QUANTIFYING NITROGEN LOADING FROM THE VILLAGE OF EAST HAMPTON TO SURROUNDING WATER BODIES AND THEIR MITIGATION BY CREATING A SEWER DISTRICT

CHRISTOPHER J. GOBLER, PHD

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Stony Brook University
School *of* Marine and Atmospheric Sciences

EXECUTIVE SUMMARY

The Village of East Hampton is located within the watersheds of Georgica Pond and Hook Pond, two water bodies deemed impaired by New York State Department of Environmental Conservation (NYSDEC) and/or US EPA standards. For more than a decade, these waters have been plagued by recurrent harmful algal blooms, low oxygen, poor water clarity, and fish kills. High levels of nitrogen have been detected in the groundwater under the Village and this nitrogen flows to coastal water bodies, and combined with phosphorus, promotes these events and poor conditions for aquatic life. Any effort to reduce the delivery of nitrogen, and to a lesser extent phosphorus, from the Village of East Hampton will help mitigate these conditions. This study was undertaken to estimate the effect of sewering various portions of the Village of East Hampton on the total nitrogen and phosphorus loads to Georgica Pond and Hook Pond, as well as the water quality within these systems. Nitrogen loading models were developed that considered nitrogen delivered to these waterbodies from three types of fertilizers, septic systems, the atmosphere, and birds whereas a phosphorus loading model considered groundwater, surface run-off, benthic fluxes, tributaries, and atmospheric deposition. The models were run for current conditions as well as for multiple phases of wastewater remediation for the Village including the creation of phased sewer districts and upgrades of on-site septic systems. The models demonstrate that wastewater is currently the largest source of nitrogen to Georgica Pond and Hook Pond (50%, and 62% of the external nitrogen load) whereas sediments and groundwater were the largest sources of phosphorus to these two systems, respectively. The completion of the proposed phase one sewering of the downtown region of the Village would divert more than 1,000 kilograms of nitrogen away from Hook Pond annually but would not significantly impact Georgica Pond which is outside of the Main Street watershed. In contrast, extending the sewers in a small area north of Main Street would have only a modest effect. Connecting the Elementary School, Middle School, and High School would collectively divert more than 1,600 kilograms of nitrogen away from Hook Pond annually. A concurrent effort to upgrade septic systems within the Village to innovative and alternative, low nitrogen systems would remove 12,000 kilograms annually, reducing total nitrogen loads to Georgica and Hook Pond by ~40% and 50%, respectively. The impact of sewering and septic systems on phosphorus loading would be less substantial due to the large role of sediments as a phosphorus source and the natural retention of phosphorus within the aquifer.

Still, sewering all proposed regions of the Village would cut phosphorus loads to Hook Pond by 4% whereas combinations of sewering and upgrading septic systems would reduce phosphorus loads to Georgica Pond and Hook Pond by 8% and 19%, respectively. Upon the reduction of nitrogen and phosphorus loads to coastal waters, it is expected that the intensity of algal blooms in Hook Pond would be reduced below NYSDEC and US EPA guidance values and that dissolved oxygen levels would increase. Additional ecosystem benefits would include improved nighttime oxygen levels, improved water clarity, increases in submerged aquatic vegetation, and improved conditions for aquatic life. Given that recent research at Stony Brook University has determined that waterfront or near-waterfront home values can be strongly affected by water clarity, improved water clarity could financially benefit homeowners in the region as well as associated tax revenues.

TASK 1 SUMMARIZE THE CURRENT STATUS OF WATER QUALITY WITHIN HOOK POND AND GEORGICA POND AND KNOWN RELATIONSHIPS TO EXCESSIVE NITROGEN LOADING IN A BRIEF REPORT.

Estuaries and other coastal ecosystems have suffered multiple anthropogenic insults in recent decades, including pollution, eutrophication, overfishing of fish and shellfish, and loss of key habitats, such as seagrass beds, salt marshes, mangroves, and oyster reefs (Valiela et al., 1992, Nixon 1995, Cloern 2001, Lotze et al. 2006). At the same time, resource value of estuaries and their various habitats has increased, as measured by monetary value (Costanza et al. 1997) or by ecosystem services provided to marine and terrestrial species, including humans (Beck et al. 2001, Bruno et al. 2003, Johnson and Heck 2006). In response to the ongoing degradation of coastal ecosystems, the current challenge to scientists and managers is to implement management schemes for estuaries and coastal waters that balance preservation, conservation, and restored ecosystem function with ever-growing human populations and human demands in the coastal zone. Anthropogenic nutrient loading is a major threat to coastal systems; it has increased world-wide and led to eutrophication in many systems (Nixon 1995, Cloern 2001, de Jonge et al. 2002). Eutrophication can have severe effects on estuaries and estuarine resources, such as hypoxia/anoxia leading to loss of benthic habitat (Breitburg 2002), harmful algal blooms (Sunda et al. 2006), shading of seagrass beds (Dennison et al. 1993), and “regime changes” from a high-biomass benthos to a pelagic, microbially-dominated system (Lotze et al. 2006).

These broad global threats to estuaries are abundantly apparent in the coastal waters surrounding the Village of East Hampton (Figure 1). As a relatively dense population hub with a main street, there is an abundance of nitrogen-rich wastewater entering the groundwater under the Village that ultimately discharges to Hook Pond, Georgica Pond, and the Atlantic Ocean (Figure 1). The first marine habitat to receive nitrogen-groundwater from the Village would be salt marshes or wetlands. Salt marshes serve as an important habitat for a variety of animals as multiple marine, terrestrial, and migratory species utilize these systems for food, shelter, and nurseries (Turner 1987; Leonard et al. 1999). Marine marshes can also serve as a buffer between the land and the adjacent marine ecosystem whereby land-derived nutrients and organic carbon may be retained and re-mineralized, potentially minimizing the effects of these constituents on the local marine environment (Valiela et al. 1978; Valiela and Teal 1979; Dame et al. 1992). The expansion of human populations along coastlines during the past century has led to the alteration and degradation of many salt marsh habitats, a process which, in turn, can impact estuaries. There has been an accelerated loss of salt marshes in recent decades all around Long Island, but most notably along the south shore (NYSDEC 2014). What was once vegetated intertidal marsh has become non-vegetated underwater lands and/or mud flats. Moreover, high marsh vegetation is being converted to low marsh vegetation or has been built upon.

The salt marshes along Hook Pond and Georgica Pond are likely degrading. It was once thought that salt marshes had an unlimited capacity to remove nitrogen and were, therefore, not susceptible to damage due to nitrogen overloading. Earlier research had shown that excess nitrogen loading can lead to an expansion of above ground, leaf biomass of salt marshes, and thus, eutrophied salt marshes can appear green and lush (Valiela 2006). There is, however, now a scientific consensus that excessive nutrient loading promotes the collapse and destruction of salt marshes. Excessive nitrogen concentrations accelerate microbial decomposition of leaves, stems, and other organic biomass in marshes sediments and prevent the ability of these marsh communities to keep up with sea level rise (Turner et al. 2009). Nutrient enrichment decreases the dense below ground biomass of bank-stabilizing plant roots and increases microbial decomposition of organic matter within the soils that underlie the marsh biomass that can cause marshes to subside (Deegan et al. 2007, 2012). Longer term exposure to enhanced nutrient levels causes an increased probability of marsh channel destabilization (Deegan et al. 2012). The tall marsh grasses in a nitrogen-enriched system produce fewer roots and rhizomes – plant attributes that are critical to stabilizing the edges and soils of marshlands (Deegan et al. 2007, 2012). The poorly rooted grasses eventually grow too tall and then fall over, thereby destabilizing the creek-edge and bay-edge marsh, causing it to slump and exposing soils to erosive forces (Deegan et al. 2012). The destabilization of creek-edge and bay-edge marshes makes these areas much more susceptible to the constant tugging and pulling of waves, accelerating erosion, and the loss of stabilizing vegetation. Ultimately, this process of root degradation and collapse of salt marshes leads to their conversion to mud flats (NYSDEC 2014). These conclusions are consistent with those of Stony Brook University scientists who have found that marsh loss in eutrophied regions, is driven by nitrogen and organic matter loading, which perturb the salt marsh sulfur cycle and lead to plant die-offs and the deterioration of marsh peat (Kolker et al. 2010).

Tidal wetlands are critically important for protecting coastal communities such as the Village of East Hampton from storm damage by dissipating wave energy and amplitude, reducing erosion from waves by slowing water velocity, and by stabilizing shorelines through sediment deposition (Möller et al., 1999). Some studies estimate that more than half of normal wave energy is dissipated within the first three meters of marsh vegetation, such as cord grass, while other studies concluded that wave height is reduced by 80 percent over fairly short distances as waves travel through marsh vegetation (Anderson et al. 2013; Jadhav and Chen 2012; Ysebaert et al. 2011). In addition, wave energy dissipation rates over the salt marsh are more than dramatically higher than non-marsh regions and are therefore important for maintaining a natural defense for coastal communities against storm surge, waves, and flooding (NYSDEC 2014). This is evident during storm events when salt marshes absorbed a large amount of tidal flooding, protecting regions of the Village of East Hampton. Beyond storm events, the amount of sea level rise in the next 30 years may also pose a risk to coastal communities such as the Village of East Hampton as the projected sea level rise for the next 30 years is likely to lead to flooding of some properties and homes. Importantly, however, these projections are assuming the current salt marshes remaining intact. If nitrogen loading continues or accelerates, they could weaken and experience a die-back and future flooding might be worsened (Deegan et al., 2012; NYSDEC, 2014). Alternatively, nitrogen mitigation could strengthen these salt marshes and enhance the protection they offer (Deegan et al., 2012; NYSDEC, 2014). Therefore, while the loss of tidal marshlands results in a direct reduction in coastal resiliency and the ability of these natural features to help protect coastal communities along the Village of East Hampton from future storm surges, projects that have the potential to remove significant amounts of nitrogen are likely to encourage salt marsh recovery and enhance community protection.

Beyond the shoreline, the release of nitrogen from groundwater into coastal waters has a strong effect on the surrounding estuarine ecosystems since nitrogen is considered the limiting element for primary producers (Nixon, 1995). Hence, more nitrogen will lead to more growth of algae. The precise levels of total nitrogen measured by the Gobler Lab in Georgica Pond (~0.6 mg nitrogen per liter) exceed the guidelines recommended by US EPA for many estuaries including the Peconic Estuary and Chesapeake Bay (< 0.4 mg per liter; PEP, 2001). These high nitrogen levels have a cascading effect on the entire estuarine ecosystem. As mentioned above, nitrogen is the limiting element in estuaries (Nixon, 1995) including Georgica Pond (Gobler et al., 2015). Hence, these high nitrogen levels lead to algal blooms (Heisler et al., 2008). Both Georgica Pond and Hook Pond regularly have levels of chlorophyll *a* that exceed the US EPA standard of 8 µg per L for freshwater bodies (Figures 3-4). During late summer months, these algae are typically dominated by cyanobacteria or blue-green algal blooms and levels of blue-green algae in both systems often exceed NYSDEC standards of 25 µg per L (Figures 4-6). Such blooms are a serious human health and ecosystem threats as the cyanobacteria create toxins that can be lethal to animals or humans if consumed (Watson et al., 2016). While Hook Pond has had occasional and modest cyanobacterial blooms during the past decade, Georgica Pond has had some of the more intense such events on Long Island (Figures 4-6), including one that causes a dog death in 2012. Blue-green algal blooms in Georgica Pond and Georgica Cove have been shown to be promoted by nitrogen (Figure 2). This has been shown for multiple nitrogen sources and at multiple temperatures (Figure 2).

Algal blooms can have additional, secondary negative impacts on marine life. The occurrence of algal blooms in general can make coastal waters extremely turbid and murky (Gobler and Sunda, 2012) leading to low water clarity. Poor water clarity has a host of primary and secondary ecosystem and economic ramifications. Firstly, low light levels from poor water clarity can lead to the loss and demise of seagrass meadows that are a critical nursery habitat for juvenile finfish and shellfish (Dennison et al., 1993). Also, recent research at Stony Brook University has determined that waterfront or near-waterfront home values can be strongly affected by water clarity, with low water clarity being associated with lower home values.

Finally, low light levels associated with poor water clarity can minimize the amount of photosynthesis in an ecosystem and thus contribute toward low oxygen levels. The decay of intense algal blooms can also promote low oxygen levels (Diaz and Rosenberg, 2008). Hook Pond and Georgica Pond have suffered from low dissolved oxygen with levels commonly falling below the minimum standard for oxygen set by the NYSDEC of 3 mg per liter (Figures 7 – 9). Low oxygen levels are associated with the loss or death of marine life (Diaz and Rosenberg, 2008).

In summary, the groundwater flowing from the Village of East Hampton into Hook Pond and Georgica Pond is highly enriched in nitrogen. This nitrogen threatens severe future flooding in the region due to the nitrogen-induced degradation of salt marshes. Nitrogen loading is promoting algal blooms that are reducing light and oxygen levels and negatively impacting finfish, shellfish, and seagrasses. Nitrogen mitigation is needed to improve water quality and protect homes in the region.

Figure 1. The Village of East Hampton and adjacent water bodies, Hook Pond, Georgica Pond, and the Atlantic Ocean.

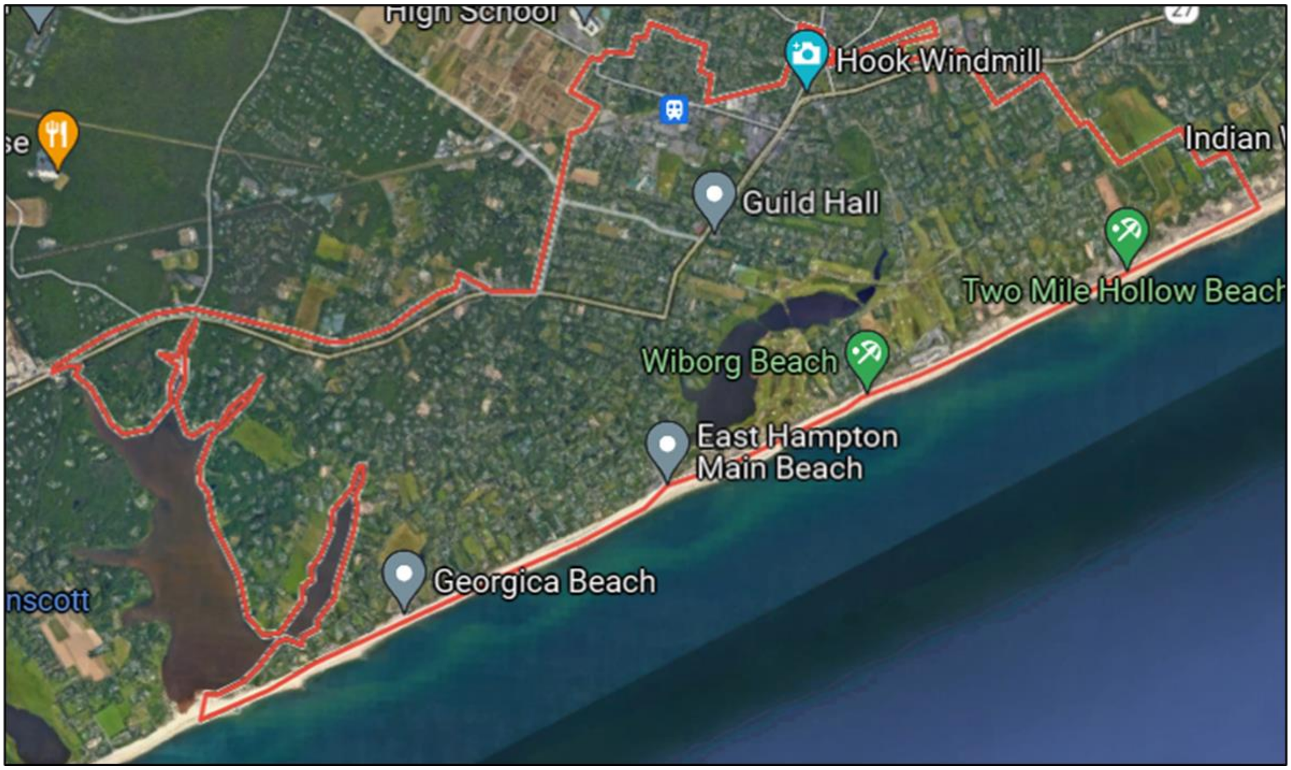


Figure 2A. Response of blue-green algae in Georgica Cove (EH-16) and Georgica Pond (EH-18) to nitrate, phosphate, of both compounds, or neither compound (control) **B.** Response of blue-green algae in Georgica Pond to nitrate, urea, phosphate, nitrate and phosphate, or an unamended control treatment grown at two temperatures. In all cases, blue-green algae (aka cyanobacteria), which can be toxic, grew faster and increased in biomass primarily in response to nitrogenous compounds.

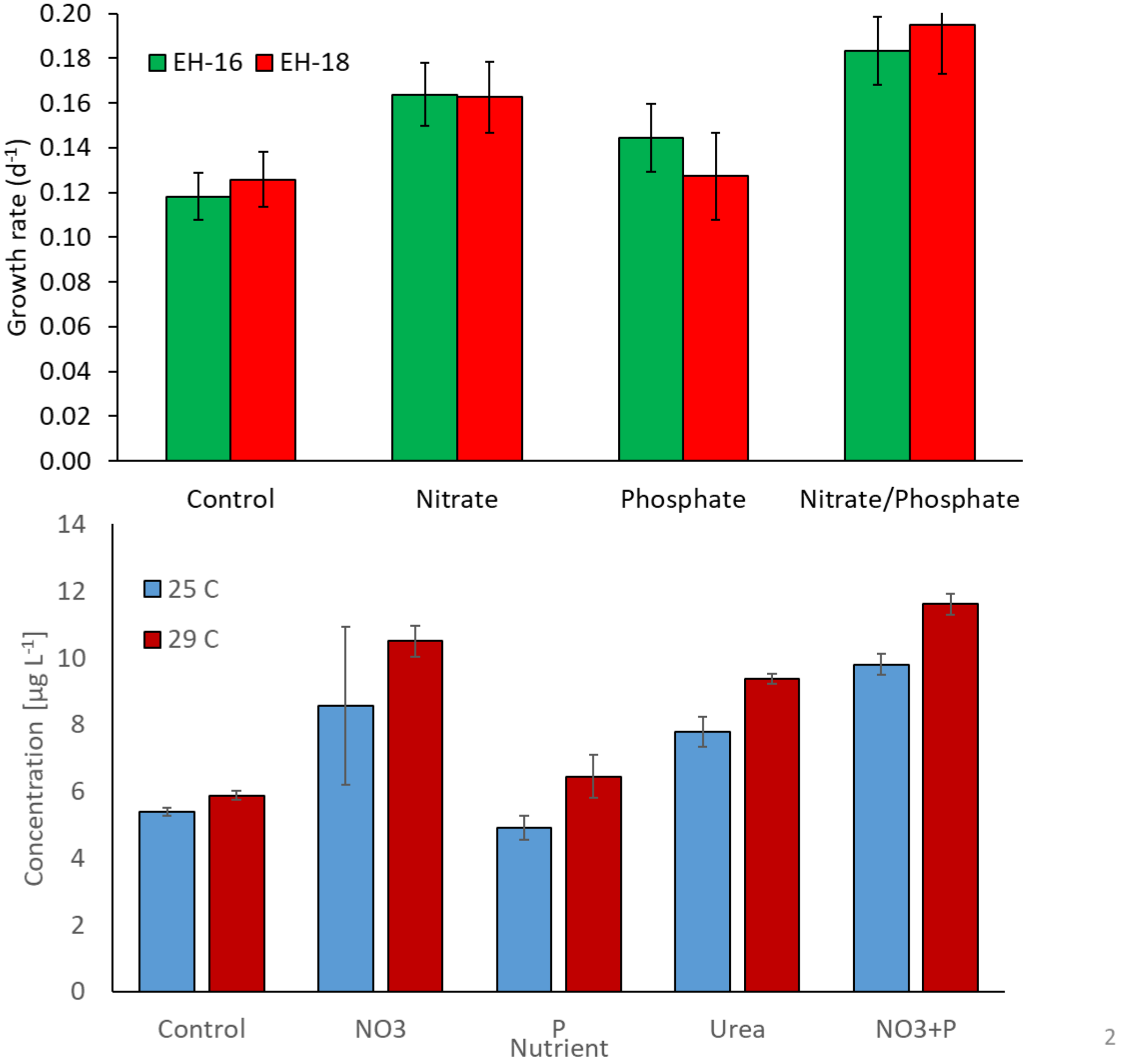


Figure 3. Continuous chlorophyll *a* concentrations (μg L^{-1}) taken from a monitoring buoy in Georgica Pond from 2015 – 2019. The Pond often has levels of algae that cause exceedances beyond the US EPA threshold level for freshwater bodies of 8 μg L^{-1}.

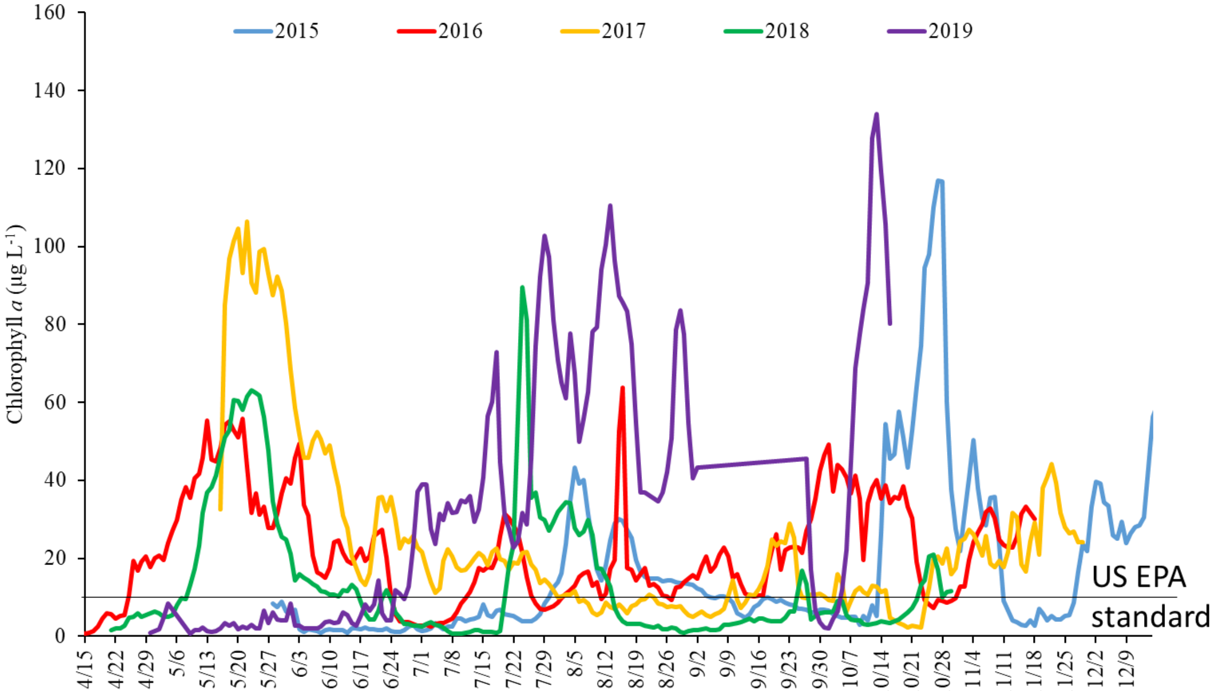


Figure 4. Annual maximum levels of total chlorophyll a and blue-green algae in Hook Pond 2013 – 2021 with US EPA and NYSDEC threshold levels displayed.

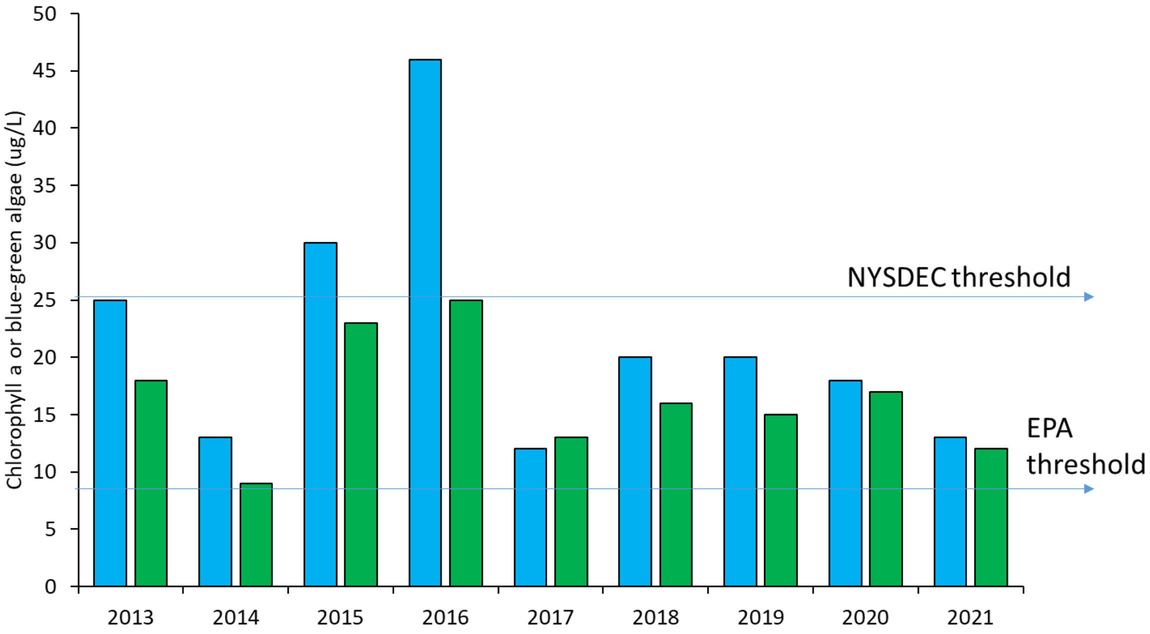


Figure 5. Annual maximum levels of blur-green algae in Georgica Pond from 2014-2020 with the NYSDEC threshold level noted.

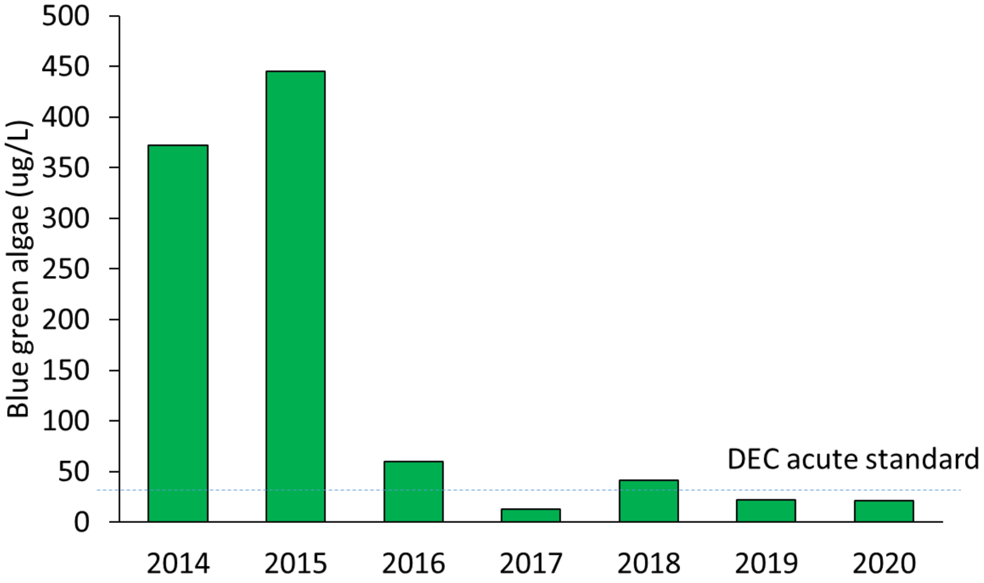


Figure 6. Levels of blue-green algae in Georgica Pond in 2021 with the NYSDEC threshold level noted.

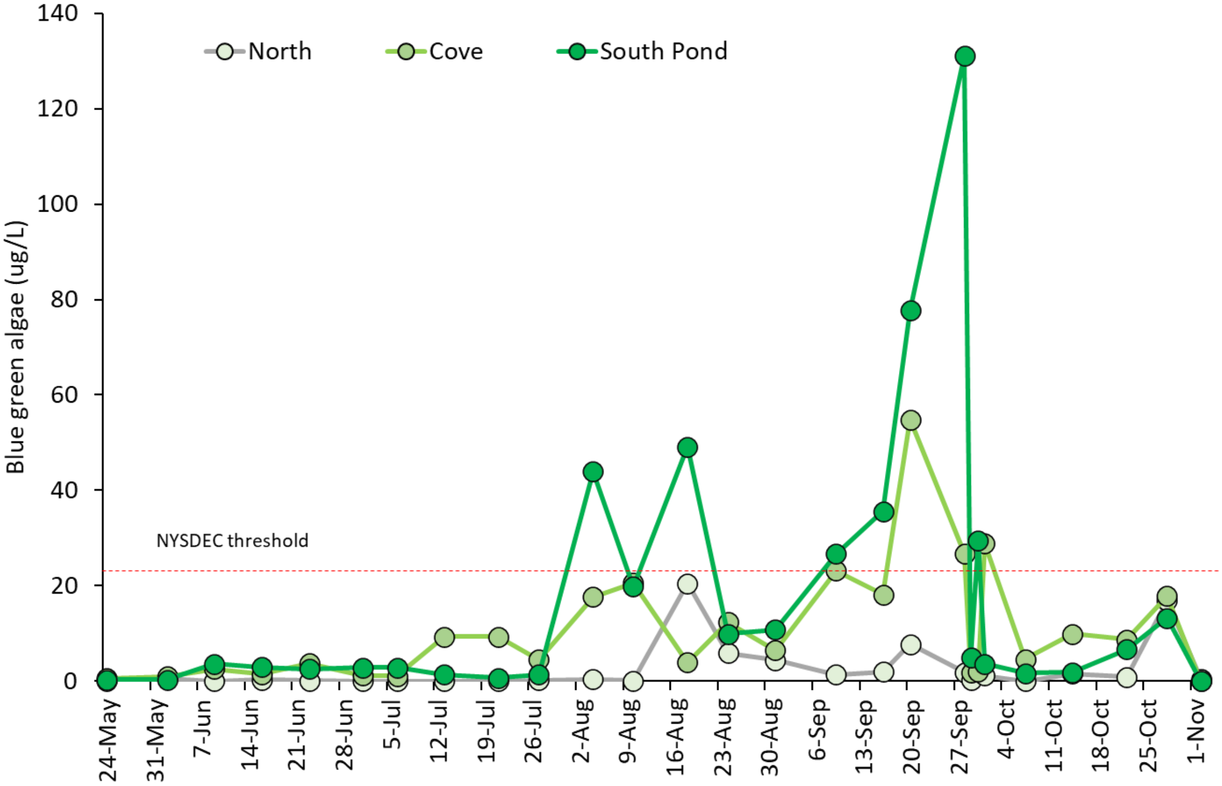


Figure 7. Levels of dissolved in Hook Pond in 2014 with the NYSDEC threshold level noted.

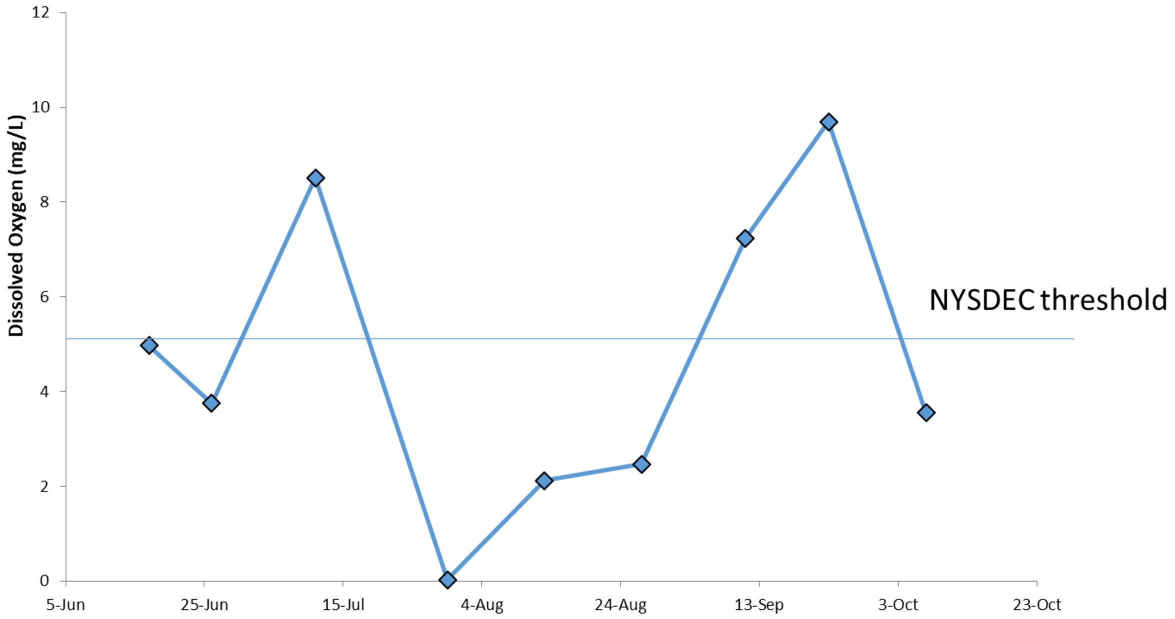


Figure 8. Summer (June – mid-August) dissolved oxygen minimums in Georgica Pond, 2013 – 2020. The NYSDEC chronic and acute thresholds for hypoxia are 5 and 3 gm/L, respectively.

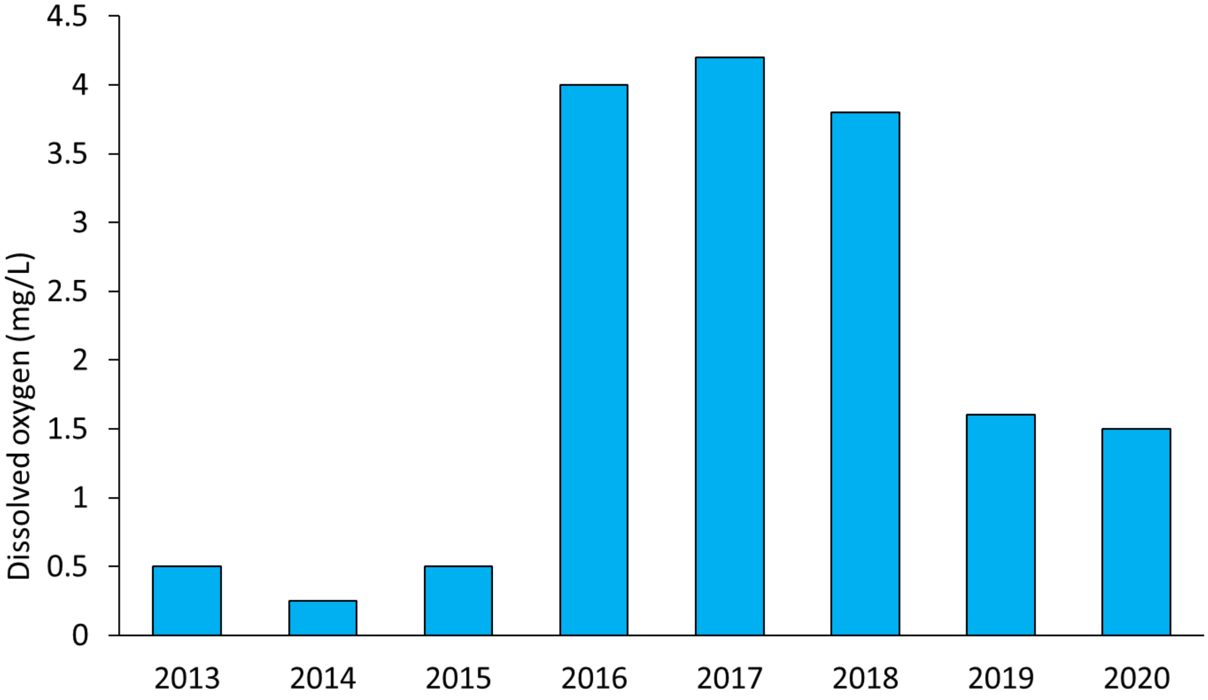
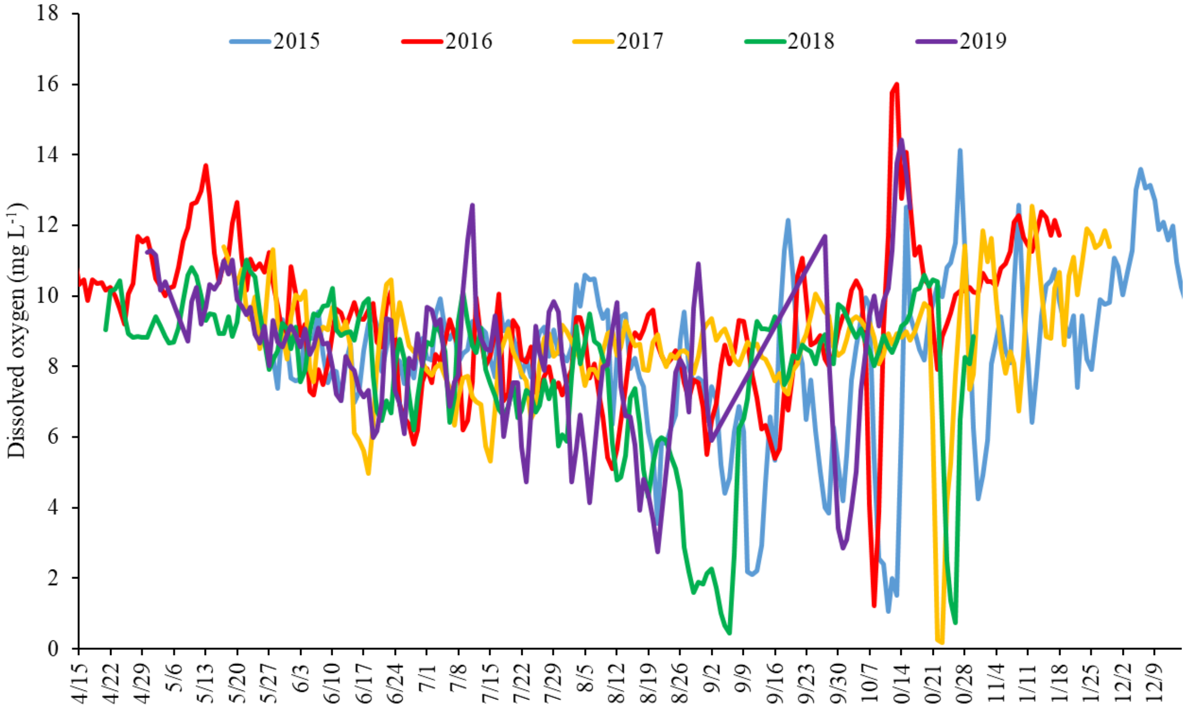


Figure 9. Dissolved oxygen in Georgica Pond, 2015 – 2019. The NYSDEC chronic and acute thresholds for hypoxia are 5 and 3 gm/L, respectively.



TASK 2. DEVELOP A DYNAMIC MODEL FOR NITROGEN LOADING RATES AND SOURCES FOR THE VILLAGE OF EAST HAMPTON TO GEORGICA POND AND HOOK POND

A Nitrogen Loading Model was developed to quantify the total dissolved nitrogen input into the waterbodies surrounding the Village of East Hampton. The original Nitrogen Loading Model (NLM; Valiela et al., 1997) is available via a web-based modeling tool (nload.mbl.edu) described in Bowen et al. (2007) and used in Bowen and Valiela (2004) and recently in Kinney and Valiela (2011) among others. The NLM uses information about land use in a defined watershed to predict both the amount of nitrogen that is released into the watershed from various sources and how much of it ends up in a corresponding waterbody. This model requires accurate land-use and land cover information, such as area of agriculture, residential areas, and impervious surfaces as well as other environmental data that was gathered for this project from scientific literature, NYS and Suffolk County GIS data bases, USGS reports, the Town of East Hampton, Suffolk County, and the US census as described in Table 1. Hence, for this project, this original model was modified to utilize more accurate, local data sources, although the underlying assumptions and several critical components were not altered. As an example, originally average roof area was multiplied by the number of buildings to approximate the total area of roofs in a watershed. With more accurate, GIS-based data, the area of each roof in the watershed was calculated and then all the individual areas were summed together.

The NLM is a good fit for watersheds around the Village of East Hampton that are a mix of residential, forested, and forest and is one of the most inclusive nitrogen loading models regarding the transformation and transport of nitrogen as it travels from watershed to estuaries.. The NLM assumes that the primary transport mechanism for nitrogen entering the bays from each watershed is groundwater flow. This assumption is consistent with data available for the region as the little inflow to the bays from streams is actually derived from groundwater and geologically, Long Island is composed of unconsolidated sands that allow for relatively easy transport of groundwater to coastal lagoons. The NLM assumes that all nitrogen entering the waterbodies from external sources originates from atmospheric deposition to the watershed, wastewater, or fertilizer. Valiela et al. (1997) validated this model by comparing its nitrogen load prediction to empirically measured nitrogen levels. They found the NLM's results to be statistically indistinguishable from measured concentrations and that a linear relationship exists between the percent contributions from wastewater that the NLM predicted and the stable isotope signature for wastewater expected from known isotopic N values of nitrate in groundwater. A recent study by Gobler (2016) came to the same conclusion for the south shore of Long Island.

The NLM utilizes multiple features, which were obtained or derived from Suffolk County and New York State datasets for the watersheds: number of people; number of people within 200 meters of shore; area of roofs; surface area of the watersheds; area of freshwater wetlands; area of agriculture; area of golf courses; lawn area on parks, athletic fields, and residential parcels; freshwater ponds; and, various impervious surfaces (Table 1). The model also includes a list of constants assigned values based on recommendations from Suffolk County (Table 1).

Watershed/Subwatershed Delineation

The surface extents of the watersheds in the study area were obtained from the U.S. Geological Survey regional MODPATH model of 2005-2015. Watersheds that extended beyond Village were not clipped. Instead, the study area was expanded to include the full extent of the watersheds so that all the N sources to the drainage areas were accounted for. Nutrient loads were determined for Georgica Pond and Hook Pond for their entire watersheds, as well as the watersheds only within Village boundaries (Figure 10 and 11). It is noted that some areas of the Village contribute groundwater to neither Hook Pond nor Georgica Pond, instead contributing to community supply well area or to the Atlantic Ocean (Figure 10). It is also noted that although the Geogica Pond watershed is larger than the Hook Pond watershed, the population density is higher in the Hook Pond watershed compared to the Georgica Pond watershed (Figure 11).

Atmospheric Deposition

Atmospheric nitrogen is delivered via precipitation (wet) or via dust (dry). Nitrogen that arrives in the watersheds through wet and dry deposition may have a varied contribution to waterbody nitrogen load depending on where the nitrogen lands. Different land use types (impervious, vegetation, developed) alters the amount of nitrogen that makes it to the waterbody. Nitrogen landing on vegetation has time to be assimilated by plants and organisms in the soils, and/or may be denitrified in the aquifer. Nitrogen that lands on impervious surfaces can runoff directly into a stream, or bay, skipping assimilation. It may also flow through a municipal separate stormwater sewer system (MS4) where it eventually seeps into sandy soils and discharges into coastal zones. In general, when atmospherically deposited nitrogen lands on impervious surfaces, significantly less is removed before entering the waterbodies. For this project, an effort was made to separate N from run-off given that once N enters the water table, there is little N attenuation within the sandy aquifer of Long Island (Kinney and Valiela, 2011; SCSWS, 2019). Hence, to isolate N that is loaded to surface waters as a consequence of surface run-off, the sum of atmospheric N landing on impervious surfaces including roads, driveways, sidewalks, roofs, parking lots, and other impervious surfaces was summed and deemed N load from run-off.

Impervious land areas were estimated by finding where the Normalized Difference Vegetation Index (NDVI) was low (NDVI<90). The NDVI was created from the USGS's high resolution orthoimagery. Parcels that were known by land type to not have any impervious surfaces were removed to improve the accuracy. The removal included the classes open water, vacant land, preserved/forested land, and agricultural land. Road area was estimated by expanding road line data into polygons obtained from the US Census Bureau. Lines for primary road, secondary roads, local roads, and ramps were expanded to a width of 12.5m, 10m, 5m, and 5m, respectively. Areas of the polygons were then calculated and summed for each watershed. Residential impervious areas were estimated by limiting the impervious layer to residential parcels. The final process considered were *direct* atmospheric deposition to the water bodies (0.16 mole m^{-2} yr^{-1} as per Gobler (2016).

Table 1. Constants and rates used in the nitrogen loading model with sources color-coded, light blue for atmospheric deposition, dark blue for wastewater, green for fertilizer, orange for pets, grey for septic system upgrades.

Constants and Calculations		
N inputs from wet and dry deposition	5.37	*kg per ha per yr*
Forest N uptake	0.75	*percent of deposition retained*
Forest N release	0.25	*percent od deposition released*
Vadose N uptake	0	*percent of deposition retained*
Vadose N release	1	*percent of deposition released*
Turf N uptake	0.7	*percent of deposition retained*
Turf N release	0.3	*percent of deposition released*
Agriculture N release	0.38	*percent of deposition released*
N throughput from freshwater ponds to aquifer	0.45	*percent of inputs*
N throughput from wetlands to aquifer	0.25	*percent of inputs*
N released per person per year	4.536	*kg per cap per yr*
Percent of N inputs released from septic tanks	0.94	*percent of added N released*
Leaching field effluent	0.9	*percent of added N released*
N released from the plume of the septic system (aquifer loss)	0.94	*percent of added N released*
N released from s4 sewers (advanced individual sewers)	7.87	*kg per sewer per yr*
Proportion of parcels with Cesspool	0.5	*percent*
Proportion of parcels with Septic	0.5	*percent*
Proportion of buildings with fertilized lawns	1	*percent*
Fertilizer applied to lawns	115	*kg per ha per yr*
Fertilizer applied to golf courses	189.269	*kg per ha per yr*
Fertilizer applied to Parks & Athletic Fields	89.654	*kg per ha per yr*
Fertilizer applied to agriculture	90.440	*kg per ha per yr*
Gaseous loss of fertilizer - residential lawns	0.3	*Percent fertilizer transported*
Gaseous loss of fertilizer - golf courses	0.3	*Percent fertilizer transported*
Gaseous loss of fertilizer - parks & athletic fields	0.3	*Percent fertilizer transported*
Gaseous loss of fertilizer - Agriculture	0.4	*Percent fertilizer transported*
Denitrification in aquifer	0.075	*percent of N entering the aquifer that is lost*
Denitrification in aquifer	0.925	*percent of N entering the aquifer that is released*
N input from cats	1.4606	*kg of n per animal per yr*
N input from dogs	1.9459	*kg of n per animal per yr*
Outdoor cats per house	0.74	*outdoor cats per house*
Dogs per house	1.4	*dogs per house*
Pet waste volatilization	0.5	*proportion*
I/A Innovative and alternative septics / cesspool upgrade - reduction	0.8	*percent reduction*

Table 2. Watershed data used within the models.

INPUTS	**Georgica Pond**	**Hook Pond**	**Georgica Pond Village Only**	**Hook Pond Village Only**	
Total Occupancy >200m of shore not on sewers	1455	4204	278	2492	people
Total Occupancy <200m of shore not on sewers	342	171	263	171	people
Area of Watershed (excluding saltwaterbodies)	1333.5	740.5	250.2	410.5	ha
Area of Waterbody (saltwater)	118.1	0.0	118.1	0.0	ha
Area of wetlands (freshwater)	15.5	18.3	11.4	18.3	ha
Area of freshwater ponds	1.1	0.7	0.7	0.6	ha
Area of agriculture	11.6	107.1	3.3	4.2	ha
Area of golf course lawns	0.0	16.8	0.0	16.8	ha
Area of parks and athletic field lawns	0.1	21.2	0.0	14.0	ha
Area of residential lawns	108.0	90.1	51.6	63.3	ha
Area of Impervious surfaces excluding roads	159.3	130.8	41.4	82.6	ha
Area of roads	37.0	35.5	9.1	21.7	ha
Count of Housing Units (for pets)	987	2360	330	1572	houses
STP Output	0.000	0.000	0.000	0.000	kg/yr

All other atmospheric deposition calculations based on land use areas were derivatives of the above processes or taken from source data. Area of turf was calculated from golf course, parks, and residential lawn area. The area of lawns was determined by combining NDVI data with LIDAR data. Any location with an elevated NDVI and did not contain objects > 10 cm above bare ground was deemed a lawn. Agriculture area was obtained from Suffolk County parcel data. Ponds and wetland areas were obtained from the USGS National Hydrography Dataset. Any area that was not included in the above categories was considered natural vegetation. Each one of these categories had appropriate attenuation factors applied.

Wastewater

The contribution of nitrogen load to the bays from wastewater treatment plants was added directly to the model based on measurements of nitrogen output from the plants. Loads were assigned to the various watersheds based on the treatment plant outfall locations. The loads were not attenuated and were directly added to the total nitrogen load for the corresponding watershed.

For parcels that were not connected to the sewer system, nitrogen output was calculated by multiplying the nitrogen released per person by the number of occupants in the watershed. The number of occupants for each parcel was determined from census tracks and parcel land use class. The total count of individuals for each census track was divided up among the residential parcels. The various types of residential parcels (one family, two family, apartment) were weighted accordingly. With each parcel assigned a number of occupants, parcels that were connected to sewer systems were removed. Then the total number of occupants in each watershed outside and within 200m of the water was tallied.

Differing levels of nitrogen were then removed from private sewer loading depending upon the type of on-site sewage disposal system (septic or cesspool) and the system's distance from shore, as there is significantly less nitrogen removed when septic tanks and cesspools are within 200m of coastal waters. Residential parcels have either an individual septic tank system or cesspool, which differ slightly in the fraction of nitrogen released to the underlying aquifer, with the less effective cesspools releasing more. Following the conclusions of the Suffolk County Subwatersheds study, it was assumed that half of the residential users were assumed to have cesspools.

The NLM breaks down the nitrogen removal in septic tank and cesspool-based systems into three steps: removal in the tank, removal in leach fields, and removal in septic plumes. Cesspools on

Long Island are typically composed of cylinders arranged vertically, eliminating any traditional leach field and the associated nitrogen removal therein. Although there is a disposal pit associated with these vertically structured cesspools, only a small amount of nitrogen is removed in this part of the system (<10%).

Regarding store fronts and schools around Main Street, the following formulas were employed to determine the nitrogen load per person:

Hotel Calculation:

# of rooms * 2 * 70% occupancy over year

Small Commercial

Property classes: retail, miscellaneous services, professional building, office building, standard bank, green houses, multi-use, downtown row type, converted residence, one story small structure, converted residence, radio / tv, sports clubs, libraries

2 people * (40-hour work week /168 hours in a week) = .**48**

Large Commercial

CSV, grocery, etc.

4 people * (105 hour work week / 168 hours in a week) **= 2.5**

Guild Hall

(360 seats + 10 staff) * 4 hours of shows per week / 168 hours in a week = 8.8

Schools

# of students + # of teachers (40 hours /168 hours in a week)

Religious institutions

50 people * 4 hours a week / 168 hours in a week

Restaurants

50 seats * 50% filled * (40 / 168 hours in a week)

Fertilizer

The NLM considers fertilizer input from agricultural uses, golf courses, parks and athletic field lawns, and manicured residential lawns. The area of each type was calculated using ArcGIS processes; residential lawn areas were found by limiting high NDVI areas (NDVI>80) to residential parcels and to areas where the LiDAR height layer was near zero (height<0.1m). The height of objects on properties (trees, buildings, decks, etc.) was determined by subtracting a Digital Elevation Model (DEM) from a Digital Surface Model (DSM). These models were created from the same USGS LiDAR point cloud data and represent the bare ground elevation (DEM) and the highest elevation of all objects on the ground (DSM). Golf course boundaries were provided by Suffolk County and were combined with the lawn dataset to obtain golf course lawn area. Agricultural land was extracted from the Suffolk County parcel data. Parks and athletic field parcels were also extracted from the Suffolk County parcel dataset but were then further limited to lawn areas within those parcels with the same process used for residential lawns.

Details of the data sources used for the NLM appear below in Table 1. Many data sources have been generated as part of the NYSDEC Long Island Nitrogen Action Plan's nitrogen loading study of Suffolk County's subwatersheds. Based on that project it is assumed that fertilizer applications rates were 3.89 lbs. per 1,000 square feet for golf courses and 1.84 lbs. per 1,000 square feet for parks and athletic fields. For residential turf fertilization it was assumed that there is a 1.0 lbs. per 1,000 square feet per application with the assumption that 49% of homes have on average 3.5 applications per year, 31% of homes have 1 application per year, 4.5% of homes have 1 application every 3 years and 15.5% of homes do not use fertilizer (Vaudrey, 2015). Therefore, when adjusted to the mean number of applications per year per home, the residential application rate was 2.04 lbs. per 1,000 square feet per year.

Pets

A module was added to NLM to consider the contribution of pets to watershed N loading. The assumptions of the module largely matched those of Suffolk County's subwatersheds studied including that each residence had on average, one dog, and one indoor cat, and 0.74 outdoor cats per home. The 45-year-old data regarding the N contribution of each animal type (Porter, 1978) was updated to reflect more recent findings (Beynen et al., 2001, 2002).

Phosphorus loading: Volumetric flow model, atmospheric deposition, and sediment fluxes

A volumetric flux model was utilized to estimate phosphorus fluxes from the Village of East Hampton. The Volumetric Flux Model (VFM) predicts phosphorus loads to the bays based on the volume of water that discharges from the watershed into the bay and the phosphorus concentrations in ground water, streams, and runoff within the watershed. The VFM has been used successfully to predict N loads to several Long Island estuaries, bays, and harbors (Gobler and Sañudo-Wilhelmy, 2001, Gobler and Boneillo 2003, Koch and Gobler 2009; Gobler, 2016). This model relies on the assumption that groundwater discharge to the bay is equal to the recharge of the aquifer (Valiela et al. 1992). In contrast to the NLM, the VFM further differentiates N inputs from stream flow and surface runoff from the groundwater flow. The VFM does not, however, break down the N loads into sources (i.e. waste water v. fertilizer) but direct atmospheric deposition to the bay was included. Variance of the VFM was determined to be 14% based on the mean relative standard deviation of the two primary factors used within the VFM, precipitation (19.7%) and phosphorus concentration (9%).

Groundwater

To determine the volume of ground water that discharges into the Village watersheds, watershed areas were multiplied by the annual average precipitation to obtain the volume of rain, which was corrected for the volume of rainfall that composes the stream flow, volume of runoff, and the fraction that does not recharge the aquifer. The value used for recharge percent was the default value of 50% based on the meta-analysis by Valiela et al. (1997). Which is consistent with prior studies of eastern Long Island (Steenhuis et al. (1985). The resulting value for volume of ground water was multiplied by groundwater phosphorus concentrations measured in samples collected in the region by the Gobler Lab, primarily discharge into eastern Georgica Pond.

The following equation summarizes the groundwater N load determined via the VFM: Ground water N load (kg yr^{--1}) = [(Watershed area (km^{2})* precipitation (m yr^{-1}) * recharge %) – stream flow volume (m^{3} yr^{-1}) – runoff volume (m^{3} yr^{-1})] * ground water [N] (kg m$^{3-1}$).

Runoff

Most of the land use nearest to the shore on southeast Long Island consists of older, larger homes that have little impervious cover, therefore it was assumed that most of the volume of runoff comes directly from the roads adjacent to the bays or through MS4 (Municipal Separate Storm Sewer Systems) systems. For this project, it was assumed that it would be primarily homes and roads within 200 m of water bodies would contribute run-off to water bodies and a percent impervious surface for that region was set at 15% of precipitation. The volume of runoff was then be multiplied by a phosphorus concentration of 0.00026 kg m^3 (measured stormwater phosphorus concentration, Gobler 2009) to obtain the total phosphorus load contribution from runoff.

Streams

With the exception of Talmage Creek, which flows into western Georgica Pond, the streams that run into Georgica Pond and Hook Pond are small or not present. Moreover, all streams are fed by groundwater and therefore, undercounting streamflow would leave the flow within the groundwater module of the VFM. The flow of Talmage Creek was measured via direct observation by the Gobler Lab in 2014 and the concentrations of phosphorus were measured as was the case for the creek entering the northeast extent of Hook Pond. The volume of precipitation that is captured in stream flow is not recharging groundwater, and thus was removed from the volume of ground water discharging into the Bays

Benthic flux

To determine benthic flux, sediment core samples were obtained from three locations in the lake: one at the north sampling station, one at the longitudinal center of the lake and one near the southern portion of the lake. Cores were extracted using a box corer dropped from the side of the boat which was then brought to 0.3 m below the water surface. An acid-washed clear polycarbonate tube (length = 26.6 cm, diameter = 9.3 cm) was then inserted through the top of the corer to collect a sediment sample. While the tube was still in the sediment, a plastic cap was placed on the bottom and then the top to capture the sediment sample and lake water immediately above the sediment. Cores were immediately placed in a cooler and transported back to the lab within one hour. A replicate and blank of the North End were also retrieved. Core samples were then incubated in similar light and temperature conditions to those measured at the lake bottom of each site. The samples were also aerated to achieve similar dissolved oxygen levels found in bottom waters of Georgica Pond using an aquarium air pump. Physical parameters were monitored using an Onset® temp/light monitor. Water samples were extracted using an acid-washed 60 ml syringe with 15 cm tubing attached to the end. Water was drawn up slowly from just above the sediment water interface and care was taken to not draw up sediment. Samples were placed in acid-washed 60 ml bottles and frozen. The incubation was allowed to run for 12 hours with a total of 5 samples obtained per core as a time course during the incubation. Samples were filtered on combusted GFF and analyzed for nutrient levels. As filtered lake water was not added to replace the volume extracted, a mass balance correction was applied using the equation $(C_0 - C_1) \times V_0 = \Delta m$ where C_0 is the starting concentration, C_1 is the ending concentration, V_0 is the starting volume and Δm is the mass change. This correction was applied to each time point in the series and the results were plotted against time. The resulting slope was used to determine the flux of nutrients out or into the sediment. Given that incubations were with mud and that sands generally do not provide benthic fluxes, flux rates were applied to only 75% of the bottom of the Lake, and the shoreline region which is at least 25% of the bay is sandy. In addition, it was assumed that benthic fluxes cease during winter (December through March) when cold temperatures restrict this process.

Atmospheric deposition

A regional literature value of 0.057 kgP/ha/yr was obtained from the Lombardo Associated Wastewater Plan for East Hampton Town (2013).

Nitrogen loading rates to Georgica Pond and Hook Pond

When considering N load, wastewater was the largest source of nitrogen to both Georgica Pond and Hook Pond which received 6,427 and 15,456 kg N per year from wastewater sources representing 50% and 62% of the total external nitrogen load to these systems, respectively (Table 3; Figures 12-15). The second largest external nitrogen source was fertilizer which was 30% and 32% of the total N load to Georgica Pond and Hook Pond with the large majority of that coming from residential lawns for Georgica Pond, whereas agriculture and golf courses were larger sources for Hook Pond (Table 3; Figures 12 - 15). Atmospheric deposition onto the land produced 19 and

5% of the external nitrogen load to the watersheds Georgica Pond and Hook Pond, respectively, while pets were ~1% (Table 3; Figures 12 - 15).

Table 3. Nitrogen loads from different sources to Georgica Pond and Hook Pond.

Total Nload (kg/yr)	Georgica Pond	Hook Pond	Georgica Pond Village Only	Hook Pond Village Only
Atmospheric	2,455	1,186	957	638
Waste Water	6,427	15,456	1,980	9,430
Fert - Residential Lawns	3,446	2,875	1,646	2,021
Fert - Agriculture	388	3,584	111	141
Fert - Parks and Golf	2	1,407	0	1,229
Pets	128	306	43	204

When considering loads from the Village only, the results were similar with some notable differences. Wastewater was still the largest source of nitrogen to both Georgica Pond and Hook Pond which received 1,980 and 9,430 kg N per year from wastewater sources representing 42% and 69% of the total external nitrogen load to these systems (Table 3; Figures 16-19). The second largest external nitrogen source was fertilizer at 38% and 36% of the total N load to Georgica Pond and Hook Pond, respectively, with the large majority of that coming from residential sources but golf courses being a larger source for Hook Pond (Table 2; Figures 16-19). Atmospheric deposition onto the land produced between 20 and 5% of the external nitrogen load to the watersheds Georgica Pond and Hook Pond, respectively, while pets were again ~1% (Figures 16-19).

Phosphorus loading rates to Georgica Pond and Hook Pond

The largest source of phosphorus to Georgica Pond and Hook Pond differed from each other. While the largest source of phosphorus to Georgica Pond was sediment, contributing more than 500 kilograms of phosphorus per year (76% of the total load), the largest contributor to Hook Pond was groundwater contributing 83 kilograms per year (51% of the total load; Table 4; Figure 18-21). Still, the second largest source to each system was groundwater for Georgica Pond (150 kilograms per year; 22%) and was benthic fluxes for Hook Pond (71 kilograms per year; 44%; Table 4; Figures 20-23). Runoff, streams, and atmospheric deposition all contributed small amounts of phosphorus to each system (<4%; Table 4 Figures 20-23). When the Village load only was considered, the importance of benthic fluxes was exacerbated since there was no clear way to divide up the bottom water / sediments of each system. As such, the benthic fluxes were unchanged while the groundwater contributions declined in proportion to the size of the watersheds that were within the Village boundaries making benthic fluxes the largest source of phosphorus to Georgica Pond and Hook Pond being 93% and 58%, respectively (Table 4; Figures 24-27). Sediments were far more important of a phosphorus source to Georgica Pond, partly because this system has a much larger waterbody-to-watershed ratio compared to the smaller Hook Pond which also is more strongly influenced by groundwater associated with the higher density of homes in this watershed compared to Georgica Pond.

Table 4. Phosphorus loads to Georgica Pond and Hook Pond for the entire waterbody and the Village boundaries only.

Georgica Pond	**kgP/yr**	**% Contribution**
Groundwater	149.64	21.93%
Runoff	5.86	0.86%
Streams	1.67	0.24%
Atmospheric deposition	7.61	1.12%
Benthic flux	517.73	75.86%
TOTAL	**682.51**	**100%**

Hook Pond	**kgP/yr**	**% Contribution**
Groundwater	82.98	51.03%
Runoff	6.51	4.00%
Streams	1.05	0.65%
Atmospheric deposition	1.04	0.64%
Benthic flux	71.02	43.68%
TOTAL	**162.60**	**100%**

Georgica Pond, Village	**kgP/yr**	**% Contribution**
Groundwater	28.08	5.21%
Runoff	1.10	0.20%
Streams	0.61	0.11%
Atmospheric deposition	7.38	1.37%
Benthic flux	501.92	93.10%
TOTAL	**539.09**	**100%**

Hook Pond, Village	**kgP/yr**	**% Contribution**
Groundwater	46.00	37.65%
Runoff	3.61	2.95%
Streams	0.50	0.41%
Atmospheric deposition	1.04	0.85%
Benthic flux	71.02	58.13%
TOTAL	**122.18**	**100%**

Figure 10. Watersheds delineated for Georgica Pond and Hook Pond as per 2022 USGS maps with each building depicted and color coded based on densities. Groundwater between and within the regions of each watershed either discharges to the Atlantic Ocean or is used for public supply wells.

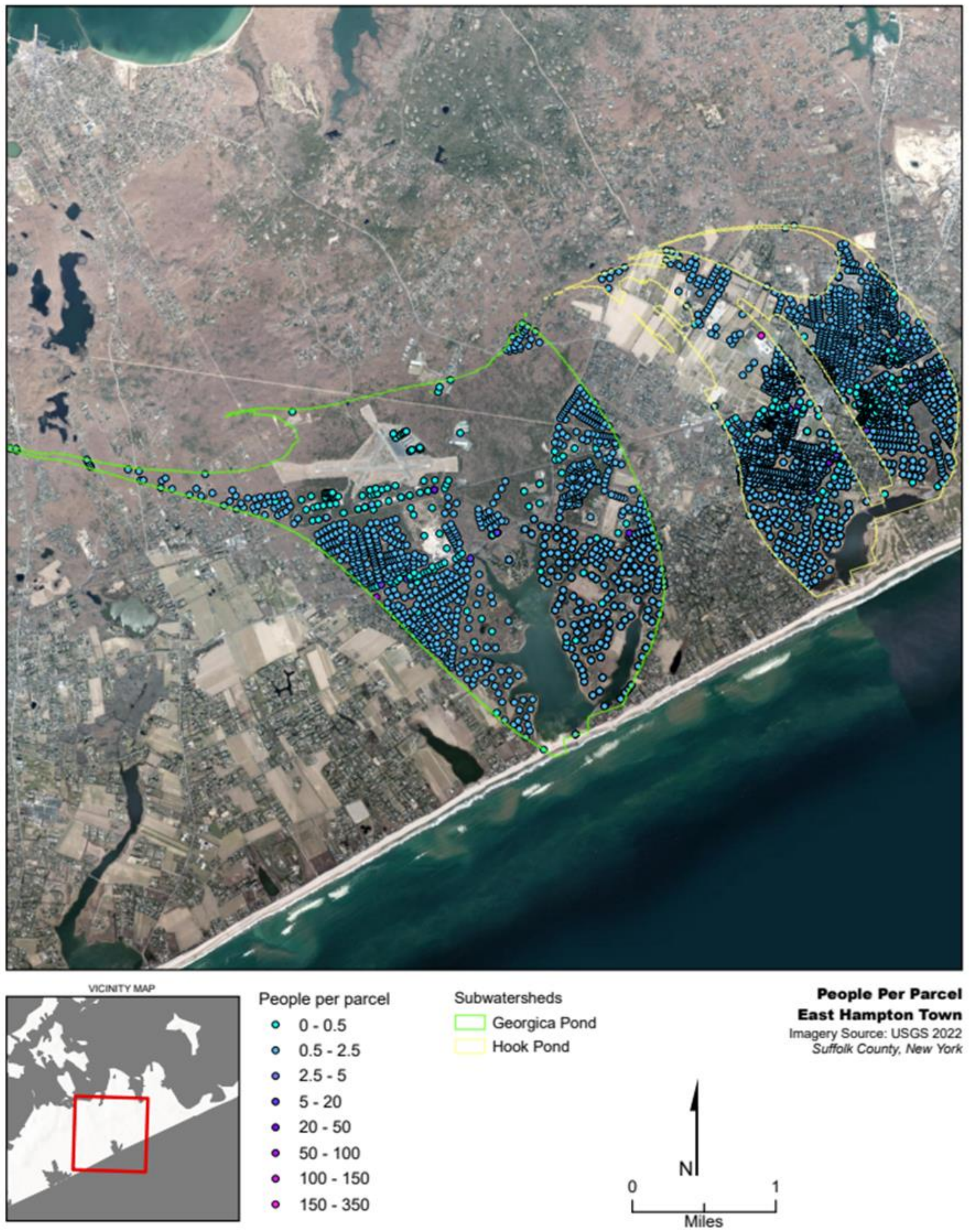


Figure 11. Watersheds delineated for Georgica Pond and Hook Pond population densities color coded. Groundwater between and within the regions of each watershed either discharges to the Atlantic Ocean or is used for public supply wells.

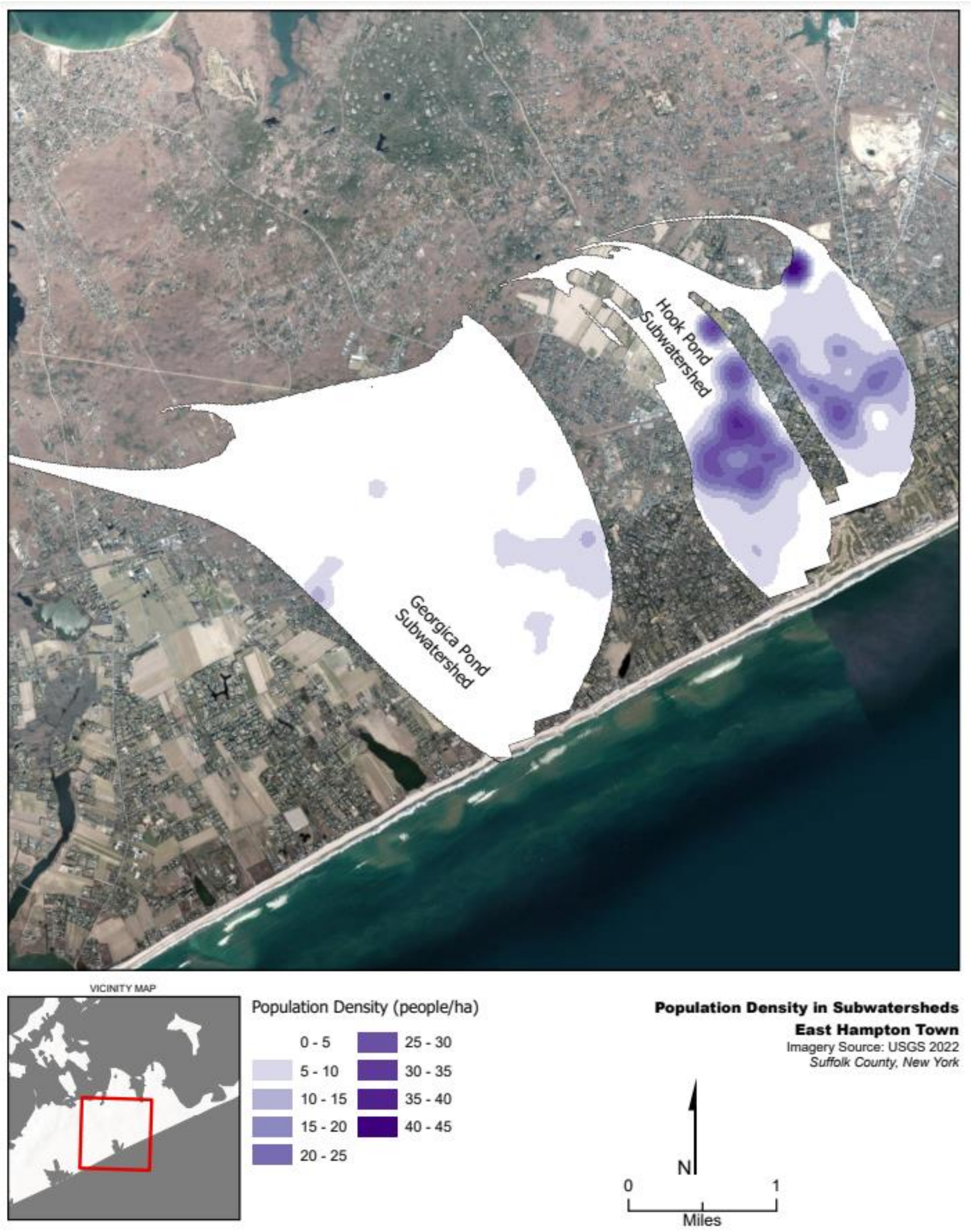


Figure 12. Nitrogen loading from different sources to Georgica Pond expressed as percentages.

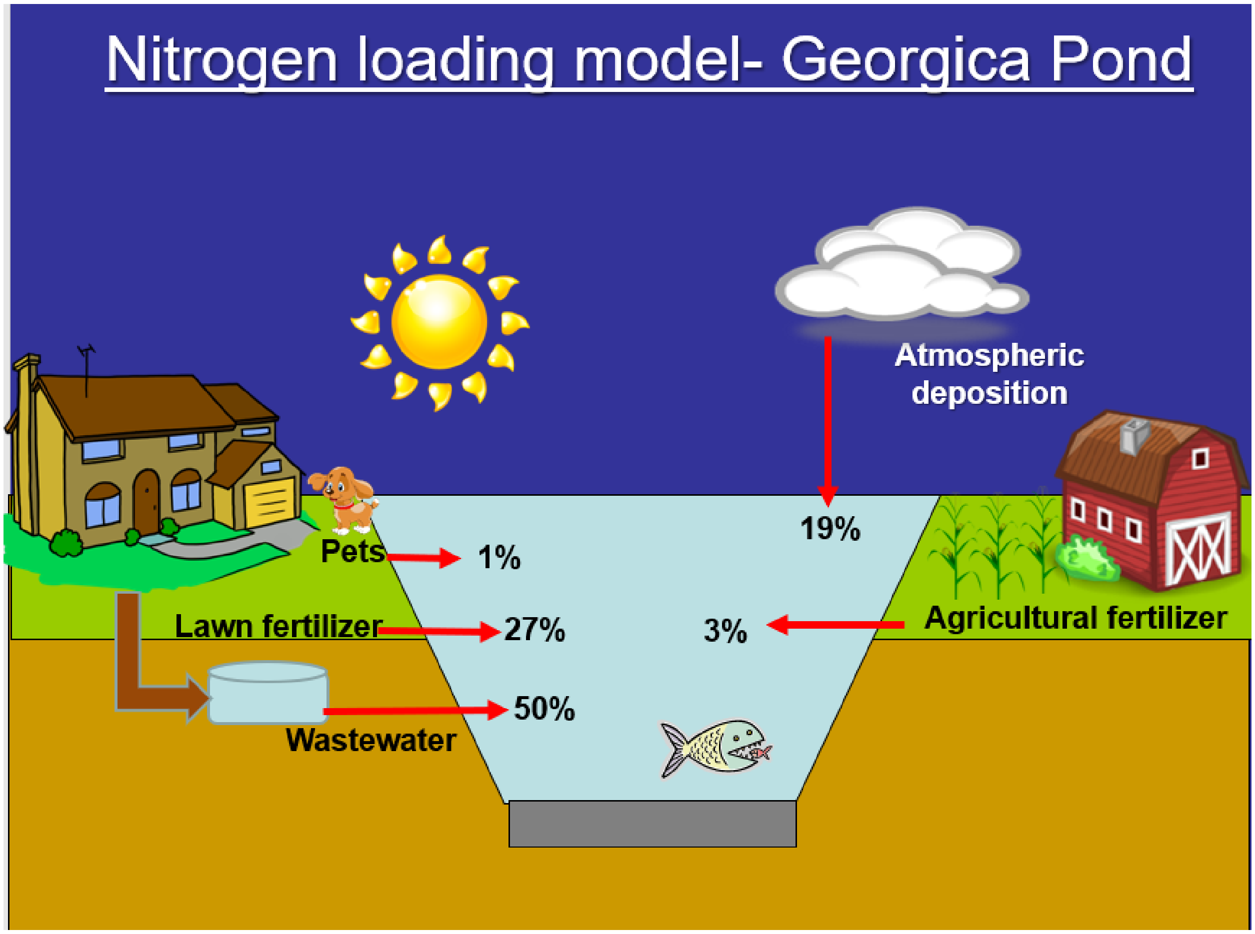


Figure 13. Nitrogen loading from different sources to Georgica Pond expressed as percentage in a pie chart.

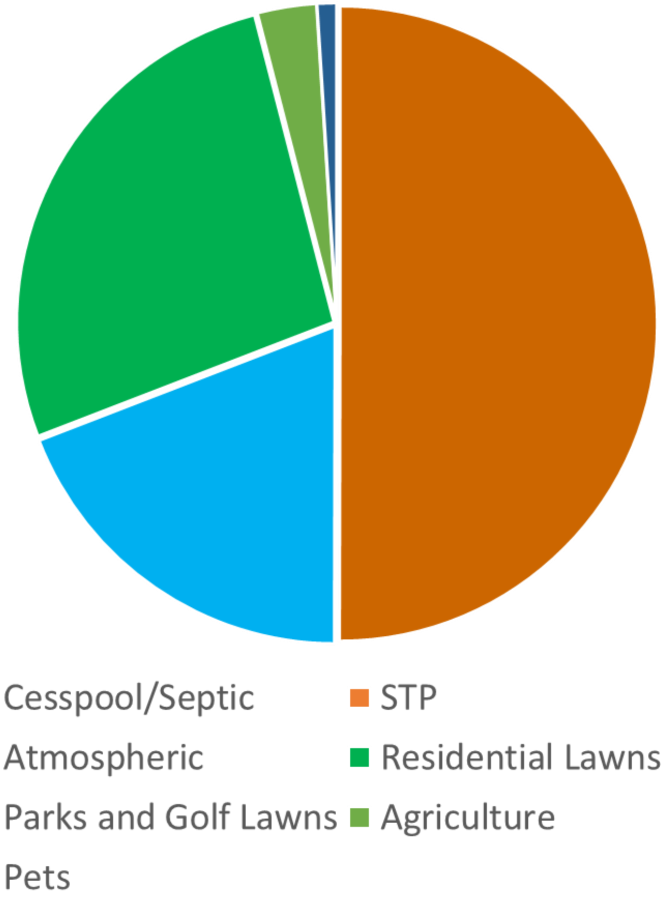


Figure 14. Nitrogen loading from different sources to Hook Pond expressed as percentages.

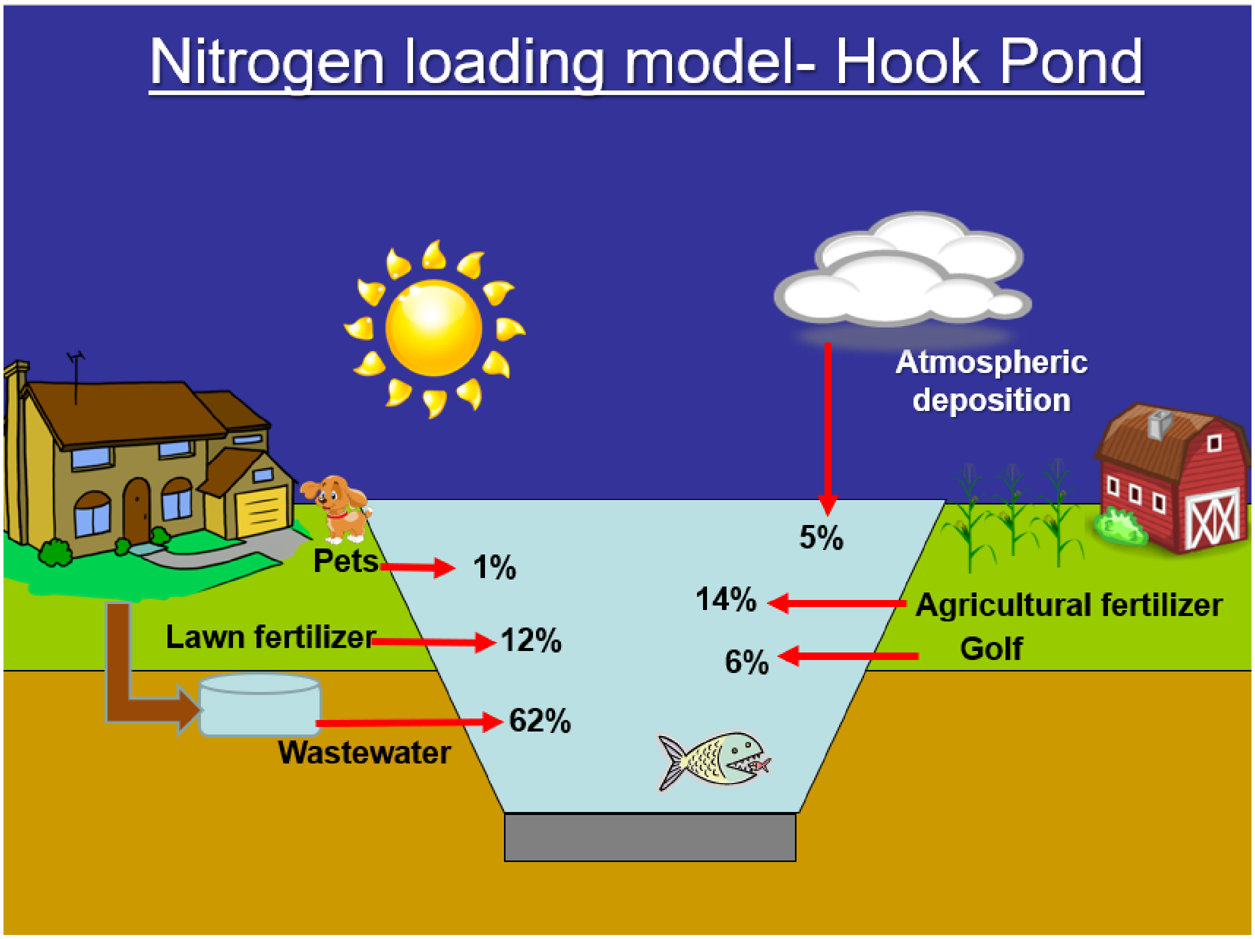


Figure 15. Nitrogen loading from different sources to Hook Pond expressed as percentages in a pie chart.

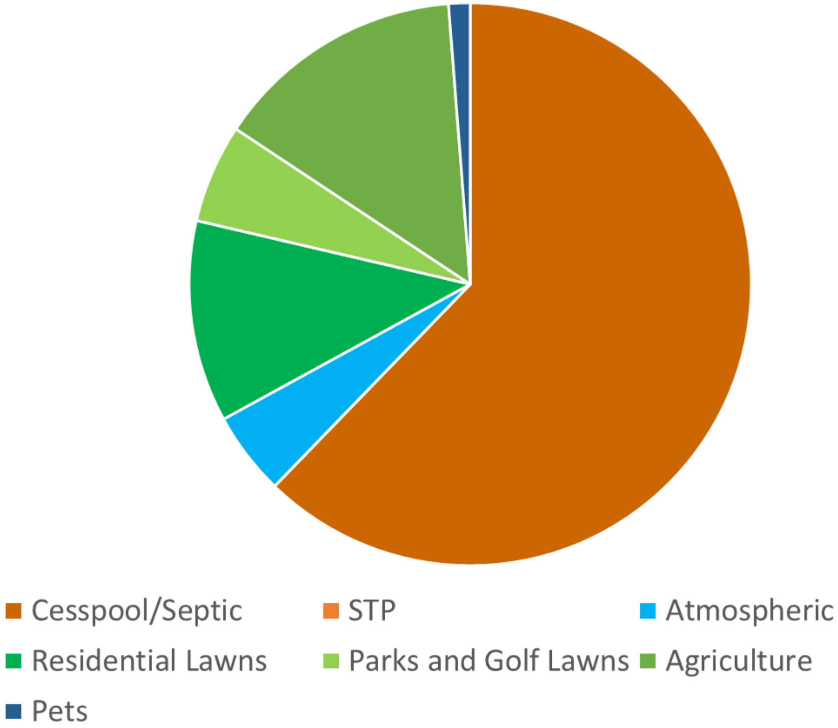
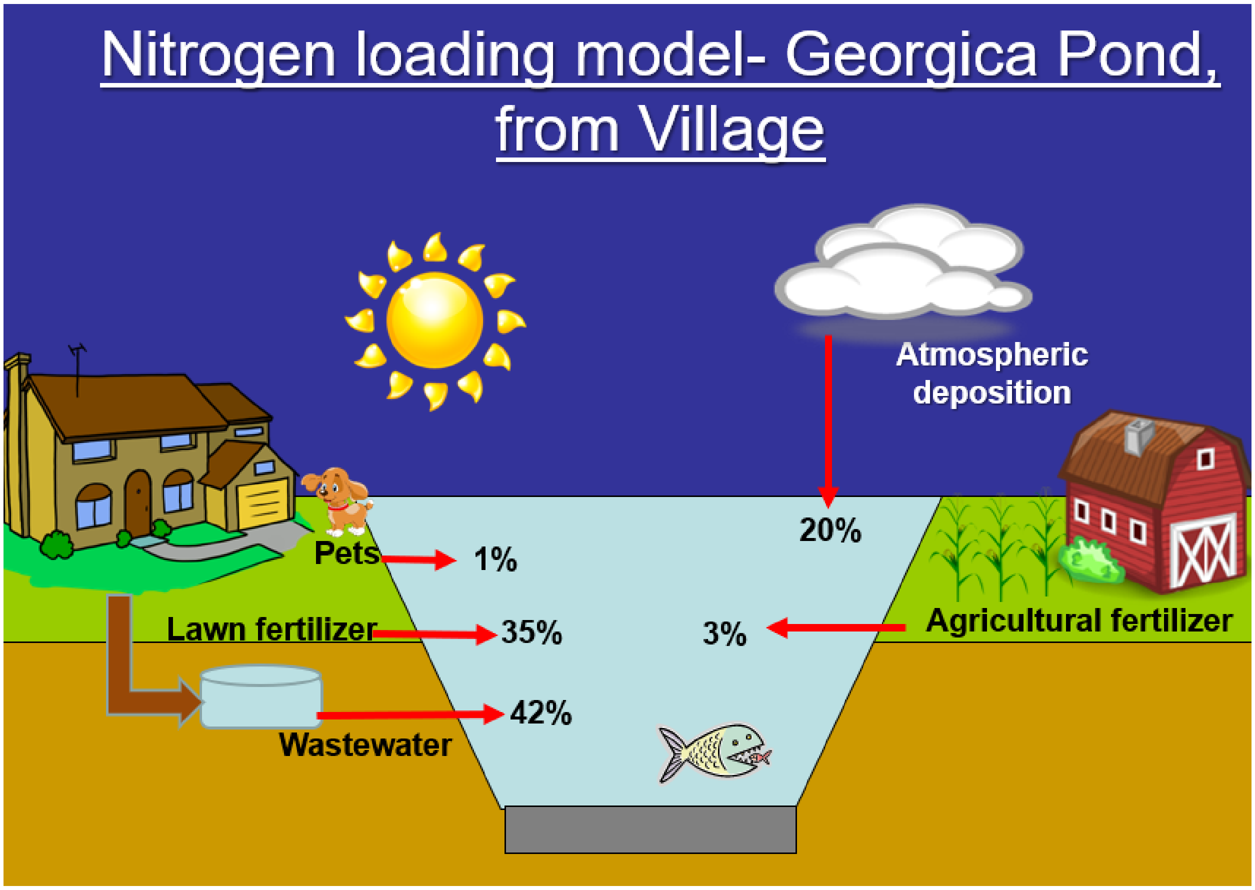


Figure 16. Nitrogen loading from different sources from East Hampton Village to Georgica Pond expressed as percentages.



Nitrogen loading model- Georgica Pond, from Village

Figure 17. Nitrogen loading from different sources from East Hampton Village to Georgica Pond expressed as percentages in a pie chart.

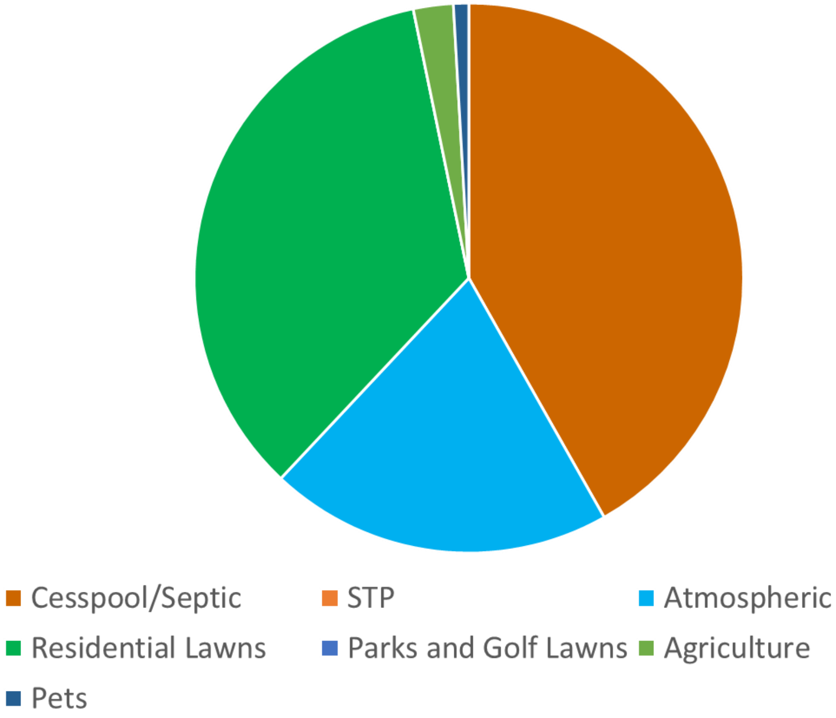


Figure 18. Nitrogen loading from different sources from East Hampton Village to Hook Pond expressed as percentages.

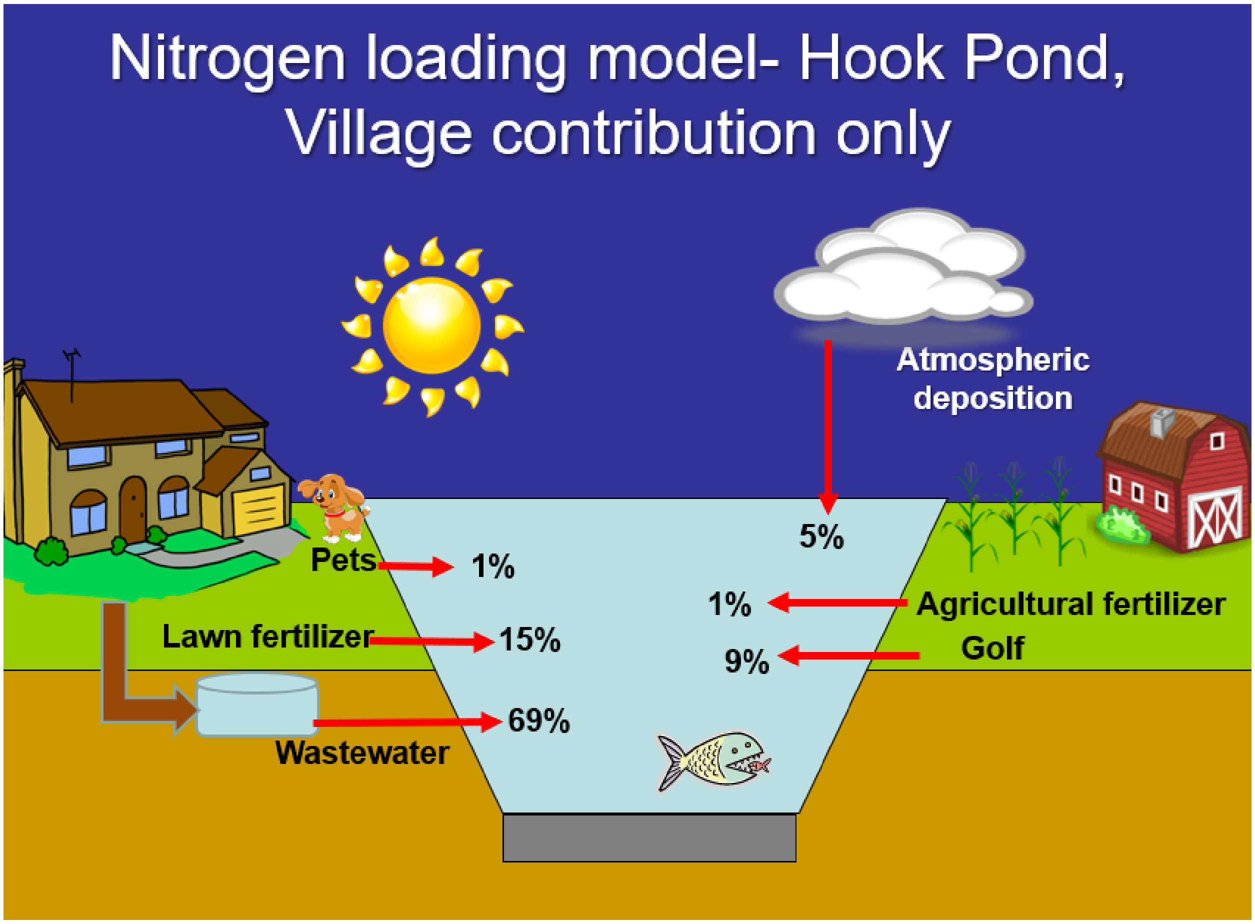


Figure 19. Nitrogen loading from different sources from East Hampton Village to Hook Pond expressed as percentages as a pie chart.

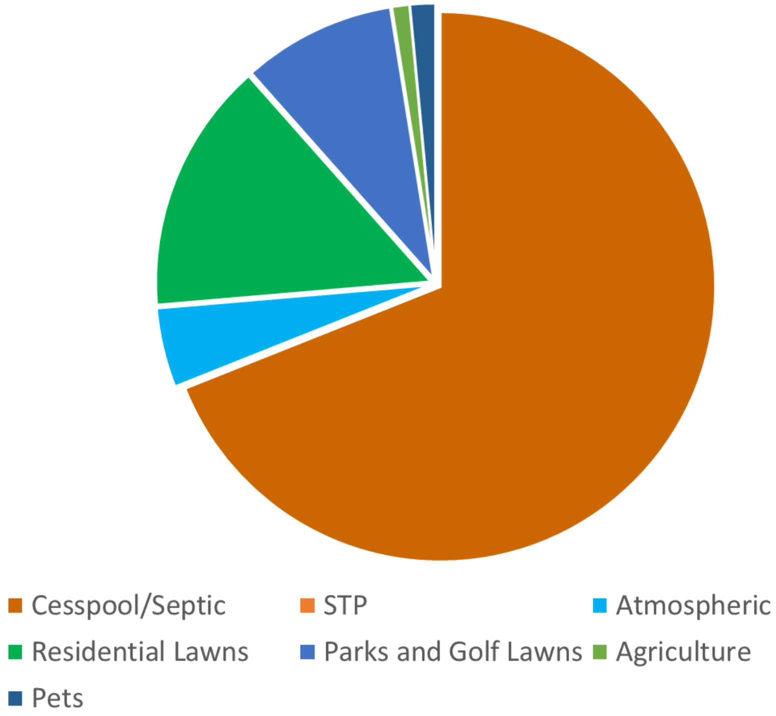


Figure 20. Phosphorus loading from different sources to Georgica Pond expressed as percentages.

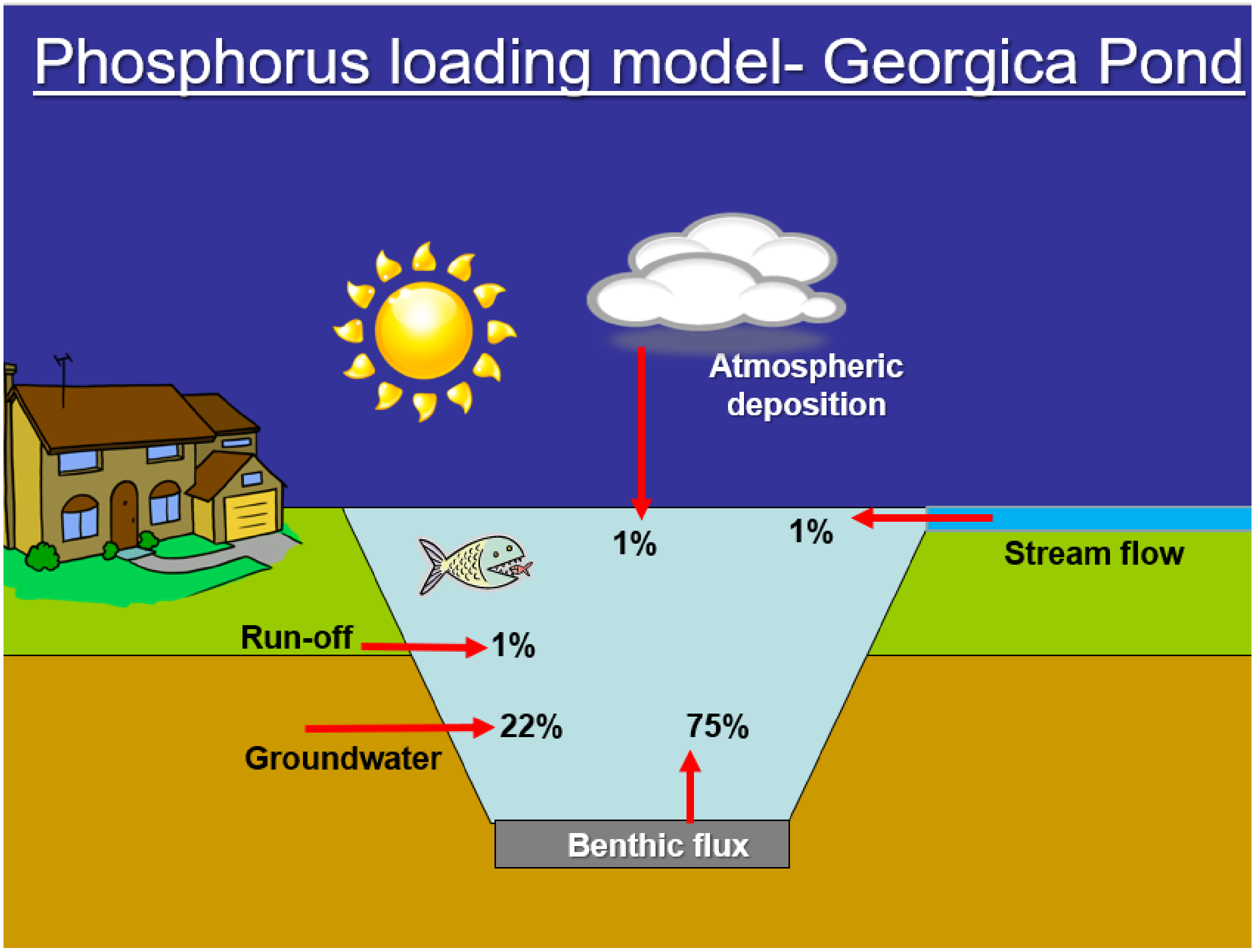


Figure 21. Phosphorus loading from different sources to Georgica Pond expressed as percentage in a pie chart.

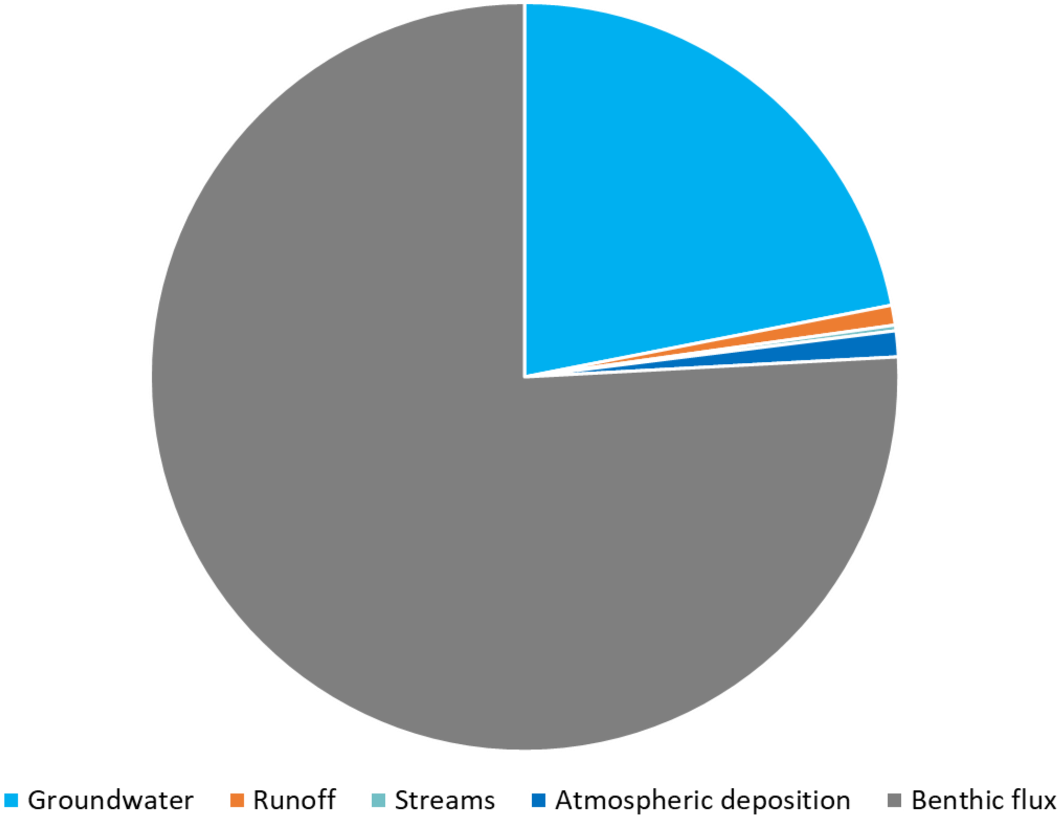


Figure 22. Phosphorus loading from different sources to Hook Pond expressed as percentages.

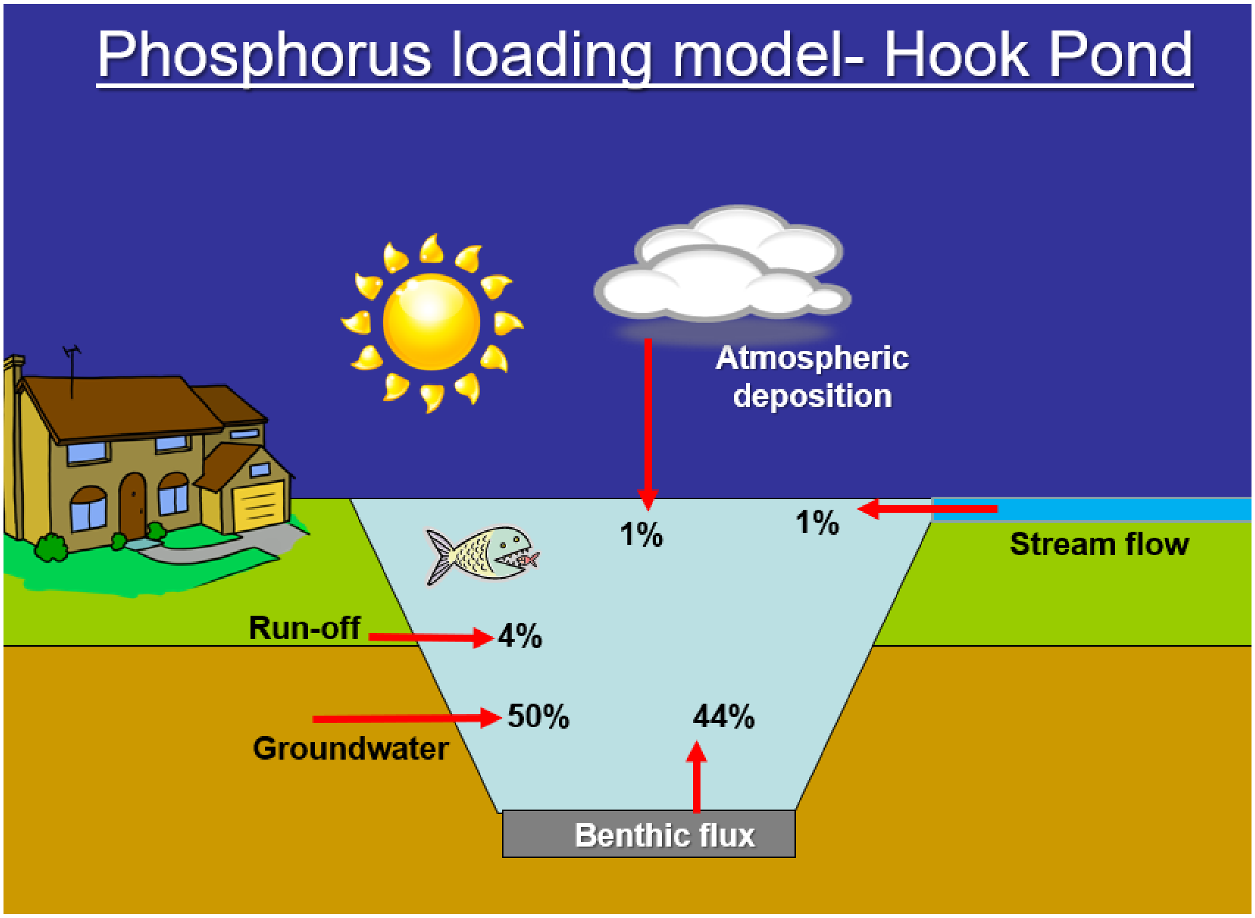


Figure 23. Phosphorus loading from different sources to Hook Pond expressed as percentages in a pie chart.

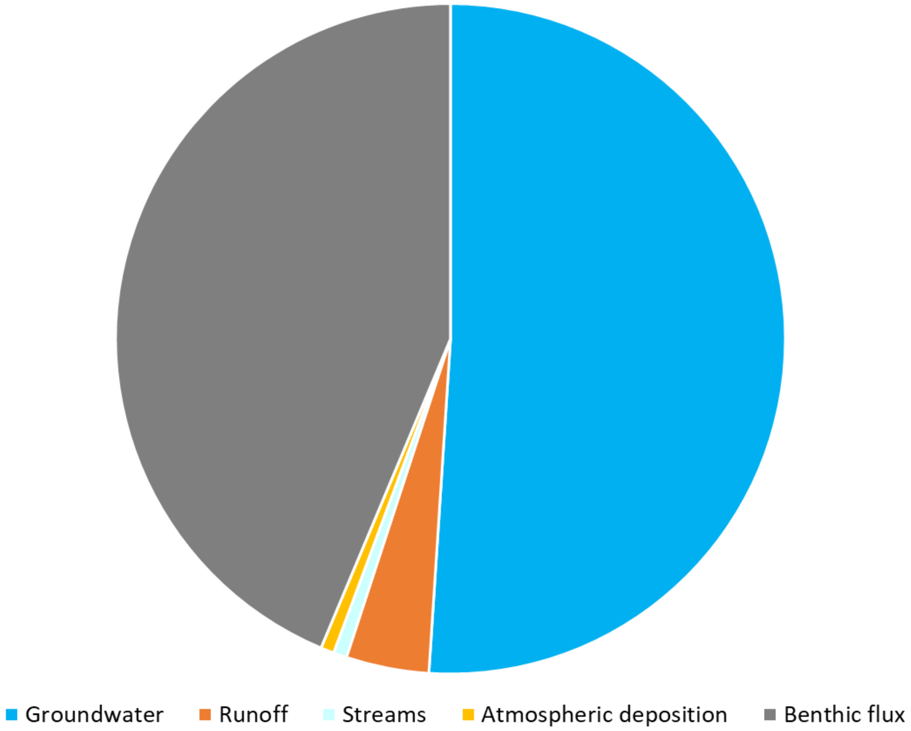


Figure 24. Phosphorus loading from different sources from East Hampton Village to Georgica Pond expressed as percentages.

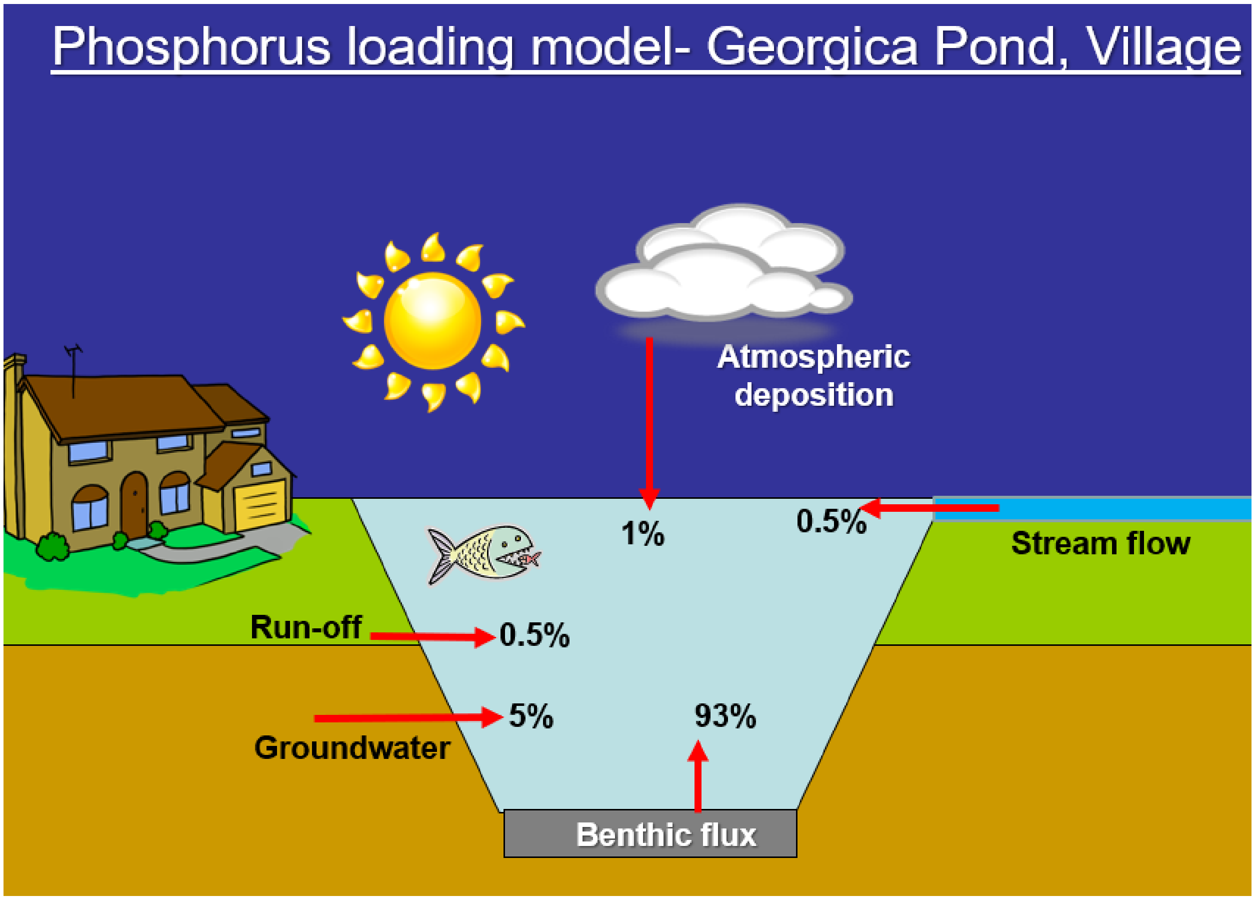


Figure 25. Phosphorus loading from different sources from East Hampton Village to Georgica Pond expressed as percentages in a pie chart.

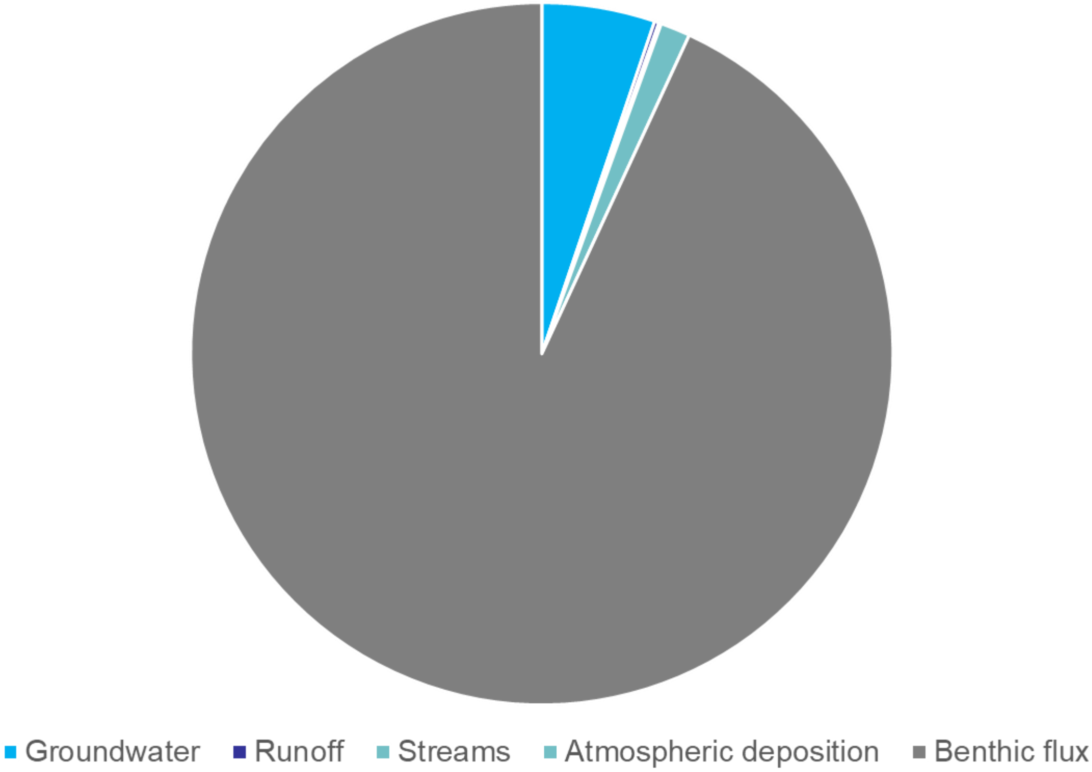


Figure 26. Phosphorus loading from different sources from East Hampton Village to Hook Pond expressed as percentages.

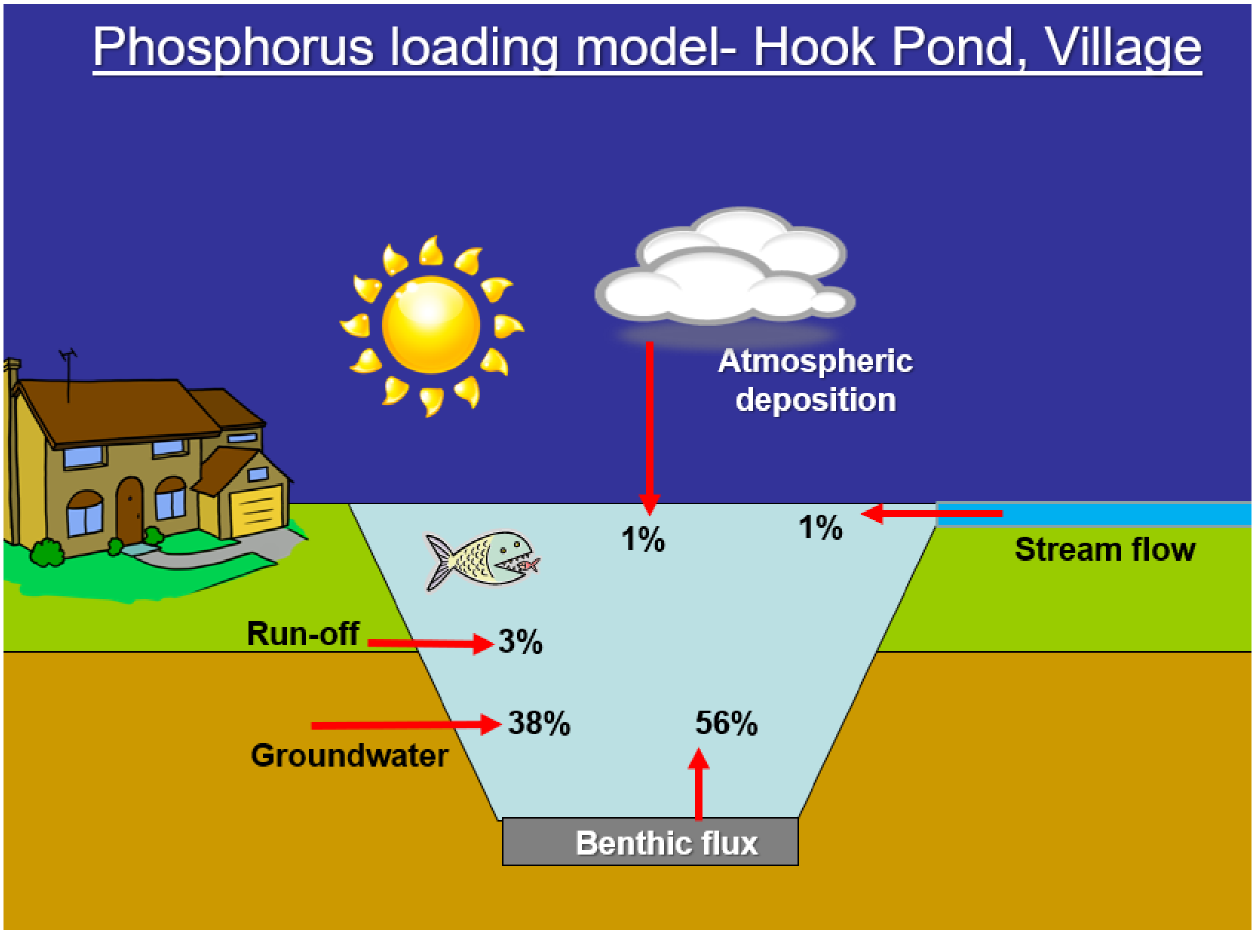
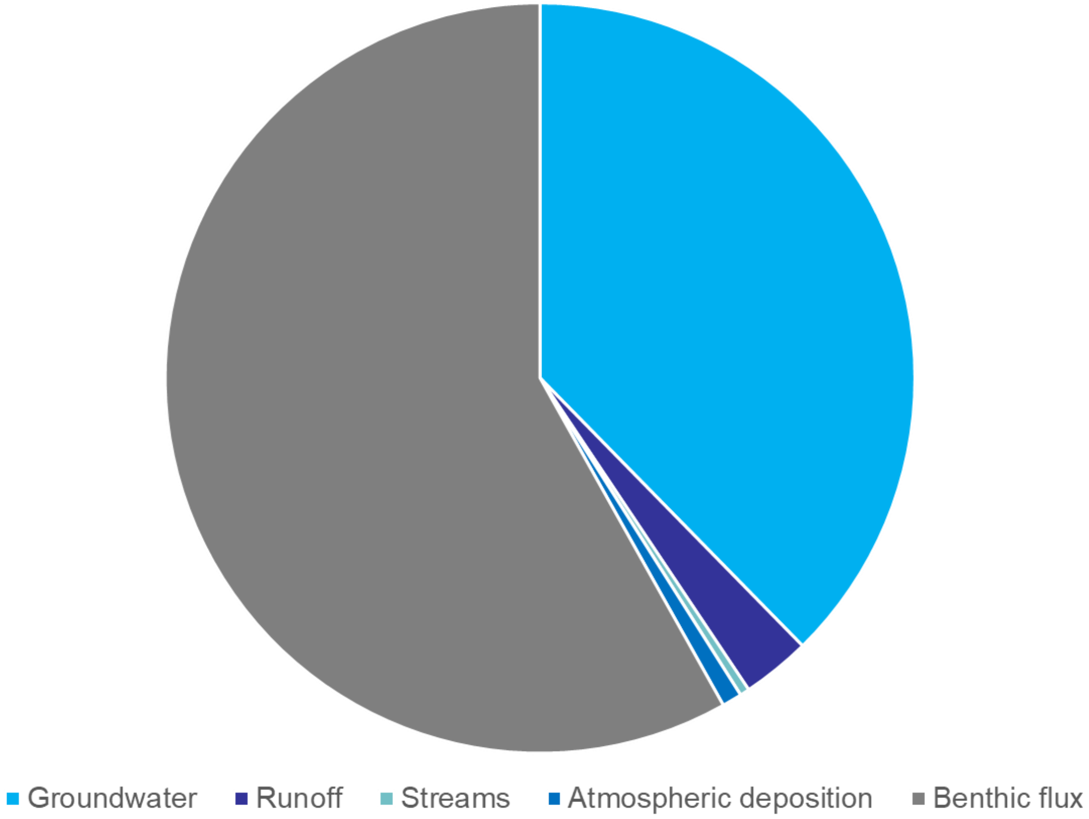


Figure 27. Phosphorus loading from different sources from East Hampton Village to Hook Pond expressed as percentages as a pie chart.



TASK 3. USE THE DYNAMIC MODEL QUANTIFY HOW CONNECTING DIFFERENT REGIONS OF THE VILLAGE OF EAST HAMPTON WILL ALTER NITROGEN LOADING RATES TO HOOK POND

For task 3, the nitrogen loading model developed for the Village of East Hampton was run again to consider five distinct scenarios of sewering and wastewater remediation. Sewering ***scenario one*** through four involve connecting individual commercial and residential parcels to a new sewage treatment plant with sewer lines running along Main Street from David's Lane through Pantigo Road up to Egypt Lane, Newtown Road from Main Street to the LIRR tracks, all of Railroad Ave, King Street from Railroad Ave to Gingerbread Road, Gingerbread Road to Toilsome Lane, between Railroad Ave and Gingerbread Lane from Toilsome Lane to Lumber Lane excluding the YMCA (Figure 28). ***Scenario two*** was a small cluster of buildings on North Main Street between Talmage Lane and Cedar Lane (Figure 28). The additional scenarios included were the connecting the middle School and elementary School (***scenario three***), connecting the high school (***scenario four***), and converting all remaining parcels to innovative and alternative, low nitrogen septic systems (***scenario five***) which is addressed in the next task.

All of the sewering scenarios (scenarios one through four) are solely within the Hook Pond watershed and therefore, would not remove nitrogen from the Georgica Pond watershed. Completion of the proposed scenario one sewering of Main Street would divert more than 1,000 kilograms of nitrogen away from Hook Pond annually, reducing the total nitrogen load to Hook Pond by 4% and the total amount from the Village by 8% (Figure 29; Table 5). Adding the small parcel on North Main Street (scenario 2) adds only a small reduction in nitrogen load to Hook Pond, about 18 kilograms per year or 0.1% of the total load (Figure 29; Table 5). Connecting the Elementary School, Middle School (scenario 3), and High School (scenario 4) would collectively divert more than 1,600 kilograms of nitrogen away from Hook Pond annually (Figure 29; Table 5), although the high school load is just outside of the Village boundaries. The connecting the Elementary School and Middle School would reduce the total load and Village only load of nitrogen to Hook Pond by 3 and 6%, respectively (Figure (Figure 19; Table 5). Connecting the High School would reduce the total load of nitrogen to Hook Pond by 3% (Figure 29; Table 5).

Figure 28. Sewer regions considered for this project, scenarios 1 – 4.

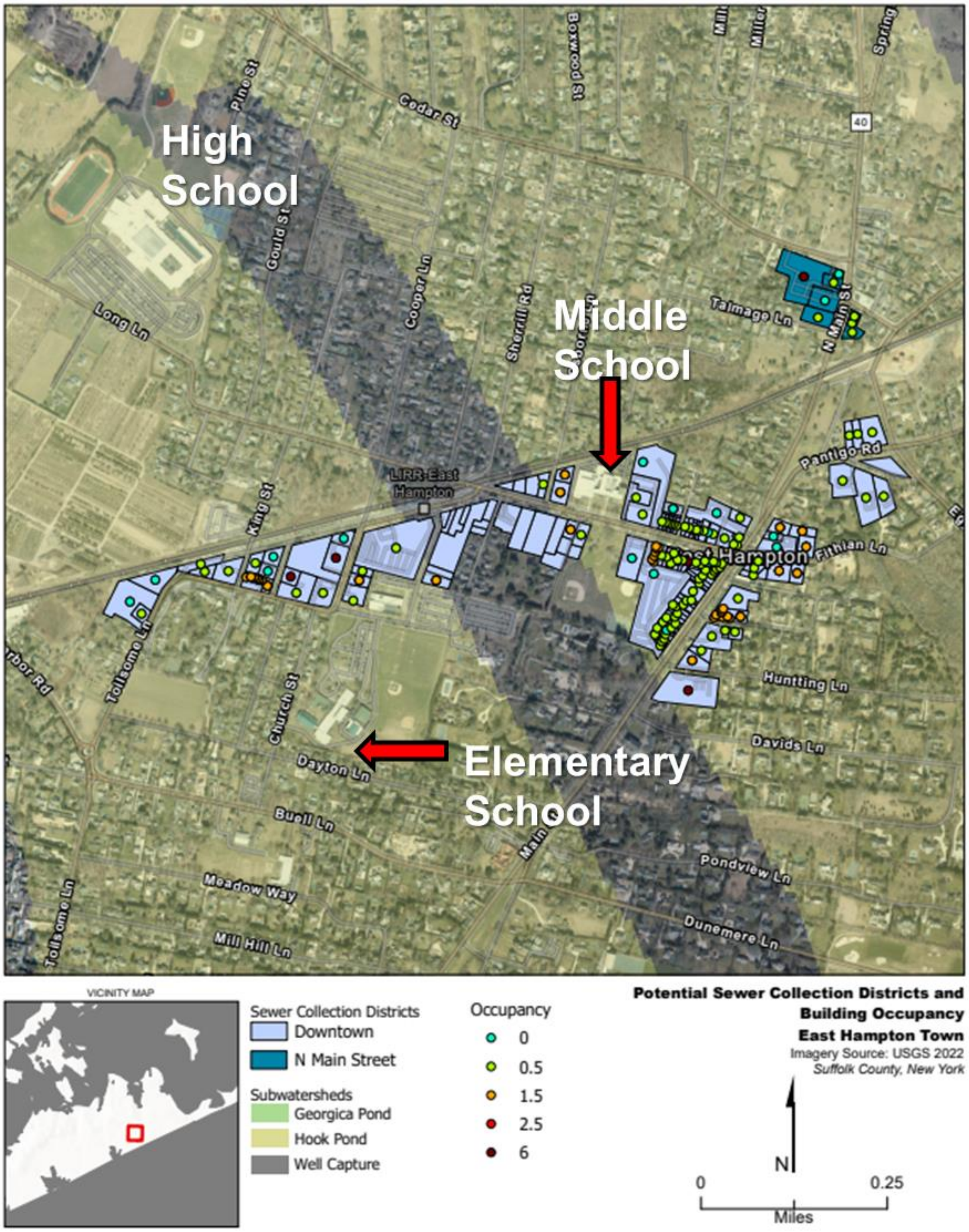


Table 5. Mass of nitrogen (kg) and percent of total nitrogen load mitigated by each sewering and/or septic mitigation scenario

Kilograms N removed

Scenarios	Region	Georgica Pond	Hook Pond	Georgica Pond, Village	Hook Pond, Village
Scenario 1	Down Town	0	1088	0	1088
Scenario 2	North Main St	0	20	0	20
Scenario 3	Middle School	0	806	0	806
Scenario 4	HS	0	845	0	0
Scenario 1-4	All sewering	0	2759	0	1894

Percent N load mitigated

Scenarios	Region	Georgica Pond	Hook Pond	Georgica Pond, Village	Hook Pond, Village
Scenario 1	Down Town	0	4	0	8
Scenario 2	North Main St	0	0	0	0
Scenario 3	Middle School	0	3	0	6
Scenario 4	HS	0	3	0	0
Scenario 1-4	All sewering	0	11	0	14

The benefits of sewering the Village for phosphorus reduction are smaller for several reasons. Firstly, a significant portion of phosphorus from wastewater is retained in the aquifer as it flows through groundwater (Wehrmann et al., 2020). Second, while groundwater is the second largest and largest contributors of phosphorus to Georgica Pond and Hook Pond, respectively, wastewater contributes only a fraction of the total groundwater phosphorus, likely around 40% with the balance coming from fertilizer, the atmosphere, and naturogenic sources. It is estimated that sewering the Downtown region (Scenario 1), the Middle School/Elementary School (Scenario 3), and the High School (Scenario 4) would prevent 2.37, 1.77, and 1.83 kilograms of phosphorus from entering Hook Pond annually with all four scenarios giving a 4% reduction in phosphorus load to Hook Pond (Table 6). These values decrease when considering the Village boundary only which increases the importance of sediments, with each scenario removing about 1 kilogram of phosphorus discharge to the Pond annually and for a 3% reduction in phosphorus loading to Hook Pond (Table 6).

Table 6. Mass and percent phosphorus reduction to Georgica Pond and Hook Pond by each of the individual sewering scenarios and the sum of scenarios.

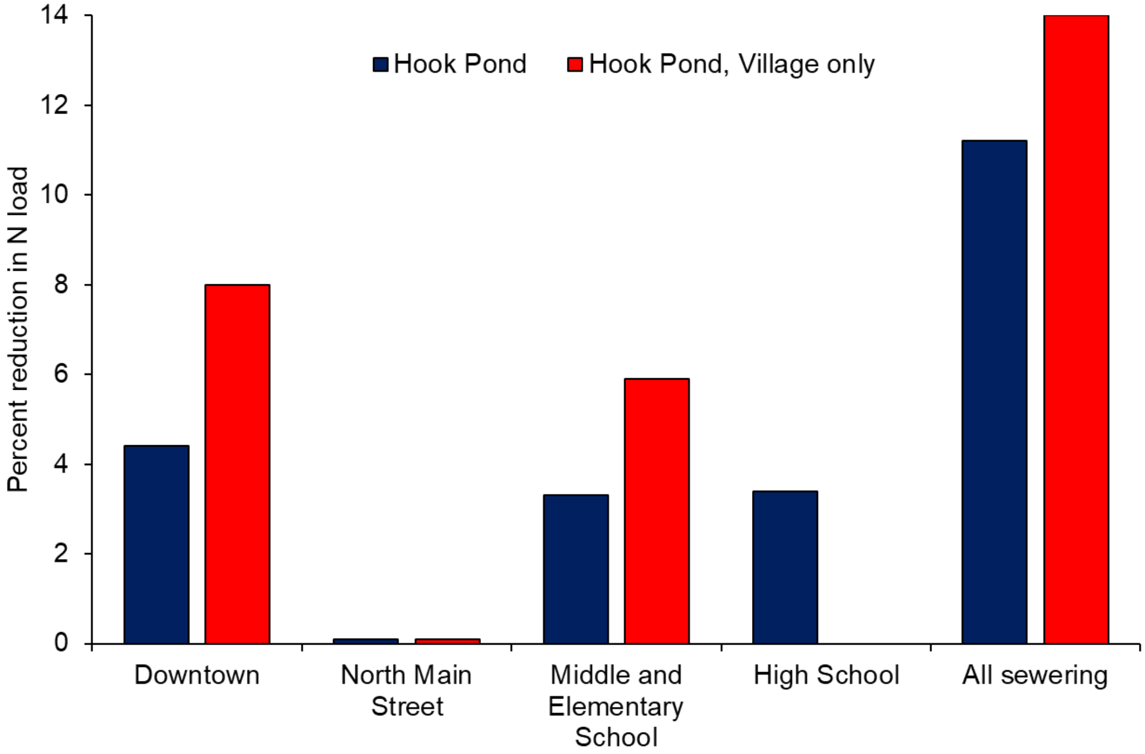
Kilograms P removed

Scenarios	Region	Georgica Pond	Hook Pond	Georgica Pond	Hook Pond, Village
Scenario 1	Downtown	0	2.4	0	1.3
Scenario 2	North Main St	0	0.1	0	0.0
Scenario 3	Middle School	0	1.8	0	1.0
Scenario 4	HS	0	1.8	0	1.0
Scenario 1-	All sewering	0	6.1	0.0	3.4

Percent P load mitigated

Scenarios	Region	Georgica Pond	Hook Pond	Georgica Pond	Hook Pond, Village
Scenario 1	Down Town	0	1.45	0	1.08
Scenario 2	North Main St	0	0.06	0	0.01
Scenario 3	Middle School	0	1.09	0	0.83
Scenario 4	HS	0	1.12	0	0.83
Scenario 1-	All sewering	0	3.72	0	2.75

Figure 29. Percent nitrogen load reductions to Hook Pond achieved by each of the sewer regions considered for this project under scenarios 1 – 4.



TASK 4. USE THE DYNAMIC MODEL QUANTIFY HOW CONNECTING DIFFERENT REGIONS OF THE VILLAGE OF EAST HAMPTON TO INNOVATIVE AND ALTERNATIVE SEPTIC SYSTEMS WILL ALTER NITROGEN LOADING RATES.

The final phase of the wastewater management plan for the Village of East Hampton is seeking to convert all homes in the Village to innovative and alternative, low nitrogen septic systems. The passage of Article 19 of Suffolk County's Health Code, implemented the means for Suffolk County to allow for innovative and alternative, denitrifying on-site septic system that reduce nitrogen effluent levels to at least 19 mg of nitrogen per liter. Some but not of the systems now allowable can reduce nitrogen in effluent to ~10 mg of nitrogen per liter. For the purposes of this study, we used an 80% reduction in total N by such systems, which is consistent with many such systems.

Due to the outsized role what wastewater plays in the nitrogen loading to Georgica Pond and Hook Pond (50% and 62%, respectively), upgrading all septic systems in the Village would have a large effect on the total nitrogen load to these waterbodies. Specifically, this approach would remove more than 5,000 kg of annual nitrogen load to Georgica Pond and nearly 10,000 kg of annual nitrogen load to Hook Pond, resulting in a 40% reduction for both systems (Figure 30). When considering the only the nitrogen emanating from the Village, this approach would remove more than 1,500 kg of annual nitrogen load to Georgica Pond and more than 6,000 kg of annual nitrogen load to Hook Pond, resulting in a 33% and 41% reduction, respectively. These approaches will also reduce the flux of phosphorus to these systems (Figure 30). If sewering was combined with septic upgrades, nitrogen loads to Georgica and Hook Ponds would decrease by 40% and 50% and by 33% and 55% if the loads from the Village only were considered (Figure 31).

An important consideration with regard to phase of this project is the precise types of alternative on-site systems that are installed. Article 19 of Suffolk County's Health Code now requires that alternative, denitrifying on-site septic system reduce nitrogen effluent levels to at least 19 mg of nitrogen per liter and this was the level used in the present study to estimate load reductions associated with phase 5 of this project. Importantly, however, some systems reduce nitrogen levels below this threshold. For example, in testing by Suffolk County the Hydro-Action and Fuji Clean systems achieve, on average, 11 mg of nitrogen per liter effluent. In addition, the New York State Center for Clean Water Technology at Stony Brook University has created a new design of septic system called Nitrogen Reducing Biofilters that, in pilot phase testing in Suffolk County has regularly achieved 10-15 mg of nitrogen per liter effluent (Gobler et al, 2021). In addition, New York State Center for Clean Water Technology has also developed nitrogen polishing units including woodchip boxes and denitrifying drainfields, that can reduce nitrate levels in final septic effluent to < 2 milligrams of nitrogen per liter. Hence, the phase 5 estimates used in this study were conservative. It is feasible that the amount of nitrogen reduction achieved in the Village of East Hampton by phase 5 could be larger if the optimal technology (i.e. best innovative and alternative, low nitrogen septic systems with nitrogen polishing units) are employed.

As was the case for sewering, the quantitative reduction in phosphorus loads to water bodies for upgrading septic septic systems across the Village is smaller than for nitrogen since, unlike nitrogen, a significant portion of phosphorus from wastewater is retained in the aquifer as it flows through groundwater (Wehrmann et al., 2020). Still, it is estimated that upgrading the Village to innovative and alternative septic systems will reduce phosphorus loads to Georgica Pond and Hook Pond by 8% and 15%, respectively (Table 7). The New York State Center for Clean Water Technology is developing phosphorus removal modules for low nitrogen septic systems. It is anticipated that these total percent removals would increase by 3 – 5% more with the addition of such technologies. If both sewering and septic upgrades were implemented, the total phosphorus loads to Georgica Pond and Hook Pond would decline by 8% and 19%, respectively, (Table 7).

Table 7. Mass and percent phosphorus reduction to Georgica Pond and Hook Pond by upgrading septics and septics combined with sewering.

Kilograms nitrogen removed by action	Georgica Pond	Hook Pond	Georgica Pond, Village	Hook Pond, Village
Upgrade septics	54.37	24.18	10.33	13.39
Upgrade septics and all sewer scenarios	54.37	30.25	10.33	16.74

Kilograms nitrogen removed by action	Georgica Pond	Hook Pond	Georgica Pond, Village	Hook Pond, Village
Upgrade septics	7.97	14.93	1.92	10.98
Upgrade septics and all sewer scenarios	7.97	18.67	1.92	13.72

Figure 30. Percent nitrogen reduction to Georgica Pond and Hook Pond by upgrading conventional septic systems in the Village outside of the sewer district to innovative and alternative systems that reduce nitrogen.

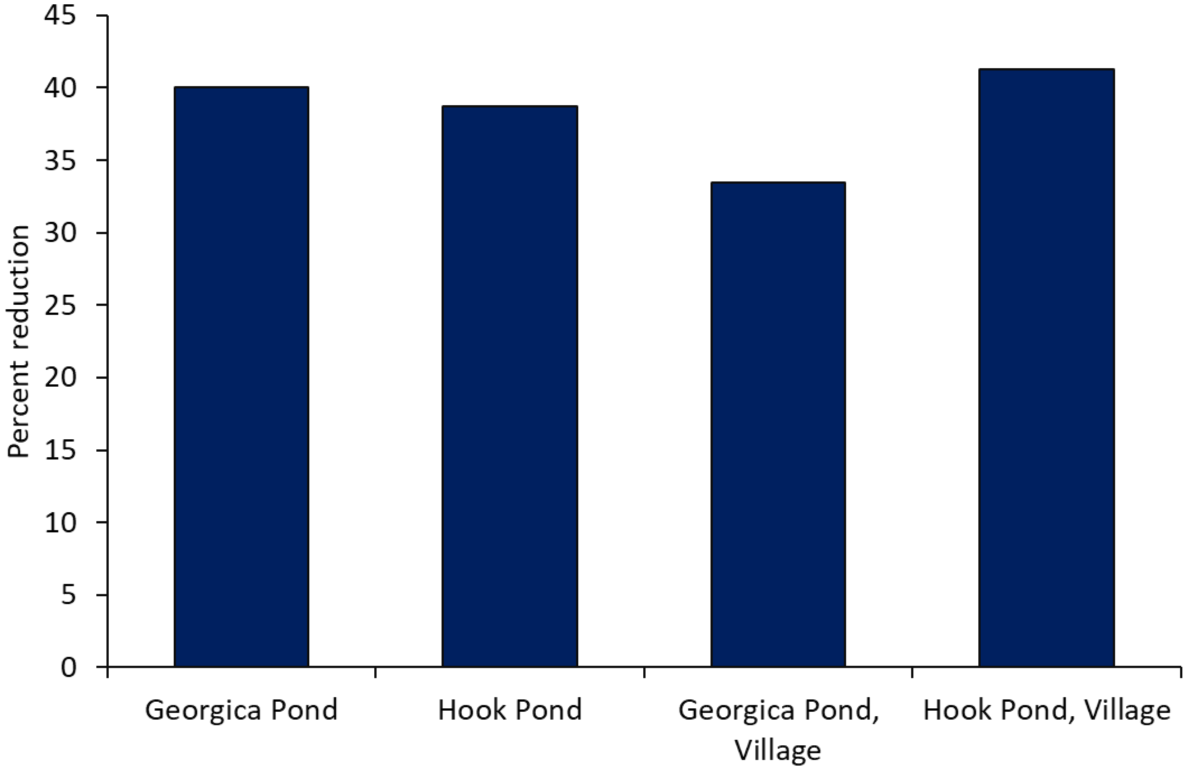
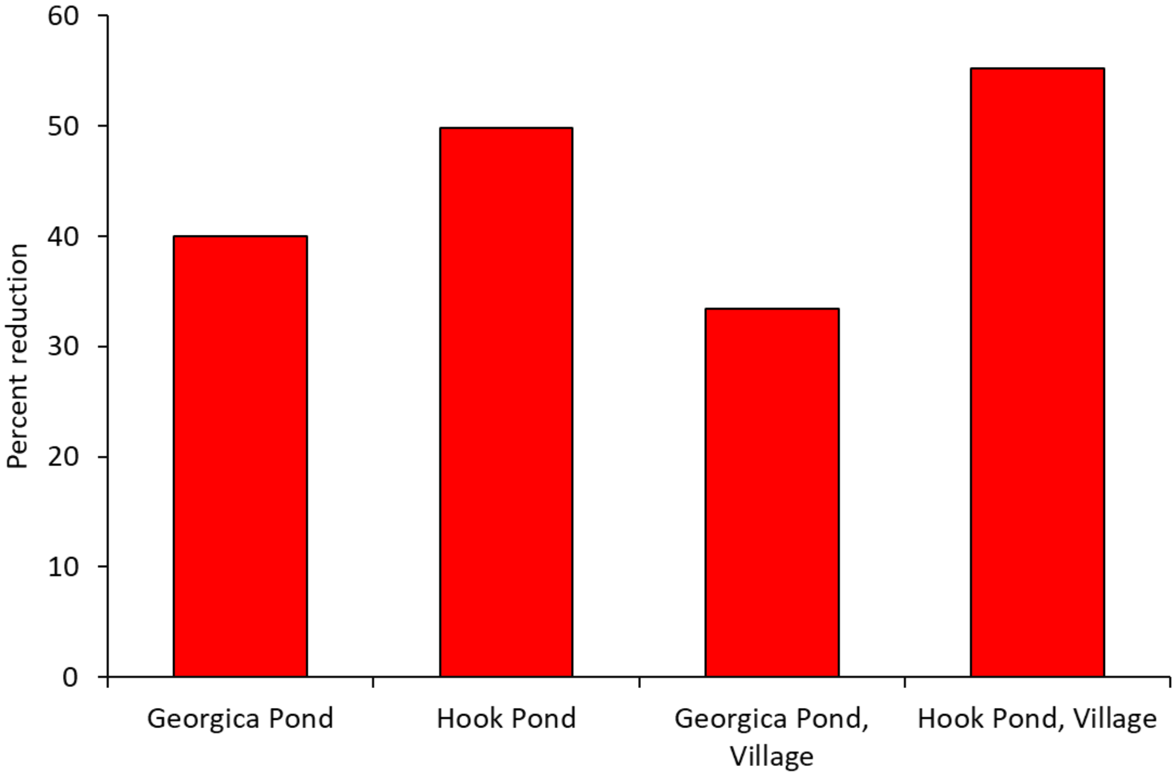


Figure 31. Percent nitrogen reduction to Georgica Pond and Hook Pond by upgrading conventional septic systems in the Village outside of the sewer district to innovative and alternative systems that reduce nitrogen coupled with the four-scenario sewer district.



TASK 5. PROJECT AND DESCRIBE HOW CONNECTING DIFFERENT REGIONS OF THE VILLAGE OF EAST HAMPTON TO A SEWAGE TREATMENT PLANT WILL IMPROVE WATER QUALITY IN HOOK POND.

The large and significant reductions in nitrogen loading, and to a lesser extent phosphorus loading, from the Village of East Hampton into surrounding water bodies will contribute toward a series of significant water quality improvements in the regions. As stated in the introduction, the first habitat to receive nitrogen-enriched groundwater from the Village are salt marshes or wetlands. These habitats are critical for the survival of marine life, birds, and even some terrestrial mammals (Turner 1987; Leonard et al. 1999). In addition, they are known to intercept and process land-derived pollutants including excessive nitrogen loading (Valiela et al. 1978; Dame et al. 1992). Finally, recent research has affirmed the key role salt marshes play in protecting coastal communities from storm surge and flooding (Anderson et al. 2013; Jadhav and Chen 2012; Ysebaert et al. 2011). In fact, mapping of the storm surge from Hurricane Sandy or the expected rise in sea level this century suggests that the salt marshes surrounding the Village of East Hampton are playing a critical role in protecting the Village against current and future storms. It is now widely recognized that excessive nitrogen loading degrades and erodes salt marshes (Turner et al. 2009; Deegan et al, 2012) making coastal communities on Long Island more vulnerable to flooding (NYSDEC 2014). Therefore, the currently proposed project that will divert and remove more than 50% of the nitrogen load to Hook Pond and Georgica Pond will play a key role in stabilizing and restoring the salt marshes in this region and thus protecting the Village from future flooding associated with sea level rise and storm events.

Beyond the shoreline, the release of nitrogen from groundwater into coastal waters has a strong effect on the estuarine ecosystem since nitrogen is considered the limiting element for primary producers (Nixon, 1995). Hence, excessive nitrogen loading from the Village is promoting algal blooms, (Figure 2), and the cascade of events that ensue from these events reduced water clarity, the loss of seagrass, low oxygen levels and the loss of marine life. Prior research across Long Island and regionally demonstrates that these processes can work in reverse if nitrogen loads are mitigated. For example, in 1980, the Southwest Sewer District was implemented and sewage from a large region of southwest Suffolk County that had flowed into Great South Bay was diverted to the Atlantic Ocean. Following this, nitrogen levels in Great South Bay declined and more than 3,000 acres of seagrass re-grew (NYSDEC, 2009). Similarly, in Mumford Cove, CT, seagrass was lost entirely as population and sewage inputs increased during the 20th century, and the Cove became overgrown with seaweeds (Vaudrey et al., 2010). In 1989, the sewage was diverted from this Cove and the seaweeds vanished and were replaced by seagrasses (Vaudrey et al., 2010). In Northport Harbor, *Alexandrium* blooms had occurred every year from 2008 to 2012, leading to the closure of more than 8,000 acres of shellfish beds due to contamination with saxitoxin and the threat of paralytic shellfish poisoning (PSP; NYSDEC, 2008-2016). In 2013, the Northport Village sewage treatment plant was upgraded and reduced its daily nitrogen discharge by more than 50%. In the years since that upgrade (2013-2017), there have been no PSP events in Northport Harbor. Finally, in 1994, a plan was devised to reduce nitrogen loading into Long Island Sound by 58.5% over a 20-year period. Reductions began in earnest at the turn of the century and through this century, the size of the 'dead zone' or low oxygen zone within Long Island Sound has progressively shrunk (CT DEEP, 2022).

With the implementation of the sewer district and the upgrading of septic systems in the Village of East Hampton, it is anticipated that similar change will occur in the surrounding water bodies, but primarily within Hook Pond and for septic upgrade, Georgica Pond as well. More specifically, by reducing nitrogen and phosphorus loadings, that water body will become less hospitable for harmful algae such as toxic blue-green algae (Gobler et al., 2016). Regarding Hook Pond, given this water body's exceedances of the NYSDEC standards for blue-green algae and US EPA standard for total chlorophyll *a* are only slightly above these thresholds, it is anticipated that sewering and septic upgrades will bring this water body into state and federal compliance with these standards. Given the periodic high intensity of algal blooms in Georgica Pond, and given the Village contributes only partly to the Georgica Pond watershed and that none of the sewering upgrades will impact this water body, it is anticipated that additional mitigation of septic systems in the larger Georgica Pond watershed will be needed to improve water quality in this system.

Reductions in blue-green algae and total algae should have whole ecosystem benefits. It is well-known that brown tides are poorly grazed by zooplankton compared to other phytoplankton (Gobler and Sunda, 2012) and during summer, bloom to the exclusion of other phytoplankton. Since zooplankton are the next step in aquatic food webs that ultimately yield fish, under current conditions, blooms of brown tides are inhibiting the productivity of finfish and shellfish populations, especially pelagic fish that feed in the water (Gobler and Sunda, 2012). Hence, as nitrogen reductions begin to alter phytoplankton populations and reduce the prevalence of brown tides and enhance phytoplankton diversity, zooplankton populations should also rebound, a change that will benefit pelagic finfish and benthic shellfish populations.

Other changes wrought by a lowered intensity of algae blooms should include increased water clarity, improved dissolved oxygen levels, and enhanced levels of submerged aquatic vegetation, and these changes are likely to have positive, synergistic effects on each other and fish populations. Finally, the reduction in algal biomass from sewering and upgrading septics should also benefit the levels of nighttime dissolved oxygen in Georgica Pond and Hook Pond. Night-time fish kills are becoming more prominent on eastern Long Island. At night, in the absence of photosynthesis, dissolved oxygen levels are controlled by respiration rates which consume oxygen. These respiration rates are proportional to the total amount of algal biomass produced in which can directly respire or can result in bacterial respiration as the carbon from the algal biomass is consumed. In either scenario, reduced algal biomass from sewering and upgrading septics will reduce the incidence and likelihood of low dissolved oxygen levels and fish kills at night in and thus will contribute toward a rebuilding of healthy fish stocks.

Finally, there will be a financial benefit of sewering the Village. Recent research at Stony Brook University has determined that waterfront or near-waterfront home values can be strongly effected by water clarity. Hence, the improved water clarity associated with lower intensity algal blooms should financially benefit home owners in the region as well as associated tax revenues. Obviously, other benefits such as fewer fish kills and algal blooms will also likely improve home values as well as the number of visitors to Hook Pond and Georgica Pond and the Village, occurrences that will have direct and indirect financial benefits for the Village and its residents.

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