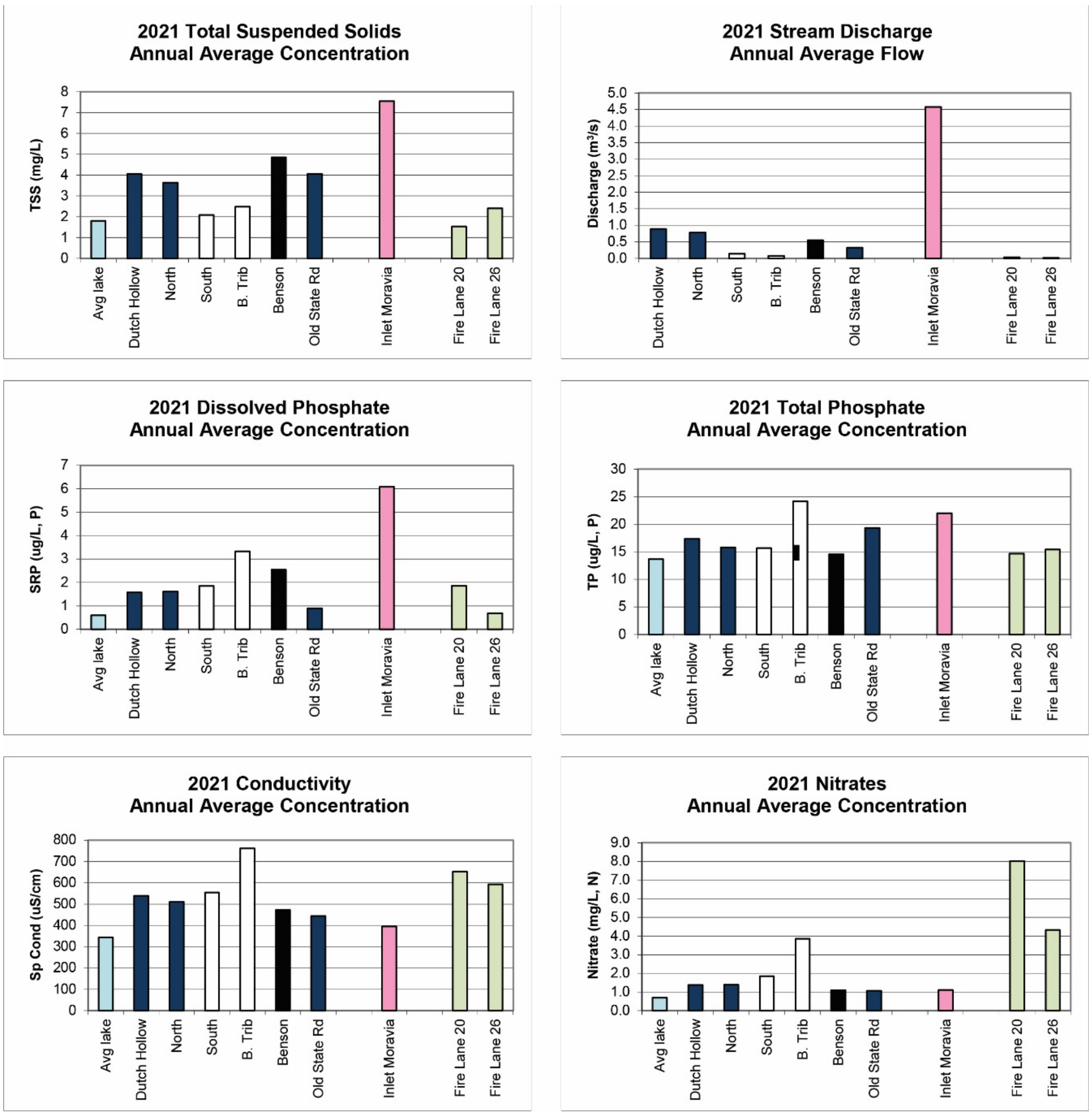


Fig. 24. Site averaged lake (light blue) and stream nutrient and suspended sediment concentrations for Dutch Hollow Brook (blue), Owasco Inlet (pink), and Fire Lane 20 & 26 (green). Tributary sites are stippled. Sites along Dutch Hollow Brook are arranged from downstream (left) to upstream (right).

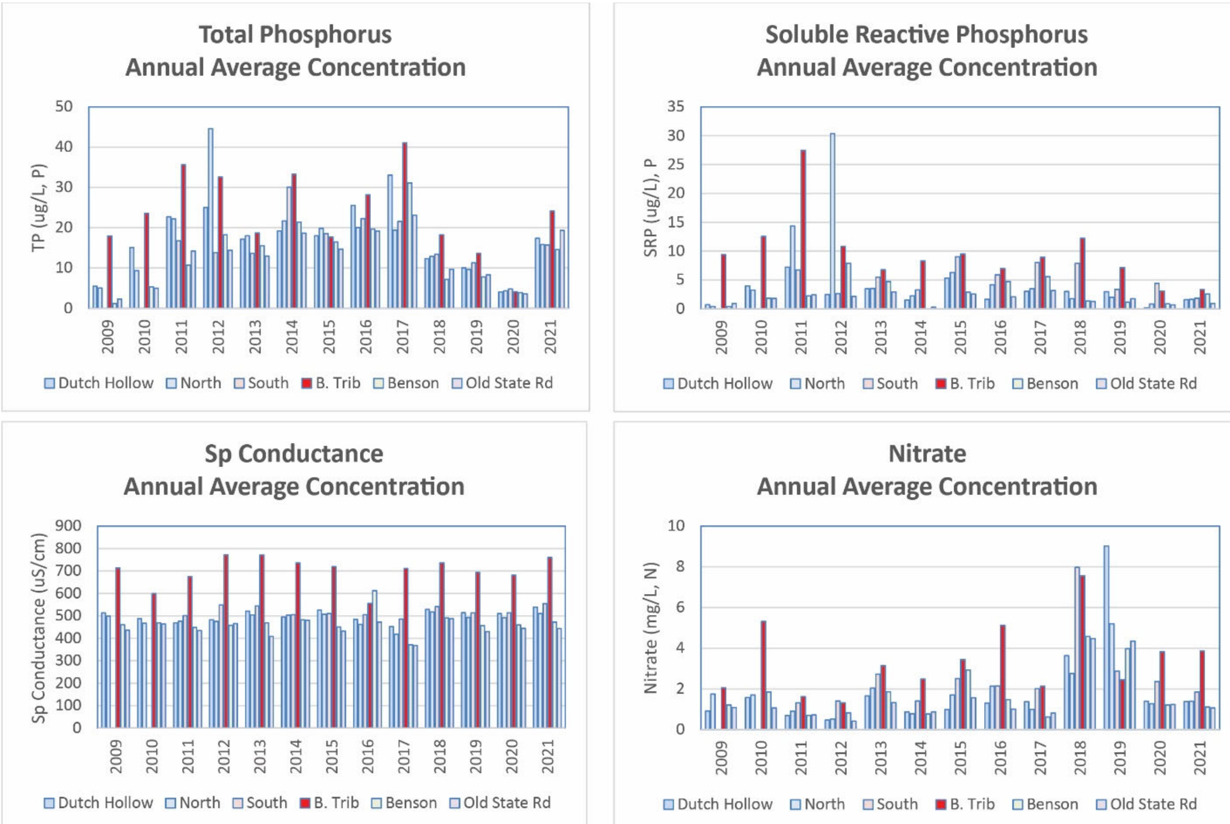


Fig. 25. Mean annual concentrations of total phosphorus, specific conductance soluble reactive phosphorus and nitrate at the Dutch Hollow Brook sites. Sites are arranged from downstream (left) to upstream (right) in each year.

Nutrient and sediment concentrations in Owasco Inlet at Moravia were similar to those at Dutch Hollow Brook. Total phosphate, soluble reactive phosphate and specific conductance concentrations at the two Fire Lane sites were similar to the other stream sites as well. In contrast, significantly larger NO_x concentrations and salinities were detected at both Fire Lane sites than at Dutch Hollow and Owasco Inlet. The larger concentrations reflect larger agricultural impacts in the headwaters of these tributaries.

Stream Fluxes: Dutch Hollow Brook revealed smaller mean fluxes of nutrients and sediments than Owasco Inlet based on grab sample data (TP 0.7 vs. 8.7 kg/day; SRP 0.1 vs. 2.4 kg/day; TSS 70 vs. 657 kg/day; N 70 vs. 436 kg/day, respectively, Fig. 26). Similar concentrations of nutrients and sediments between these two streams, but significantly larger discharges down the larger Owasco Inlet, resulted in its larger fluxes to the lake.

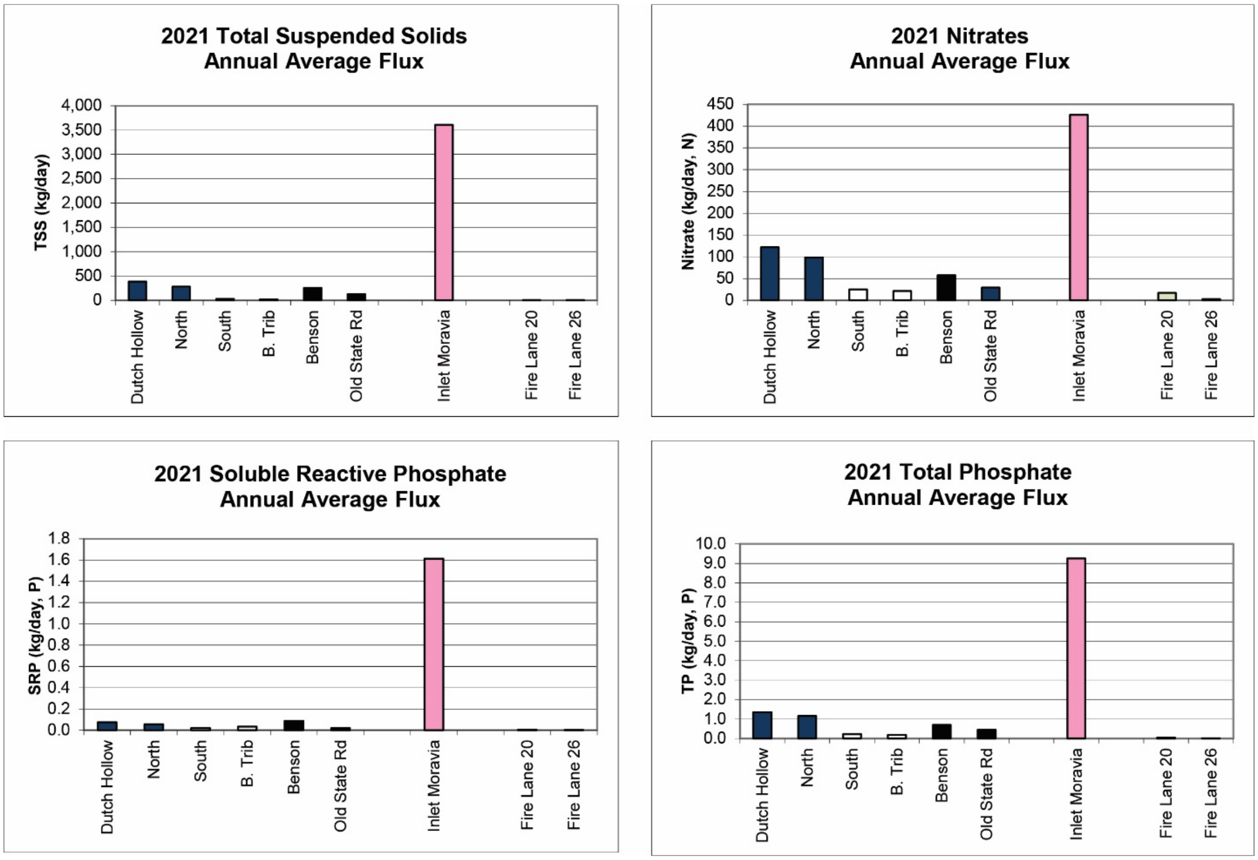
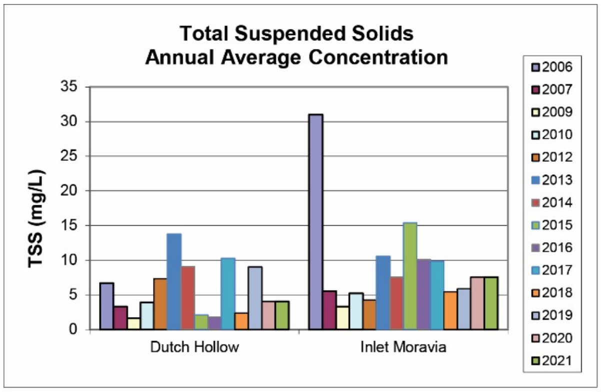
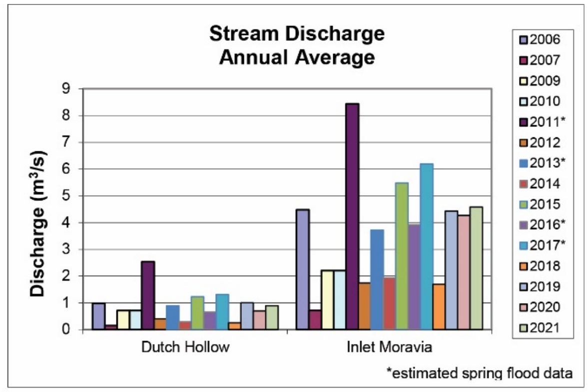


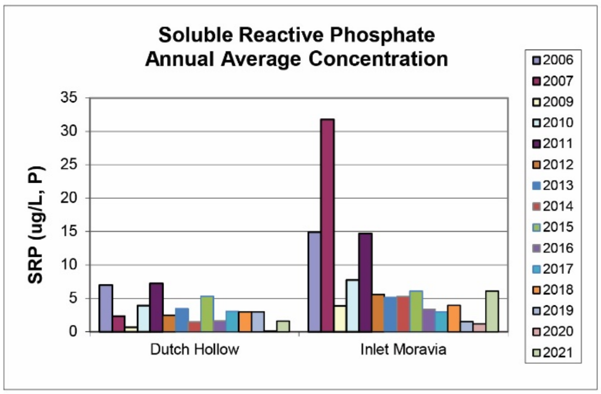
Fig. 26. Site averaged nutrient and sediment fluxes for Dutch Hollow (blue), Owasco Inlet (orange), and Fire Lane 20 & 26 (green). Tributary sites along Dutch Hollow Brook are stippled. Sites along Dutch Hollow Brook are arranged from downstream (left) to upstream (right).

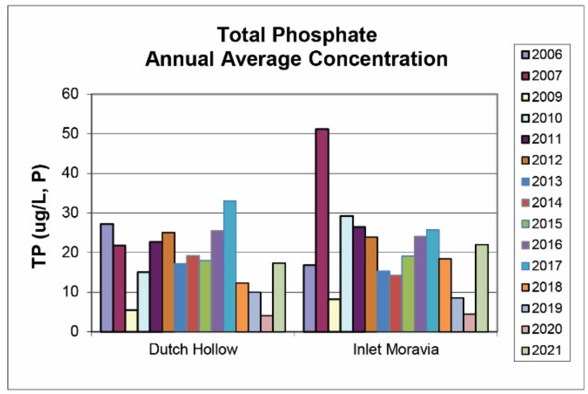
At the small end of the spectrum, fluxes at the Dutch Hollow Brook tributary sites (Benson and South tributary sites) and the two Fire Lane sites were smaller than the other sites in the survey. These small fluxes parallel the smaller discharges at these sites and smaller drainage areas. It follows that smaller watersheds with smaller discharges delivered the smallest fluxes, and larger watersheds with larger discharges delivered the largest fluxes. However, many small, 1st or 2nd order, tributaries (~40 in Fig. 1) like Fire Lane 20 and 26 drain into Owasco Lake. The combined TP load by all these small tributaries, assuming they have similar concentrations as Fire Lane 20 & 26 is estimated to be similar to the load from Dutch Hollow Brook. Variability in land use also influences phosphorus loading. See the SWAT modeling and phosphorus loading sections below.

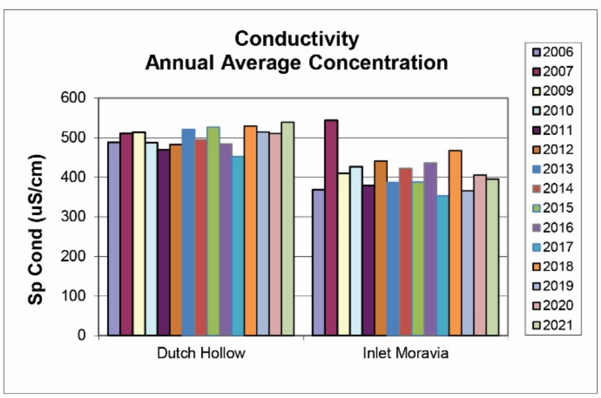
Annual average concentrations and fluxes at the terminus of Dutch Hollow Brook and the Owasco Inlet are shown in Figure 27. In 2021, stream discharge, and TP, SRP and nitrate concentrations were larger than past years, whereas salinity decreased and TSS remained nearly the same. Lower or similar mean grad sample concentrations and fluxes at Dutch Hollow Brook than earlier years most likely reflected the lower rainfall in May and early June during 2021.

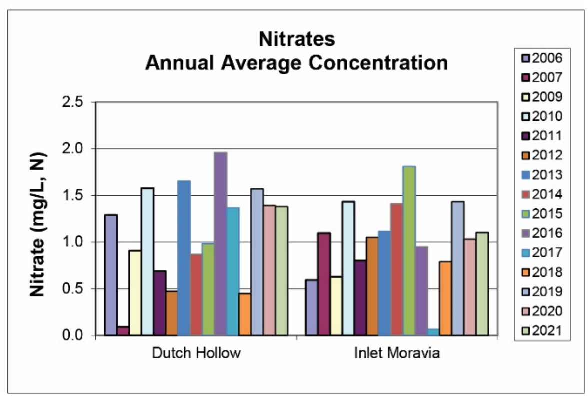












Concentrations above, Fluxes below.

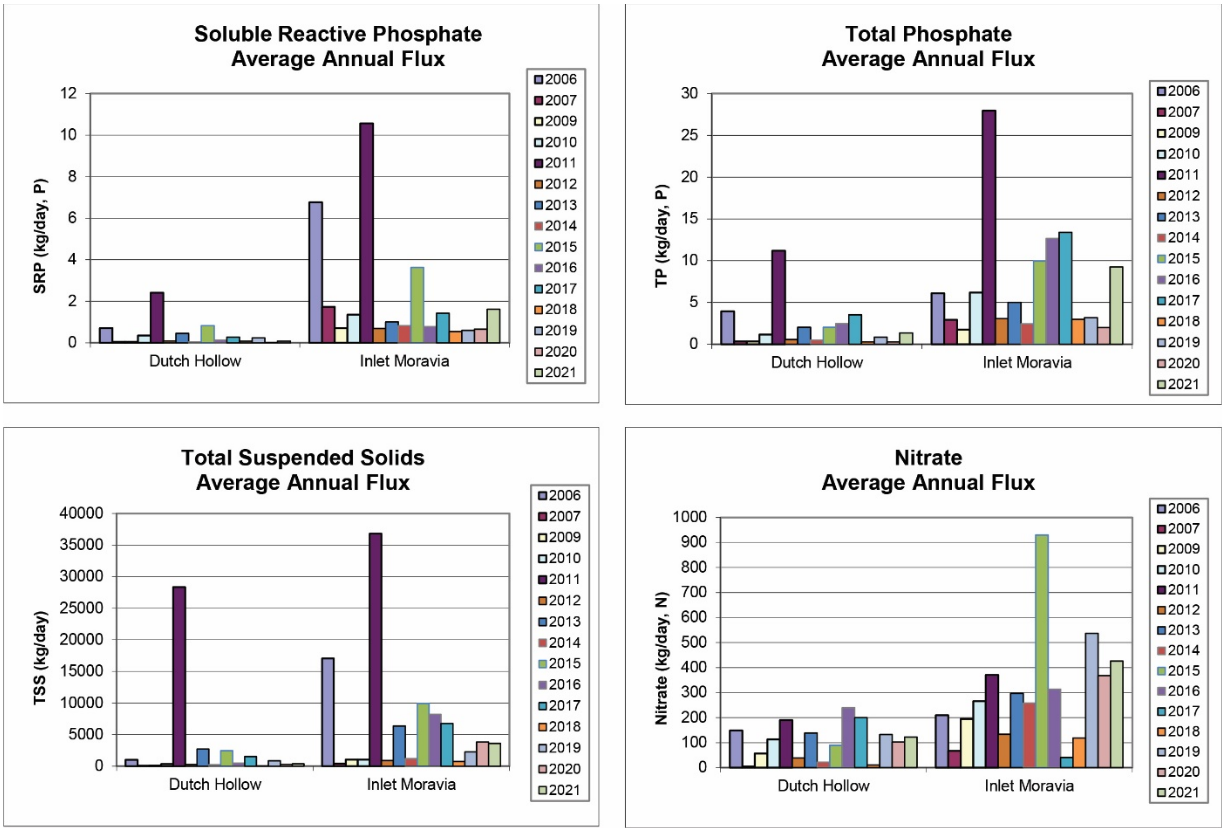


Fig. 27. Annual average stream grab sample concentrations (above) and fluxes (below).

As in previous years, Dutch Hollow Brook steadily gained nutrients along its entire course. No one site along Dutch Hollow Brook had a significantly larger flux of nutrients. Thus, no one segment of this stream was the "primary" source of nutrients and sediments. This is consistent with the pervasive nature of nonpoint sources throughout the watershed, and the drainage of agricultural land, animal feedlot operations, road-side ditches, drainage tiles, golf courses, suburban homes, and other nonpoint sources. The implications are critical. To remediate Dutch Hollow Brook's nonpoint source nutrient loading problem is more challenging than remediating a point source like Groton's wastewater treatment facility, because nonpoint source remediation efforts must be applied throughout the entire watershed, demanding cooperation by every land owner in the watershed. Interestingly, in "dry" years, total phosphate, soluble reactive phosphate and total suspended sediment concentrations and fluxes typically decrease from the North St site downstream to 38A. Presumably the decline in those years was due to the reduced flow, sediment deposition and nutrient uptake between these two sites.

The total phosphate contribution to the Owasco Inlet by Groton wastewater treatment facility has been significantly smaller since 2007 when the DEC mandated a phosphorus load limit for the facility's effluent (Fig. 28). 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).

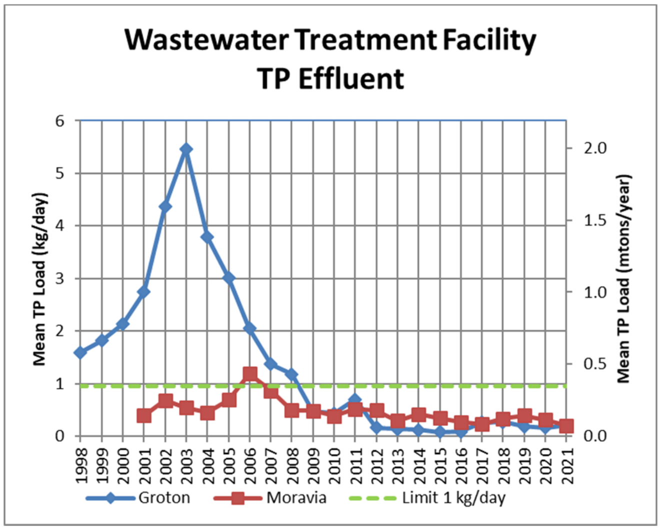


Fig. 28. Phosphorus loads to the Owasco Inlet from the Moravia and Groton wastewater treatment facilities.

EVENT SAMPLING AT DUTCH HOLLOW BROOK

Detailed Stage Data @ 38A along Dutch Hollow Brook: The 2021 stage data at Dutch Hollow Brook revealed textbook responses to precipitation events (Fig. 29). These abrupt increases in stream stage for individual events ranged from approximately 5 to 250 cm above the preceding baseflow levels. In the past, not all precipitation events induced a proportional stream response, especially during the spring when increases in stage were larger for similar sized precipitation events than the other seasons. The differences are interpreted to reflect seasonal changes in, for example, ground saturation, rainfall intensity, runoff/infiltration ratios and evapotranspiration. This year was unique, the decline in stream discharge over the course of the field season was not as extensive as previous years, and the event increases in stage detected in 2021 were the largest on record. The mid to late season heavy rain events, e.g., mid-June, mid-August and October, maintained higher baseflows through the summer and fall, and maintained higher groundwater tables as well. The two largest storms, in August and October, were intense enough to displace the deployed loggers and autosampler at the site. The events also increased lake levels above the summer rule curve and cooled water temperature as well (Fig. 30).

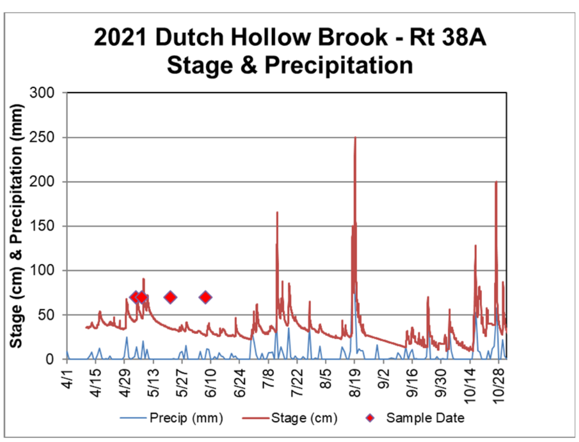


Fig. 29. Dutch Hollow Brook estimated discharge, precipitation, stream sample dates and measured discharge data for 2021 at Rt 38A. Precipitation data was from NY-CY-8, a CoCoRaHS station within the Dutch Hollow watershed.

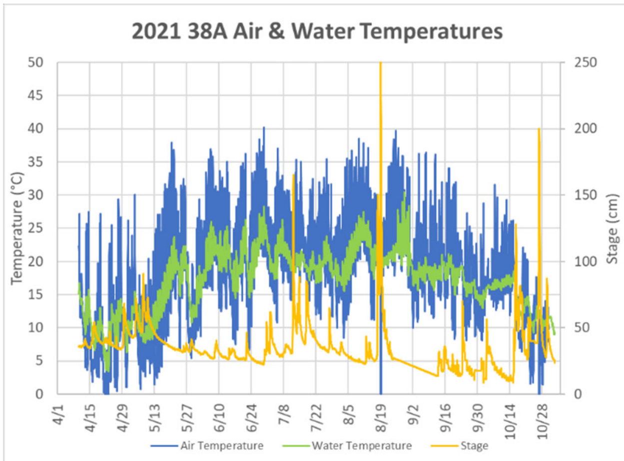


Fig. 30. Data logger stage, air and water temperature data at 38A.

Detailed Nutrient Results @ 38A: Nutrient and suspended sediment concentrations increased markedly during precipitation events in 2021 like earlier years (Fig. 31). Total suspended sediments (TSS) increased from an average baseflow concentration of ~2 mg/L to an average event flow concentration of 100 mg/L. The maximum measured concentration was 1,000 mg/L on 9/28. The large TSS concentrations were restricted to rain events, and declined quickly to baseflow turbidities, typically before the stream stage returned to baseflow. TSS event concentrations were estimated when the autosampler was displaced using the best-fit linear relationship ($r^2 = 0.70$) between the available (116 samples) event discharges (defined by an increase in discharge of 0.75 m^3/s over the preceding baseflow) and fluxes from 2016 through 2021 (Fig. 32). The estimated concentrations are shown in light green in Figure 31. The event signature highlights the importance of large events, in that, events transported significantly more soil particles than baseflow, and as a result, had a greater impact on water quality than baseflows.

Total (TP) and soluble reactive phosphorus (SRP) concentrations revealed event responses as well. Mean TP and SRP event concentrations were significantly larger than baseflow concentrations, increasing from baseflow means of 11 and 9 μg/L to event means of 29 and 26 μg/L, respectively. Maximum event concentrations were 360 μg/L for TP and 1,200 μg/L for SRP (this large SRP lacked a corresponding TP sample). TP and SRP event concentrations were also estimated when the autosampler was displaced using the best-fit linear relationship ($r^2 = 0.70$) between the available (116) event discharges (defined by an increase in discharge of 0.75 m^3/s over the preceding baseflow) and fluxes from 2016 through 2021 (Fig. 32). These estimated concentrations are shown in green in Figure 31. The event concentrations suggest a direct linkage to and the importance of precipitation induced runoff events for phosphorus loading to the lake. Thus, the remediation steps to reduce phosphate loading are similar to remediating suspended sediment, i.e., reduce the movement of soil particles from the watershed to the lake.

The literature indicates that drain tiles are an important source of SRP as well. Tiles increase the release of dissolved and particulate phosphorus from the soils. Drain tiles and the ditches that tiles drain into should be mapped, sampled and remediated in the watershed. Drone flown infrared photography might differentiate drain tile locations. The analysis of drain tile effluent samples during and just after rain events would quantify their contributions.

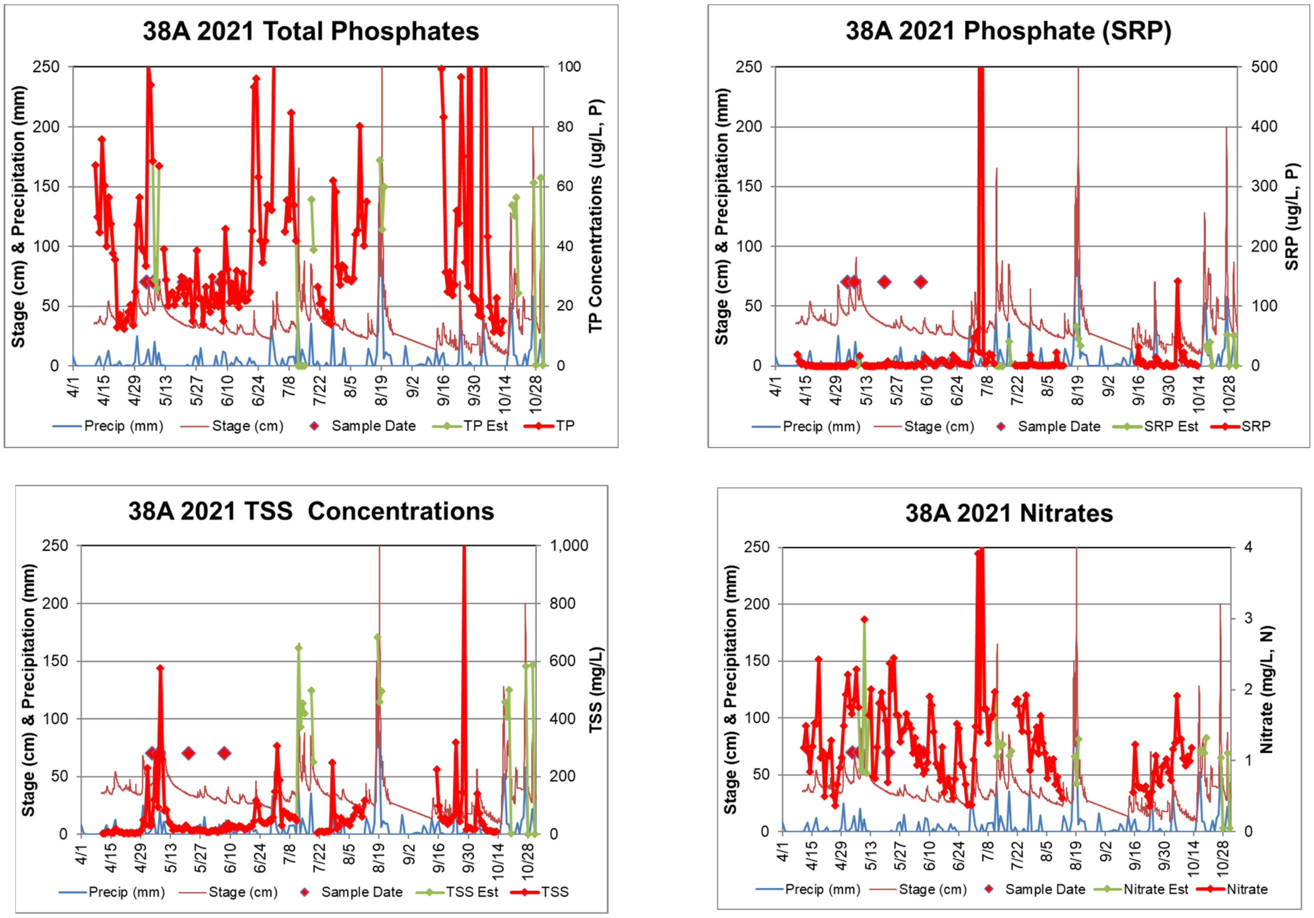


Fig. 31. Daily nutrient and suspended sediment concentrations at Rt 38A. The estimated event concentrations for the missing autosampler data are shown in green.

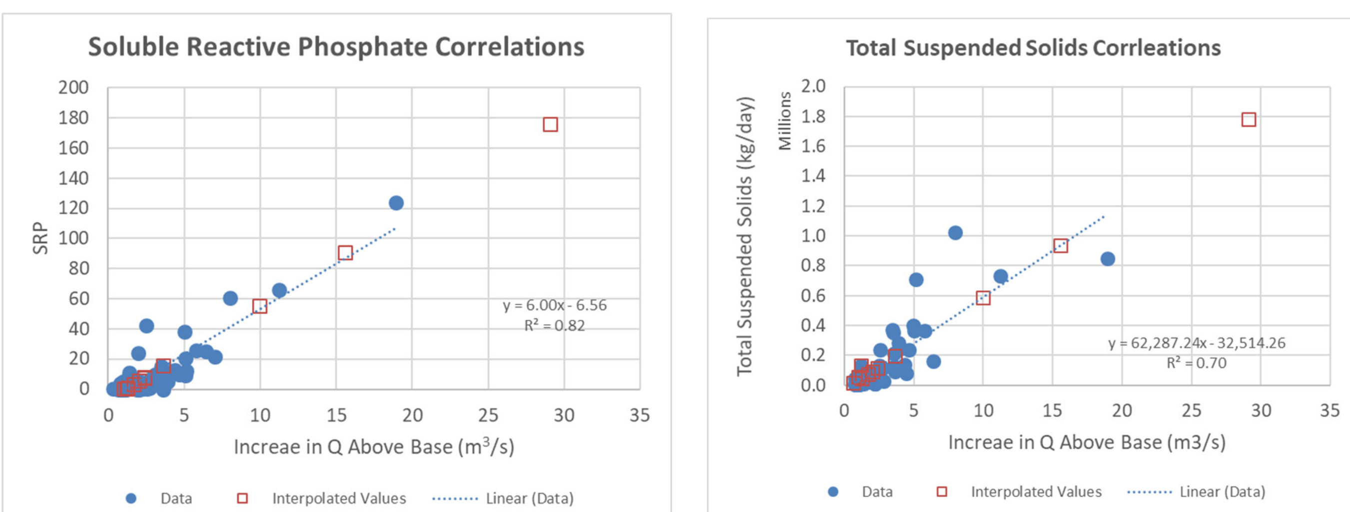


Fig. 32. The linear relationship between all available event discharge vs flux data (116 samples) from 2016 through 2021. Also shown are the interpolated results for the missing 2021 data. The scatter reflects season variability in ground saturation and plant cover, the intensity, duration and frequency of rain events, and the timing of the water sample in relation to the climbing and descending limbs of the event hydrograph. Concentrations were calculated from each estimated flux.

The event *versus* baseflow differences suggest a number of potential remediation practices to reduce TP, SRP and TSS impairments as recommended in previous reports. The 9E Plan SWAT model results reaffirm these recommendations. In particular it highlights three agricultural remediation practices for the watershed.

1. Farmers should plant a winter crop cover.
2. All farms should utilize nutrient management plans.
3. All farms should significantly restrict manure spreading and fertilizer use.

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.

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.

Annual mean nitrate concentrations did not correlate to TP, SRP and TSS ($r^2 < 0.2$), suggesting a unique source. The maximum event NO_x concentration was 4.9 mg/L, larger than the mean baseflow concentration of 0.01 mg/L, but the event increase above baseflow was much smaller than those observed in the TSS, TP and SRP data. The increase to peak concentration and subsequent decline to baseflow conditions took slightly longer for NO_x as well. It indicates that runoff provided extra NO_x to the stream but not to the same extent as the other nutrients. The difference us explained by nitrates unique chemistry. Nitrates are water soluble and not bound to particles, thus they can enter a stream by both runoff and groundwater routes. In contrast, phosphates are typically particle bound, and thus particles and phosphorus do not readily flow through groundwater systems. Thus groundwater does not transport TP, SRP and TSS. Precipitation events also rejuvenate near-surface groundwater flow, which contributed to the delayed NO_x load as well. It extended the NO_x events response as runoff flows faster than groundwater flow.

Event vs. Baseflow Fluxes @ 38A: To calculate daily fluxes at Dutch Hollow Brook, a discharge was determined for each stage using a best-fit, 2nd order, polynomial relationship between the data logger stage data and weekly to bi-monthly discharge measurements at 38A ($r^2 = 0.60$). The HyFi stage data was measured at 10-minute intervals at the same site, and was used to provide stage data when the data loggers were displaced during the 8/18 and 10/17 floods. It established a stage/discharge rating curve for the site (Fig. 33). The estimated discharge data were proportional to the season changes in discharge recorded at the Owasco Inlet (Fig. 33). Differences can be attributed to localized differences in rainfall and basin size. The parallel nature of these data and the HyFi stage data discussed above suggests that the adjusted made in 2021 were reliable.

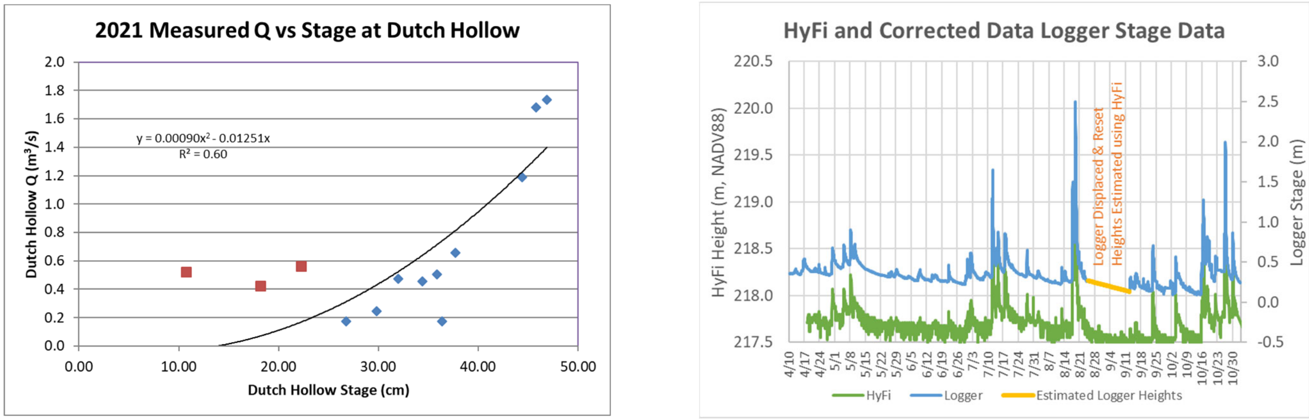
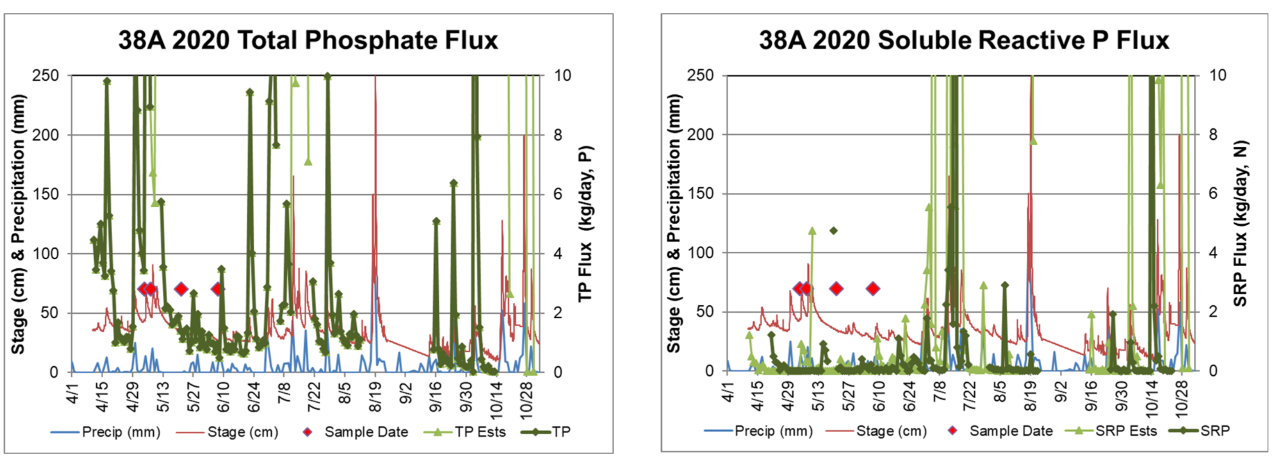
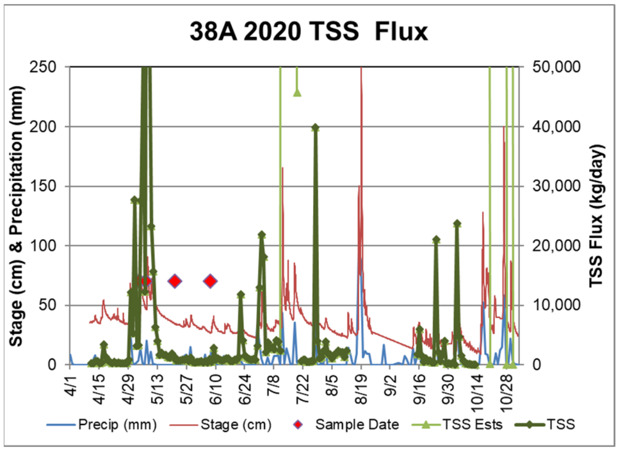


Fig. 33. Best fit correlations between weekly to bi-weekly measured discharge and data logger stage data at 38A site (above). The red points to the left of the best fit curve were suspect but included in the best-fit polynomial. HyFi and corrected Data Logger stage data (below). The stage scales are purposely offset to reveal the correlation between the data sets. The HyFi raw data also revealed daily noise brought on by changing air temperatures (B Wong, pers. comm., 2021). HyFi has since fixed the noise issue.

The TSS, TP, SRP and N fluxes were clearly event driven (Table 8, Fig. 34). The estimated fluxes during equipment displacement are shown in light green and respond as expected to the rainfall events. In 2021, TSS, TP, SRP and N event *vs.* baseflow fluxes at 38A averaged 50,352 *vs.* 170, 8.1 *vs.* 0.6, 5.1 *vs.* 0.04, and 173 *vs.* 0.5 kg/day, respectively. During the 2021 April through October deployment, Dutch Hollow provided 5,690,000 kg of sediment to the lake during events, but only 15,800 kg during baseflow conditions. In a similar light, the 2021 events delivered 916 kg of TP, 575 kg of SRP and 19,560 kg of N to the lake compared to baseflow contributions of 54 kg of TP, 4 kg of SRP and 42 kg of N. Thus, over 95% of the suspended sediments, total phosphorus and soluble reactive phosphate were delivered to Owasco Lake by Dutch Hollow Brook during events over the course of this monitoring program (Table 8). More importantly, the mid-August, 8/19, event supplied over 50% of the total seasonal TSS load, and 22, 29 and 47% of the nitrate, TP and SRP loads to the lake.

Care must be observed as these loads included the estimated event loads during the missing autosampler data. The missing data was calculated assuming a linear relationship. However, it probably should have been an exponential relationship, and suggests that this largest event probably input much more TSS, N, TP and SRP to the lake than estimated above.





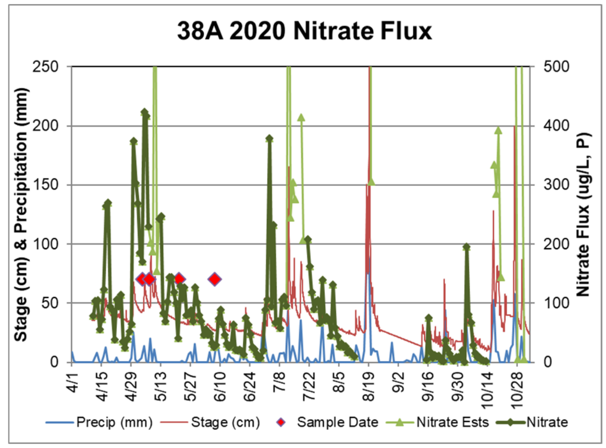


Fig. 34. Autosampler nutrient and suspended sediment fluxes. The estimated fluxes for the missing autosampler data are shown in light green.

The event *versus* baseflow data indicate that 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.

Table 8: 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

PHOSPHORUS BUDGET:

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. 35). The net change (Inputs – Outputs) is critical because the amount of phosphorus will increase in the lake, if inputs exceed outputs. Phosphorus will decrease in the lake, if inputs are less than outputs. 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 leave by the outlet or be buried in the sediments, and increasingly limit algal growth and improve water quality and clarity.

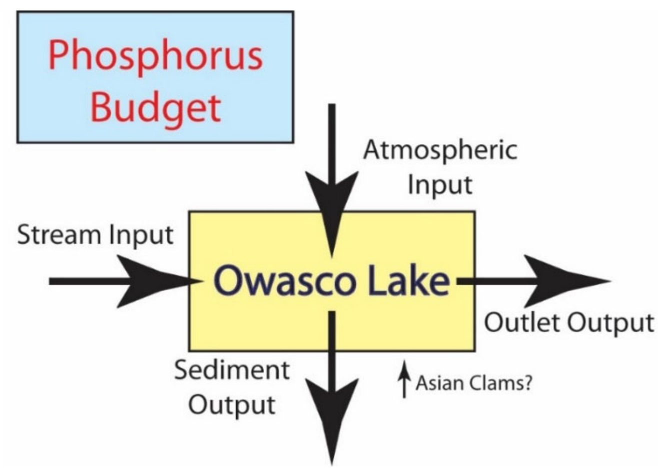


Fig. 35. The Owasco Lake phosphorus budget: Sources and sinks for phosphorus in Owasco Lake. Water quality improves if **inputs are less than outputs, for a number of years**.

The Inputs:

Stream Inputs: The detailed 38A autosampler data calculated a mean total phosphate flux of 4.7 kg/day from Dutch Hollow Brook in 2021. This includes the estimated event loads when the autosampler was displaced. If these event estimates were not included, the Dutch Hollow load would only be 2.1 kg/day, a significant change that highlights the important of measuring every event. Owasco Inlet delivered 8.7 kg/day based on the available 2021 stream grab data (baseflow data). The 2021 total loads from Owasco Inlet was estimated at 30.2 kg/day assuming a proportional change between the mean grab sample total phosphorus loads to the detailed autosampler loads from Dutch Hollow Brook. An extrapolation of fluxes and surface areas from Dutch Hollow Brook and Owasco Inlet to the entire Owasco watershed, estimated an annual input of 19.3 metric tons of phosphorus from every remaining stream to the lake in 2021. The stream extrapolation incorporates the input from all the 1st and 2nd order (small) tributaries like Fire Lane 20 and 26.

Other Inputs: The Moravia and Groton WWTFs added a combined 0.1 metric tons P to the Owasco Inlet in 2021[12]. The 2011 report estimated atmospheric and septic system inputs at 0.1 metric tons/year and ~1 metric ton/year, respectively. The septic estimate used here is slightly larger than N. Colas' estimate of 0.5 mtons P/year from septic systems using GIS modeling[13]. 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[14], 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/year is similar to the SWAT Model predictions.

The total 2021 influx of phosphorus is estimated at 20.6 metric tons/year.

The Outputs: Phosphorus is lost from the lake through the Outlet in the form of algae, dissolved organic-rich compounds, organic-rich particulates, and the occasional larger organism (e.g., fish). Approximately 5.5 metric tons of phosphorus escaped out the Outlet in 2021 assuming a 2021 annual mean total phosphate concentration in the lake of 13.7 μg/L, and a 2021 mean daily discharge of 12.7 m^3/s through the Owasco Outlet (USGS Owasco Outlet Gauge #04235440). The 2011 report estimated the flux of phosphorus to the sediments of a few metric tons per year and this estimate was again used here. The earlier report cautioned that more work was required to firm up this sediment burial estimate, because the flux was based on only a few sediment cores.

The total 2021 efflux of phosphorus is estimated at 8.3 metric tons/year.

The Net Flux: Owasco Lake gained 12.3 (20.6 – 8.3) metric tons of phosphorus in 2021 (Figs. 36 & 37). Both the input and output increased from previous years, with a significantly larger increase in the input. It indicates that the largest events were most critical to the P budget of the lake. Up to 2016, inputs > outputs. Since 2016, net P losses or steady state conditions were estimated. The recent, multi-year, negative or steady state P fluxes suggests that the current level of remediation efforts in the watershed were kept the lake at a steady state, but was 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. Unfortunately, the current level of remediation efforts were insufficient to curtail the larger inputs of 2021, a "normal" rainfall year. This past year also 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] http://cfpub.epa.gov/dmr/facility_search.cfm Groton: NY0025585, Moravia: NY0022756.
[13] Colas, N., 2021. Estimated contributions from Septic Systems. 9E Plan Public Meeting #2, 9/21/21.
[14] Fleming and Fraser, 2001. The impact of water fowl on water quality – a literature review. Ridgetown College, U of Guelph, Ontario, Canada.

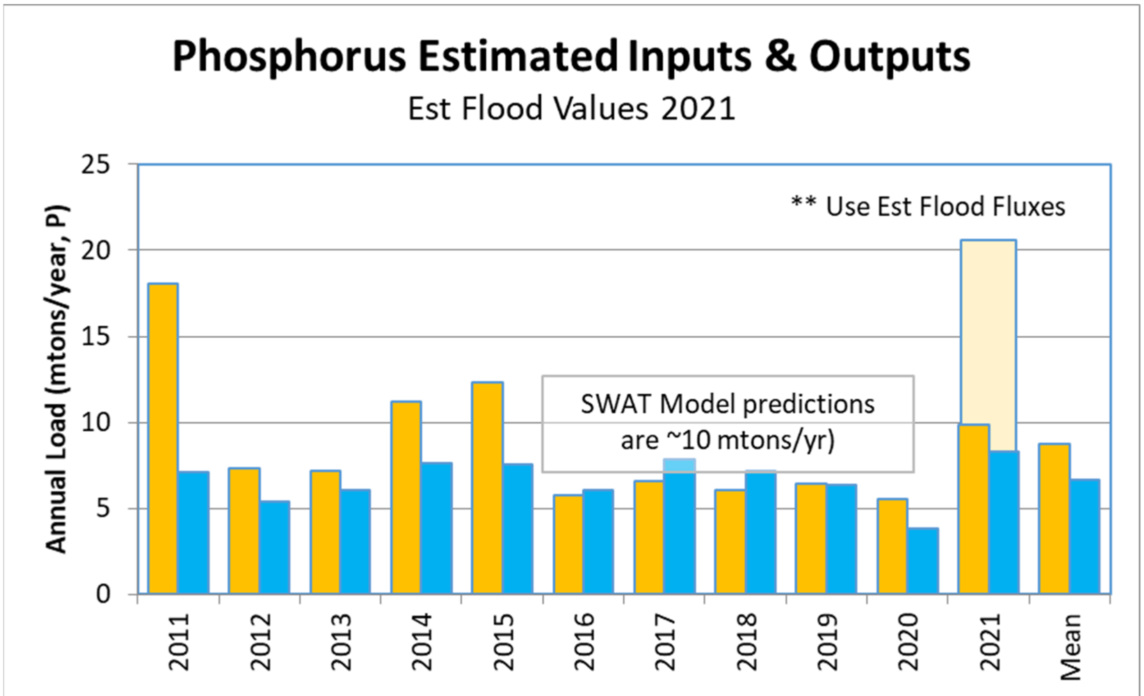

Fig. 36. Estimated annual total phosphorus inputs and outputs for Owasco Lake. The 2021 light orange bar included the interpolated flood event data.

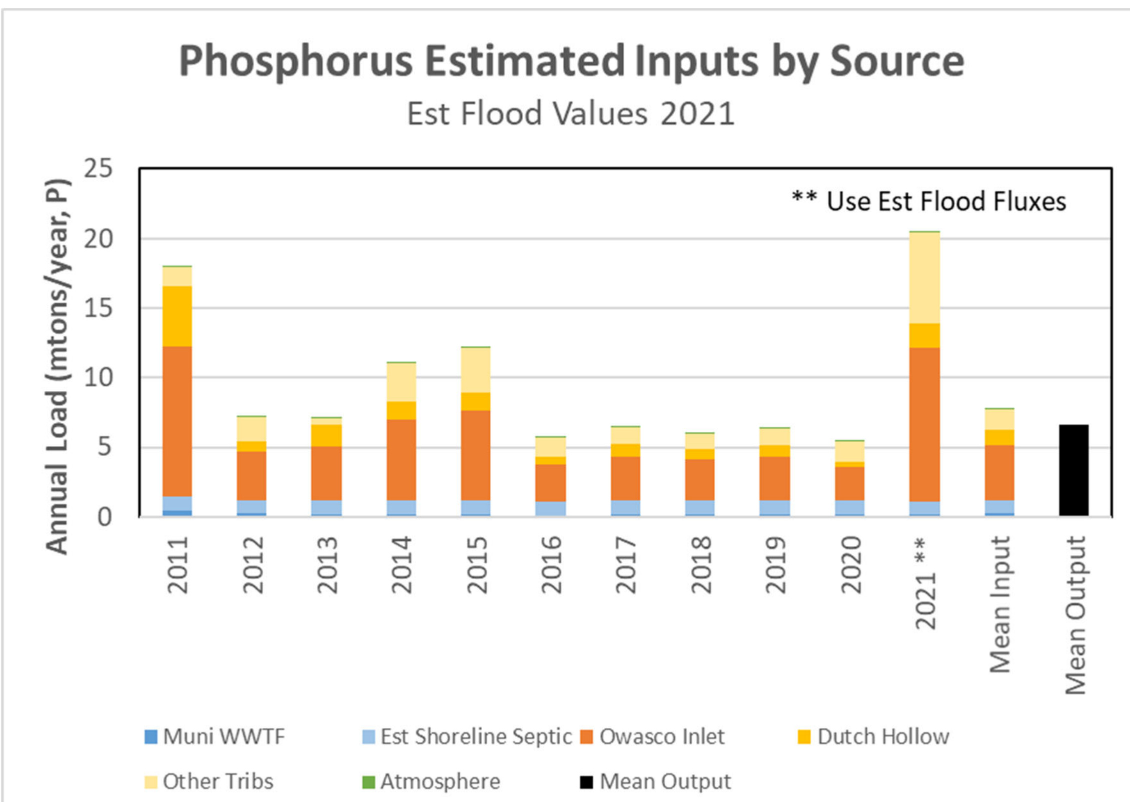

Fig. 37. Estimated annual inputs of phosphorus by source for Owasco Lake. The 2021 light orange bar included the missing flood event data.

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 larger than the relatively constant inputs from other sources (Fig. 37). 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 clearly pinpoints where additional remediation efforts must be focused to reduce phosphorus loads to the lake.

The 9E Plan's SWAT Model predicted that the annual TP load is from Cultivated Crops (53%), Pasture/Hay Fields (36%), Forested Lands (6%) and Developed Lands (5%)[15]. The reason is simple, agricultural land is a primary land use in the watershed and agricultural land contributes proportionally more nutrients and suspended sediments per acre than any other land use in the watershed (Table 9). 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 road-side ditches and construction sites.

Table 9: 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 **will result** from three remediation practices (Table 10)[16]:

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 are integrated into the SWAT model, it predicted significant reductions in the phosphorus loading to the lake (Table 10). The different phosphorus reduction percentages in each subwatershed primarily reflected the different land use percentages in each subwatershed.

[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.

Table 10: Percent Phosphorus Reduction from Selected Agricultural Activities.[17]

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	--

CONCLUSIONS & RECOMMENDATIONS:

This report confirms and expands on earlier findings.

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 and 2021 is attributed to the heavy rains and/or intense precipitation events in those years, typically in the spring. The events were spread throughout the field season in 2021.
- 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 lake surveys.
- Finally, water quality in the lake has not significantly improved over the past decade.

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 and 2021.
- 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:

- 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.
- Segment analysis did not identify significant point sources along Dutch Hollow Brook, and indicates that non-point sources of nutrients and sediments dominate loads in this watershed.

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

- 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 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.
- Partitioning 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 sources of P included lakeshore onsite septic systems, municipal wastewater treatment facilities, and the atmosphere.
- 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.
- Both the Moravia and Groton MWWTFs have done an amazing job maintaining their annual phosphorus loads to a minimum.
- Septic systems contribute a smaller amount of phosphorus 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.
- 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.

Remediation Strategies:

- o 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. 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 phosphorus to the lake. It commands the immediate use of additional and extensive remediation strategies.
- o Clearly, implementation of the revised Owasco Lake Watershed Rules and Regulations and reduction strategies outlined in the pending 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 original oligotrophic state.
- o 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.
- o 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 the current practices. 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, at the opening of drain tiles and manure before spreading to reduce phosphorus loads from these sources.
- Bio-manipulation is a poor option because lake-wide recreation 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 2. 2021 Date Averaged bbe FluoroProbe Data

Owasco Lake Date Averaged bbe FluoroProbe Data					
Date	Green	Cyanobacteria	Diatoms	Cryptophyta	Total Algae
Offshore Sites					
5/26	5.6	0.0	14.7	0.0	20.3
6/15	2.9	0.0	2.3	0.1	5.3
7/6	3.3	0.0	3.2	0.0	6.4
7/15	1.5	0.0	0.8	0.3	2.7
7/20	1.0	0.2	0.7	1.4	3.3
8/3	0.4	0.2	1.6	1.0	3.2
8/10	1.3	0.0	3.0	1.5	5.9
8/17	1.5	0.7	1.3	1.1	4.6
8/24	3.1	0.2	4.1	4.0	11.5
8/31	0.0	1.7	2.2	3.3	7.2
9/7	0.1	1.3	1.6	1.4	4.4
9/14	1.0	1.5	2.0	3.7	8.2
9/24	0.1	2.3	1.9	0.6	4.8
9/28	0.1	2.2	0.5	0.4	3.2
Dock SItes					
6/17	0.0	1.9	0.2	0.4	2.6
7/28	1.0	0.1	1.2	0.4	2.8
8/16	1.7	2.4	1.5	0.9	6.5
9/3	0.4	0.4	0.5	1.9	3.2
10/13	0.0	0.1	0.2	0.3	0.5

Table 3. 2021 Lake Data.

2021 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	2.0	13.6	0.6	0.7		3.7
Buoy	3.8						
2	3.8	1.7	13.9	0.3	0.7		3.2
Average	**3.8**	**1.8**	**13.7**	**0.5**	**0.7**	**No Data**	**3.4**

Site Averaged Bottom Water Data

Site	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
1	---	1.0	10.4	0.3	1.1		0.9
Buoy							
2	---	1.2	9.0	1.0	1.1		0.7
Average	**---**	**1.1**	**9.7**	**0.6**	**1.1**	**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)
5/26/21	2.6	3.5	12.3	0.6	1.4		4.6
6/15/21	6.2	2.4	19.4	0.0	0.9		2.9
7/6/21	3.1	1.7	18.7	0.1	0.6		2.5
7/15/21	2.8	1.3	10.4	0.0	0.6		2.1
7/20/21	4.1	1.2	10.6	0.2	0.7		1.6
7/27/21	3.9	1.3	19.1	0.6	0.7		2.4
8/3/21	4.4	1.4	9.0	1.2	0.7		2.4
8/10/21	3.4	1.5	12.1	0.5	0.5		1.8
8/17/21	3.2	2.2	13.8	1.5	0.6		3.4
8/24/21	2.9	2.2	12.3	0.8	0.5		6.1
8/31/21	3.0	2.1	12.4	0.0	0.5		5.0
9/7/21	4.8	2.8	13.4	0.1	0.6		2.5
9/14/21	4.3	1.2	14.2	0.1	0.6		6.4
9/24/21	3.6	1.5	14.9	0.7	0.6		3.6
9/28/21	4.3	1.5	13.4	0.6	0.7		4.3
Average	**3.8**	**1.8**	**13.7**	**0.5**	**0.7**	**No Data**	**3.4**

Date Averaged Bottom Water Data

Date	Secchi Depth	Suspended Solids	Total Phosphate	Dissolved Phosphate	Nitrate	Silica	Chlorophyll
	(m)	(TSS, mg/L)	(TP, ug/L)	(SRP, ug/L)	(N, mg/L)	(Si, ug/L)	(a, ug/L)
5/26/21	---	0.9	9.6	0.4	1.4		0.9
6/15/21	---	1.2	14.3	0.3	1.0		1.5
7/6/21	---	0.8	10.3	0.2	0.9		1.0
7/15/21	---	0.7	7.0	0.0	0.9		1.3
7/20/21	---	0.9	8.1	0.2	1.1		0.6
7/27/21	---	0.8	8.2	1.0	0.9		0.6
8/3/21	---	1.2	6.4	1.1	1.0		0.7
8/10/21	---	0.8	8.0	0.6	1.0		0.8
8/17/21	---	1.4	8.5	0.0	1.1		0.9
8/24/21	---	1.5	15.5	0.0	1.3		0.7
8/31/21	---	1.5	9.0	2.5	1.1		0.7
9/7/21	---	1.2	11.9	0.1	1.1		0.6
9/14/21	---	1.5	7.5	0.9	1.1		0.5
9/24/21	---	0.7	11.3	1.9	1.2		0.6
9/28/21	---	1.6	9.6	0.5	1.2		0.8
Average	**---**	**1.1**	**9.7**	**0.6**	**1.1**	**No Data**	**0.8**

Table 5. Annual Average Plankton Data from 2005 through 2021, and Daily Average Data for 2021.

Plankton Group	Diatoms							Dinoflagellates			Rotifers & Zooplankton					Blue Greens	
Plankton Species	Fragillaria %	Tabellaria %	Diatoma %	Asterionella %	Melosira %	Synedra %	Rhizoselenia %	Dinobryon %	Ceratium %	Coalcium %	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		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		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		0.4	0.6	0.4	3.8	2.8	0.4	7.7
2008 Average	52.3	0.1	0.0	14.6	0.2	0.1	1.2	18.7	0.6	0.2	0.4	0.3	0.9	4.3	0.6	0.4	1.5
2009 Average	9.7	7.1	0.0	12.3	0.2	1.0	7.8	26.6	0.7	2.0	0.7	3.6	0.7	4.3	2.1	3.4	4.8
2010 Average	36.8	0.5	0.0	19.1	0.2	1.4	0.7	4.6	0.0	2.6	0.6	3.3	0.7	3.2	5.6	0.1	6.1
2011 Average	26.0	14.1	0.0	15.0	0.4	1.4	15.0	5.3	0.5	1.8	0.9	2.8	1.0	3.9	2.0	0.2	2.6
2012 Average	27.0	25.5	0.0	10.9	13.0	2.2	1.1	8.1	0.3	0.2	0.5	0.3	1.5	0.9	0.6	0.3	0.8
2013 Average	27.6	0.3	26.9	3.9	3.8	0.0	5.9	0.0	0.1	2.1	0.5	1.3	2.4	1.2	4.1	0.3	0.6
2014 Average	21.8	0.3	5.8	15.2	0.2	1.5	2.5	20.2	0.1	0.0	2.7	1.1	6.4	1.8	1.1	0.1	2.6
2015 Average	28.6	7.5	1.0	20.2	0.3	0.8	3.9	3.7	0.1	0.1	0.7	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	0.7	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	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	0.2	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	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	0.4	3.3	0.0	5.1	0.3	4.4	49.6
5/25/21	0.0	0.0	91.4	0.6	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6/15/21	1.9	0.0	25.7	0.0	0.0	8.8	0.0	1.0	0.0	0.0	3.3	12.0	2.9	0.0	0.0	0.0	1.2
7/6/21	0.4	0.0	20.4	10.9	0.0	6.2	0.0	2.1	0.0	0.0	0.2	26.7	0.6	0.0	0.4	0.0	11.6
7/15/21	9.3	0.0	12.7	0.9	4.6	1.2	0.0	0.0	0.5	0.0	0.0	30.4	0.2	1.4	0.5	1.6	20.9
7/20/21	0.6	0.0	12.8	0.8	0.8	3.7	0.0	0.0	0.4	0.0	0.4	29.4	0.2	5.1	1.8	3.5	16.1
7/27/21	0.0	0.0	4.5	2.7	0.0	3.8	0.0	0.0	0.0	0.0	0.4	3.4	1.7	12.0	1.9	37.2	22.7
8/3/21	3.5	0.0	11.6	4.8	0.0	2.7	0.0	0.2	0.0	0.0	3.6	1.6	0.5	2.8	4.8	8.6	36.7
8/10/21	6.9	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.4	0.0	5.0	1.1	1.1	27.1
8/17/21	23.4	0.0	0.0	0.6	0.0	0.0	0.3	0.3	0.9	0.0	0.0	0.3	0.0	9.4	1.6	0.0	61.5
8/24/21	38.2	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.5	0.0	2.6	0.3	0.0	5.0	1.9	0.0	39.6
8/31/21	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.9	1.4	2.2	0.0	84.4
9/7/21	1.4	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.5	1.2	0.0	0.3	11.1	2.8	3.5	57.7
9/14/21	20.4	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.6	1.4	3.5	0.0	50.9
9/24/21	37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.3	0.3	4.6	3.0	0.0	42.7
9/28/21	32.2	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.8	0.0	1.4	0.5	0.3	13.0	0.6	0.8	41.8
2021 Average	11.8	0.0	11.9	1.7	0.4	1.8	0.0	0.7	0.2	0.0	1.2	7.0	0.6	4.8	1.7	3.8	34.3

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

Table 6: Annual Average 2021 Limnological Data from the monthly Finger Lake Survey.

2021 Average Values (± 1s)	Honeoye	Canandaigua	Keuka	Seneca	Cayuga	Owasco	Skaneateles	Otisco
Secchi Depth (m)	3.1 ± 1.2	6.5 ± 1.1	5.5 ± 1.3	4.0 ± 1.2	3.5 ± 0.9	3.7 ± 1.4	7.2 ± 2.8	Not Sampled
Total Suspended Solids (mg/L), Surface	3.5 ± 3.0	1.0 ± 0.5	0.9 ± 0.3	1.5 ± 0.5	2.0 ± 1.4	2.0 ± 1.0	1.6 ± 0.9	
Total Suspended Solids (mg/L), Bottom	2.6 ± 1.6	0.5 ± 0.2	0.8 ± 0.3	1.2 ± 0.4	1.9 ± 0.8	0.9 ± 0.3	0.7 ± 0.4	
Total Phosphate (μg/L, TP), Surface	30.7 ± 19.6	10.1 ± 1.6	11.9 ± 2.8	15.3 ± 5.2	15.5 ± 2.9	13.8 ± 4.1	67.1 ± 182.5	
Total Phosphate (μg/L, TP), Bottom	31.3 ± 13.4	7.6 ± 1.6	10.3 ± 3.7	12.6 ± 4.0	15.2 ± 5.8	10.1 ± 3.7	13.8 ± 13.1	
Dissolved Phosphate (μg/L, SRP), Surface	2.2 ± 3.4	0.7 ± 0.5	1.4 ± 2.4	1.2 ± 2.3	0.7 ± 1.0	0.4 ± 0.4	0.5 ± 0.5	
Dissolved Phosphate (μg/L, SRP), Bottom	2.9 ± 4.0	0.4 ± 0.3	0.7 ± 0.4	2.8 ± 3.4	5.5 ± 3.7	0.6 ± 1.1	0.5 ± 0.5	
Nitrate as N (mg/L), Surface	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	1.0 ± 0.4	0.8 ± 0.3	0.3 ± 0.1	
Nitrate as N (mg/L), Bottom	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	1.3 ± 0.4	1.1 ± 0.2	0.4 ± 0.1	
Silica (SR μg/L), Surface	Not Measured							
Silica (SR μg/L), Bottom	Not Measured							
Chlorphyll a (μg/L), Surface	9.4 ± 6.6	1.3 ± 0.6	1.7 ± 0.7	3.1 ± 1.7	3.7 ± 1.7	3.0 ± 1.6	1.5 ± 1.1	
Chlorphyll a (μg/L), Bottom	6.9 ± 5.8	0.6 ± 0.2	0.8 ± 0.4	1.5 ± 1.2	0.5 ± 0.2	1.0 ± 0.5	0.6 ± 0.3	

Table 7. 2021 Stream Data.

2021 Stream Segment Analysis Data							
Date & Location	Discharge (m^3/s)	Specific Conductance (µS/cm)	Water Temp (°C)	Nitrate (mg/L, N)	Suspended Solids (mg/L)	Total Phosphate (µg/L, TP as P)	SRP Phosphate (µg/L, SRP as P)
5/4/2021							
Dutch Hollow 38A	1.19	534	12.7	1.1	4.3	16.7	1.0
Dutch Hollow North St	1.14	495	12.6	1.0	3.2	13.3	0.9
Dutch Hollow South Trib	0.17	528	12.9	1.6	2.3	12.9	0.9
Dutch Hollow Benson Trib	0.85	432	13.0	1.2	5.6	12.5	3.1
Dutch Hollow Benson Rd	0.10	753	13.7	2.5	3.0	22.2	1.5
Dutch Hollow Old State Rd	0.46	400	13.9	0.9	3.6	17.9	1.7
Owasco Inlet Moravia Rt 38*	6.46	361	14.0	0.8	9.4	20.1	0.4
Fire Lane 20	0.02	661	12.9	6.8	1.6	19.1	0.4
Fire Lane 26	0.01	601	12.9	3.8	2.4	13.1	0.7
5/7/2021							
Dutch Hollow 38A	1.73	533	9.0	2.0	6.2	19.9	0.9
Dutch Hollow North St	1.35	487	8.9	1.8	5.7	22.0	0.6
Dutch Hollow South Trib	0.28	538	9.0	2.6	2.7	24.6	2.3
Dutch Hollow Benson Trib	0.88	444	8.7	1.3	6.1	18.3	0.7
Dutch Hollow Benson Rd	0.17	748	10.1	3.4	3.3	33.2	8.5
Dutch Hollow Old State Rd	0.60	399	10.0	1.1	5.9	15.1	0.3
Owasco Inlet Moravia Rt 38*	8.07	353	10.2	1.3	10.8	28.4	3.2
Fire Lane 20	0.08	682	9.1	5.1	1.6	15.9	2.1
Fire Lane 26	0.02	617	8.9	1.6	1.9	18.3	1.0
5/21/2021							
Dutch Hollow 38A	0.46	519	18.8	1.7	3.5	10.0	0.0
Dutch Hollow North St	0.46	510	19.3	1.7	3.0	13.5	0.0
Dutch Hollow South Trib	0.07	539	17.4	1.8	1.7	8.2	0.0
Dutch Hollow Benson Trib	0.34	482	19.3	1.2	3.6	10.9	0.0
Dutch Hollow Benson Rd	0.03	776	19.7	4.1	2.3	17.8	0.0
Dutch Hollow Old State Rd	0.17	467	19.1	1.2	4.3	12.3	0.1
Owasco Inlet Moravia Rt 38*	2.49	409	18.7	1.0	5.1	15.7	16.0
Fire Lane 20	0.02	633	17.3	8.3	1.2	9.8	0.8
Fire Lane 26	0.01	572	16.6	5.8	2.3	10.2	0.0
6/7/2021							
Dutch Hollow 38A	0.17	571	19.9	0.8	2.2	23.0	4.4
Dutch Hollow North St	0.17	549	20.7	1.0	2.6	14.3	5.0
Dutch Hollow South Trib	0.03	613	18.5	1.5	1.6	17.1	4.2
Dutch Hollow Benson Trib	0.14	532	20.7	0.7	4.1	16.5	6.4
Dutch Hollow Benson Rd	0.01	768	19.0	5.4	1.3	23.3	3.3
Dutch Hollow Old State Rd	0.04	509	20.4	1.0	2.4	31.9	1.6
Owasco Inlet Moravia Rt 38*	1.29	458	20.1	1.3	4.9	23.9	4.7
Fire Lane 20	0.01	633	18.6	11.9	1.7	14.0	4.1
Fire Lane 26	0.00	580	19.0	6.1	3.0	20.2	1.0
*Used USGS Gauge at Moravia for Owasco Inlet Discharge Data							
20201Average Values							
Dutch Hollow 38A	0.89	539.10	15.10	1.38	4.05	17.36	1.57
Dutch Hollow North Rd	0.78	510.30	15.38	1.39	3.63	15.80	1.61
Dutch Hollow South Trib	0.14	554.48	14.45	1.84	2.08	15.70	1.85
Dutch Hollow Benson Trib	0.55	472.48	15.43	1.10	4.85	14.55	2.55
Dutch Hollow Benson Rd	0.08	761.18	15.63	3.86	2.48	24.14	3.33
Dutch Hollow Old State Rd	0.32	443.63	15.85	1.07	4.05	19.31	0.89
Owasco Inlet Rt 38 Moravia	4.58	395.10	15.75	1.10	7.55	22.01	6.08
Fire Lane 20	0.03	652.20	14.48	8.02	1.53	14.66	1.86
Fire Lane 26	0.01	592.35	14.35	4.33	2.40	15.43	0.68
2021 Average Fluxes				N kg/day	TSS kg/day	TP kg/day	SRP kg/day
Dutch Hollow 38A				105.9	310.6	1.3	0.1
Dutch Hollow North Rd				93.8	244.7	1.1	0.1
Dutch Hollow South Trib				22.0	24.7	0.2	0.0
Dutch Hollow Benson Trib				52.3	230.2	0.7	0.1
Dutch Hollow Benson Rd				25.6	16.4	0.2	0.0
Dutch Hollow Old State Rd				29.2	110.8	0.5	0.0
Owasco Inlet Rt 38 Moravia				436.1	2986.0	8.7	2.4
Fire Lane 20				21.9	4.2	0.0	0.0
Fire Lane 26				3.6	2.0	0.0	0.0