Modeling nitrogen source loads on the north shore of Long Island

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Synopsis

The best available spatial and tabular data on land use/land cover, population statistics, atmospheric deposition rates, on-site wastewater systems, sewage treatment plants, and fertilizer application rates were input into the Nitrogen Loading Model (NLM) to quantify nitrogen loads from wastewater, fertilizer, and atmospheric deposition sources to the north shore of Long Island from Little Neck Bay to Northport Bay. Wastewater was found to be the largest land-based contributor of nitrogen in the thirteen subwatersheds modeled. In particular, on-site waste disposal systems (septic systems and cesspools) were the major source in all except one subwatershed. To a lesser degree, atmospheric deposition and fertilizer sources contribute to the total loading. While similar nitrogen reduction measures will be needed across the study area in order to reduce the harmful symptoms of eutrophication, the total load and characteristics of each subwatershed and embayment vary, and strategies to reach specific nitrogen load reduction targets should be tailored to the conditions of each subwatershed.

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Introduction

Excessive loading of reactive forms of nitrogen to surface waters is degrading estuaries and coastal waters around the world (Smith 2003). In and around Long Island NY, eutrophication is causing hypoxia, harmful algal blooms, fish kills, acidification, and loss of critical habitats such as seagrasses and salt marshes (Cloern 2001, Deegan *et al*. 2012, Latimer and Charpentier 2010). While the impacts of nitrogen pollution may vary from embayment to embayment, the north shore of Long Island has not been spared its harmful effects. As long ago as 1975, local planners stated that "the increased nitrate content of ground water and streams, mainly due to infiltration of sewage and leachate from chemical fertilizers, is a major water quality problem in Nassau County" (Nassau and Suffolk Counties 1975). Since that time, two large sewage treatment plants were built to service Nassau County's southern and central sections, but a considerable portion of the north shore remains unsewered. Beginning in the 1980s, harbor protection committees were established by municipal agreement on the north shore to deal with pollution from a variety of sources, including sewage from both onsite systems and the few small sewage treatment plants that service population centers on the north shore. In 2014, five New York State agencies recommended financial assistance to Nassau County "to assist in addressing priority water quality problems involving…sub-standard septic system 'hot-spots' in northern Nassau County." (NYS DEC 2014) There are also multiple documentations of harmful algal blooms in the Northport-Huntington Harbor complex (Hattenrath-Lehmann *et al*. 2013), including types that cause paralytic and diarrhetic shellfish poisoning.

Excessive nitrogen loading primarily derives from anthropogenic wastewater, fertilizer application, and atmospheric deposition and is conveyed to receiving water bodies through ground and surface water flow as well as directly to the embayment surface from the atmosphere (Valiela *et al*. 1997). The first step to address the problem of nitrogen pollution is to understand the relative magnitude of these sources and the total nitrogen load entering particular bays and harbors. This type of information serves multiple purposes. Firstly, it can help educate communities as to the primary sources of nitrogen pollution in their location such that further study and action can be taken. Secondly, it provides watershed comparisons and first order baseline load estimates against which nitrogen reduction targets may be set to try to achieve a desired state of ecosystem recovery. Thirdly, once a baseline is established, the model input can be adjusted to forecast the nitrogen load impact of anticipated land use, land cover, or wastewater management changes based on build-out or various mitigation scenarios.

With the foregoing in mind, the purpose of this study was to model the current sources and loading rates of nitrogen in thirteen subwatersheds along the north shore of Long Island. The outputs of such a model in combination with stakeholder input and other hydrologic, water quality and ecological data can be used to develop nitrogen reduction targets and strategies at the subwatershed scale. In this region, some of the sources of reactive nitrogen that load surface waters (cesspools and septic systems) are also a significant source of pathogen pollution that is closing bathing beaches and contaminating shellfishing area (Environmental Technology Group 2013, Ruiz 2014). Because pathogen pollution is a human health, quality of life, and economic threat, reducing pathogen pollution is a regulatory mandate passed down to communities and the local governments that represent them. The findings of this report highlight the value of considering strategies and projects that will simultaneously mitigate both nitrogen and pathogen pollution where they are originating from the same source(s).

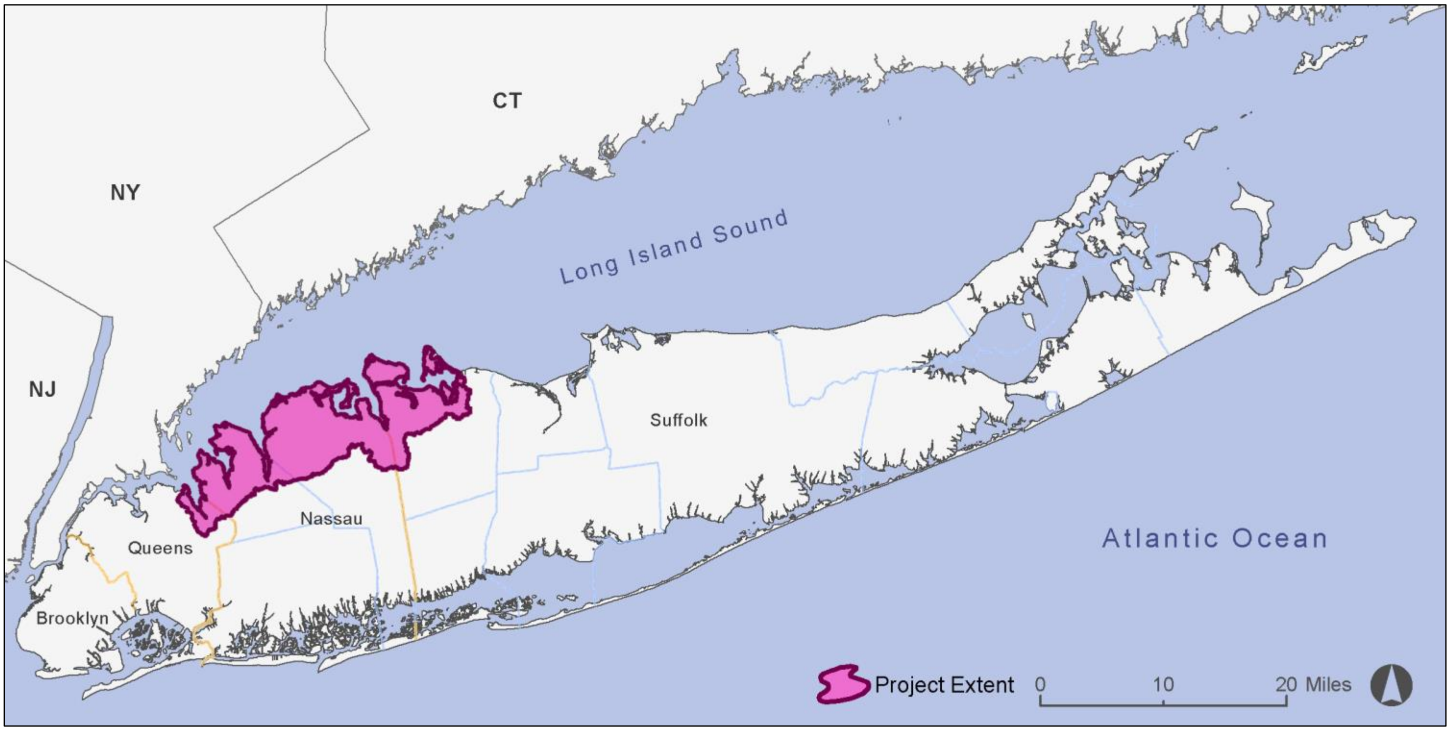

Figure 1 - Project area extent

Methodology

Nitrogen loading is caused directly by human activity on the land and indirectly by land cover changes that affect the rates and concentrations at which nitrogen is transported through the system. The availability of well-tested models and high resolution land use/land cover data makes it possible to reliably estimate the relative and absolute contributions of nitrogen from wastewater, fertilizer, and atmospheric deposition at a watershed or subwatershed scale.

Model selection

The model selected for use in this study is the Nitrogen Loading Model (NLM) developed by researchers at the Marine Biological Laboratory in Woods Hole, MA. NLM has been used widely along the Northeast coast, in part because it can quantify sources of nitrogen with relative ease and accuracy, utilizing existing information about atmospheric deposition rates, on-site wastewater systems, sewage treatment plant outputs, fertilizer application rates, and spatial data on population, land use, and land cover (Bowen and Valiela 2004). NLM has been used by academic researchers and the US Environmental Protection Agency; it has been validated in other watersheds (Valiela *et al*. 1997) and against other models such as the US Geological Survey SPARROW model (Valiela *et al*. 2000, Latimer and Charpentier 2010). The NLM is also intended for use in primarily groundwater-driven systems, which makes it particularly applicable to Long Island. Lastly, although it is a relatively simple model, most of the inputs and parameters can be made site-specific where there is locally available data or expert knowledge. The NLM has previously been used locally and regionally to model nitrogen loading to Great South Bay (Kinney and Valiela 2011), Shinnecock and Moriches Bays (Stinnette 2014), select Long Island Sound estuaries (Woods Hole Group 2014), select watersheds across southern New England (Latimer and Charpentier 2010), and across the full Long Island Sound region (Vaudrey *et al.* 2016)

Modeling approach

While the model may be run with its default parameters, the more the model is tailored to the local context, the more meaningful the results. To obtain locally relevant information, The Nature Conservancy met with representatives of three Harbor Protection Committees (Manhasset Bay PC, Hempstead Harbor PC, and Oyster Bay/Cold Spring Harbor PC) throughout the modeling process. An initial meeting was held June 2nd, 2015 to explain the model and its assumptions and to refine NLM's data inputs and parameters. A preliminary version of the model was then completed and results were presented to the stakeholder group on September 29th, 2015. Additional feedback was obtained and incorporated into the final model, where feasible.

Project area extent and subwatershed delineation

The area of this study is focused on thirteen embayments along the north shore of Nassau County and northwestern Suffolk County bounded on the west by Little Neck Bay on the Queens/Nassau County border and on the east by Northport Bay in the Town of Huntington. For the model to have greatest accuracy and utility, delineating subwatersheds is a key first step. The development of subwatersheds enables the calculation of total nitrogen load and percent contribution by source at the scale at which the delineations are made. Although the United States Geological Survey (USGS) is currently working on updating precise maps of groundwatersheds throughout Long Island, the results are not yet available. For this analysis, delineations at the embayment level were produced using ArcHydro 2.0 tools and a digital elevation model to determine the catchment areas, using USGS HUC-level 12 (Hydrologic Unit Codes) as a guideline. The catchments were aggregated by the embayment to which water flows to create the subwatershed dataset as shown in Figure 2.

Figure 2 - Subwatershed boundaries

Model inputs and parameters

The NLM estimates nitrogen load from three major sources: fertilizer (residential, agricultural, and recreational (golf courses, parks, athletic fields)), wastewater (cesspools, septic systems, and sewage treatment plants), and atmospheric deposition (wet and dry deposition). For each of these inputs, a number of datasets were collated at the highest resolution available and summarized at the subwatershed scale in a geographic information system. In the absence of localized data, we utilized the NLM default parameters that are described in Bowen and Valiela 2004 and Valiela *et al*. 1997. The data collected and assumptions made for the three major nitrogen sources are described in the following sections and in Appendix B and C. For further background on the assumptions and development of NLM, see: Kinney and Valiela 2011, Latimer and Charpentier 2010, Bowen and Valiela 2004, Valiela *et al*. 2000, Valiela *et al*. 1997.

Wastewater

The NLM calculates the contribution of nitrogen load from on-site cesspools and septic systems and sewage treatment plants. Sewage treatment plant locations were obtained for both Suffolk and Nassau County and those within the subwatershed boundaries were selected for inclusion in the analysis; these facilities included: Belgrave, Glen Cove, Great Neck, Oyster Bay, Port Washington, Huntington, and Northport. Tabular data summarizing pounds of nitrogen per day for these facilities was obtained from the NYS Department of Environmental Conservation. Initially this data was then converted into an average annual load in kilograms of nitrogen based on five years of data; however, due to recent upgrades and the consolidation of the Great Neck and Great Neck Village plants, the most recent two-year average was determined to be a more accurate representation of current loading, while still accounting for some yearly variation. These total annual loads were attributed to the receiving embayment based on their outfall location. It is important to note that because most sewer districts do not align with watershed boundaries the total load from sewage treatment plants is not always entirely representative of the population living within the watershed. For example, a sewered community may contribute its wastewater loading to an adjacent watershed and embayment rather than the one where the homes and businesses hooked up to it are located.

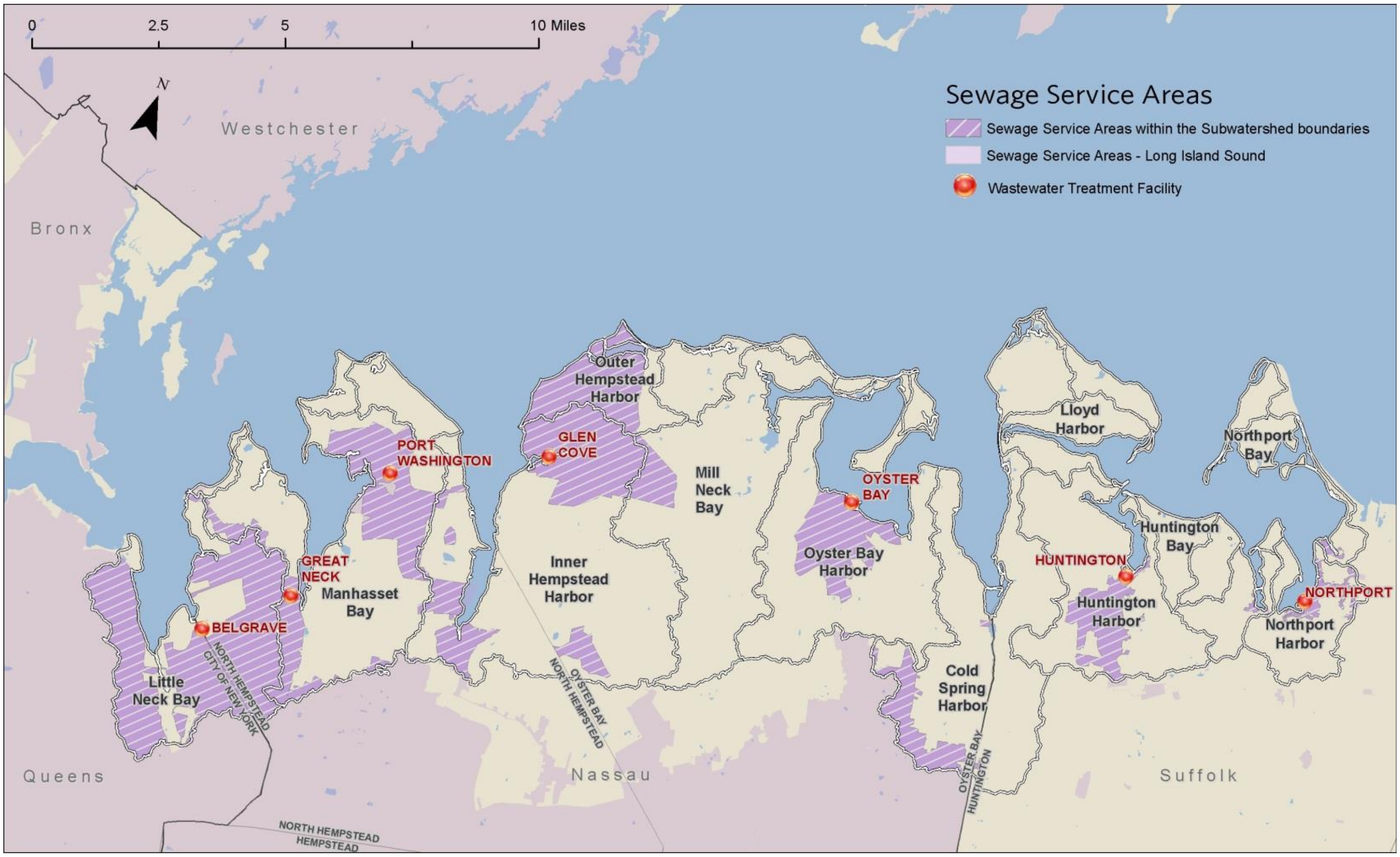

Figure 3 - Sewage treatment plants and sewered areas

For non-point wastewater sources, the NLM uses a set of researched assumptions on cesspools and septic systems because there is usually a lack of data on their precise locations and loading rates. The NLM estimates this load based on the number of people within a subwatershed and an assumption of per- person nitrogen loading of 4.8 kg N/year (Valiela *et al.* 1997). This is the amount of nitrogen entering a septic or cesspool system, which is then multiplied by transport rates of nitrogen as water moves through these systems, the subsurface, and aquifer. On Long Island, where by regulation septic systems use leaching pits as opposed to leaching fields, there is a less substantial difference between a septic system and a cesspool in terms of removal of nitrogen. While census data is the best available data on population, it unfortunately is not at an ideal representation of population at a watershed scale because census blocks cross watershed boundaries. As such, we used parcel data and sewer district boundaries to determine the number of unsewered residential housing units for each subwatershed. This was then multiplied by an average household size based on an area-weighted average of the census block groups within a particular subwatershed to yield a total population by subwatershed. In addition, the unsewered population within 200m and outside 200m of the embayment was calculated as the NLM equation assumes no further loss of nitrogen within the aquifer for the those households very close to shore (Valiela *et al.* 1997).

Unfortunately, calculating nitrogen loading from cesspools and septic systems in this way does not capture the input from non-residential septic systems. Businesses, restaurants, offices, and other building types are not accounted for in the non-point source wastewater load calculation. This is in part because the model assumes that non-residential facilities within a subwatershed are primarily used by people living in that area. In other words, if a person within the watershed utilized a septic system at a nearby restaurant, this would substitute for the load they would have contributed at home. This assumption breaks down when a large number of people live outside the watershed but use non-residential systems within it. These types of on-site systems can vary in size and usage, making it difficult to estimate their average annual nitrogen load. Estimates of the number of non-residential on-site systems were included in the results as a supplemental analysis. In contrast, non-residential inputs are accounted for from sewage treatment plants because those inputs are reported by NYS DEC based on what is discharged in the cumulative sewage effluent. In sum, estimates of nitrogen loading from cesspools and septic systems in this study are likely conservative because they do not include non-residential inputs.

Atmospheric deposition

How much nitrogen from atmospheric deposition reaches the embayment is determined by the rate of wet and dry deposition as well as the type of land surface upon which nitrogen is deposited. The NLM utilizes nitrogen transport rates associated with different land cover types, such as natural vegetation, turf, and impervious surfaces, which determines how much nitrogen travels from the surface to the vadose zone, to the aquifer, and eventually to the receiving water body. For instance, naturally vegetated areas are assumed to transport only 35% of nitrogen to the vadose zone, whereas agricultural lands transport 38% (Valiela *et al.* 1997). For impervious surfaces such as roads and parking lots, on the other hand, there is no uptake by plants and soils as nitrogen largely flows into gutters and drains where it collects in catch basins in the vadose zone (Valiela *et al.* 1997). In addition, there is direct loading to embayment surface from atmospheric nitrogen.

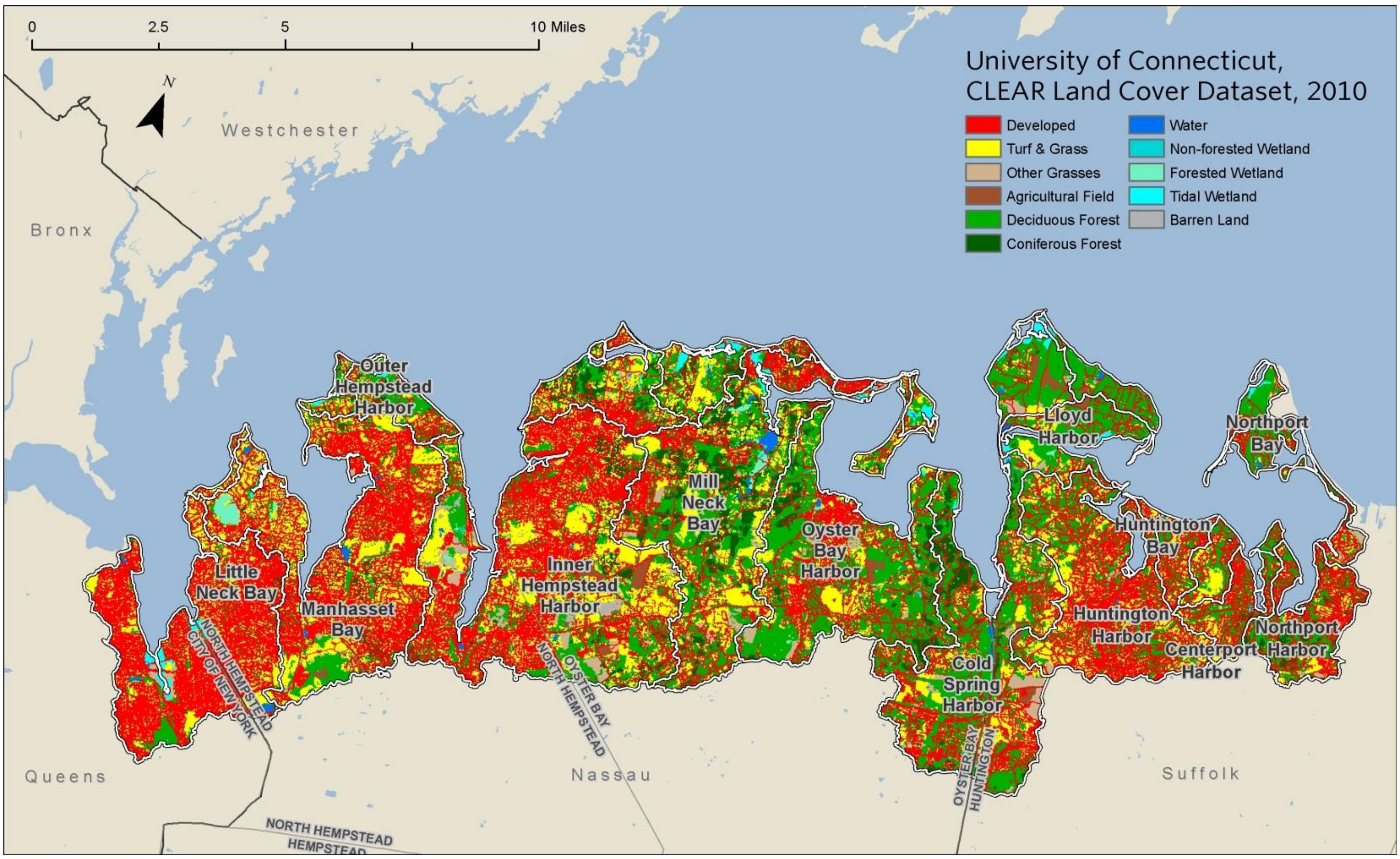

Figure 4 - Land cover within project area extent (UCONN CLEAR 2010)

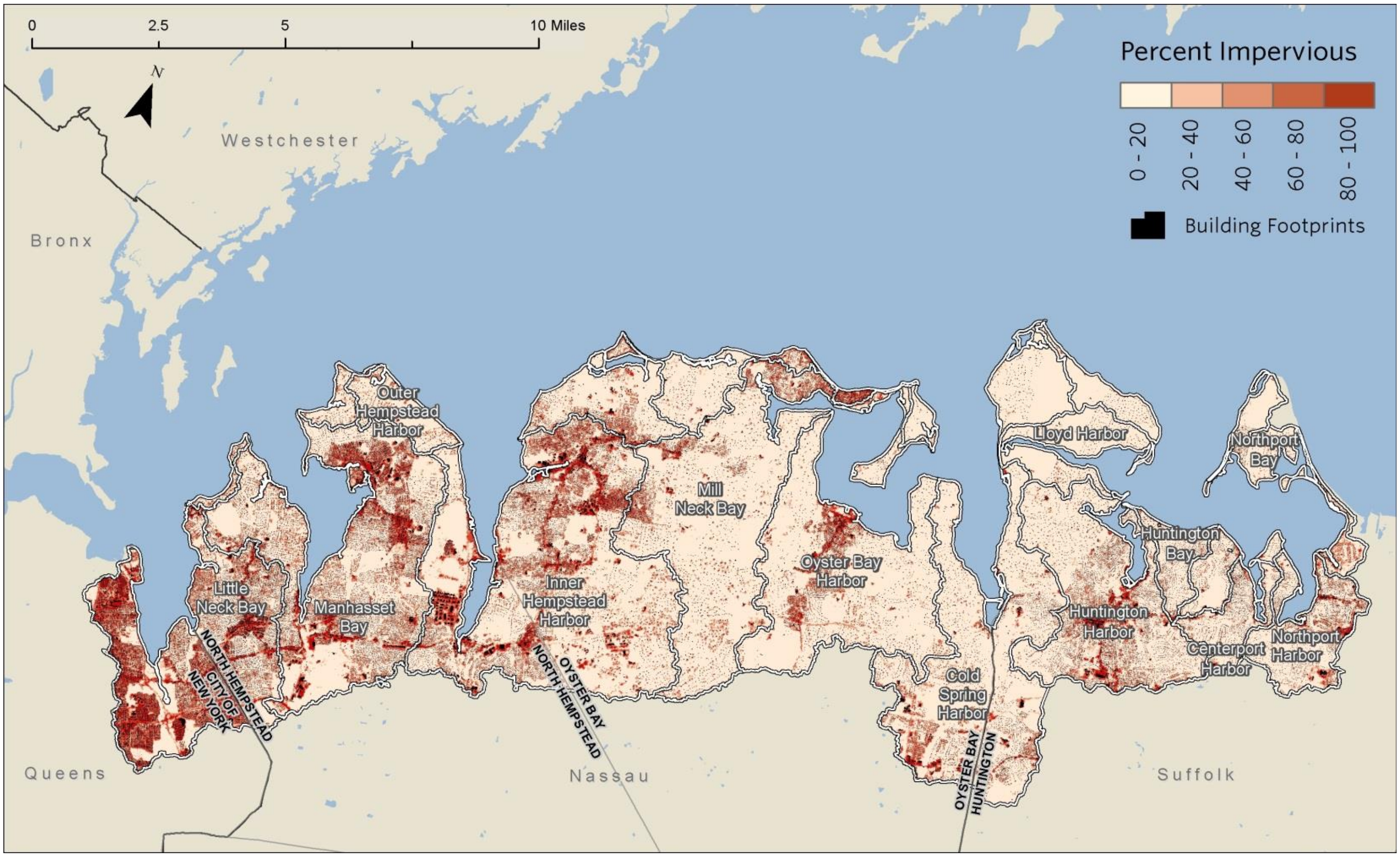

Figure 5 - Impervious surfaces (National Land Cover Dataset 2011) and building footprints (Suffolk and Nassau Co.)

The model requires two major datasets summarized by subwatershed: 1) rates of wet and dry deposition 2) land cover types by area (including area of the embayment surface itself). Atmospheric deposition rates were obtained from the National Atmospheric Deposition Program's (NADP) for wet deposition rates, and supplemented by data from Clean Air Status and Trends Network (CASTNET) to get an average annual loading from dry deposition. We averaged the three most recent years of data, across two sites for wet deposition (Cedar Beach, NY; Bronx, NY) and three sites for dry deposition (Abington, CT; Claryville NY; Washington Crossing, NJ) to get a total nitrogen deposition rate. This total average nitrogen deposition rate was applied equally to all land and water in the study area. The best available land cover data for the study area came from UCONN Center for Land Use Education and Research (CLEAR). Because this dataset, however, did not contain impervious surface information, it was supplemented with data from the National Land Cover Dataset (NLCD), and with building footprint data from Nassau and Suffolk County to estimate impervious surfaces by subwatershed for the model. These datasets were synthesized to produce simplified land cover area statistics for each subwatershed to input into the spreadsheet NLM.

Fertilizer

As with atmospheric deposition, fertilizer inputs to the model are based on two general assumptions: rates of application and the amount of land area being fertilized. When combined, these two figures provide an estimate of the total nitrogen load from fertilizer applied to the surface of the watershed. Fertilizer in the model was categorized as residential (lawn application), agricultural, and recreational (golf course, park/athletic field application). For each, rates of application and land areas were needed. Land areas were obtained in a two-step process. Parcel data from Nassau and Suffolk County were first utilized to extract residential, agricultural, and recreational parcels based on their corresponding land use codes. An individual parcel, however, is not likely to be entirely fertilized, as it is often comprised of a variety of land cover types including naturally vegetated areas, water, buildings and other impervious surfaces. Therefore, the CLEAR Land Cover data that contains information on the location of turf lands was merged with the extracted parcels to get a more accurate spatial representation of fertilized lands by each type (Figure 6).

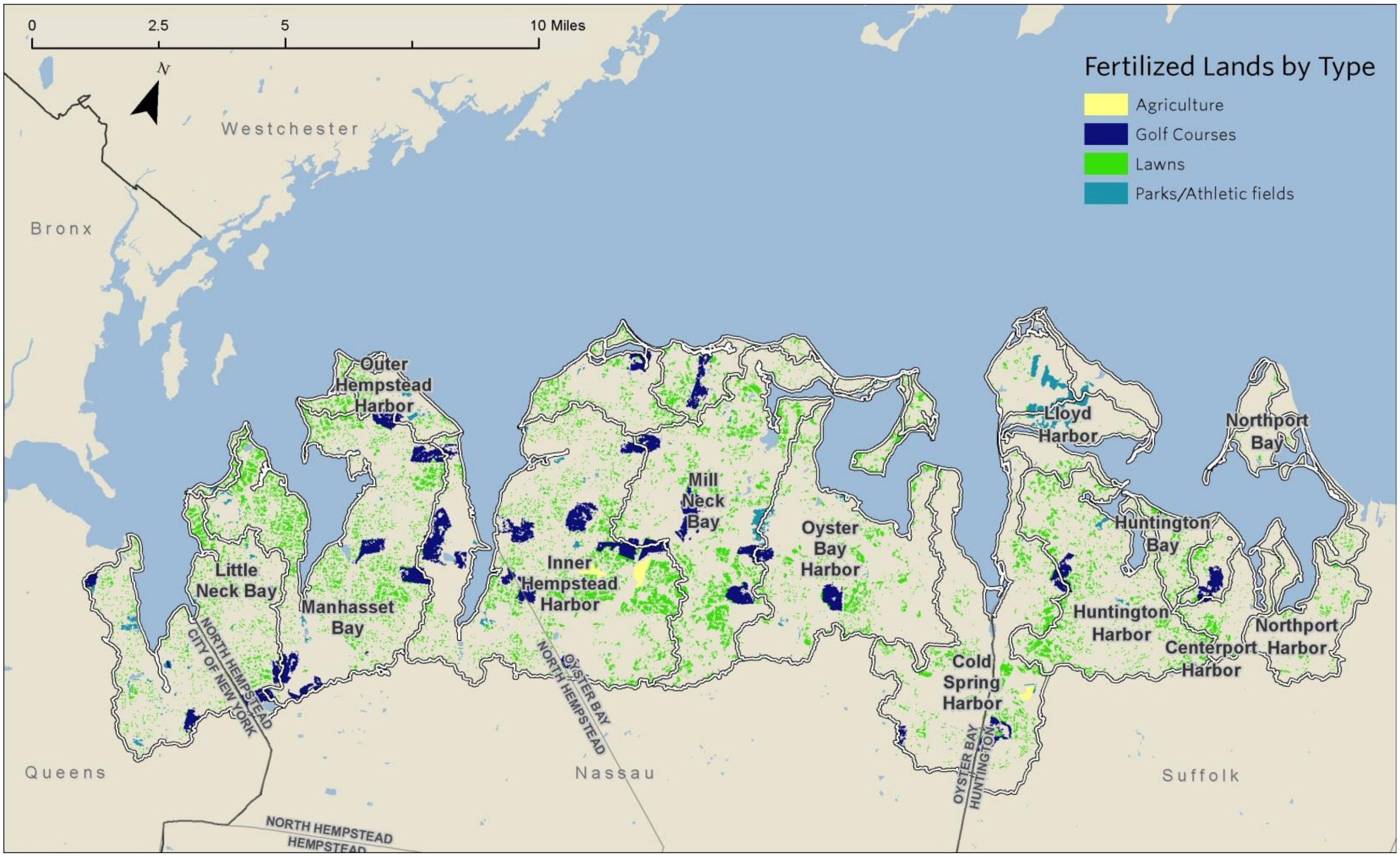

Figure 6 - Derived fertilized areas from parcel and land cover data

For each fertilizer type, a different average annual application rate was applied based on the best available information. For residential lawns, rates were calculated as a weighted average based on the typical amount of nitrogen applied per square foot and the percent of the population that applies 'multiple times a year,' 'once a year,' 'less than once,' and 'not at all' based on a public perception survey for Long Island Sound (LISS 2006). Golf fertilizer rates, were based on an estimated 3 lbs N per 1000 sq foot annual average (May 2009), whereas parks and athletic fields typically average to less than 2 lbs N per 1000 sq ft (Guillard and Fitzpatrick 2011). Agricultural lands are a very small proportion of the study area and the model default (Valiela *et al* 1997) for fertilizer application rate was utilized. Each of these rates was multiplied by its respective land use/land cover area to get the total nitrogen load from fertilizers applied to the surface of the watershed. As with the other components of the model, nitrogen transport factors associated with the surface, subsurface, and aquifer are applied before the nitrogen load enters the embayment itself (see Appendix B and C).

Results and discussion

The NLM was run across the thirteen subwatersheds utilizing 1) a geographic information system (GIS) to summarize the spatial data, and 2) an Excel-based version of the model to calculate the nitrogen source loads. The final loads account for all transport or losses of nitrogen as it passes through the system, including uptake by plants and soils, gaseous losses of fertilizer, losses in septic tanks and leaching pits, and denitrification in the aquifer[1]. The results from the final model output are shown in visual form (Figure 7 and 8), and in tabular form (Tables 1 and 2). The nitrogen source loads shown in Figures 7 and 8 do not include the direct atmospheric deposition to the embayment surface. The analysis was summarized in this way to highlight those source loads where local decision-makers are likely to have the most impact in the development of nitrogen reduction strategies.

Our analysis found that primary source of nitrogen entering all of the subwatersheds from the land is wastewater. In all of the subwatersheds, over a third of the load was contributed by wastewater, and over 80% in four of the subwatersheds (Manhasset Bay, Huntington Harbor, Centerport Harbor, and Northport Harbor). Moreover, the non-point wastewater loading (cesspools, septic systems) was the primary source in all the subwatersheds modeled with the exception of Manhasset Bay, where point sources from sewage treatment plants were more significant. Although Manhasset Bay had the largest sewage treatment plant load, its sewer districts service communities outside its watershed boundary, which is partly the cause of this result. For a similar reason, Little Neck Bay, though largely sewered, has a relatively small sewage treatment plant load as some of the watershed’s residents are serviced by sewage treatment plants with an outfall outside the watershed. While sewage treatment plant loads are substantial in a few subwatersheds, the general trend over time has shown a decrease in loading from sewage treatment plants as a result of recent upgrades pursuant to the Long Island Sound Total Maximum Daily Load. In addition, on a per household level the contribution from a household that is sewered is significantly less than one that utilizes a standard septic system or cesspool. Sewage treatment plants within the study area remove between 77-92% of the nitrogen load from a typical household, whereas only 38-50% is removed from a household that uses a septic system or cesspool, between the time the nitrogen enters the system and ends up in the embayment. This means that within this study area, a household of equivalent size on a septic system or cesspool contributes 2.1-7.8 times more nitrogen to an embayment than a household that is connected to one of the seven sewage treatment plants in the area (See Appendix D for details on these calculations). Other factors also limit a septic or cesspool’s ability to remove nitrogen including how often it is serviced. There are alternative on-site systems, however, that can remove more than 90% of the nitrogen load, although they are not yet approved for general use in Nassau or Suffolk County.

[1] Denitrification is the conversion of dissolved nitrates to inert nitrogen gas that comprises 78% of the atmosphere through a series of biochemical processes.

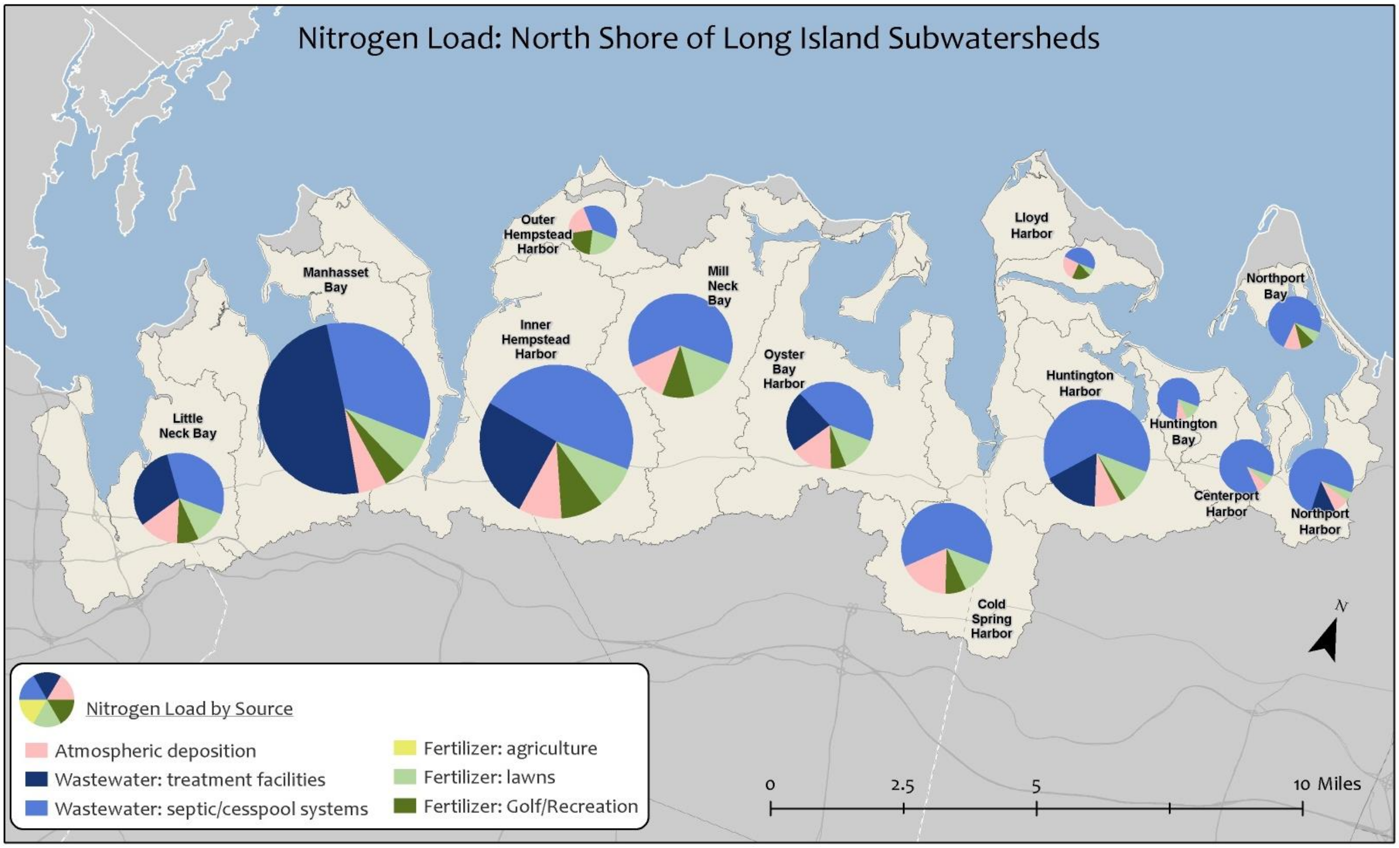

Figure 7 - Nitrogen loading model results by subwatershed. These loads do not include direct atmospheric deposition to the embayment surface. The size of each pie chart indicates its relative total load within the project area.

Nitrogen source loads from fertilizer types combined were generally smaller, ranging from 4% in Outer Hempstead Harbor to a high of 35% in Northport Harbor. Lawns were the primary contributor of fertilizer loads among the three types summarized, with the exception of in Lloyd Harbor and Northport Bay where recreation-based sources were higher (19% and 8% of the total respectively).

Atmospheric deposition to the watershed was as low as 5% of the total load in Manhasset Bay and as high as 25% in Lloyd Harbor. These relative contributions to the total load increase once direct atmospheric deposition to the embayment surface is included, driven largely by the size of the embayment surface relative to the size of the watershed.

In general, the percent contribution by nitrogen source was relatively similar across the thirteen subwatersheds. The northwestern portion of Nassau County and Suffolk County have more development and as a result showed slightly greater contributions from wastewater as compared to subwatersheds in the northeastern part of Nassau with more open space.

The total nitrogen load from each subwatershed, however, varies substantially across the project area. Six subwatersheds (Outer Hempstead Harbor, Lloyd Harbor, Huntington Bay, Centerport Harbor, Northport Harbor, Northport Bay) had relatively low total annual loads of less than 25,000 kg N /year; five (Little Neck Bay, Mill Neck Bay, Oyster Bay, Cold Spring Harbor, and Huntington Harbor) had a mid-range load of 25,000-60,000 kg N / year; and two subwatersheds (Manhasset, Inner Hempstead) had significantly higher annual total loads of greater than 120,000 kg N / year. These relative differences are driven in part by the relative size of their respective subwatershed, in addition to the population densities and land cover characteristics that drive the model.

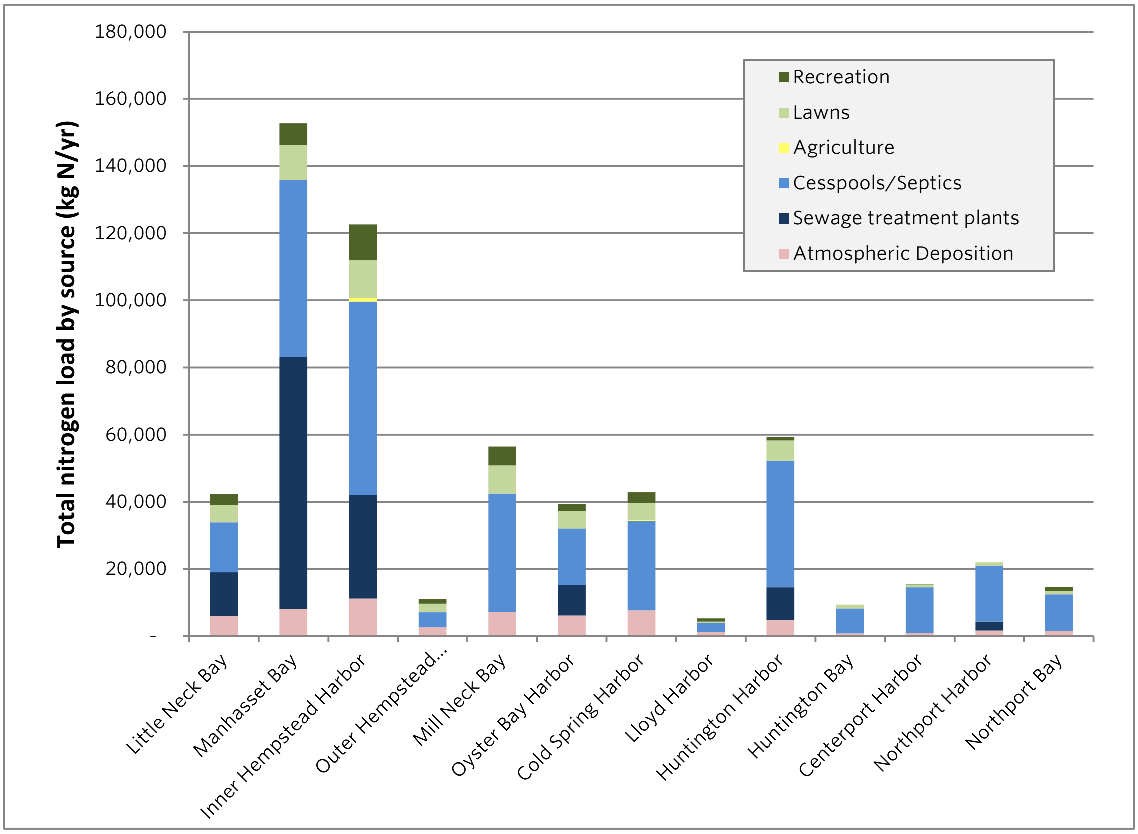

Figure 8 - Total nitrogen load by source (not including direct atmospheric deposition to embayments)

	Atmospheric Deposition				Wastewater				Fertilizer					
	Subwatershed load		Direct to embayment		Sewage Treatment Plants		Septic/Cesspool		Agriculture		Lawns		Recreation (golf and parks)	
Subwatershed	kg N/yr	% of water-shed load	kg N/yr	% of load to embay ment	kg N/yr	% of water-shed load	kg N/yr	% of water-shed load	kg N/yr	% of water-shed load	kg N/yr	% of water-shed load	kg N/yr	% of water-shed load
Little Neck Bay	5,992	**14%**	9,196	18%	12,997	**31%**	14,899	**35%**	-	**0%**	5,126	**12%**	3,284	**8%**
Manhasset Bay	8,117	**5%**	12,062	7%	75,036	**49%**	52,671	**34%**	-	**0%**	10,482	**7%**	6,394	**4%**
Inner Hempstead Harbor	11,177	**9%**	9,104	7%	30,829	**25%**	57,588	**47%**	1,142	**1%**	11,157	**9%**	10,743	**9%**
Outer Hempstead Harbor	2,592	**21%**	18,594	60%	-	**0%**	4,506	**37%**	-	**0%**	2,587	**21%**	1,297	**12%**
Mill Neck Bay	7,158	**13%**	1,755	3%	-	**0%**	35,285	**63%**	-	**0%**	8,431	**15%**	5,565	**10%**
Oyster Bay Harbor	6,145	**16%**	15,052	28%	9,033	**23%**	16,860	**43%**	-	**0%**	5,139	**13%**	2,172	**6%**
Cold Spring Harbor	7,635	**18%**	17,262	29%	-	**0%**	26,580	**62%**	319	**1%**	5,188	**12%**	3,148	**7%**
Lloyd Harbor	1,313	**25%**	3,369	39%	-	**0%**	2,582	**49%**	-	**0%**	394	**7%**	977	**19%**
Huntington Harbor	4,849	**8%**	2,205	4%	9,675	**16%**	37,744	**64%**	-	**0%**	5,994	**10%**	925	**2%**
Huntington Bay	800	**9%**	5,401	37%	-	**0%**	7,396	**79%**	-	**0%**	1,162	**12%**	-	**0%**
Centerport Harbor	974	**6%**	918	6%	-	**0%**	13,529	**87%**	-	**0%**	926	**6%**	140	**1%**
Northport Harbor	1,703	**8%**	2,207	9%	2,656	**12%**	16,620	**76%**	-	**0%**	971	**4%**	-	**0%**
Northport Bay	1,565	**11%**	14,191	49%	-	**0%**	10,865	**74%**	-	**0%**	997	**7%**	1,221	**8%**

Table 1 - Nitrogen loads by source and subwatershed

			Total Load & Area Normalized Load			
			Subwatershed (land-based) load		Load w. direct deposition to embayment	
Subwatershed	Subwatershed Area (ha)	Embayment Area (ha)	kg N/yr	Total per area of subwatershed (kg N/yr/ha)	kg N/yr	Total per area of embayment (kg N/yr/ha)
Little Neck Bay	2,857	630	42,298	14.8	51,494	81.7
Manhasset Bay	3,752	827	152,701	40.7	164,763	199.3
Inner Hempstead Harbor	5,111	624	122,636	24.0	131,740	211.1
Outer Hempstead Harbor	1,275	1,274	10,982	8.6	29,577	23.2
Mill Neck Bay	3,434	120	56,438	16.4	58,193	483.8
Oyster Bay Harbor	3,141	1,032	39,349	12.5	54,400	52.7
Cold Spring Harbor	3,938	1,183	42,870	10.9	60,132	50.8
Lloyd Harbor	688	231	5,266	7.7	8,634	37.4
Huntington Harbor	2,413	151	59,187	24.5	61,392	406.2
Huntington Bay	401	370	9,359	23.3	14,760	39.9
Centerport Harbor	512	63	15,570	30.4	16,488	262.0
Northport Harbor	929	151	21,950	23.6	24,157	159.7
Northport Bay	786	973	14,648	18.6	28,839	29.7

Table 2 - Total and area-normalized nitrogen loads by subwatershed

As described previously, the septic system and cesspool model outputs do not include non-residential nitrogen loading. Because we do not have data on the precise size and location of non-residential systems they were not included in the overall nitrogen load summary. We did, however, summarize the number of non-residential unsewered parcels by type to get a first order approximation of the number of non-residential septic/cesspool systems and their distribution in the study area (Table 3). Generally, subwatersheds with larger numbers of residential septic/cesspool systems also had the higher number of non-residential systems. While the number of these systems is small compared to residential, further study into their size is needed as many of these will have a much larger capacity and nitrogen loading than a household-sized system.

Subwatershed	*Residential*	Commercial	Institutional	Parks, Recreation	Other/Unknown	**Total non-residential**
Little Neck Bay	*2431*	14	11	4	11	**40**
Manhasset Bay	*7244*	121	60	19	88	**288**
Inner Hempstead Harbor	*8181*	184	74	31	150	**439**
Outer Hempstead	*667*	3	6	4	12	**25**
Mill Neck Bay	*4774*	70	27	17	55	**169**
Oyster Bay Harbor	*2295*	20	18	13	29	**80**
Cold Spring Harbor	*3723*	80	28	12	52	**172**
Lloyd Harbor	*328*	0	4	0	0	**4**
Huntington Harbor	*5550*	57	29	11	18	**115**
Huntington Bay	*1154*	12	0	5	2	**19**
Centerport Harbor	*1911*	23	6	3	2	**34**
Northport Harbor	*2423*	43	8	3	13	**67**
Northport Bay	*1572*	12	4	8	2	**26**

Table 3- Summary of non-residential septic/cesspool systems as estimated by unsewered parcels

In addition to total loads and source loads of nitrogen, we also normalized the loads by the size of the subwatershed and embayments as another set of indicators. As previously mentioned, the size of the subwatershed can largely drive the total nitrogen load an embayment receives. Thus, normalizing outputs by the area provides an indication of the relative intensity of nitrogen loading occurring on the land. These results are summarized in Table 2 and visualized spatially in Figure 9. The results show a somewhat different pattern when compared to the total nitrogen loads. For example, Centerport, which has a fairly small total load, has a high normalized load due to its small watershed size. This information provides an indication within the project area as to which subwatersheds have the greatest intensity of land-based nitrogen loading, and therefore the greatest potential for reduction in the sources of nitrogen modeled. Because this is a relative measure, however, it does not imply that some subwatersheds are not receiving significant amounts of nitrogen loading.

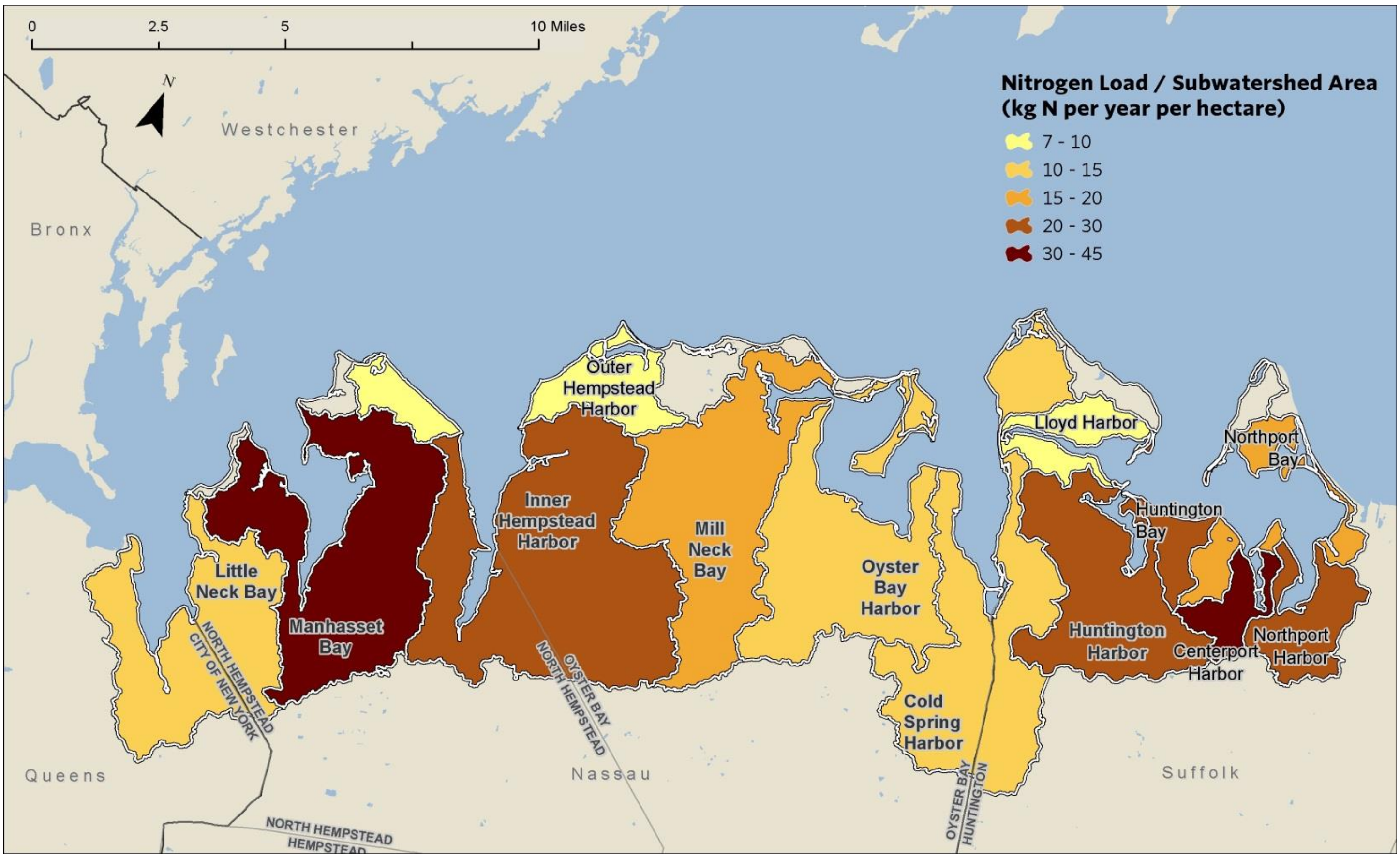

Figure 9 - Total nitrogen load normalized by subwatershed area (excludes direct atmospheric deposition to embayment surface)

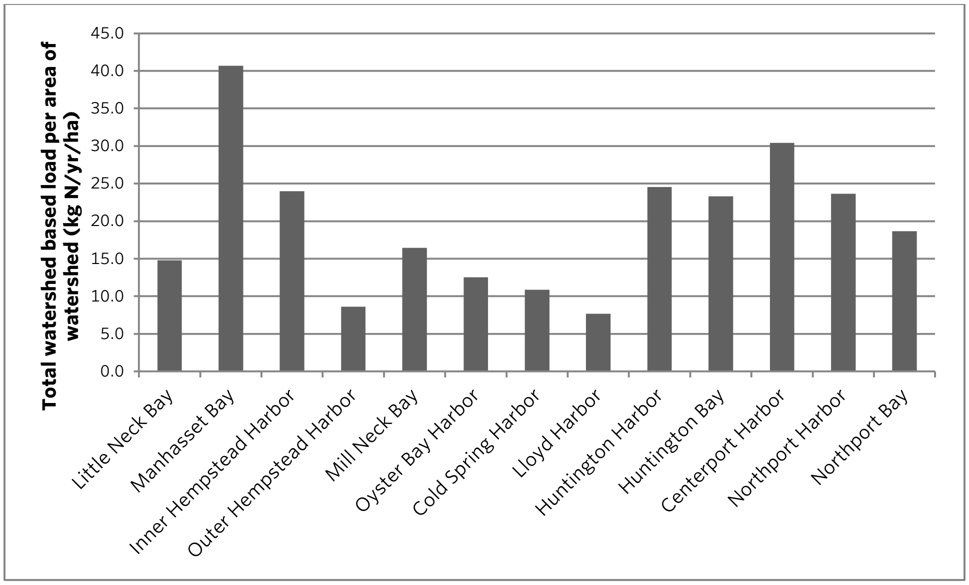

Figure 10 – (Chart) Total nitrogen load normalized by subwatershed area (excludes direct atmospheric deposition to embayment surface)

Additionally, the total nitrogen load (including direct atmospheric deposition to the embayment surface) was normalized to the area of the embayment. These values give an indication of the intensity of nitrogen loading to the individual embayment, and suggest which waterbodies are likely most susceptible to nitrogen loading. For example, depending on their shape, larger embayments are likely to have greater flushing rates, which means a large total nitrogen load could have a smaller impact on the embayment itself. Conversely, a small embayment with little flushing may be more susceptible to nitrogen loading even though the total load it receives could be relatively small. As shown in Figures 11 and 12, it is the smaller embayments, such as Mill Neck Bay and Huntington Harbor that have the greatest load per area of their respective embayments. This type of information can be a useful indication as to which embayments within the project area may warrant intervention. Because this is a relative measure, however, it does not imply that other waterbodies are not susceptible to significant amounts of nitrogen loading.

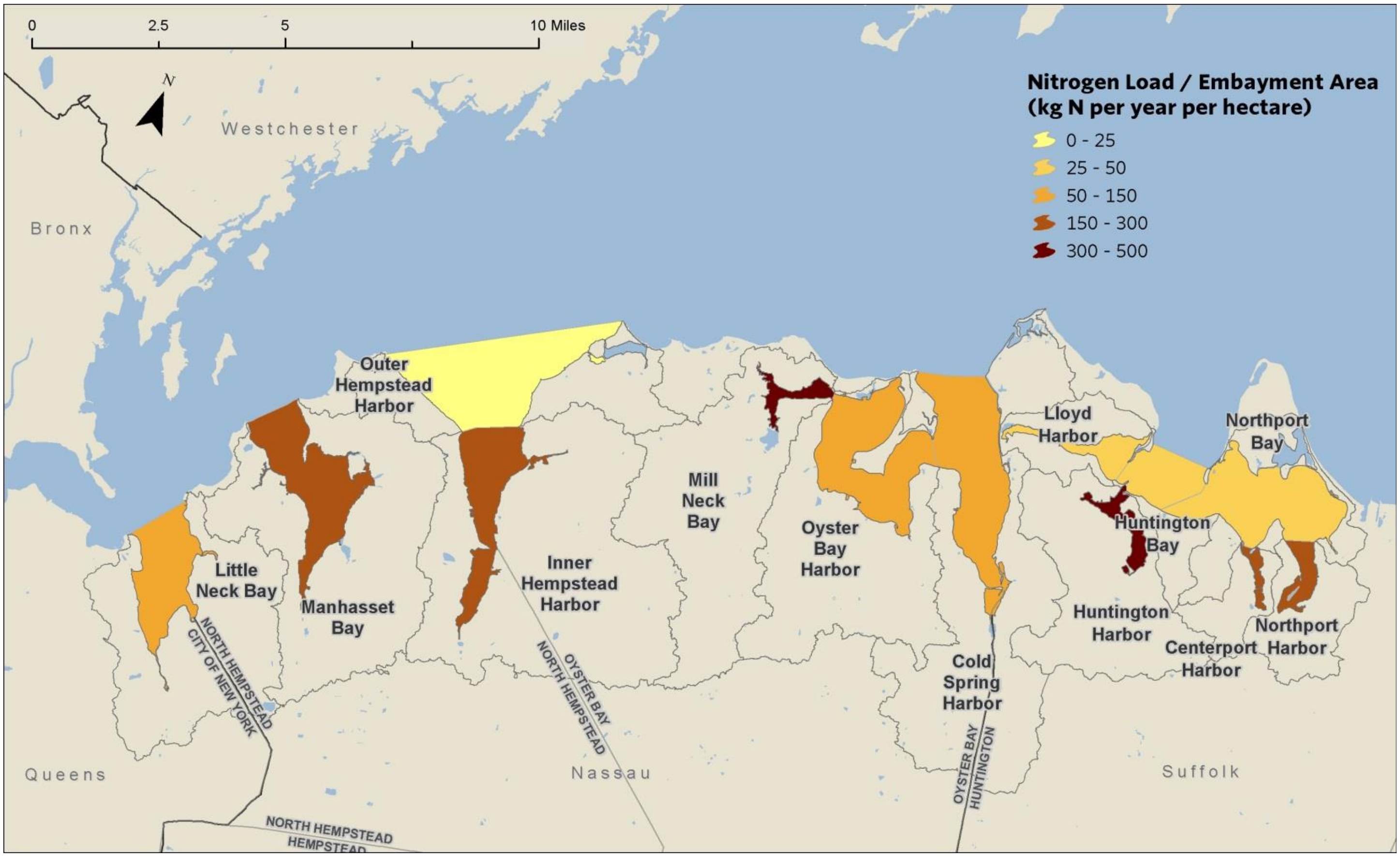

Figure 11 - Total nitrogen load normalized by embayment area (includes direct atmospheric deposition to embayment surface)

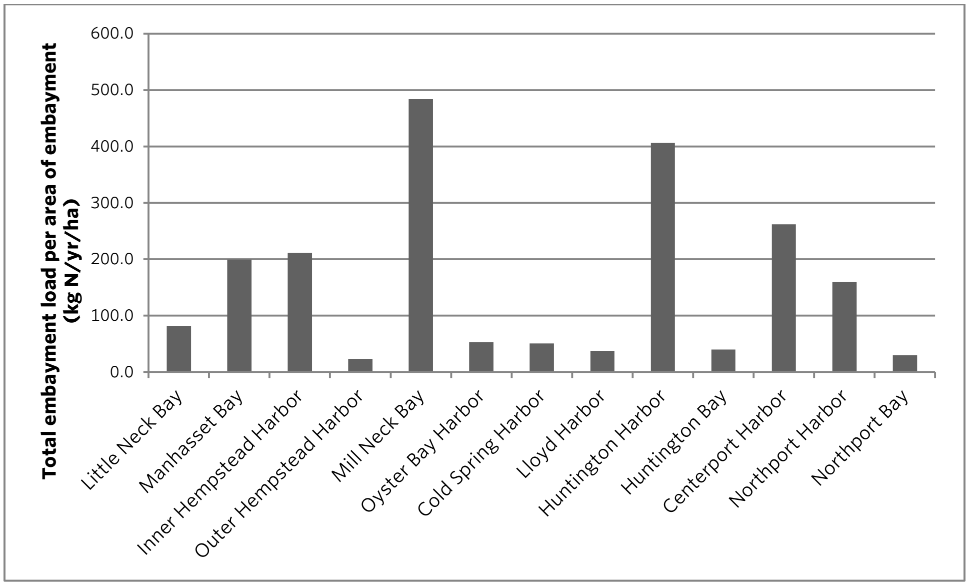

Figure 12 – (Chart) Total nitrogen load normalized by embayment area (includes direct atmospheric deposition to embayment surface)

Conclusion

The results generated by the NLM used in this study for the north shore of Long Island indicate that wastewater is the most significant contributing source of nitrogen across thirteen subwatersheds. Furthermore, on-site septic systems and cesspools were the primary source in all but one subwatershed. The relative sources of nitrogen were relatively consistent across the project area, with higher relative contributions from fertilizers and atmospheric deposition in less developed areas. Nonetheless, there is significant variation in total loading as well as loading normalized to the area of each subwatershed and embayment. Any strategies to reduce nitrogen and set nitrogen reduction targets need to consider not just sources of nitrogen, but total loads, as well as an understanding of the size and hydrodynamics of each embayment, which would require further modeling. Each embayment is unique and load estimates will vary from place to place and therefore solutions should be considered at the subwatershed scale. A model such as the NLM can be further utilized to explore future loading scenarios that can inform how nitrogen load targets by subwatershed may be reached. This type of scenario modeling considering potential changes in technology and behavior (e.g. wastewater infrastructure, fertilizer application practices), and changes in land use/land cover (e.g. development, open space protection) is key to informing solutions in order to reach nitrogen load reduction targets to ultimately achieve water quality improvements and ecosystem recovery.

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APPENDIX

A. Data sources

Dataset	Source
Land cover	UCONN CLEAR (2010)
Impervious surfaces	MRLC National Land Cover Dataset (2011)
Building footprints	Suffolk County (2010), Nassau County (2014)
Population statistics	US Census (2010)
Tax map parcels	Suffolk County (2014), Nassau County (2014)
Sewer districts	Suffolk County (2013), Nassau County (2014)
Sewage treatment plants	Suffolk County (2013), Nassau County (2014)
STP flows and nitrogen concentrations	NYS DEC (2014)
Fertilizer rates	Valiela *et al* 1997, Long Island Sound Study 2006
Subwatershed boundaries	TNC (2015)
Atmospheric deposition rates	National Atmospheric Deposition Program (NADP), Clean Air Status and Trends Network (CASTNET)

B. Nitrogen Loading Model equations

Nitrogen to and through watershed surfaces:

Via atmospheric deposition to:

a. Natural vegetation: atmospheric deposition (kg N ha^{-1} yr^{-1}) x area of naturally vegetated land (ha) x 35% not retained in plants & soils.

b. Turf: atmospheric deposition (kg N ha^{-1} yr^{-1}) x area of turf (ha) x 38% not retained in plants & soils.

c. Agricultural land*: atmospheric deposition (kg N ha^{-1} yr^{-1}) x area of agricultural lands (ha) x 38% not retained in plants & soils.

d. Impervious surfaces: {atmospheric deposition (kg N ha^{-1} yr^{-1}) x area of roofs + driveways (ha) x 38% not retained in plants & soils} + {atmospheric deposition (kg N ha^{-1} yr^{-1})x area of other impervious surfaces such as roads/parking lots/runways (ha)}

e. Wetlands: atmospheric deposition (kg N ha^{-1} yr^{-1}) x area of wetlands (ha) x 22% throughput to aquifer

f. Freshwater ponds: atmospheric deposition (kg N ha^{-1} yr^{-1}) x area of freshwater ponds (ha) x 45% throughput to aquifer.

Via fertilizer application to:

g. Turf: lawn fertilizer application rate (kg N ha^{-1} yr^{-1}) x area of lawns (ha) x 61% not lost as gases.

h. Agricultural land*: agricultural fertilizer application rate (kg N ha^{-1} yr^{-1}) x area of agricultural lands (ha) x 61% not lost as gases.

i. Golf courses: golf fertilizer application rate (kg N ha^{-1} yr^{-1}) x area of golf courses (ha) x 61% not lost as gases.

j. Parks/Athletic fields: golf fertilizer application rate (kg N ha^{-1} yr^{-1}) x area of golf courses (ha) x 61% not lost as gases.

Nitrogen to and through vadose zone and aquifer:

Via nitrogen percolating diffusely from watershed surface:

k. (sum of a though j) x 39% not lost in vadose zone x 85% not lost in aquifer

Via wastewater from

l. Septic systems*: N released $person^{-1}$ yr^{-1} x average household size x number of homes with septic systems x 94% not lost in septic tank x 95% not lost through leaching field x 66% not lost in plumes x 85% not lost in aquifer.

m. Cesspools*: N released $person^{-1}$ yr^{-1} per year x average household size x number of homes with cesspools x 94% not lost in tank x 66% not lost in plumes x 85% not lost in aquifer.

n. Wastewater treatment facilities: average annual N concentration (kg N L^{-1}) x total average annual flow (L).

Nitrogen loading to estuary:

Sum of k + l + m + n

*Septic or cesspool systems closer than 200m from shore are not allotted to losses in the aquifer.

C. Model parameters

Inputs below are those that were applied across all subwatersheds. Information on acreage of land cover types, amount of impervious surfaces, building and lawn counts, and population were based on inputs specific to each subwatershed calculated using the datasets mentioned in the methods section.

Total atmospheric deposition (wet and dry)	14.6 kg ha^{-1} yr^{-1}
% atmos N transported from Nat'l Veg Soils	35%
% atmos N transported from Turf Soils	38%
% atmos N transported from Agri. Soils	38%
% atmos N transported from wetlands	25%
% atmos N transported from freshwater ponds	45%
% atmos N transported from Impervious surfaces (roof/driveway)	38%
Fertilizer N applied to lawns	100 kg N/ha
Fertilizer N applied to agriculture	136 kg N/ha
Fertilizer N applied to parks/athletic fields	90 kg N/ha
Fertilizer N applied to golf courses	146 kg N/ha
% of fertilizer N transported from Turf Soils	61%
% of fertilizer N transported from Agri Soils	61%
% of fertilizer N transported from Rec. Soils	61%
percent of on-site wastewater systems that are cesspools	53%
Per capita human N excretion rate	4.8 kg N/pp/yr
% N transported from septic tank	94%
% N transported through leaching field	95%
% waste transported from septic plumes	66%
% watershed N transported from vadose zone	39%
% N transported from aquifer	85%

D. Comparison of nitrogen removal between sewage treatment plants and septic systems or cesspools

I. Percent nitrogen removal from sewage treatment plants (within study area)

	Influent lbs/day	Effluent lbs/day	**% N removed**
Belgrave	466	72	**85%**
Great Neck	1002	208	**79%**
Port Washington	1202	138	**89%**
Glen Cove	810	188	**77%**
Oyster Bay	321	53	**83%**
Huntington	635	52	**92%**
Northport	84	15	**82%**

From data report provided by NYS DEC. Influent and Effluent rates are from 2014 after recent upgrades pursuant to the Long Island Sound TMDL.

II. Percent nitrogen removal from septic systems and cesspools (including removal in the subsurface and aquifer)

	% N transported by septic tank/cesspool	% N transported by leaching pit	% N transported by plume	% N transported by aquifer	% N transported (Total)	**% N removed (Total)**
Septic system (further than 200m from shore)	94%	95%	66%	85%	50%	**50%**
Septic system (less than 200m from shore)	94%	95%	66%	N/A	59%	**41%**
Cesspool (further than 200m from shore)	94%	N/A	66%	85%	53%	**47%**
Cesspool (less than 200m from shore)	94%	N/A	66%	N/A	62%	**38%**

Rates above are based off the NLM parameter values used in this analysis.

III. Percent nitrogen removal comparison matrix of study area sewage treatment plants to NLM septic/cesspool parameter values for an equivalent sized household.

For example, a household with a septic system further than 200 meters from shore is contributing 2.2 times more nitrogen to Hempstead Harbor than an otherwise identical home that is connected to the Glen Cove sewage treatment plant.

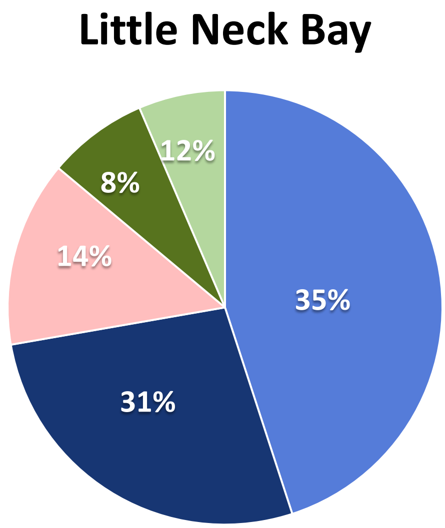
		Septic system (further than 200m from shore)	Septic system (less than 200m from shore)	Cesspool (further than 200m from shore)	Cesspool (less than 200m from shore)
	Percent N removed	*50%*	*41%*	*47%*	*38%*
Belgrave	*85%*	3.3x	3.9x	3.5x	4.1x
Great Neck	*79%*	2.4x	2.8x	2.5x	3x
Port Washington	*89%*	4.5x	5.4x	4.8x	5.6x
Glen Cove	*77%*	**2.2x**	2.6x	2.3x	2.7x
Oyster Bay	*83%*	2.9x	3.5x	3.1x	3.6x
Huntington	*92%*	6.3x	7.4x	6.6x	**7.8x**
Northport	*82%*	2.8x	3.3x	2.9x	3.4x

E. Individual subwatershed results

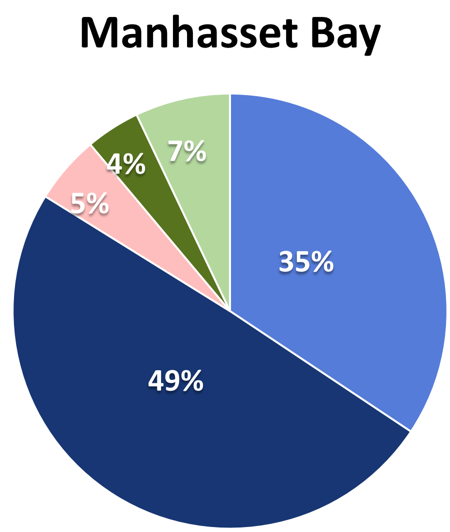
*Total watershed-based load refers to the total nitrogen load to all land (or freshwater) within the subwatershed, and does not include direct atmospheric deposition to the embayment surface.

**Total embayment load refers to the total nitrogen load to the embayment, which is the subwatershed load plus the direct atmospheric deposition to the embayment surface.

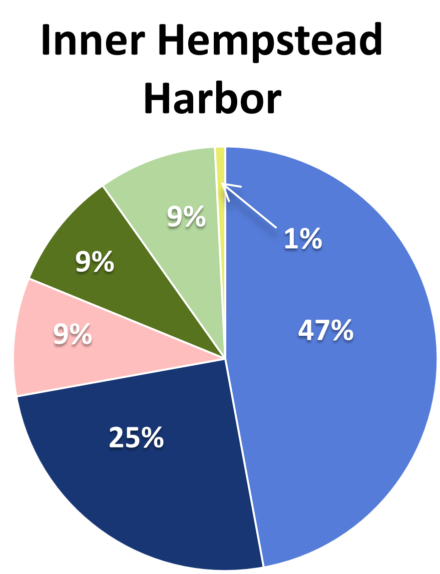
Little Neck Bay	
Atmospheric deposition (kg N/yr)	
To watershed surface	5,992
Direct to embayment surface	9,196
Wastewater (kg N/yr)	
Septic systems/cesspools	14,899
Sewage treatment plants	12,997
Fertilizer (kg N/yr)	
Lawns	5,126
Recreation (golf and parks)	3,284
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	42,298
Subwatershed area (ha)	2,857
Load normalized by subwatershed area (kg N/yr/ha)	14.8
TOTAL Embayment Load (kg N/yr)**	51,494
Embayment area (ha)	630
Load normalized by embayment area (kg N/yr/ha)	81.7



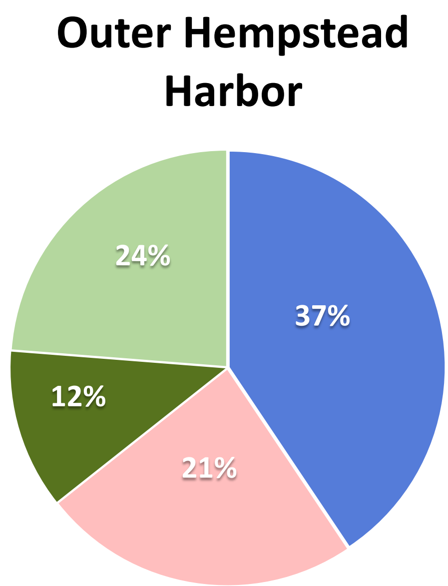
Manhasset Bay	
Atmospheric deposition (kg N/yr)	
To watershed surface	**8,117**
Direct to embayment surface	**12,062**
Wastewater (kg N/yr)	
Septic systems/cesspools	**52,671**
Sewage treatment plants	**75,036**
Fertilizer (kg N/yr)	
Lawns	**10,482**
Recreation (golf and parks)	**6,394**
Agriculture	**-**
TOTAL Watershed-based Load* (kg N/yr)	**152,701**
Subwatershed area (ha)	**3,752**
Load normalized by subwatershed area (kg N/yr/ha)	**40.7**
TOTAL Embayment Load (kg N/yr)**	**164,763**
Embayment area (ha)	**827**
Load normalized by embayment area (kg N/yr/ha)	**199.3**



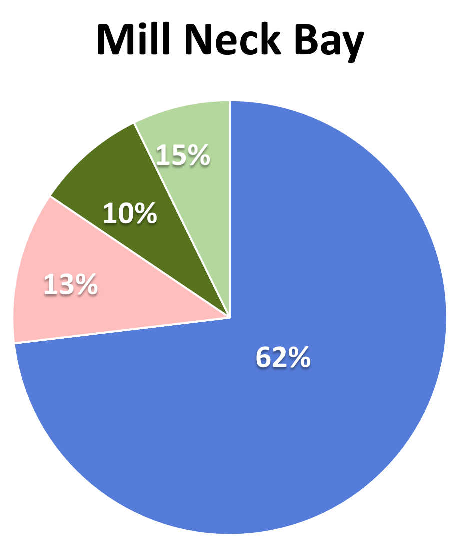
Inner Hempstead Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	**11,177**
Direct to embayment surface	**9,104**
Wastewater (kg N/yr)	
Septic systems/cesspools	**57,588**
Sewage treatment plants	**30,829**
Fertilizer (kg N/yr)	
Lawns	**11,157**
Recreation (golf and parks)	**10,743**
Agriculture	**1,142**
TOTAL Watershed-based Load* (kg N/yr)	**122,636**
Subwatershed area (ha)	**5,111**
Load normalized by subwatershed area (kg N/yr/ha)	**24.0**
TOTAL Embayment Load (kg N/yr)**	**131,740**
Embayment area (ha)	**624**
Load normalized by embayment area (kg N/yr/ha)	**211.1**



Outer Hempstead Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	**2,592**
Direct to embayment surface	**18,594**
Wastewater (kg N/yr)	
Septic systems/cesspools	**4,506**
Sewage treatment plants	**-**
Fertilizer (kg N/yr)	
Lawns	**2,587**
Recreation (golf and parks)	**1,297**
Agriculture	**-**
TOTAL Watershed-based Load* (kg N/yr)	**10,982**
Subwatershed area (ha)	**1,275**
Load normalized by subwatershed area (kg N/yr/ha)	**8.6**
TOTAL Embayment Load (kg N/yr)**	**29,577**
Embayment area (ha)	**1,274**
Load normalized by embayment area (kg N/yr/ha)	**23.2**

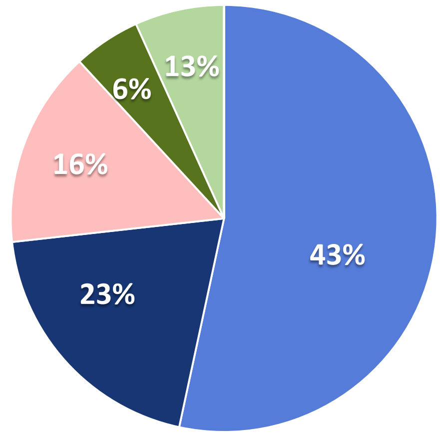


Mill Neck Bay	
Atmospheric deposition (kg N/yr)	
To watershed surface	**7,158**
Direct to embayment surface	**1,755**
Wastewater (kg N/yr)	
Septic systems/cesspools	**35,285**
Sewage treatment plants	**-**
Fertilizer (kg N/yr)	
Lawns	**8,431**
Recreation (golf and parks)	**5,565**
Agriculture	**-**
TOTAL Watershed-based Load* (kg N/yr)	**56,438**
Subwatershed area (ha)	**3,434**
Load normalized by subwatershed area (kg N/yr/ha)	**16.4**
TOTAL Embayment Load (kg N/yr)**	**58,193**
Embayment area (ha)	**120**
Load normalized by embayment area (kg N/yr/ha)	**483.8**



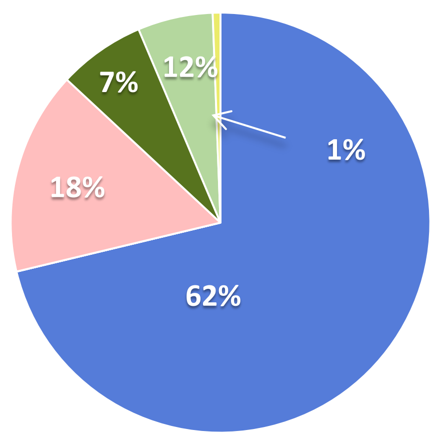
Oyster Bay Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	6,145
Direct to embayment surface	15,052
Wastewater (kg N/yr)	
Septic systems/cesspools	16,860
Sewage treatment plants	9,033
Fertilizer (kg N/yr)	
Lawns	5,139
Recreation (golf and parks)	2,172
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	39,349
Subwatershed area (ha)	3,141
Load normalized by subwatershed area (kg N/yr/ha)	12.5
TOTAL Embayment Load (kg N/yr)**	54,400
Embayment area (ha)	1,032
Load normalized by embayment area (kg N/yr/ha)	52.7

Oyster Bay Harbor

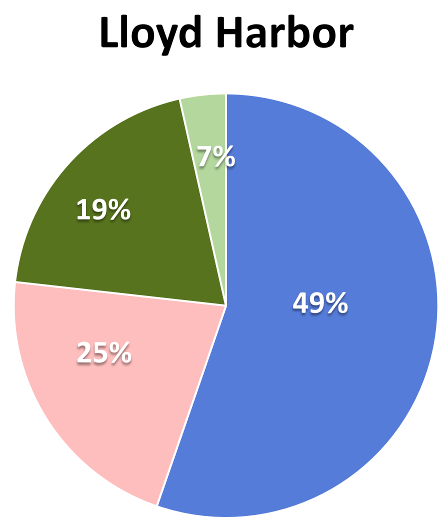


Cold Spring Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	7,635
Direct to embayment surface	17,262
Wastewater (kg N/yr)	
Septic systems/cesspools	26,580
Sewage treatment plants	-
Fertilizer (kg N/yr)	
Lawns	5,188
Recreation (golf and parks)	3,148
Agriculture	319
TOTAL Watershed-based Load* (kg N/yr)	42,870
Subwatershed area (ha)	3,938
Load normalized by subwatershed area (kg N/yr/ha)	10.9
TOTAL Embayment Load (kg N/yr)**	60,132
Embayment area (ha)	1,183
Load normalized by embayment area (kg N/yr/ha)	50.8

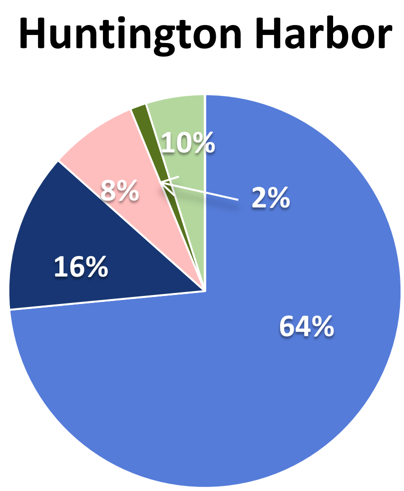
Cold Spring Harbor



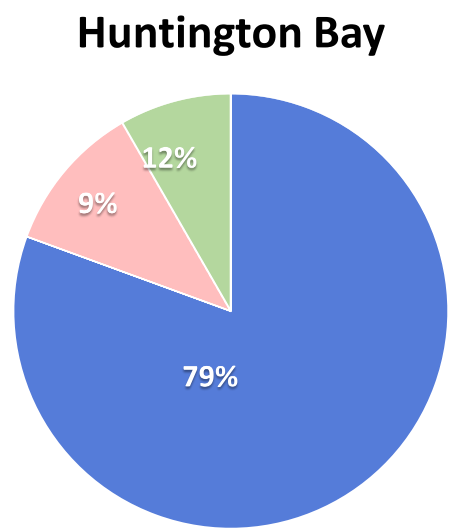
Lloyd Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	1,313
Direct to embayment surface	3,369
Wastewater (kg N/yr)	
Septic systems/cesspools	2,582
Sewage treatment plants	-
Fertilizer (kg N/yr)	
Lawns	394
Recreation (golf and parks)	977
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	5,266
Subwatershed area (ha)	688
Load normalized by subwatershed area (kg N/yr/ha)	7.7
TOTAL Embayment Load (kg N/yr)**	8,634
Embayment area (ha)	231
Load normalized by embayment area (kg N/yr/ha)	37.4



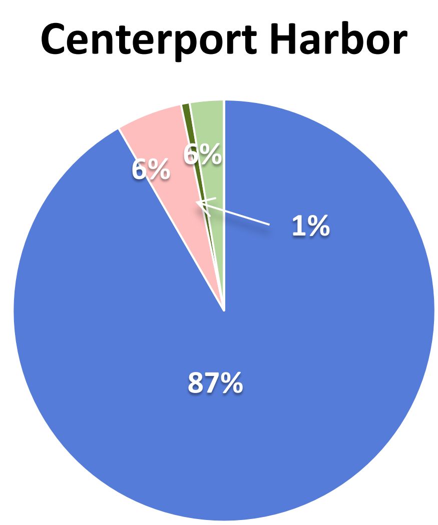
Huntington Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	4,849
Direct to embayment surface	2,205
Wastewater (kg N/yr)	
Septic systems/cesspools	37,744
Sewage treatment plants	9,675
Fertilizer (kg N/yr)	
Lawns	5,994
Recreation (golf and parks)	925
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	59,187
Subwatershed area (ha)	2,413
Load normalized by subwatershed area (kg N/yr/ha)	24.5
TOTAL Embayment Load (kg N/yr)**	61,392
Embayment area (ha)	151
Load normalized by embayment area (kg N/yr/ha)	406.2



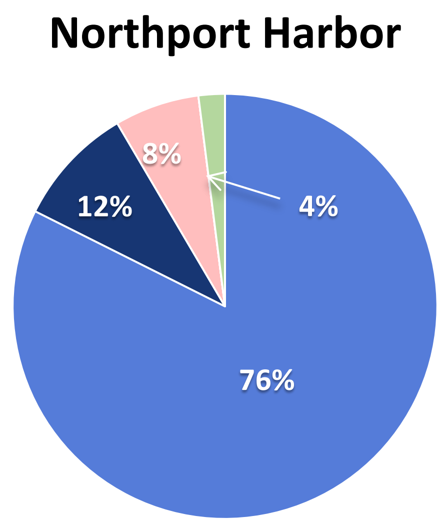
Huntington Bay	
Atmospheric deposition (kg N/yr)	
To watershed surface	800
Direct to embayment surface	5,401
Wastewater (kg N/yr)	
Septic systems/cesspools	7,396
Sewage treatment plants	-
Fertilizer (kg N/yr)	
Lawns	1,162
Recreation (golf and parks)	-
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	9,359
Subwatershed area (ha)	401
Load normalized by subwatershed area (kg N/yr/ha)	23.3
TOTAL Embayment Load (kg N/yr)**	14,760
Embayment area (ha)	370
Load normalized by embayment area (kg N/yr/ha)	39.9



Centerport Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	974
Direct to embayment surface	918
Wastewater (kg N/yr)	
Septic systems/cesspools	13,529
Sewage treatment plants	-
Fertilizer (kg N/yr)	
Lawns	926
Recreation (golf and parks)	140
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	15,570
Subwatershed area (ha)	512
Load normalized by subwatershed area (kg N/yr/ha)	30.4
TOTAL Embayment Load (kg N/yr)**	16,488
Embayment area (ha)	63
Load normalized by embayment area (kg N/yr/ha)	262.0



Northport Harbor	
Atmospheric deposition (kg N/yr)	
To watershed surface	1,703
Direct to embayment surface	2,207
Wastewater (kg N/yr)	
Septic systems/cesspools	16,620
Sewage treatment plants	2,656
Fertilizer (kg N/yr)	
Lawns	971
Recreation (golf and parks)	-
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	21,950
Subwatershed area (ha)	929
Load normalized by subwatershed area (kg N/yr/ha)	23.6
TOTAL Embayment Load (kg N/yr)**	24,157
Embayment area (ha)	151
Load normalized by embayment area (kg N/yr/ha)	159.7



Northport Bay	
Atmospheric deposition (kg N/yr)	
To watershed surface	1,565
Direct to embayment surface	14,191
Wastewater (kg N/yr)	
Septic systems/cesspools	10,865
Sewage treatment plants	-
Fertilizer (kg N/yr)	
Lawns	997
Recreation (golf and parks)	1,221
Agriculture	-
TOTAL Watershed-based Load* (kg N/yr)	14,648
Subwatershed area (ha)	786
Load normalized by subwatershed area (kg N/yr/ha)	18.6
TOTAL Embayment Load (kg N/yr)**	28,839
Embayment area (ha)	973
Load normalized by embayment area (kg N/yr/ha)	29.7