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

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EXECUTIVE SUMMARY

The Village of Westhampton Beach is located within the watersheds of Moniebogue Bay, Quantuck Bay, and Moriches Bay, all water bodies declared impaired by the New York State Department of Environmental Conservation (NYSDEC). For more than 30 years, these waters have been plagued by recurrent brown tides more frequently than any other water body across Long Island leading to significant losses of shellfish and eelgrass. High levels of nitrogen have been detected in the groundwater under the Village and this nitrogen flows to coastal water bodies, promoting these brown tides while also contributing toward other nitrogen-related impairments including the loss of salt marshes, the loss of eelgrass, poor water clarity, low oxygen levels, and poor conditions for fish populations. Any effort to reduce the delivery of nitrogen from the Village of Westhampton Beach will help mitigate these conditions. This study was undertaken to estimate the effect of sewering various portions of the Village of Westhampton Beach on the total nitrogen loads to Eastern Moriches, Moniebogue Bay, and Quantuck Bay, as well as the water quality within these systems. A nitrogen loading model was developed that considered nitrogen delivered to these waterbodies from three types of fertilizers, septic systems, the atmosphere, surface-run-off, storm drains, sediments, and birds. The model was run for current conditions as well as for four phases of wastewater remediation for the Village including the creation of phased sewer districts and upgrades of on-site septic systems. The subsequent effects on water quality in the surrounding water bodies was quantified. The models demonstrate that wastewater is currently the largest source of nitrogen to East Moriches, Moniebogue, and Quantuck (58%, 78% and 62% of the external nitrogen load). The completion of the proposed phase 1 sewering of Main Street would divert nearly 5,000 lbs of nitrogen away from Moniebogue Bay annually, reducing its total nitrogen load by 24% and its external nitrogen load by 30% but would not significantly impact East Moriches and Quantuck Bays which are outside of the Main Street watershed. Phases 2 and 3 would expand sewering to regions beyond Main Street bringing a 30% reduction of total nitrogen load and ~40% reduction of external loads to Moniebogue Bay and modest reductions to East Moriches and Quantuck Bays (0 – 5%). Phase 4 of the plan would bring alternative, denitrifying septic systems to the remainder of the Village and lead to the largest total nitrogen reductions to all waterbodies with the total load reduction of 12% for East Moriches Bay, 56% for Moniebogue Bay, and 8% for Quantuck Bay and external loads reductions of 18% for East Moriches Bay, 70% for Moniebogue Bay, and 13% for Quantuck Bay. Given that Moniebogue Bay is the only water

body fully within the Village's watershed, and that the Village comprises ~20% of the other watersheds, the 70% reduction in nitrogen load to this water body is the most realistic assessment of the efficacy of this project. Upon the reduction of nitrogen loads to coastal waters, it is expected that the intensity of brown tides and other algal blooms would be reduced. Additional ecosystem benefits would include improved nighttime oxygen levels, improved water clarity, increases in submerged aquatic vegetation, and improved conditions for pelagic fish. Given that recent research at Stony Brook University has determined that waterfront or near-waterfront home values can be strongly effected by water clarity, improved water clarity could financially benefit home owners in the region as well as associated tax revenues.

Task 1 Summarize the current status of water quality within Moniebogue and Quantuck Bay 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 Westhampton Beach. As a relatively dense population hub with a main street and a series of condominiums in the Village, there is an abundance of nitrogen-rich wastewater entering the groundwater under the Village. A GIS-based map of nitrogen levels in groundwater across Westhampton measured by Suffolk County shows that levels are relatively low north of the Village and in the region of the Pine Barrens (<1 mg N per liter; Figure 1). In strong contrast, the Village of Westhampton Beach and surrounding regions stand out as having exceedingly high levels of nitrogen in groundwater, in some cases exceeding 20 mg nitrogen per liter (Figure 1). Due to the low elevation of the Village and shallow groundwater, this nitrogen is likely to quickly traverse through the aquifer and directly into coastal water with little processing or denitrification.

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 Westhampton Beach and Moniebogue Bay, despite their vast, potentially healthy-appearance, 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 Westhampton Beach 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 3 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 very obviously in the vicinity of the Village of Westhampton Beach. Large stands of salt marshes line the entire eastern bank of Moniebogue Bay (Figure 2). During Hurricane Sandy, these salt marshes absorbed a large amount of tidal flooding, protecting many regions of the Village of Westhampton Beach (Figure 2). In contrast, regions on the west side of Moniebogue Bay without salt marshes were badly flooded (Figure 2). 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 Westhampton Beach. In a manner similar to Hurricane Sandy, the projected sea level rise for the next 30 years is likely to lead to flooding of some properties and homes along the western shore of Moniebogue Bay whereas the salt marshes on the eastern shore should protect the homes behind it, as well as the Village (Figure 2). 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 Westhampton Beach 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. An examination of 40 years of marine monitoring data from Suffolk County's Department of Health Services clearly illustrates the impact excessive nitrogen loading is having on regional estuaries and water quality. In compiling all of the data from Shinnecock, Quantuck, and Moriches Bay from 1976 - 2014, no site monitored had higher levels of total nitrogen in bay waters than Quantuck and Moniebogue Bay (Figure 3). The precise levels (~0.6 mg nitrogen per liter) exceeded 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 Quantuck Bay (Gobler et al., 2004, 2011). Hence, these high nitrogen levels lead to algal blooms. The highest levels of chlorophyll *a* (a proxy for the biomass of microalgae) anywhere across Shinnecock, Quantuck, and Moriches Bays (Figure 3) and across most of Long Island (Figure 4) are found in Moniebogue and Quantuck Bays. In fact, of >30 sites monitored by the Gobler lab since 2014, only the Forge River has had higher levels (Figure 4). During late spring and summer months, these algae are typically dominated by the brown tide alga, *Aureococcus anophagefferens* (Gobler et al., 2004, 2011). Such brown tides are a serious ecosystem threat as they are lethal and toxic to bivalves such as clams, oysters, scallops, and mussels and they can kill of seagrasses (Gobler and Sunda, 2012). During the past 30 years, no place on Earth has had more intense brown tides than Quantuck Bay, eastern Moriches Bay, and western Shinnecock Bay (Figure 3). Consistent with Suffolk County's data, monitoring across all of Long Island by the Gobler Laboratory has revealed the precise same trend (Figure 5). In fact, during the past decade, these brown tides have become more frequent and more severe than they had been from 1985 – 2005 (Figure 6). Beyond brown tides, an even more dangerous algae is *Alexandrium*, a dinoflagellate that synthesizes saxitoxin, a compound 1,000-times more potent and dangerous than cyanide (Anderson, 1997). This algae and toxin can cause paralytic shellfish poisoning when humans consume shellfish contaminated with saxitoxin (Anderson, 1997). There have been four PSP-induced shellfish bed closures in Shinnecock Bay during the past seven years and high levels of *Alexandrium* have been detected in Moniebogue Bay and Quantuck Bay (Figure 7). Blooms of *Alexandrium* and *Aureococcus* have both been shown to be strongly promoted by nitrogen loading (Hattenrath et al., 2010; Gobler et al., 2005, 2011).

Algal blooms can have additional, secondary negative impacts on marine life. Both the occurrence of brown tides and the occurrence of algal blooms in general can make coastal waters extremely turbid and murky (Gobler and Sunda, 2012). Accordingly, the region of Quantuck Bay, eastern Moriches Bay, and western Shinnecock Bay is the epicenter for low water clarity across the south shore of Long Island (Figure 3). Monitoring by the Gobler laboratory across all of Long Island during the past three years has demonstrated that Moniebogue Bay and Quantuck Bay have the lowest water clarity of any locations monitored (n=30; Figure 8). 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 effected 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). Quantuck Bay, eastern Moriches Bay, and western Shinnecock Bay have the lowest oxygen levels across Long Island's southeast shoreline (Figure 3) and monitoring across Long Island has demonstrated that this region has some of the lowest oxygen levels anywhere (Figure 9), commonly falling below the minimum standard for oxygen set by the NYSDEC of 3 mg per liter. 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 Westhampton Beach into Moniebogue and Quantuck Bay 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 brown tides, *Alexandrium*, and other algal blooms that are reducing light and oxygen levels and negatively impacting finfish, shellfish, and seagrasses. The severity of the problem in the Village of Westhampton Beach is clear as the near-by coastal water bodies have some of the worst water quality on Long Island. Nitrogen mitigation is needed to improve water quality and protect homes in the region.

TASK 2. DEVELOP A DYNAMIC MODEL FOR NITROGEN LOADING RATES AND SOURCES FOR THE VILLAGE OF WESTHAMPTON BEACH TO MONIEBOGUE, QUANTUCK, AND EASTERN MORICHES BAY.

A Nitrogen Loading Model was developed to quantify the total dissolved nitrogen input into the waterbodies surrounding the Village of Westhampton Beach. 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 Southampton, 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 Westhampton Beach 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 delineation

The surface extent of the East Moriches Bay, Moniebogue Bay, and Quantuck Bay watersheds were determined using a combination of CDM's ground water travel time analysis and groundwater flow patterns, which have been previously found to generally follow hydraulic gradients established by surface topography (Figure 10). Surface topography was determined using United States Geological Survey LiDAR data. Watersheds were limited on the northern edges by the 50-year groundwater travel time line provided by H2M, with the western edge of the East Moriches watershed was drawn roughly half way down the complete Moriches watershed, and the Quantuck Bay watershed as previously established (Gobler, 2016). As described later in this document, the multi-phase wastewater mitigation strategy being implemented by the Village encompasses all of the Moniebogue Bay watershed, 23% of the western Quantuck Bay watershed, and 19% of the eastern Moriches Bay watershed (Figure 11).

Atmospheric Deposition of Nitrogen

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) alter the amount of nitrogen that passes through to groundwater and enters a waterbody. Nitrogen deposited 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, less is removed before entering the waterbodies.

Nitrogen inputs from wet and dry deposition were determined using the National Atmospheric Deposition Program (NADP; wet) and the EPA's Clean Air Status and Trends Network (CASTNET; dry). Data from the closest NADP monitoring station is in Southold, NY, 10 miles from eastern Shinnecock Bay, were utilized. Two years (2010-2011) of monitoring from CASTNET's three closest monitoring stations (Washington Crossing, NJ, Claryville, NY, and Abington, CT) were averaged to determine the dry deposition input. Atmospheric deposition rates often only consider inorganic forms of nitrogen despite the fact that organic nitrogen contribution to atmospheric deposition can be considerable. While direct measurements are not available, a 1:1 ratio of inorganic to organic deposition of nitrogen has been suggested by

Cornell et al. (1995). Hence, the value of wet and dry deposition was doubled to account for organic nitrogen loading from these sources. As a result total input for atmospheric deposition amounted to 5.4 kg N per hectare yr^{-1} (=4.8 lb N per acre per year). Direct atmospheric deposition rate to the bays was added to the nitrogen load from wastewater and fertilizer for a final nitrogen load rate for each subwatershed.

Nitrogen runoff from driveways, roofs, and other impervious surfaces was attenuated because it first passes through turf and/or soils. All atmospheric depositions also go through a limited amount of denitrification in the aquifer. The atmospheric deposition of nitrogen is decreasing on Long Island and the Northeast in general, a trend expected to continue due to changes in industrial atmospheric discharge in the Midwest (Gobler, 2016).

The land-use and land cover information used for the NLM was ascertained through the Suffolk County Land Use and Land Cover parcel dataset for all watersheds. This layer includes all taxable parcels, but areas like public roads are not covered. All inputs to the NLM and their sources are referenced in Table 1. Impervious land areas were estimated by finding where the Normalized Difference Vegetation Index (NDVI) was low (NDVI<80). 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 limiting this impervious layer to areas where land parcels did not exist. Driveway areas were estimated by limiting the impervious layer to residential parcels and where the height of objects on the properties were close to zero. The height of objects on properties (trees, buildings, decks, etc.) was determined by subtracting a Digital Elevation Model from a Digital Surface Model. These models were created from the same USGS LiDAR point cloud data. Total roof area was quantified by summing the area of each building footprint within the watershed. Footprint data was supplied by Suffolk County.

Wastewater

The contribution of nitrogen load to the bays from wastewater was calculated in the NLM by multiplying the nitrogen released per person by the number of occupants in the watershed. The number of occupants for most parcels in each watershed was determined by using CDM's model results. They determined that one residential parcel produces 300 gpd of sewage. Using 2010 census data for the region, occupancy of 2.8 people per one year round residential parcel. Hence, it was estimated that 2.8 people produce 300gpd. With this ratio and the modeled sewage output, the occupancy for other property types was determined. Most commercial and industrial properties were included in H2M's study, but it did not fully cover the watersheds. Year-round residential properties outside of H2M's study were assigned 2.8 people and seasonal occupancy properties were assigned 0.92 people assuming three months of occupancy and an average of 5.5 people per seasonal home, numbers acquired from the recent NYSDEC's Long Island Nitrogen Action Plan Subwatersheds study. Properties were determined as year round or seasonal based on the permanent address of the owner.

Differing levels of nitrogen were then removed from wastewater 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 200 m of coastal waters. Residential and commercial 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. In Suffolk County, a law was passed in 1973 requiring all newly constructed buildings to include a septic tank system instead of a cesspool. For this study, half of the residential and commercial uses were assumed to have cesspools. The study area does not contain any municipal wastewater treatment facilities.

The NLM breaks down the nitrogen removal in septic tank and cesspool-based systems into three steps: removal in the tank, removal in leach rings, and removal in septic plumes (Table 1). Cesspools on Long Island are typically composed of cylinders arranged vertically, eliminating any traditional leaching rings and the associated nitrogen removal therein. Although there is a disposal pit associated with these vertically structured cesspools systems, only a small amount of nitrogen is removed in this part of the system (<10%).

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<0.05m). Golf courses were extracted from the Open Street Map and were further manually edited. Agricultural land was extracted from the Suffolk County Land Use and Cover dataset and manually verified with satellite imagery. Parks and athletic field parcels were also extracted from the Suffolk County Land Use and Land Cover dataset but were then further limited to lawn areas within those parcels with the same process used for residential lawns.

Sediments, birds, and waterfowl

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 Quantuck Bay 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.

Final processes considered were direct atmospheric deposition to the water bodies (0.16 mole m^{-2} yr^{-1} as per Gobler (2016) and waterfowl. Fleming, R. and H. Fraser (2001) reported the nitrogen content of Canadian geese droppings as: 3,168 mg/goose/day and 608 to 1,819 mg/bird/day. Bird populations of East Moriches, Moniebogue, and Quantuck were estimated at 100, 100, and 300 birds, respectively, and a loading rate of 2,000mg/bird/day was used.

Nitrogen loading rates to East Moriches, Moniebogue, and Quantuck Bays

Recently, nitrogen loads have been quantified for many watersheds across Suffolk County. In most of these efforts, load calculations have been based exclusively on external nitrogen loads from watersheds to the ecosystem and have not considered processes within the waterbody. For this study, both internal and external nitrogen loads to East Moriches, Moniebogue, and Quantuck Bays were quantified. When considering external loads only, wastewater was the largest source of nitrogen to all three waterbodies. East Moriches, Moniebogue, and Quantuck Bays received 25,087, 6,909, and 11,889 kg N per year from wastewater sources representing 74%, 89%, and 80% of the total external nitrogen load to these three systems (Table 2). The second largest external nitrogen source was fertilizer comprising 19%, 7%, and 11% of the total nitrogen load to East Moriches, Moniebogue, and Quantuck Bays (Table 2). Atmospheric deposition onto the land, the last external source, produced between 4 and 9% of the external nitrogen load to the watersheds.

When considering internal and external loads, wastewater was still the largest source of nitrogen to the waterbodies and represented 49%, 72%, and 53% of the total nitrogen load to East Moriches, Moniebogue, and Quantuck Bays respectively (Table 3; Figure 11-13). The next largest source of nitrogen was an internal source, specifically direct atmospheric deposition to the waterbodies that contributed 9,578, 1,043, and 4,072 kg N per year that represented 19%, 11%, and 18% of the total nitrogen loads to these systems (Table 3). Benthic fluxes, another internal source, followed with 7,647, 832, and 3,251 kg N per year representing 15%, 9%, and 15%. Thereafter, fertilizer emanating from homes, golf courses, and public parks were the fourth largest source of nitrogen contributing 13%, 6%, and 7% of the total nitrogen loads East Moriches, Moniebogue, and Quantuck Bays, respectively (Table 3; Figure 11-13). Atmospheric deposition to the land contributed less than 6% of the total nitrogen load and nitrogen from birds was below 1% for each waterbody (Table 3). These distributions of nitrogen loads are similar to recent studies in Suffolk County (Kinney and Valiela, 2011; Lloyd, 2014, 2016; Gobler, 2016).

Recently, the NYSDEC's Long Island Nitrogen Action Plan (LINAP) has made significant progress in accessing nitrogen loads to coastal water bodies. One of the earliest actions of LINAP has been the formation of the Suffolk County Subwatersheds Study and committee. As part of that effort, individuals from US EPA, USGS, Cornell University, Stony Brook University, Suffolk County, NYSDEC, and The Nature Conservancy have been collaborating to consider the manner in which nitrogen from land is transported to bays, harbors, lakes, and estuaries in Suffolk County. Through that process, two important and new consensus facts have been established. First, the existing cesspools and septic systems across Suffolk County have been found to be releasing significantly more nitrogen than had previously been thought. For example, in the original NLM model developed by Bowen et al., (2007) it was assumed that there was a 35% reduction in nitrogen within septic tanks, within leaching pits, and as groundwater traverses through the aquifer. While subsequent studies on Long Island began to reduce the removal rates for each step, LINAP has determined that the loss of nitrogen from each of these processes is between 5 and 10%, making wastewater a significantly stronger nitrogen source within the ecosystem (Figure 11-13). Another major change initiated by LINAP has been with regard to lawns. While NLM originally assumed lawns allowed 40% of nitrogen applied to enter groundwater, LINAP has compiled enough information to feel confident that the transmission rate is 30% (Table 1). Finally, although NLM had assumed there would be a large vadose zone removal of nitrogen applied to land surfaces, LINAP has concluded such a process does not exist on Long Island and thus it has been eliminated. This project used the most up-to-date information available regarding nitrogen loading on Long Island as developed by LINAP. As a result, the total nitrogen loads are higher since nitrogen is not being removed within the aquifer at the rates previously assumed but rather at much lower rates and more nitrogen is being transmitted by septic systems and lawns to groundwater. These changes were slightly larger for wastewater than for fertilizer, making the later process more important. Regardless, the findings of this study are generally consistent with recent studies that have found that wastewater is usually the largest source of nitrogen to a given watershed, although fertilizer can sometimes be larger (Kinney and Valiela, 2011; Lloyd, 2014, 2016; Gobler and Stinnette, 2016).

TASK 3. USE THE DYNAMIC MODEL QUANTIFY HOW CONNECTING DIFFERENT REGIONS OF THE VILLAGE OF WESTHAMPTON BEACH WILL ALTER NITROGEN LOADING RATES TO MONIEBOGUE, QUANTUCK, AND EASTERN MORICHES BAY.

For task 3, the nitrogen loading model developed for the Village of Westhampton was built to consider the different proposed phases of sewers. This was done in multiple phases (Table 4; Figures 14-15). Phases one through three will involve connecting individual commercial and residential parcels to the sewer treatment plant at Gabreski Airport in phases (Table 4; Figures 14). Phase one focuses on Main Street and a section of residential properties south of Main Street connecting 68 commercial properties and 88 residential properties (Table 4; Figures 14). Phase two focuses on regions north of Main Street and connects 46 commercial properties and 23 residential properties (Table 4; Figures 14). Phase three incorporates 55 commercial properties and 97 residential properties between Montauk Highway and the south edge of Gabreski Airport (Table 4; Figures 14). Phase Four, which will be addressed concurrently with phases 1- 3, will involve an upgrade of on-site septic systems to denitrifying systems recently approved as Article 19 of the Suffolk County Health Code which requires that denitrifying systems reduce nitrogen discharge to at least 19 mg nitrogen per liter. Phase 4 will specifically involve 96 commercial properties and 1,955 residential properties across the Village (Table 4; Figures 15). For phases 1 – 3, wastewater diverted from on-site systems and delivered to the sewer treatment plant at Gabreski Airport was added to the nitrogen loads to the Quantuck Bay watershed assuming a treatment level of 10 mg N per liter.

The first important observation of this task is that the region under consideration for phase 1 sewering falls entirely within the watershed of Moniebogue Bay, meaning that the proposed phase 1 sewer district will benefit this water body but is not expected to have any effect on East Moriches Bay and will add very modestly to the nitrogen loads of Quantuck Bay (2%) (Figures 16, 18). The proposed sewer district for phase 1, however, will have a substantial impact on nitrogen loading to Moniebogue Bay (Figure 17). Beyond the phase 1 sewer district falling entirely within the Moniebogue Bay watershed (Figure 14), it is also important to note that the very large majority of nitrogen entering the waterbody comes from wastewater (72%; Figure 12) and hence the proposed project which will divert a large fraction of this nitrogen load out of the watershed will have a significant impact on loading to regional waterbodies. Quantitatively, the nitrogen load that will be removed from Moniebogue Bay with the implementation of this phase 1 sewer district is 2,167 kg of N per year (~5,000 pounds; Figure 17), representing 22% of the total nitrogen load into Moniebogue Bay (Table 5, Table 13) and 28% of externally sourced nitrogen loads (Table 6, Table 14). Given that the overwhelming majority of nitrogen load to the waterbody is from wastewater, expanding the size of sewer district will further decrease the total nitrogen load to this system.

Phase 2 and 3 are an expansion of the sewer district to a larger area focusing on properties north of the downtown commercial area (Figure 15). Phase 2 would not bring any reduction to Eastern Moriches Bay but phase 3 would bring a reduction of 1,388 kg of nitrogen removed per year to this system (Tables 7 - 10; Figure 16) representing 3 and 4% of total and external nitrogen loads, respectively (Tables 13 and 14). Phase 2 would also have an additional benefit to Moniebogue Bay, removing another ~700 kg of nitrogen per year (Tables 7 and 8; Figure 17), bringing the reduction in nitrogen load to the bay to ~30% of the total load and 37% of the external loads (Tables 13 and 14). In contrast, phase 3 would target few homes within the Moniebogue Bay watershed and this would have only a minor impact on this system (Tables 9 and 10; Figure 17). For Quantuck Bay phase 2 and 3 would have almost not net effect as the nitrogen removed from this watershed is nearly equal to the nitrogen imported from the others via the sewage treatment plant (Tables 7 – 10, 13-14; Figure 18).

Finally, phase 4 of the Village of Westhampton Beach sewage mitigation program would entail upgrading more than 2,000 onsite septic systems to systems that denitrify and remove large amount of nitrogen. This phase targets nearly five-times more systems than phases 1 – 3 combined and thus would remove the largest amounts of nitrogen. Numerically, for Eastern Moriches Bay, this phase would remove 3,876 kg or more than four tons of nitrogen leading to a cumulative reduction of 12% of the total load and 18% of the external load (Tables 11-13; Figure 16). For Moniebogue Bay, this phase would remove an additional 4,121 kg of nitrogen leading to a cumulative reduction of 56% of the total load and 70% of the external load (Tables 11-13; Figure 17). Finally, for Quantuck Bay this phase would remove nearly 2,000 kg of nitrogen leading to a cumulative reduction of 8% of the total load and 13% of the external load (Tables 11-13; Figure 18).

The three waterbodies studied here are interconnected and therefore have a degree of mixing, in this way it is possible to look at the results as one mixed waterbody. In that context, for all three watersheds combined, these projects would amount to reductions of 16 – 23% (Tables 13 and 14), percentages much smaller than the effect on Moniebogue Bay (70% reduction) which is wholly within the Village watershed. These differences arise from the Eastern Moriches watershed and Quantuck watershed each being individually much larger than the entire Village of Westhampton Beach. For example, the phase 4 area is roughly 1,500 acres whereas the Eastern Moriches Bay watershed is 3,950 acres and the Quantuck Bay watershed is 2,370 acres. Again, while the Moniebogue Bay watershed is completely contained within the phase 4 area, only 19% of the Eastern Moriches Bay watershed and 23% of the Quantuck Bay watershed is contained within the phase 4 area (Figure 6). Hence, going forward it will be important for the Village to partner with the Town of Southampton, Suffolk County, and NYSDEC to address larger scale nitrogen loading and wastewater issues as related to these larger water bodies. The extension of the Community Preservation Fund and the inclusion of water quality improvement projects in that fund in the future should provide millions of dollars to the Town of Southampton to address on-site wastewater loading within coastal watersheds. Suffolk County's Reclaim Our Waters Initiative will seek to reduce nitrogen loading rates to coastal water bodies that are highly impaired. This will specifically be facilitated via NYSDEC's Long Island Nitrogen Action Plan's Subwatersheds study of Suffolk County that will specifically seek to identify regions most in need of septic upgrades. Given the severe water quality impairment in eastern Moriches Bay, Quantuck Bay, and western Shinnecock Bay (Figures 1-9), it seems certain this region will become a high priority for wastewater mitigation in the near term. This study provides the background and justification for this region to be 'shovel ready' for future wastewater mitigation projects.

Given that some of the study areas examined here are large watersheds outside of the Village boundaries, a final way of examining these project is to assess the proportion of the total nitrogen load from the Village to the surrounding water bodies. All combined, there is 21,431 kg of nitrogen per year delivered from land and sea into the water bodies receiving discharge from the Village as its own watershed including internal (bay) and external (land, atmosphere) and roughly 16,500 kg of nitrogen per year when controllable, land-based sources only are considered (i.e. wastewater and fertilizer; Figures 19, 20). When considering these loads only, phase 1 reduces the total nitrogen load the Village is responsible for by 10 - 14% (for total and land-only based loads), whereas phase 2 is a 16 - 21% reduction, phase 3 is a 23 - 30% reduction, and phase 4 leads to a 66 – 70% reduction of the total nitrogen load the Village is responsible for (Figures 19, 20; Table 15). The higher estimates are likely more important for the Village to consider since internal nitrogen sources like benthic flux and atmospheric deposition cannot be easily mitigated or controlled.

A final thought with regard to phase 4 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 4 of this project. Importantly, however, some systems reduce nitrogen levels below this threshold. For example, in pilot phase testing in Suffolk County the Hydro-Action system achieved, on average, 12 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 Massachusetts, has regularly achieved < 10 mg of nitrogen per liter effluent (CCWT, 2016). Hence, the phase 4 estimates used in this study were conservative and based on the realistic information available as of 2017. It is feasible that the amount of nitrogen reduction achieved in the Village of Westhampton Beach by phase 4 could be twice as large as estimated here which could be up to a 90% reduction in the wastewater loading of nitrogen to Moniebogue Bay, for example.

TASK 4. USE THE DYNAMIC MODEL QUANTIFY HOW BUILDING OUT THE VILLAGE OF WESTHAMPTON BEACH WITH AND WITHOUT CONNECTING DIFFERENT REGIONS OF WESTHAMPTON VILLAGE TO A SEWAGE TREATMENT PLANT WILL ALTER NITROGEN LOADING RATES TO MONIEBOGUE, QUANTUCK, AND EASTERN MORICHES BAY.

With the implementation of phase 1 of the sewer district, nearly 5,000 lbs of nitrogen will be diverted from Moniebogue Bay annually while completion of phase 4 will divert 10,000 lbs annually. The creation of the sewage district will also allow for an expansion of building within the Village with the newly constructed structures being connected to the sewage treatment plant which will treat the sewage to a 10 mg N per liter standard. Hence, for this task, the Moniebogue Bay watershed nitrogen loading model was run under six scenarios: Current nitrogen loading, nitrogen loading with the addition of 100,000 square feet of commercial space within the Village, nitrogen loading with the implementation of the sewer district (phase 1), nitrogen loading with the addition of 100,000 square feet of commercial space within the Village along with the implementation of the sewer district, nitrogen loading with the implementation of the sewer district and denitrifying septic systems (phase four), and nitrogen loading with the implementation of the sewer district and denitrifying septic systems and 100,000 square feet of commercial space within the Village. It should be noted that this much building is unlikely to occur within the Village in the near future or potentially ever. This level was specifically chosen to represent a large growth scenario to assess how the implementation of the sewer district would affect nitrogen loading future growth in the region.

As shown in Figure 22, if 100,000 square feet of commercial space was added to the Village without the sewer district, this would ***increase*** nitrogen loading rates to Moniebogue Bay by 64 kg of N per year, likely exacerbating environmental degradation of this water body (Figure 21). Alternatively, if the same growth occurred but the new structures were hooked up to the new sewage treatment plant, the net effect on Moniebogue Bay will be a 2,100 kg N per year ***reduction*** in nitrogen loading to this water body (Figure 21). If this project was carried out to phase four with denitrfying septic systems also added, even 100,000 square feet of commercial space would yield a net decrease in nitrogen loading by more than 50% (Figure 21). Hence, while increased building can lead to significant increases in nitrogen loading to coastal water bodies, when such growth occurs in parallel to the implementation of a sewer district, net nitrogen loading can be reduced.

TASK 5. PROJECT AND DESCRIBE HOW CONNECTING DIFFERENT REGIONS OF THE VILLAGE OF WESTHAMPTON BEACH TO A SEWAGE TREATMENT PLANT WILL IMPROVE WATER QUALITY IN MONIEBOGUE BAY.

The large and significant reductions in nitrogen loading from the Village of Westhampton Beach into surrounding water bodies will contribute toward a series of significant water quality improvements in the regions. As stated in the introduction, the first marine 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 Westhampton Beach are playing a critical role in protecting the Village against current and future storms (Figure 2). 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 up to 70% of the nitrogen load to Moniebogue Bay 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, brown tides, and *Alexandrium* blooms in near-by waters (Figures 3 – 7), and the cascade of events that ensue from these events such as paralytic shellfish poisoning, reduced water clarity, the loss of seagrass, low oxygen levels and the loss of marine life (Figures 3 - 9). 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 to the point that in 2015, for the first time since records began, there was no dead zone in Long Island South (CT DEEP, 2015).

With the implementation of the sewer district and the upgrading of septic systems in the Village of Westhampton Beach, it is anticipated that similar change will occur in the surrounding water bodies, but primarily within Moniebogue Bay. More specifically, by reducing nitrogen loadings, that water body will become less hospitable for harmful algae such as brown tides and *Alexandrium* (Hattenrath et al., 2010; Gobler and Sunda, 2012). This will lead to improved water clarity and higher oxygen levels and thus will promote the re-colonization of seagrasses. This, in turn, along with lower levels of brown tide, will benefit regional finfish and shellfish populations. This will also increase the diversity of the phytoplankton community in Moniebogue Bay. Brown tides compete with diatoms and green algae for dominance in this region (Gobler et al., 2011) and prior research has shown that nutrient reductions selectively reduce harmful algae biomass more than other phytoplankton in general (Heisler et al., 2008). This change will 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. More than a decade of research in Moniebogue Bay has shown that water clarity is highly correlated with the levels of algal biomass ($p<0.001$) and hence, the 40% reduction in nitrogen loads should translate into a similar reduction in algal biomass. Additional water clarity will allow more light to penetrate to the bottom of Moniebogue Bay which will promote the growth of submerged aquatic vegetation in regions that previously received less light. Such vegetation can benefit to fish populations whose juvenile forms may utilize the vegetation as a nursery habitat. These aquatic plants will also produce oxygen as they photosynthesize, thus enhancing oxygen levels in Moniebogue Bay. Finally, the reduction in algal biomass from sewering should also benefit the levels of nighttime dissolved oxygen in Moniebogue Bay. 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 Moniebogue Bay 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 will reduce the incidence and likelihood of low dissolved oxygen levels and fish kills at night in Moniebogue Bay and thus will contribute toward a rebuilding of healthy fish stocks in Moniebogue Bay.

Recently, a study performed for the Town of Southampton estimated the effects of removing nitrogen loads on the intensity of brown tide blooms in Quantuck Bay (Figure 22). If that results from that same study were applied to the nitrogen mitigation that would be associated with this project and focused on Moniebogue Bay, it seems likely this system would see a significantly lessening of brown tide intensity. For example, the 56% reduction in total nitrogen loads to Moniebogue Bay associated with completion of phase 4 of the Village of Westhampton sewage mitigation plan might result in a drop of total nitrogen in the Bay of more than 70%, a 50% reduction in brown tide cells densities, and a 40% reduction in total algae (Figure 22). Collectively, these changes would have many of the ecosystem benefits described above.

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 Moniebogue Bay and the Village, occurrences that will have direct and indirect financial benefits for the Village and its residents.

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Figure 1. Nitrogen concentrations in groundwater under and surrounding Westhampton Beach Village.

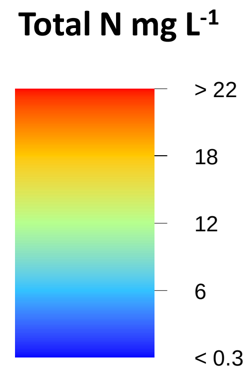
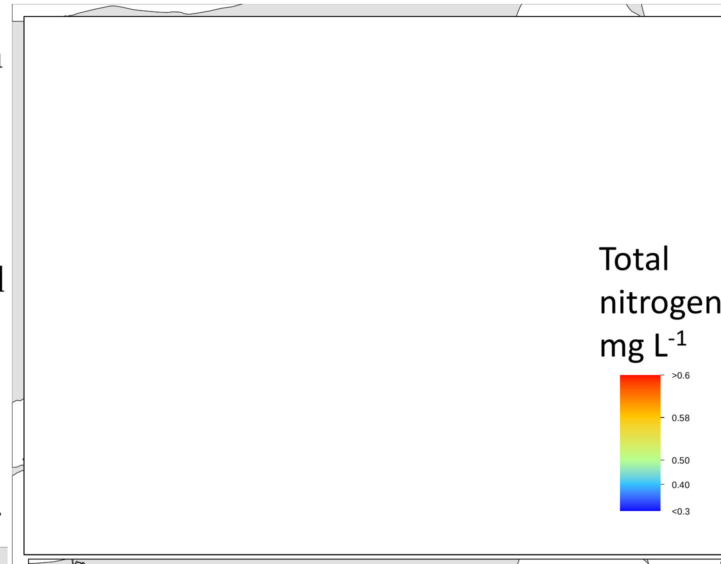


Figure 2. Westhampton Beach Village Right: highlighting surrounding salt marshes on Moniebogue Bay. Below left: Flooding that occurred during Hurricane Sandy. Below right: Expected sea level due to sea level rise by the year 2050. The images below highlight the key role salt marshes / tidal wetland play in protecting Westhampton Beach Village from flooding. This protection is at risk from the degradation wrought by excessive nitrogen loading

Flooding, Hurricane Sandy

Sea level by year 2050

Figure 3. Water quality coastal waters within Moriches, Quantuck, and Moriches Bay as measured by Suffolk County Department of Health Services 1976 – 2014 specifically showing (clockwise from the upper right) total nitrogen, brown tide densities, dissolved oxygen levels, secchi disc depth, and chlorophyll *a* levels, a proxy for phytoplankton. The data shows that the waters surrounding Westhampton Beach Village have the lowest quality in this region.



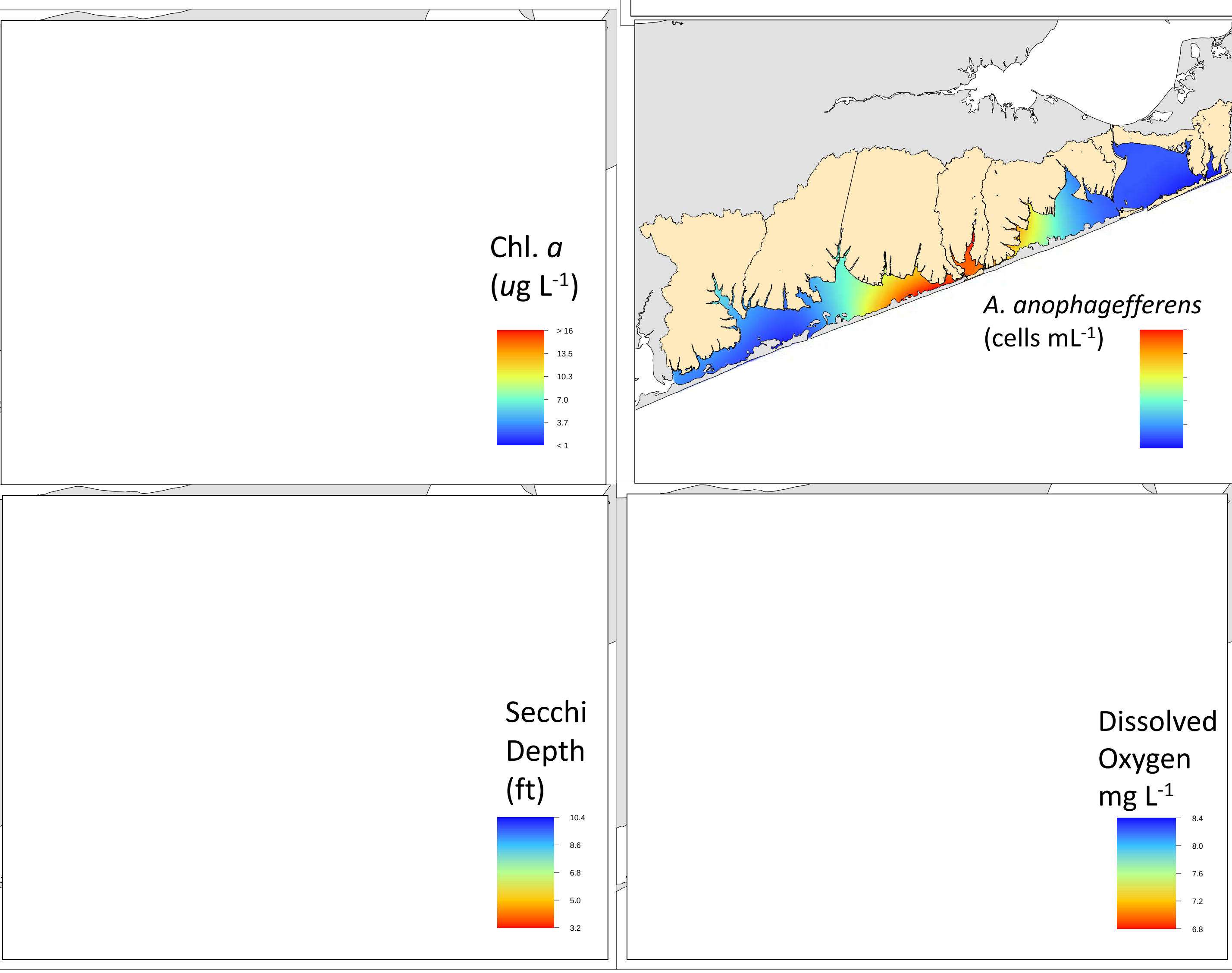


Figure 4. Chlorophyll *a* levels across 28 sites around Long Island as measured during the summers of 2014-2016 by the Gobler Lab's water quality reporting to News 12. Moniebogue Bay was the second worst site across all of Long Island.

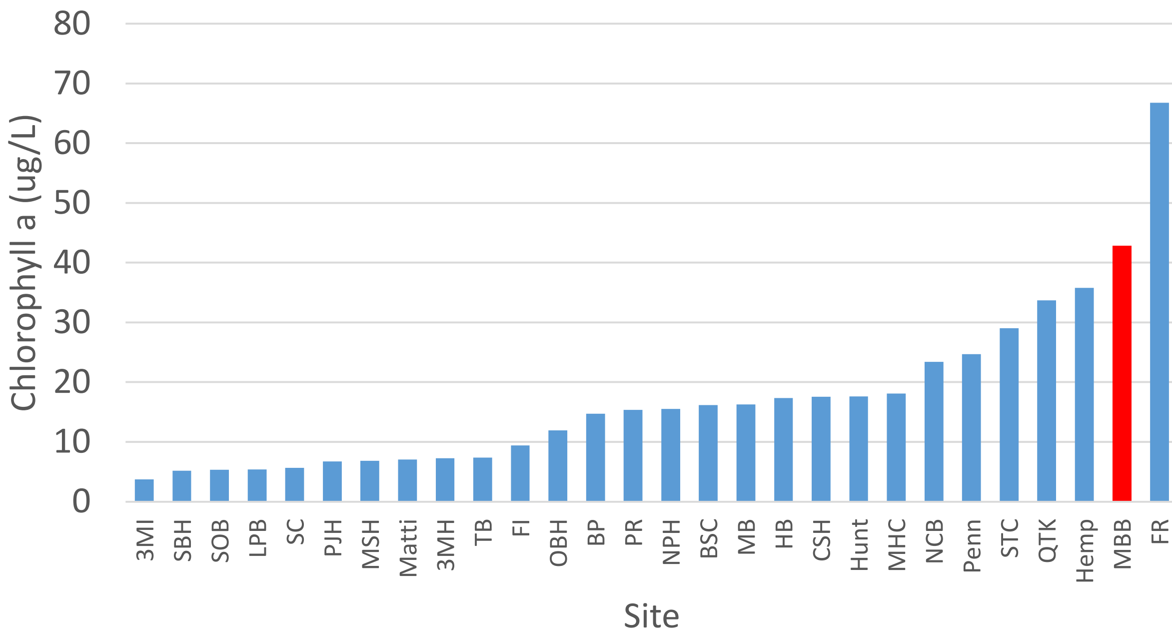


Figure 5. Brown tide levels across 28 sites around Long Island as measured during the summers of 2014-2016 by the Gobler Lab's water quality reporting to News 12. Moniebogue Bay was the worst site across all of Long Island.

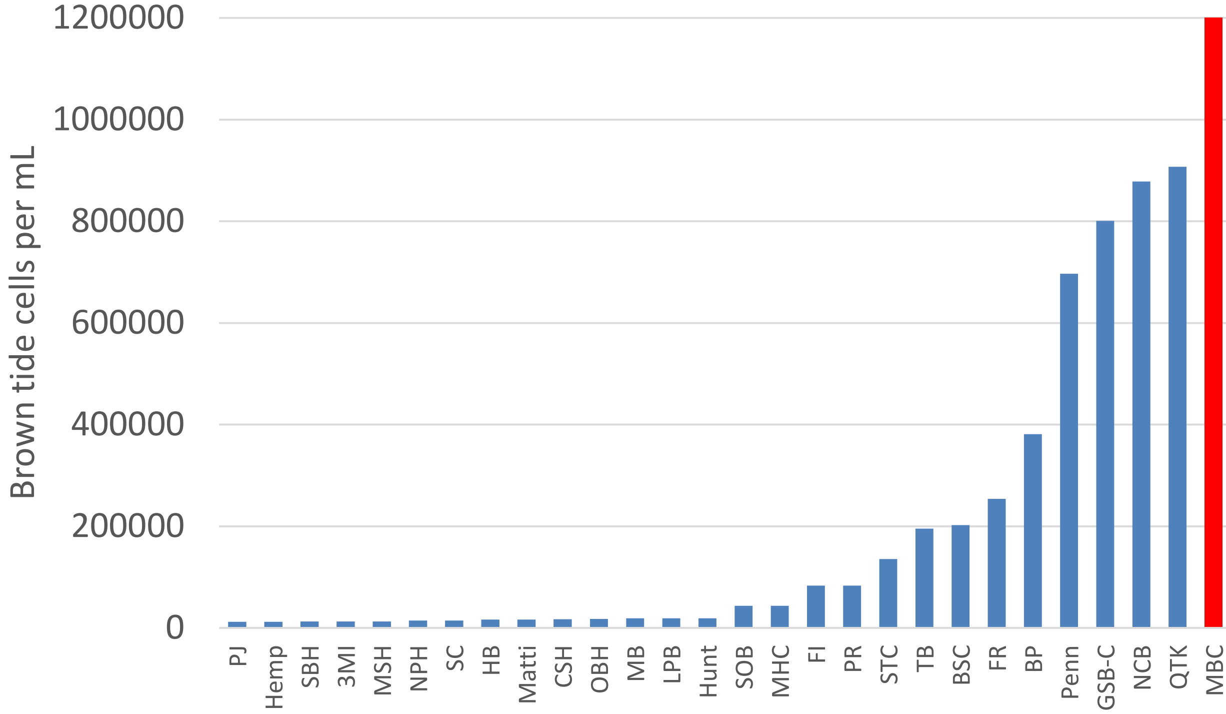


Figure 6. Brown tide levels in Quantuck Bay from 1989 through 2016. In the last decade brown tides have gotten more intense and more frequent.

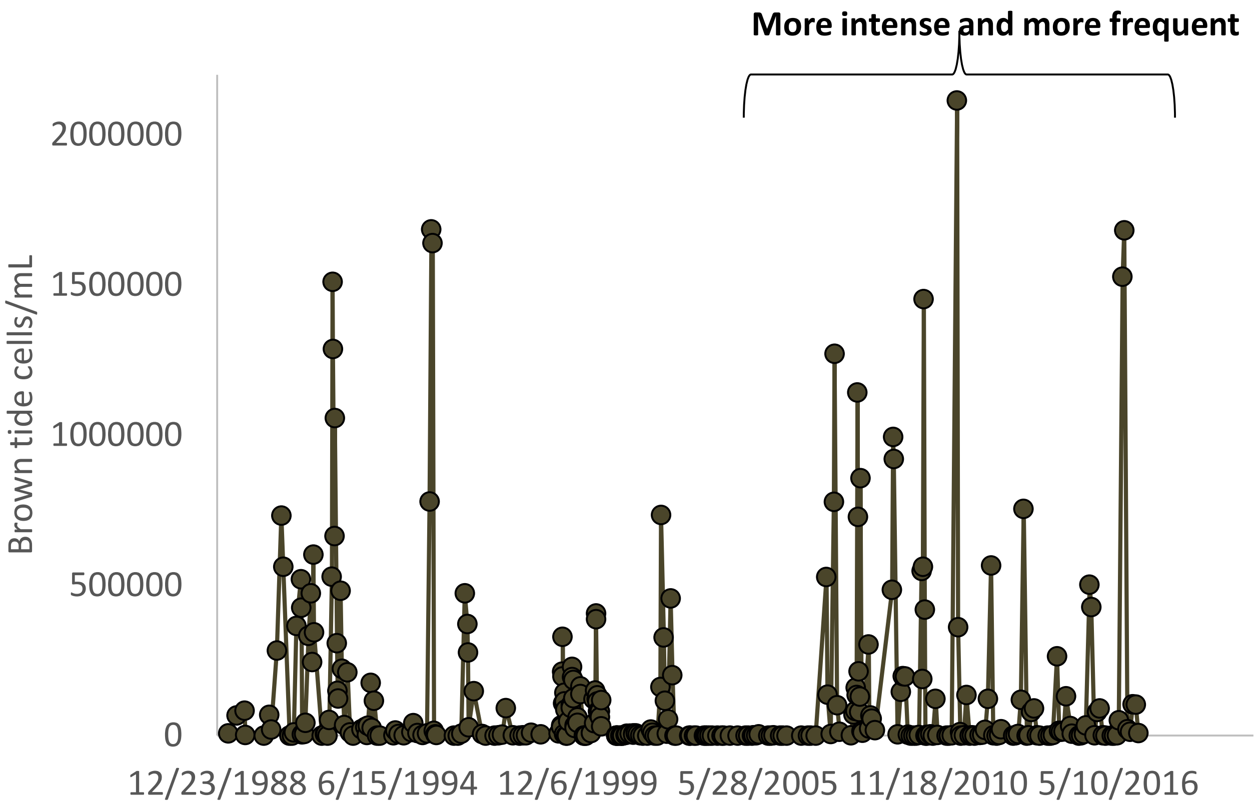


Figure 7. Densities of the toxic algae, *Alexandrium*, across Long Island 2007 – 2015, and the 2017 shellfish bed closure in Shinnecock Bay in the region within the Westhampton Beach Village watershed.

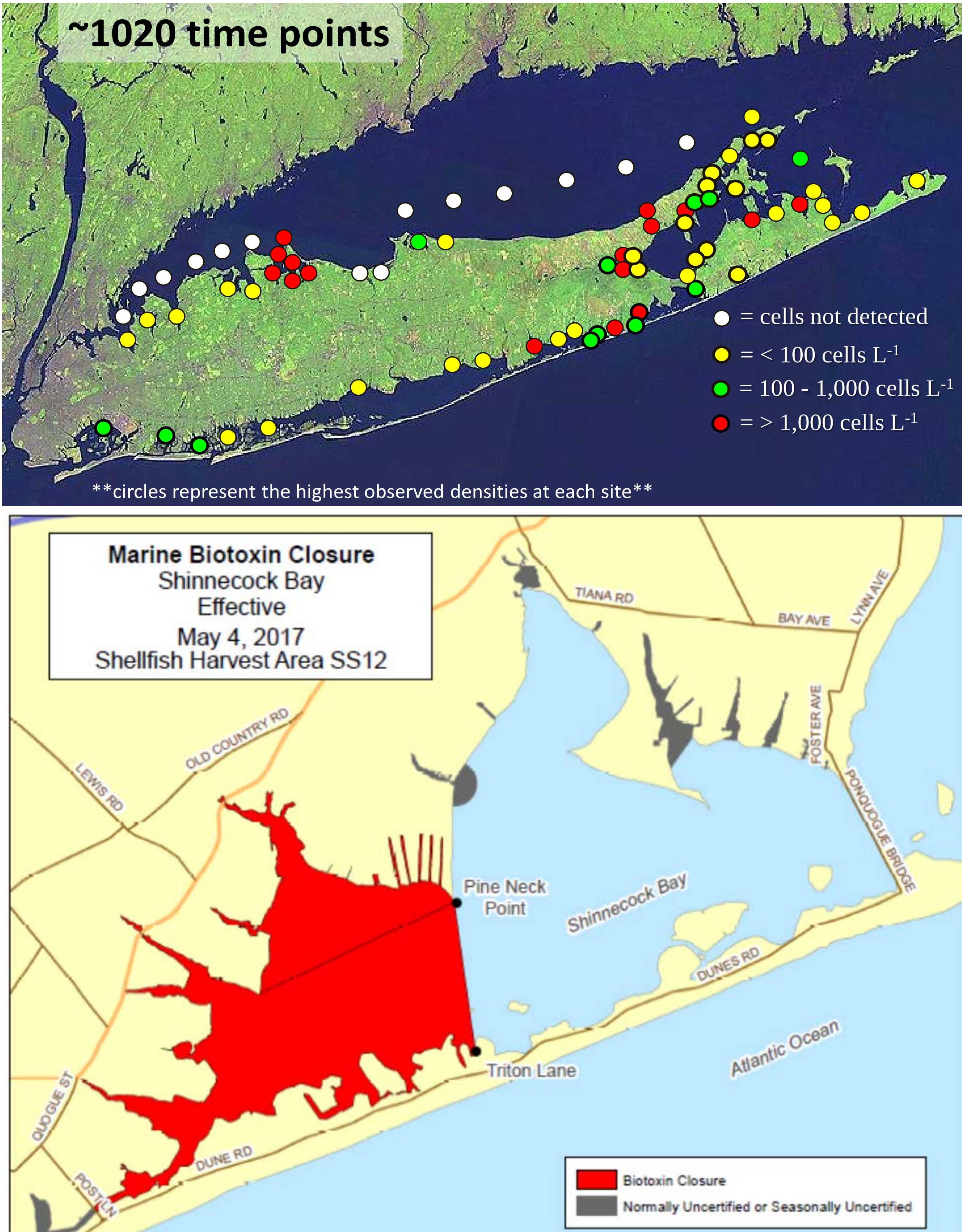


Figure 8. Water clarity across 28 sites around Long Island as measured during the summers of 2014-2016 by the Gobler Lab's water quality reporting to News 12. Moniebogue Bay was the worst site across all of Long Island.

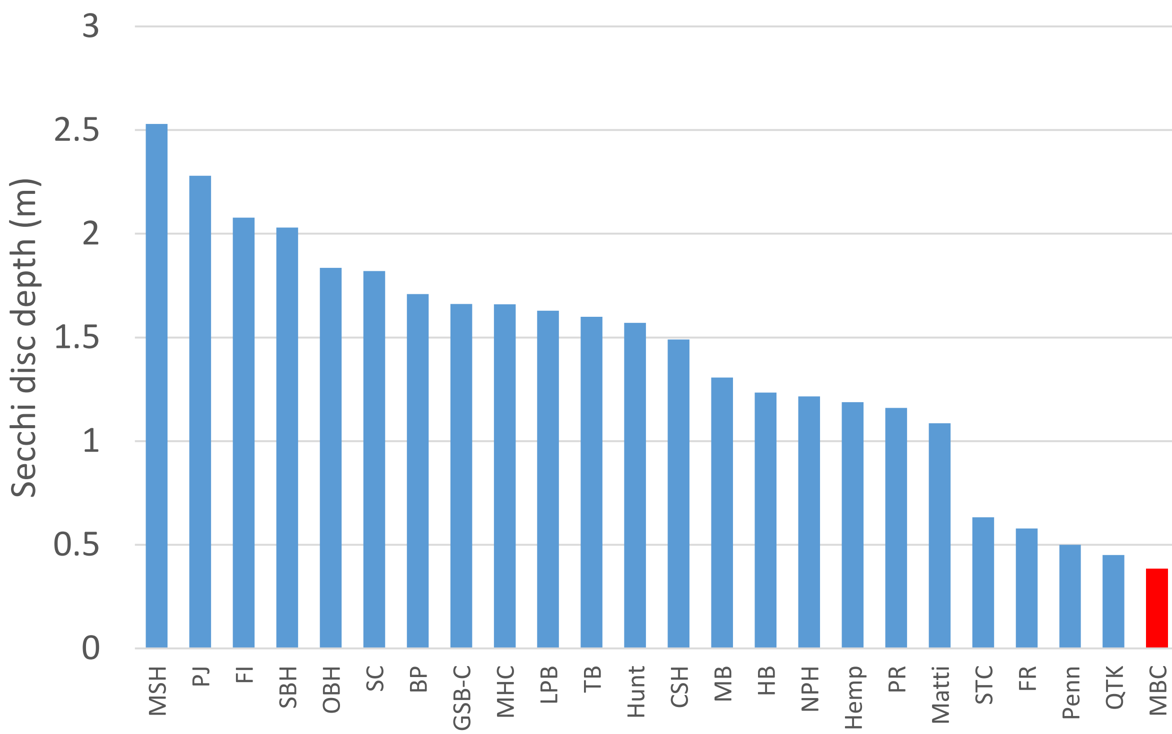
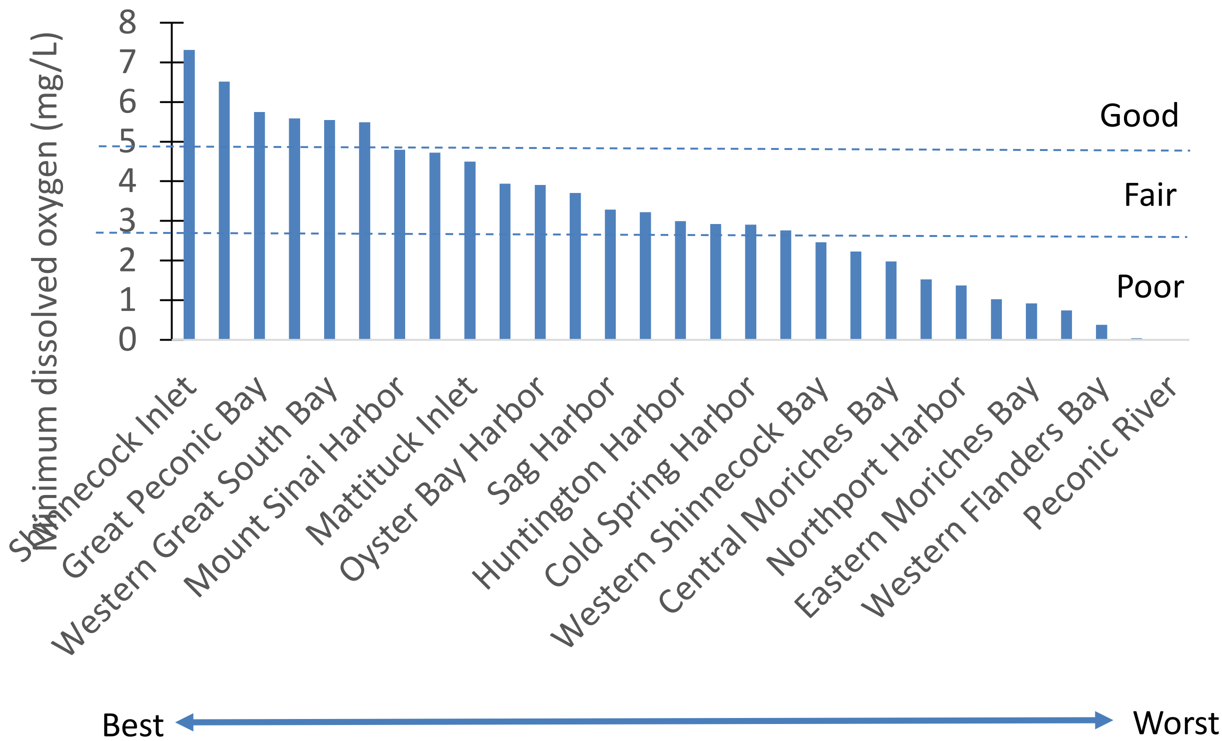


Figure 9. Dissolved oxygen levels across sites around Long Island as measured during the summers of 2014-2016 by the Gobler Lab's water quality reporting to News 12. Eastern Moriches Bay was the third worst site across all of Long Island. Rankings of good, fair, and poor follow NYSDEC standards.



Good, fair, poor based on NYSDEC standards

Figure 10. Watersheds for East Moriches, Moniebogue, and Quantuck used in this study.

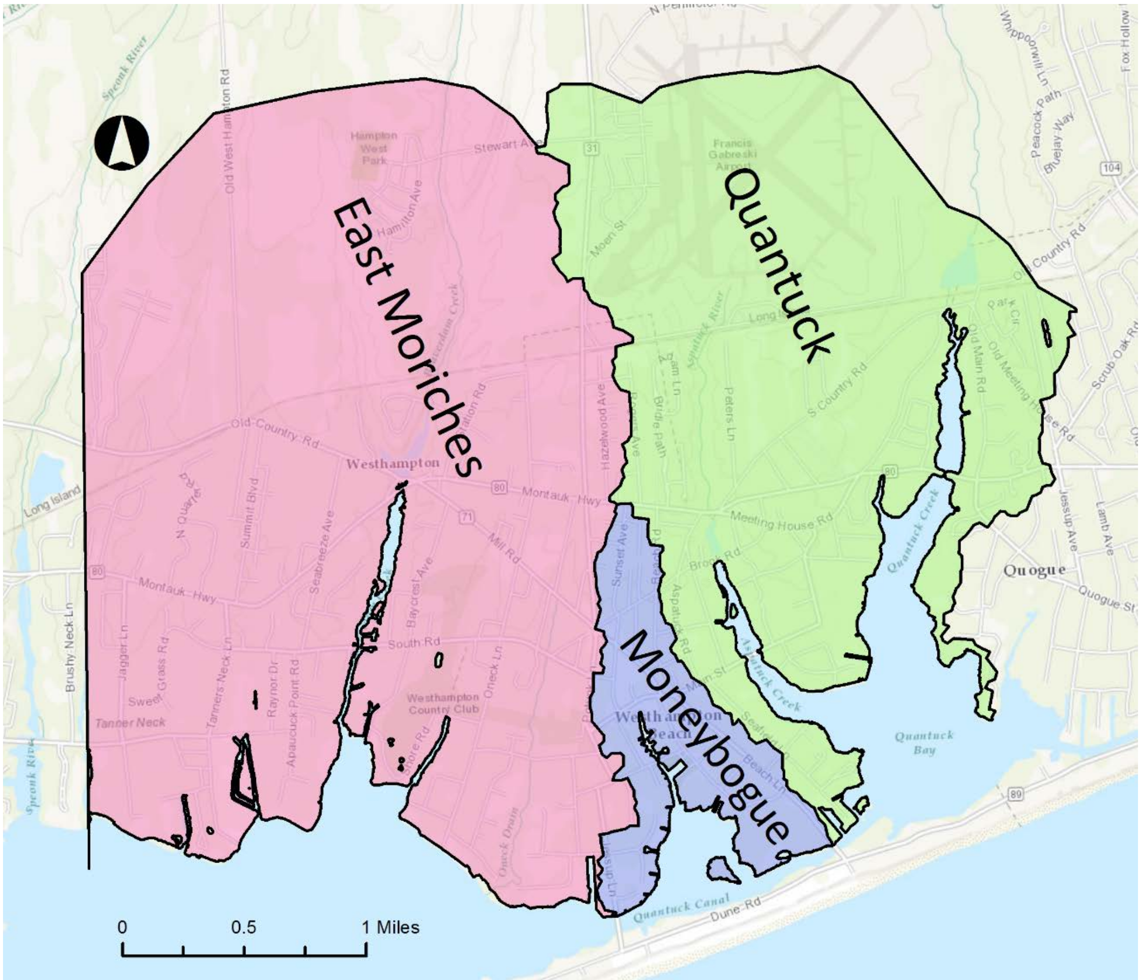
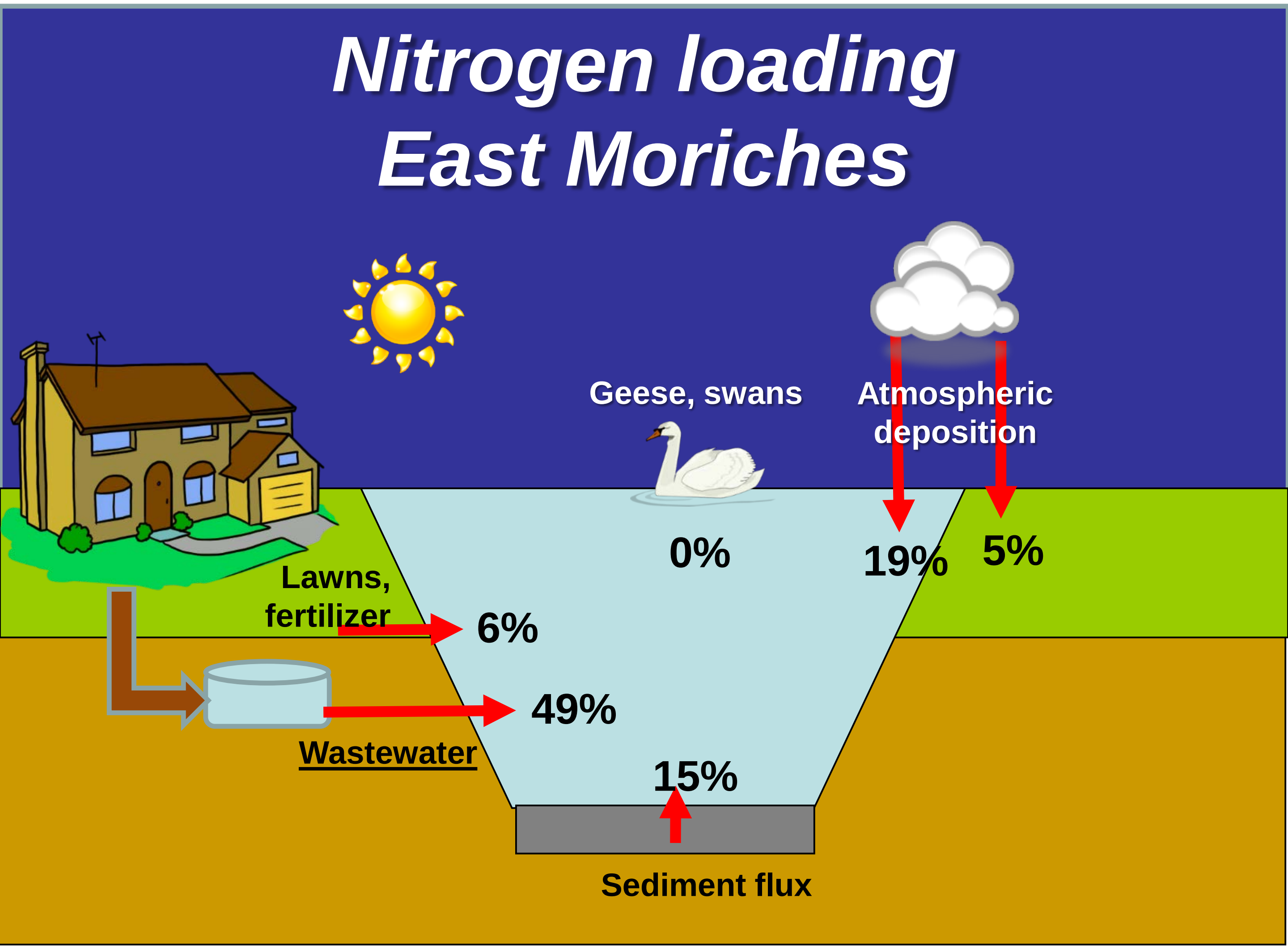


Figure 11. Current relative contribution of various nutrient loading processes to the total nitrogen load to East Moriches.



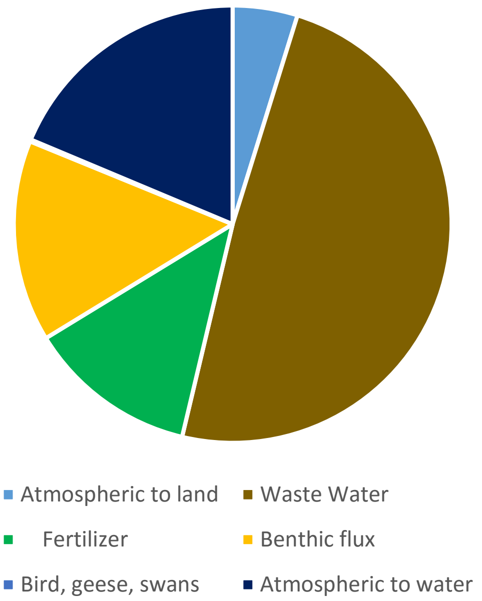
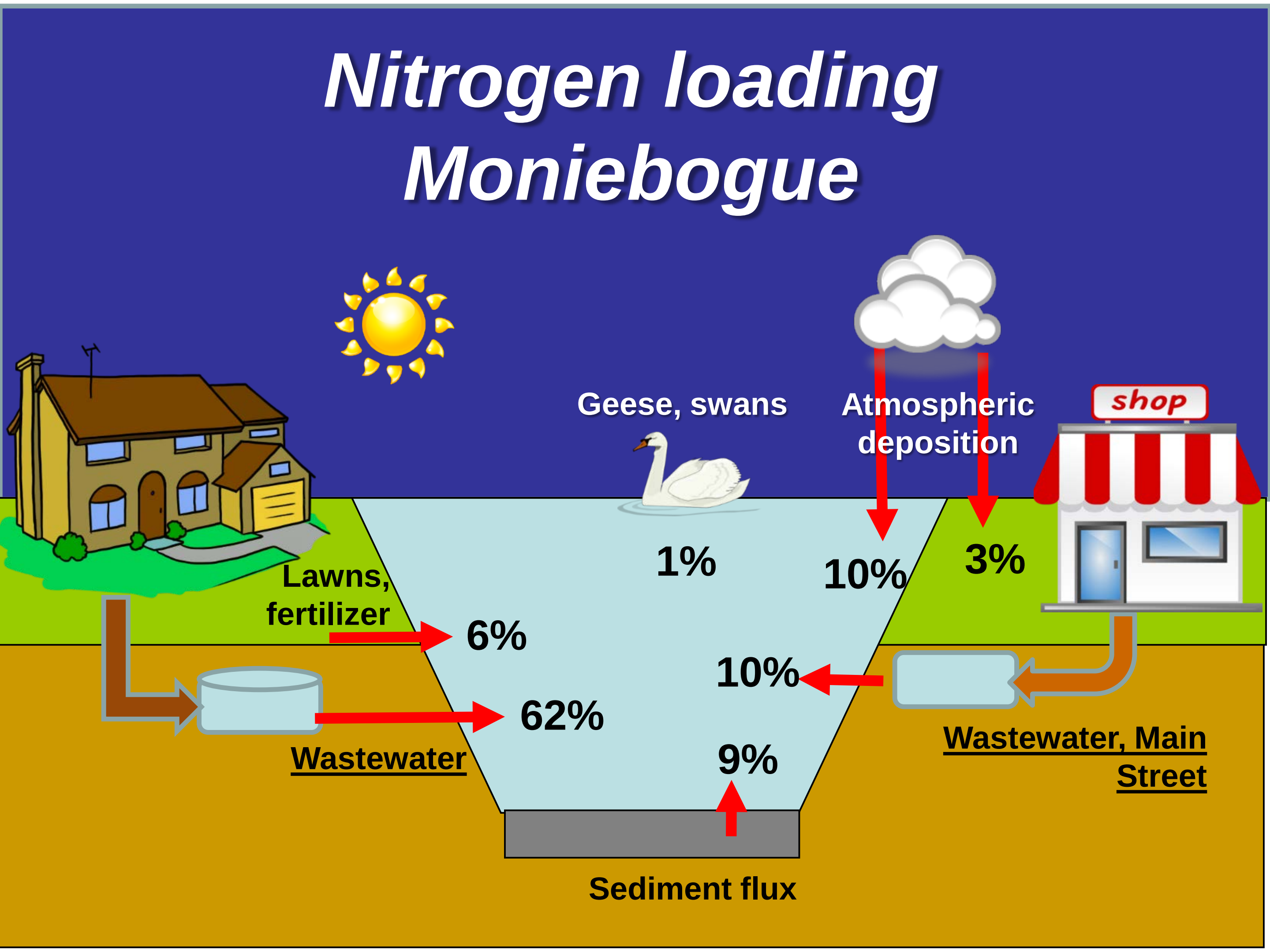


Figure 12. Current relative contribution of various nutrient loading processes to the total nitrogen load to Moniebogue bay.



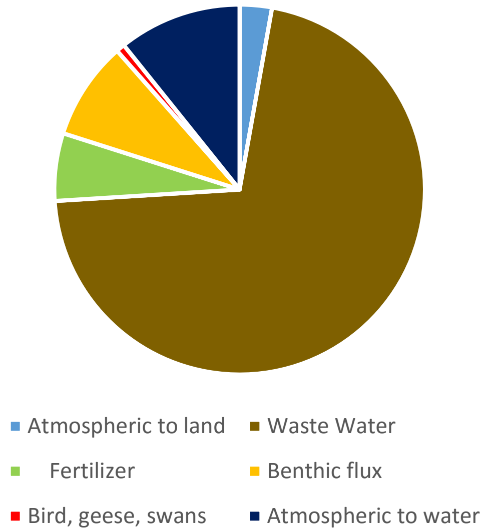


Figure 13. Current relative contribution of various nutrient loading processes to the total nitrogen load to Quantuck bay.

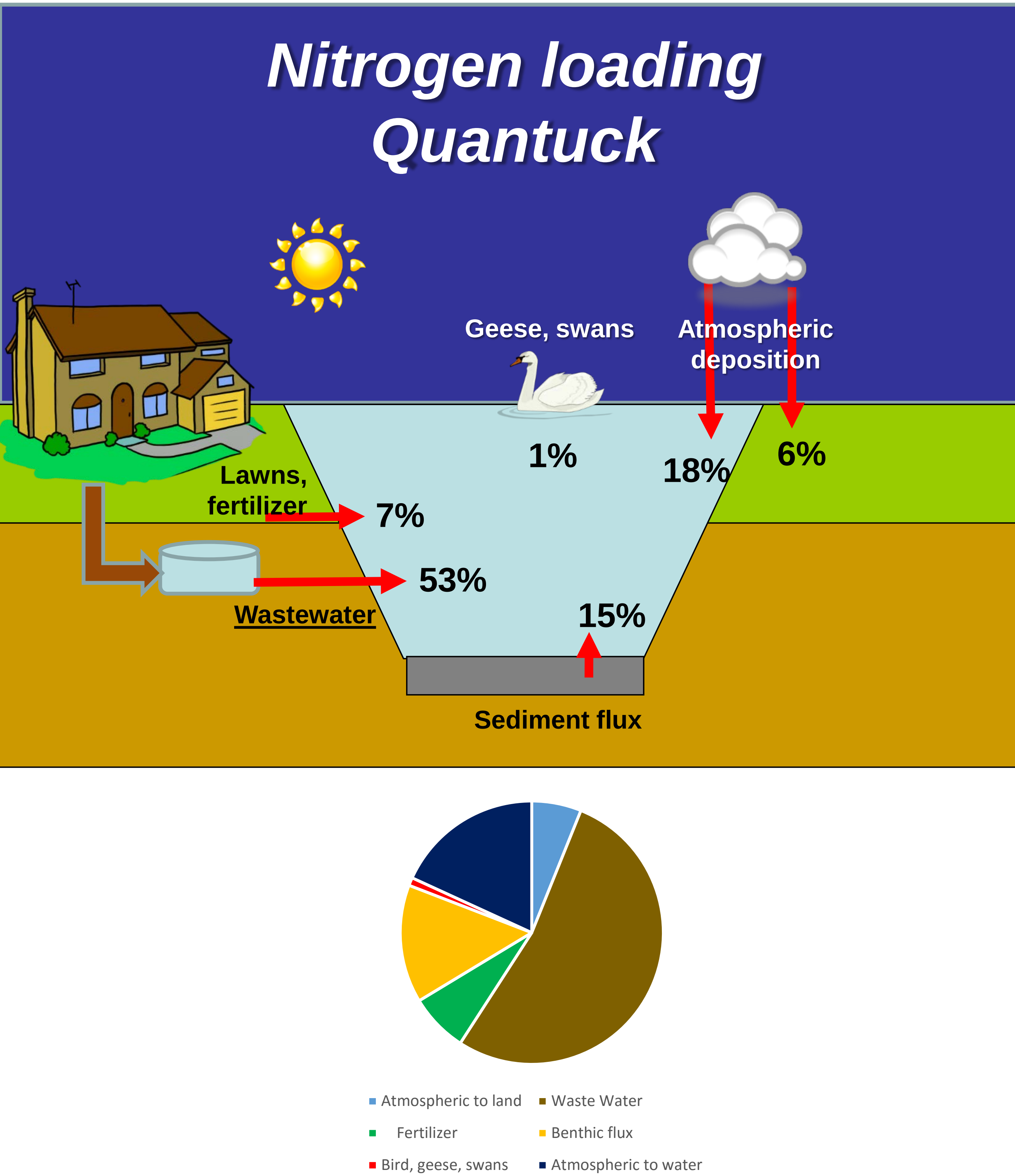


Figure 14. Extent of proposed sewer improvement areas for phases 1 – 3.

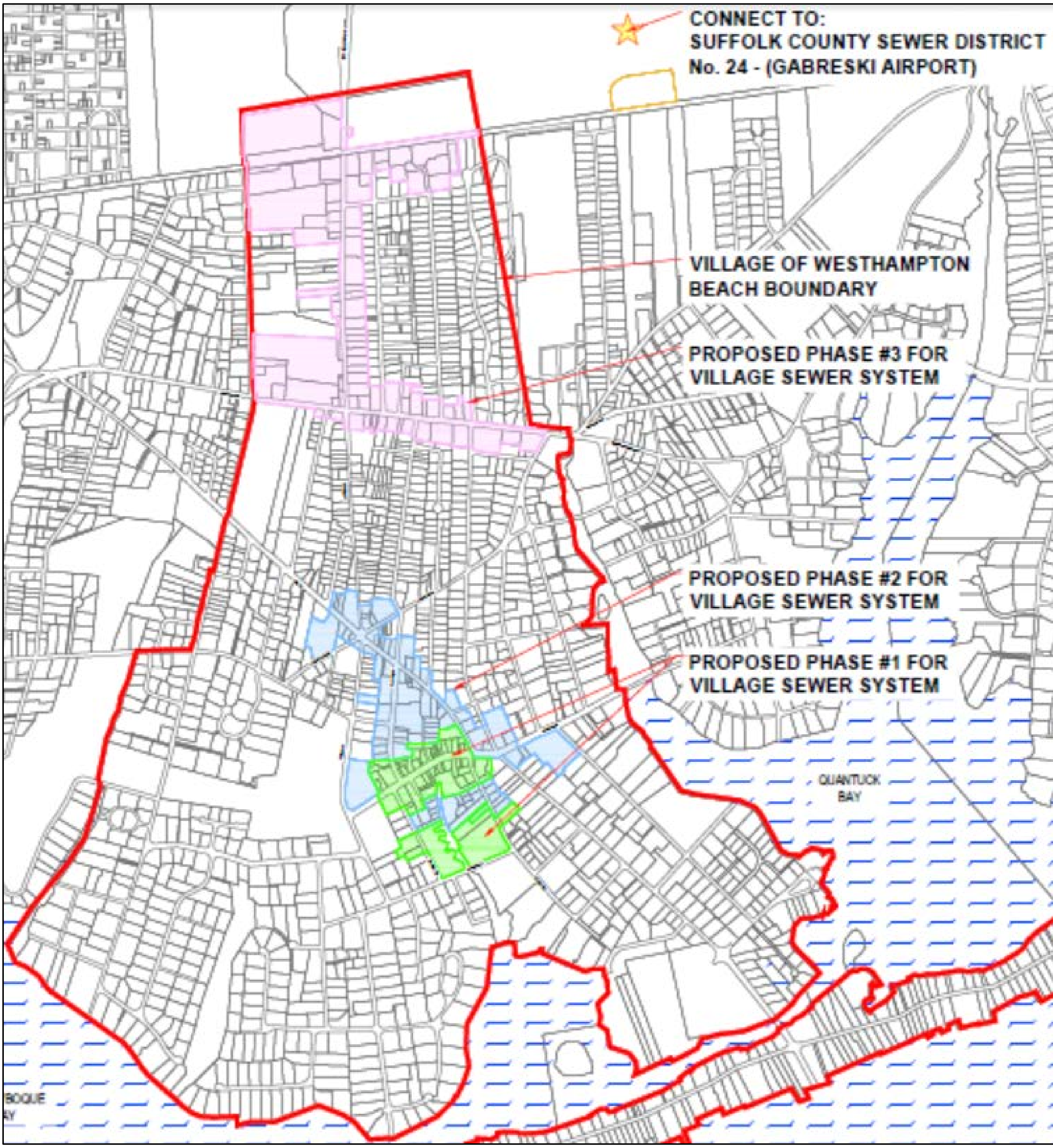


Figure 15. Extent of proposed sewer improvement area through phase 4 is outline in orange. The percent of watershed area captured by phase 4 proposal are labeled in the sections of phase 4 boundary.

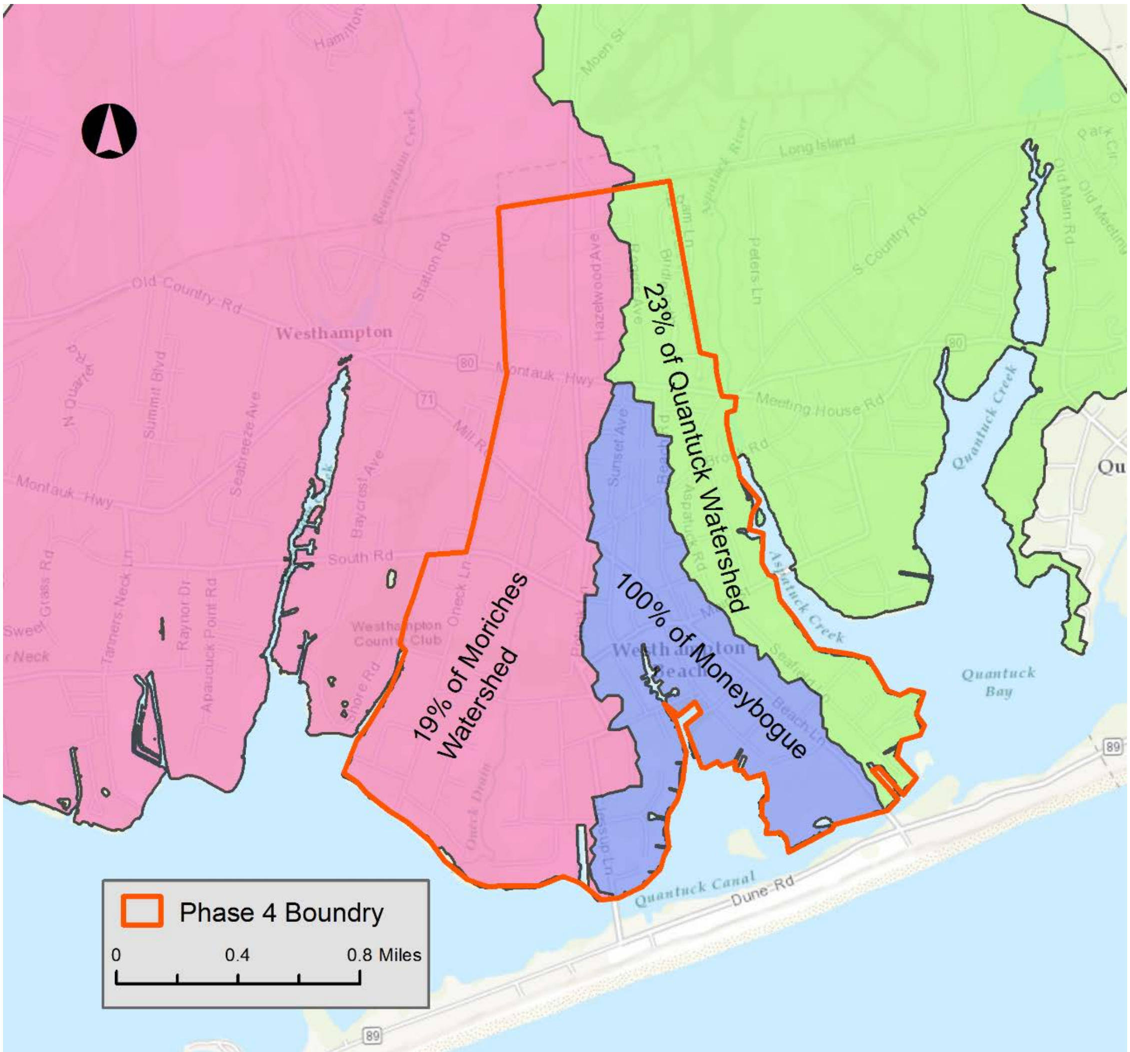


Figure 16. Modeled total nitrogen loads in East Moriches for each proposed phase.

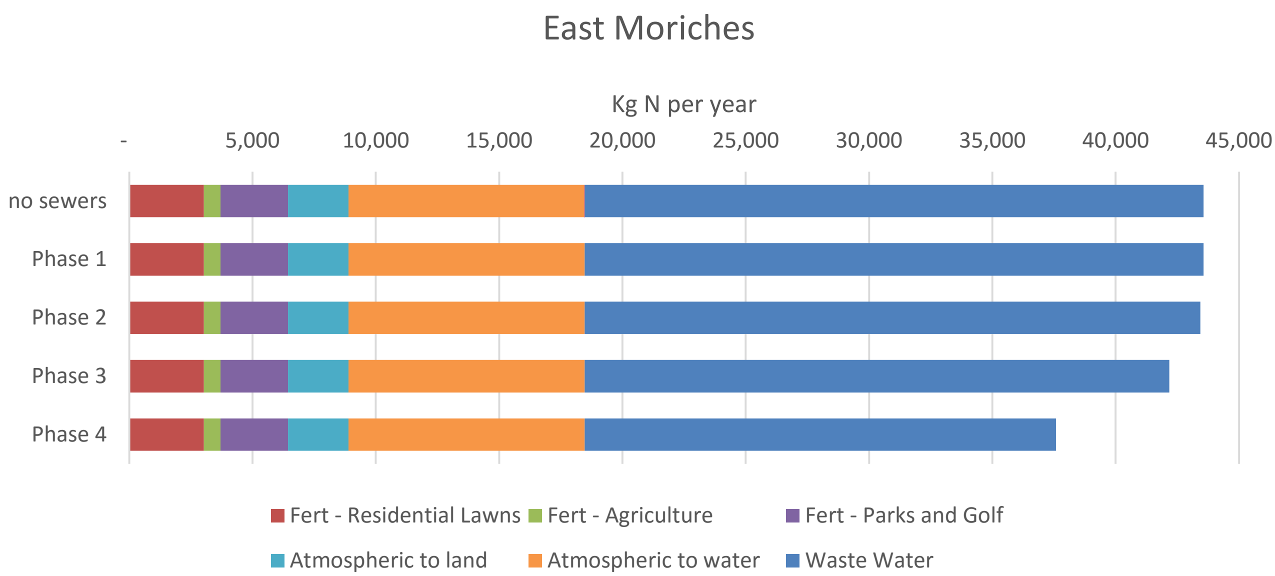


Figure 17. Modeled total nitrogen loads in Moniebogue for each proposed phase.

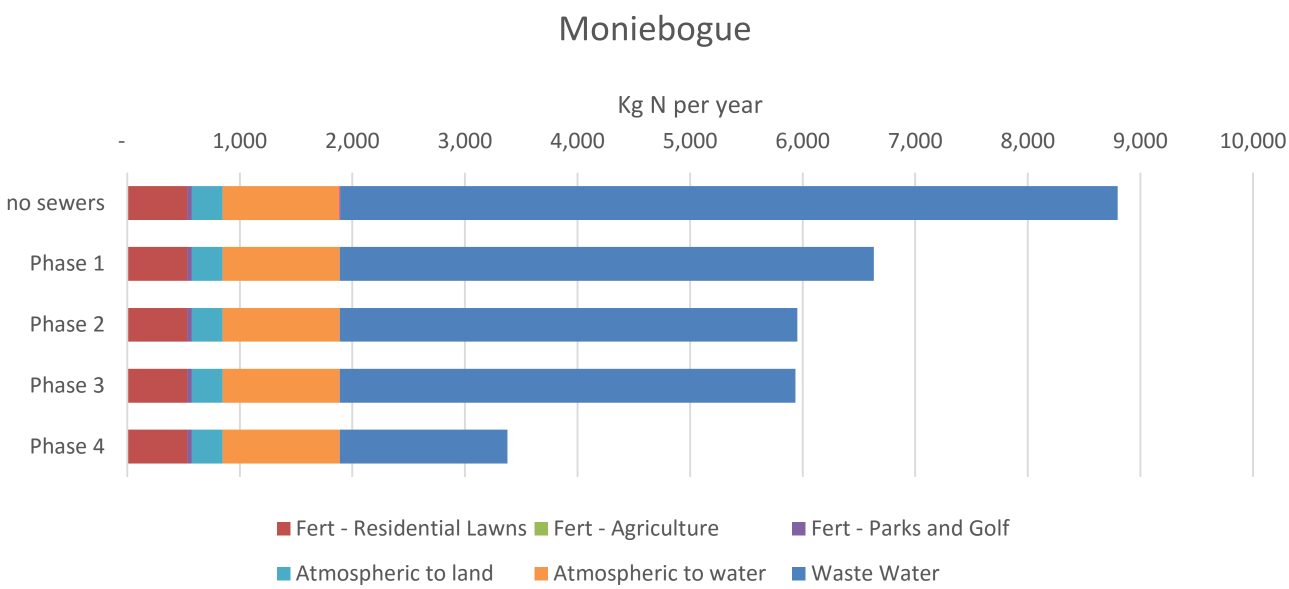


Figure 18. Modeled total nitrogen loads in Quantuck for each proposed phase.

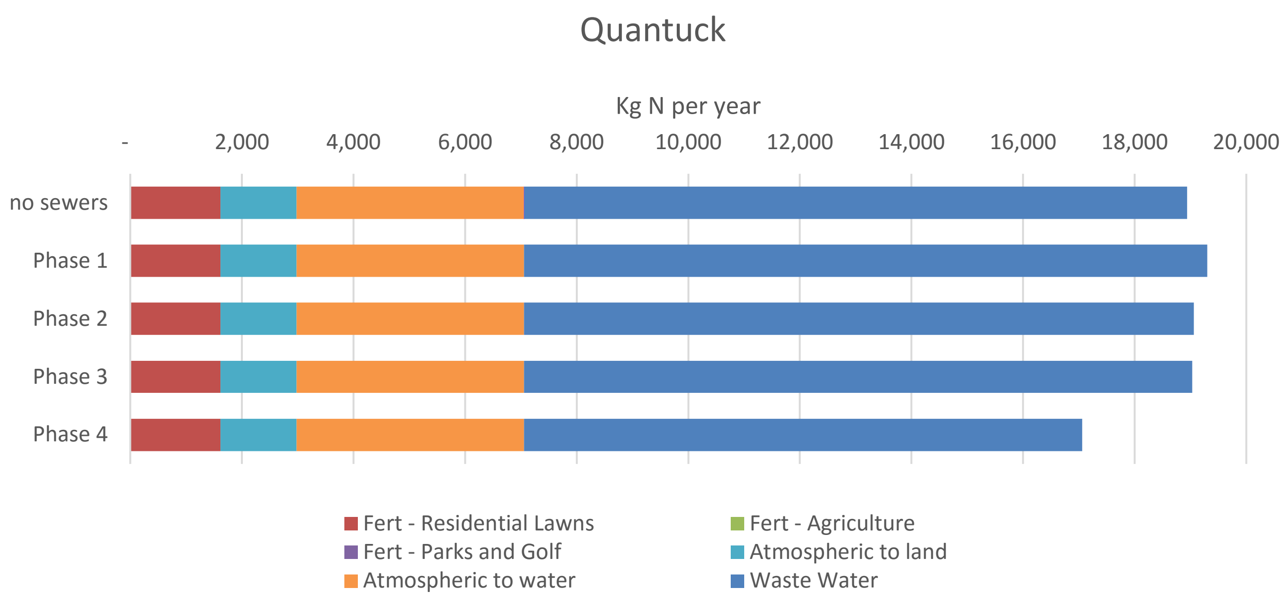


Figure 19. The village only contains a small portion of the larger watersheds, this plot scales back the total N load to 21,431 kg per year which is the amount the Village is geographically responsible for. It essentially limits the study area to the village boundaries instead of the watershed boundaries. All sources of nitrogen, external and internal, are included.

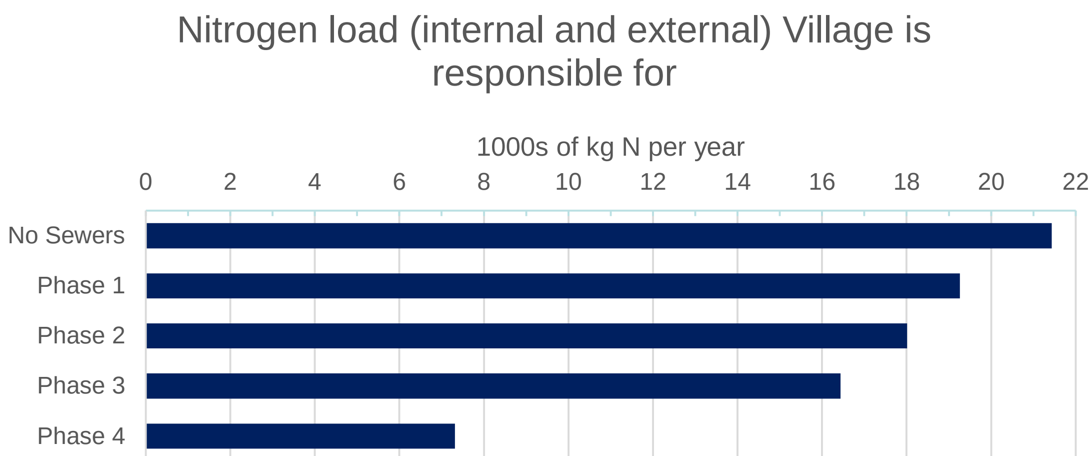


Figure 20. Wastewater and fertilizer sourced nitrogen load with the study area limited to the village boundaries instead of the watershed boundaries.

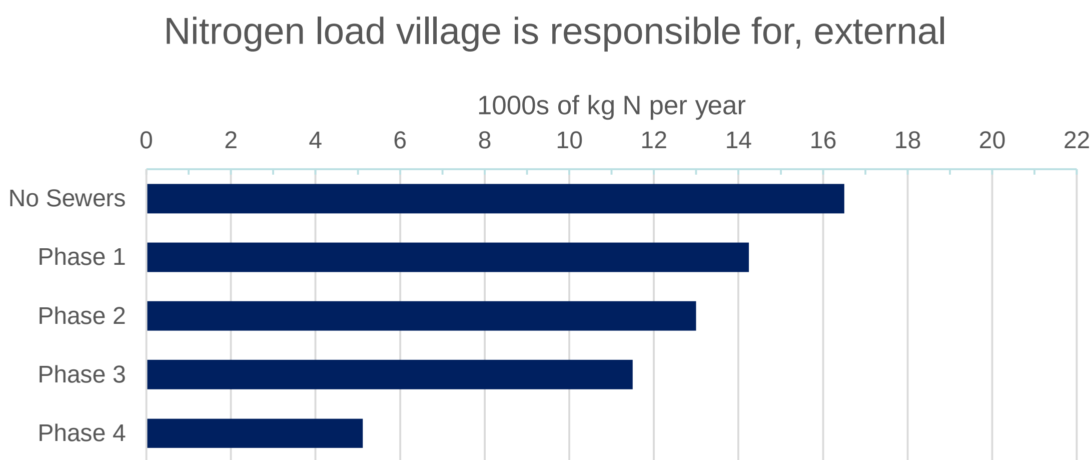


Figure 21. Nitrogen loading rates from the Village of Westhampton Beach with and without future growth of 100,000 square feet of space and with and without the implementation of the sewer district (phase 1) and advanced septic systems (phase 4).

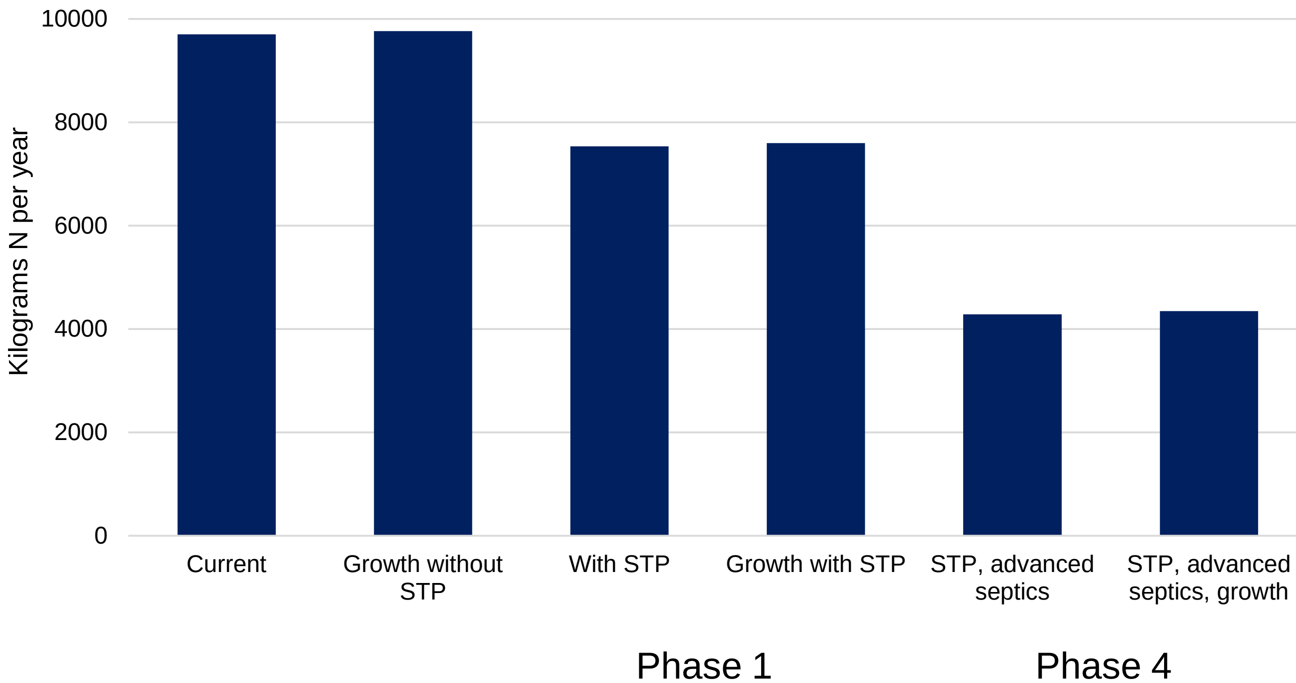


Figure 22. Changes in nitrogen levels, brown tide, and chlorophyll levels with differing levels of nitrogen reduction as modeled for Quantuck Bay.

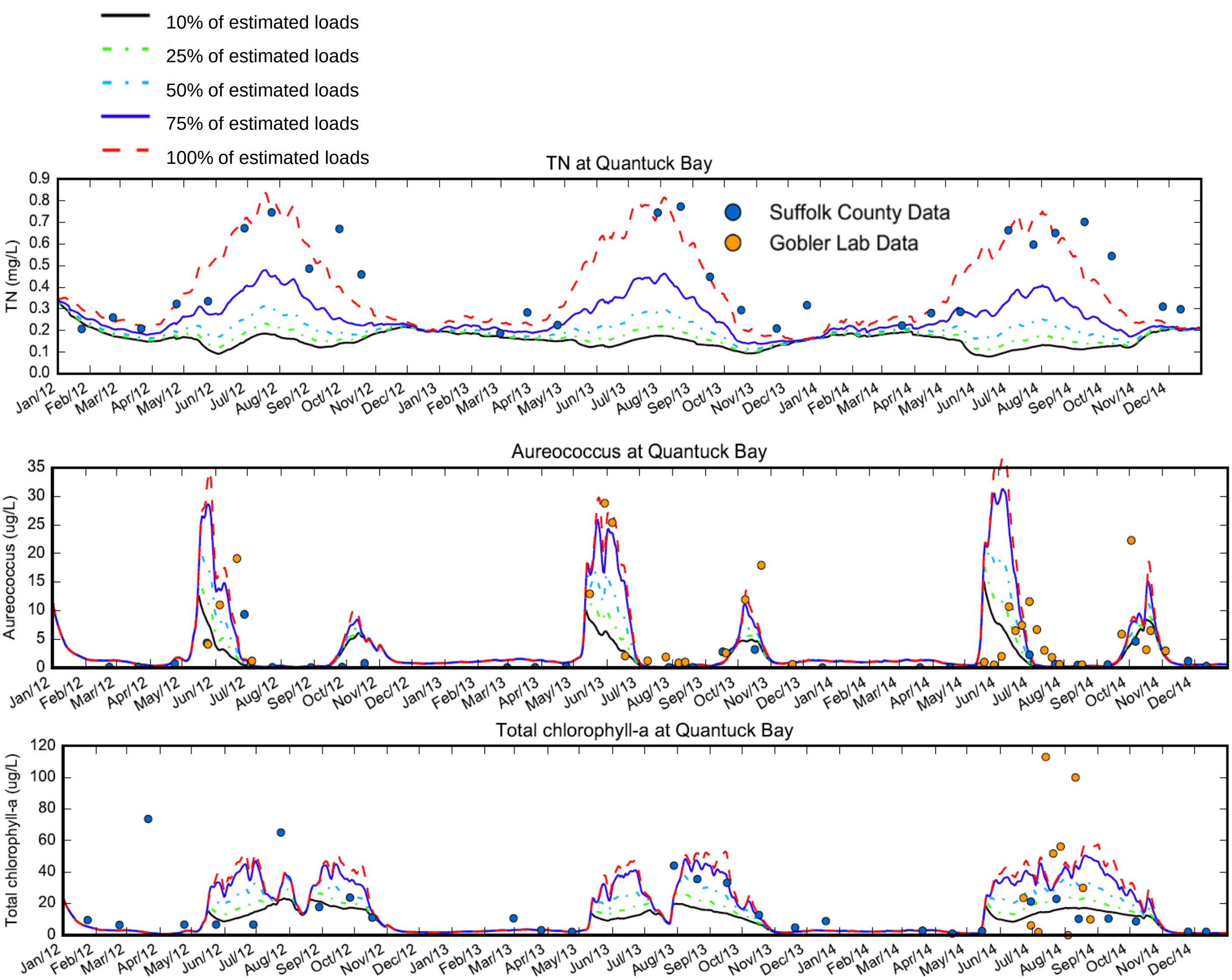


Table 1. Inputs used for the nitrogen loading model constructed for this study.

	E Moriches	Moniebogue	Quantuck	Units	Source
Watershed area	1598	172	962	ha	ArcGIS®
Area of wetlands (freshwater)	225	0	110	ha	NYS freshwater wetlands maps
Area of agriculture	19	0	0	ha	Suffolk County Land Use and Land Cover dataset
Area of golf courses	41	0	0	ha	Open Street Map, Manual Delineation
Area of parks and athletic field lawns	23	2	0	ha	Suffolk County Land Use and Land Cover dataset
Impervious surfaces total	274	43	192	ha	Low NDVI created from USGS High Resolution Orthoimagery, open water areas removed.
Area of freshwater ponds	10	0	6	ha	Suffolk County Land Use and Land Cover dataset
Percent of buildings with cesspools	50	50	50	%	Southampton GIS department (houses built before 1973 have cesspools) (SB, QB), estimate MB
Area of residential lawns	248	44	133		High NDVI (USGS HRO), limited to residential parcels, limited to areas where LiDAR height data was near zero. (USGS LiDAR)
Percent of parcels with fertilized lawns	90	90	90	%	Suffolk County Recommendations
Total area of roofs	63	14	35	ha	Suffolk County building footprint dataset, 2006
Area of Driveways	123	19	132	Ha	Impervious layer limited to developed parcels
Area of road	49	11	24	ha	Impervious layer limited to non-taxed parcels
Nitrogen inputs from wet and dry deposition	5.37	5.37	5.37	kg N ha^{-1} yr^{-1}	Suffolk County Recommendations
Fertilizer applied to golf courses	189.9	189.9	189.9	kg N ha^{-1} yr^{-1}	Suffolk County Recommendations
Fertilizer applied to parks and athletic fields	89.8	89.8	89.8	kg N ha^{-1} yr^{-1}	Suffolk County Recommendations
Fertilizer applied to agriculture	97.6	97.6	97.6	kg N ha-1 yr-1	Suffolk County Recommendations
Denitrification in the	7.5	7.5	7.5	%	Suffolk County Recommendations

Table 2. Current annual external nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

No Sewers	East Moriches (kg/yr)	Moniebogue (kg/yr)	Quantuck (kg/yr)	East Moriches (%)	Moniebogue (%)	Quantuck (%)
Atmospheric to land	2,457	273	1,367	7%	4%	9%
Waste Water	25,087	6,909	11,889	74%	89%	80%
Fert - Residential Lawns	3,027	534	1,615	9%	7%	11%
Fert - Agriculture	679	0	0	2%	0%	0%
Fert - Parks and Golf	2,733	40	0	8%	1%	0%
Fertilizer - all	6,440	574	1,615	19%	7%	11%
Total	33,983	7,755	14,871	100%	100%	100%

Table 3. Current annual nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

No Sewers	East Moriches	Moniebogue	Quantuck	East Moriches	Moniebogue	Quantuck
	(kg/yr)	(kg/yr)	(kg/yr)	(%)	(%)	(%)
Atmospheric to land	2,457	273	1,367	5%	3%	6%
Waste Water	25,087	6,909	11,889	49%	71%	53%
Fert - Residential Lawns	3,027	534	1,615	6%	6%	7%
Fert - Agriculture	679	0	0	1%	0%	0%
Fert - Parks and Golf	2,733	40	0	5%	0%	0%
Fertilizer - all	6,440	574	1,615	13%	6%	7%
Benthic flux	7,647	832	3,251	15%	9%	15%
Bird, geese, swans	73	73	219	0%	1%	1%
Atmospheric to water	9,578	1,043	4,072	19%	11%	18%
Total	51,282	9,703	22,413	100%	100%	100%

Table 4. Numbers of commercial and residential properties connected to the sewage treatment or receiving upgraded septic systems under the proposed Village of Westhampton Beach plan.

		Commercial	Residential	Total
Phase 1	Sewage treatment plant connections	68	88	156
Phase 2	Sewage treatment plant connections	46	23	69
Phase 3	Sewage treatment plant connections	55	97	152
Phase 4	Alternative onsite systems	96	1,955	2,051
Whole project	Sewage treatment plant connections and onsite systems	264	2,164	2,428

Table 5. Phase 1 annual nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load

Phase 1	East Moriches (kg/yr)	Moniebogue (kg/yr)	Quantuck (kg/yr)	East Moriches (%)	Moniebogue (%)	Quantuck (%)
Atmospheric to land	2,457	273	1,367	5%	4%	6%
Waste Water	25,087	4,742	12,250	49%	63%	54%
Fert - Residential Lawns	3,027	534	1,615	6%	7%	7%
Fert - Agriculture	679	0	0	1%	0%	0%
Fert - Parks and Golf	2,733	40	0	5%	1%	0%
Fertilizer - all	6,440	574	1,615	13%	8%	7%
Benthic flux	7,647	832	3,251	15%	11%	14%
Bird, geese, swans	73	73	219	0%	1%	1%
Atmospheric to water	9,578	1,043	4,072	19%	14%	18%
Total	51,282	7,537	22,774	100%	100%	100%

Table 6 . Phase 1 annual external nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

Phase 1	East Moriches (kg/yr)	Moniebogue (kg/yr)	Quantuck (kg/yr)	East Moriches (%)	Moniebogue (%)	Quantuck (%)
Atmospheric to land	2,457	273	1,367	7%	5%	9%
Waste Water	25,087	4,742	12,250	74%	85%	80%
Fert - Residential Lawns	3,027	534	1,615	9%	10%	11%
Fert - Agriculture	679	0	0	2%	0%	0%
Fert - Parks and Golf	2,733	40	0	8%	1%	0%
Fertilizer - all	6,440	574	1,615	19%	10%	11%
Total	33,983	5,589	15,232	100%	100%	100%

Table 7. Phase 2 annual nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

Phase 2	East Moriches	Moniebogue	Quantuck	East Moriches	Moniebogue	Quantuck
	(kg/yr)	(kg/yr)	(kg/yr)	(%)	(%)	(%)
Atmospheric to land	2,457	273	1,367	5%	4%	6%
Waste Water	24,967	4,063	11,438	49%	59%	53%
Fert - Residential Lawns	3,027	534	1,615	6%	8%	7%
Fert - Agriculture	679	0	0	1%	0%	0%
Fert - Parks and Golf	2,733	40	0	5%	1%	0%
Fertilizer - all	6,440	574	1,615	13%	8%	7%
Benthic flux	7,647	832	3,251	15%	12%	14%
Bird, geese, swans	73	73	219	0%	1%	1%
Atmospheric to water	9,578	1,043	4,072	19%	15%	18%
Total	51,162	6,858	21,962	100%	100%	100%

Table 8. Phase 2 annual external nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

Phase 2	East Moriches	Moniebogue	Quantuck	East Moriches	Moniebogue	Quantuck
	(kg/yr)	(kg/yr)	(kg/yr)	(%)	(%)	(%)
Atmospheric to land	2,457	273	1,367	7%	6%	9%
Waste Water	24,967	4,063	12,007	74%	83%	80%
Fert - Residential Lawns	3,027	534	1615	9%	11%	11%
Fert - Agriculture	679	0	0	2%	0%	0%
Fert - Parks and Golf	2,733	40	0	8%	1%	0%
Fertilizer - all	6,440	574	1615	19%	12%	11%
Total	33,864	4,910	14,989	100%	100%	100%

Table 9. Phase 3 annual nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

Phase 3	East Moriches (kg/yr)	Moniebogue (kg/yr)	Quantuck (kg/yr)	East Moriches (%)	Moniebogue (%)	Quantuck (%)
Atmospheric to land	2,457	273	1,367	5%	4%	6%
Waste Water	23,699	4,045	11,980	47%	59%	53%
Fert - Residential Lawns	3,027	534	1,615	6%	8%	7%
Fert - Agriculture	679	0	0	1%	0%	0%
Fert - Parks and Golf	2,733	40	0	5%	1%	0%
Fertilizer - all	6,440	574	1615	13%	8%	7%
Benthic flux	7,647	832	3251	15%	12%	14%
Bird, geese, swans	73	73	219	0%	1%	1%
Atmospheric to water	9,578	1,043	4072	19%	15%	18%
Total	49,894	6,840	22,504	100%	100%	100%

Table 10. Phase 3 annual external nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

Phase 3	East Moriches (kg/yr)	Moniebogue (kg/yr)	Quantuck (kg/yr)	East Moriches (%)	Moniebogue (%)	Quantuck (%)
Atmospheric to land	2,457	273	1,367	8%	6%	9%
Waste Water	23,699	4,045	11,149	73%	83%	80%
Fert - Residential Lawns	3,027	534	1,615	9%	11%	11%
Fert - Agriculture	679	0	0	2%	0%	0%
Fert - Parks and Golf	2,733	40	0	8%	1%	0%
Fertilizer - all	6,440	574	1,615	20%	12%	11%
Total	32,596	4,892	14,131	100%	100%	100%

Table 11. Phase 4 annual nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

Phase 4	East Moriches (kg/yr)	Moniebogue (kg/yr)	Quantuck (kg/yr)	East Moriches (%)	Moniebogue (%)	Quantuck (%)
Atmospheric to land	2,457	273	1,367	5%	6%	7%
Waste Water	19,106	1,488	10,005	42%	35%	49%
Fert - Residential Lawns	3,027	534	1615	7%	12%	8%
Fert - Agriculture	679	0	0	1%	0%	0%
Fert - Parks and Golf	2,733	40	0	6%	1%	0%
Fertilizer - all	6,440	574	1615	14%	13%	8%
Benthic flux	7,647	832	3251	17%	19%	16%
Bird, geese, swans	73	73	219	0%	2%	1%
Atmospheric to water	9,578	1043	4072	21%	24%	20%
Total	45,301	4,283	20,528	100%	100%	100%

Table 12. Phase 4 annual external nitrogen loading rates from the watershed to East Moriches, Moniebogue, and Quantuck in kilograms of nitrogen per year with percentages of the total nitrogen load represented by each process also shown.

Phase 4	East Moriches (kg/yr)	Moniebogue (kg/yr)	Quantuck (kg/yr)	East Moriches (%)	Moniebogue (%)	Quantuck (%)
Atmospheric to land	2,457	273	1,367	9%	12%	11%
Waste Water	19,106	1,488	9,174	68%	64%	77%
Fert - Residential Lawns	3,027	534	1,615	11%	23%	12%
Fert - Agriculture	679	0	0	2%	0%	0%
Fert - Parks and Golf	2,733	40	0	10%	2%	0%
Fertilizer - all	6,440	574	1,615	23%	25%	12%
Total	28,003	2,335	12,156	100%	100%	100%

Table 13. Percent reduction of nitrogen load each phase would achieve compared against current nitrogen loads considering internal and external nitrogen loading.

% reduction of N from phase	East Moriches	Moniebogue	Quantuck	All Combined
Phase 1	0%	22%	0%	2%
Phase 2	0%	29%	0%	3%
Phase 3	3%	30%	0%	5%
Phase 4	12%	56%	8%	16%

Table 14. Percent reduction of nitrogen load each phase would achieve compared against current nitrogen loads considering external nitrogen loading only.

% reduction of N from phase	East Moriches	Moniebogue	Quantuck	All Combined
Phase 1	0%	28%	0%	3%
Phase 2	0%	37%	0%	5%
Phase 3	4%	37%	0%	7%
Phase 4	18%	70%	13%	23%

Table 15. Percent reduction of nitrogen load each phase would achieve. The first column contains all sources of nitrogen load to the waterbody, the second only contains external sources controllable by the Village, wastewater and fertilizer

	Wastewater, Fertilizer, Atmospheric to land, Atmospheric to water, Benthic, Birds	Wastewater, Fertilizer, Atmospheric to Land
Phase 1	10%	14%
Phase 2	16%	21%
Phase 3	23%	30%
Phase 4	66%	70%