Nitrogen load modeling to forty-three subwatersheds of the Peconic Estuary

prepared by
Stephen Lloyd
The Nature Conservancy in partnership with the Peconic Estuary Program
May 2014

Synopsis

The best available third-party data on land use/land cover, population statistics, atmospheric deposition rates, on-site wastewater systems, sewage treatment plant outputs, and fertilizer application rates were analyzed using the Nitrogen Loading Model (NLM) to compare nitrogen loads from wastewater, fertilizer, and atmospheric deposition sources to the Peconic Estuary as a whole and as contributed by forty-three individual subwatersheds. Considering only land-based sources of nitrogen, wastewater was found to be the largest single contributor of nitrogen for the estuary as a whole (49.6%), with fertilizer (26.4%) and atmospheric deposition (24%) following. Wastewater from residential on-site septic systems and cesspools was found to be the largest contributor of nitrogen in twenty-five of the forty-three subwatersheds. There was significant variation in the results among subwatersheds and any potential reduction strategies should be spatially explicit and at the subwatershed scale when feasible. Given the Peconic Estuary boundary, direct atmospheric deposition to the water surface was also found to be quite large and its effect should be explored further to assess its relative impact on the system.

Introduction

While some nitrogen is a natural and necessary nutrient in estuarine ecosystems, excessive quantities of nitrogen have been shown to cause eutrophication, leading to fish kills, harmful algal blooms, loss of seagrass and marsh habitat, low dissolved oxygen conditions, and over-sedimentation (Cloern 2001, Deegan *et al.* 2012, Latimer and Charpentier 2010,). These issues have been documented across Long Island and are becoming increasingly pervasive and problematic. The Peconic Estuary is no exception and, with its valuable coastal resources, the issue of nutrient pollution is a priority for coastal management of the estuary.

It is well understood that nitrogen from wastewater, fertilizer, and atmospheric deposition accounts for most of the nitrogen reaching estuaries (Valiela *et al*. 1997). Nitrogen originating from these sources reaches receiving water bodies through both ground and surface water flow. Significant nitrogen loading is therefore 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. In order to maximize the success of nitrogen reduction efforts, it is necessary to understand the magnitude and location of each source. 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 subwatershed scale. Such analyses have been completed in Great South Bay (Kinney and Valiela 2011), Shinnecock and Moriches Bays (Stinnette 2014), Long Island Sound estuaries

(Woods Hole Group 2014), and other geographies in southern New England (Latimer and Charpentier 2010). At the request of the Peconic Estuary Program (PEP), The Nature Conservancy has completed such an analysis for forty-three subwatersheds of the Peconic Estuary.

Methods

Model selection

Land use and land cover conditions drive nitrogen loading and these data are used in a number of models to estimate nitrogen loading. The Nitrogen Loading Model (NLM) is one such model that has been used widely, 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 (USGS) SPARROW model (Valiela *et al*. 2000, Latimer and Charpentier 2010). The NLM also enables decision-makers to explore scenarios for potential land use or technological change that might alter future nitrogen load. For these reasons the NLM was selected as the best option for application in the Peconic Estuary.

For more background on the development of the NLM as well as other applications, see: Kinney and Valiela 2011, Latimer and Charpentier 2010, Bowen and Valiela 2004, Valiela *et al*. 2000, Valiela *et al*. 1997.

Area of study – subwatershed delineation

The area of study for this analysis was the Peconic Estuary groundwater contributing area (Figure 1). The area is wholly situated within eastern Suffolk County and includes portions of six towns: Brookhaven, Riverhead, Southold, Southampton, East Hampton, and Shelter Island.

Figure 1. Peconic Estuary groundwater contributing area. (Source: Google Earth)

For the model to have greatest utility in nitrogen management decisions, delineating subwatersheds is critical to understanding finer spatial patterns of nitrogen loading to the estuary. This delineation enables the calculation of total load and percent contributions by source at the subwatershed level. Subwatersheds can be defined either using surface or groundwater elevation. Due to the low slope environment of the Peconic Estuary, where the surface topography does not always align with the water table, we concluded that utilizing published groundwater contours would yield the most reliable modeling results. This approach was selected instead of generating subwatersheds using LiDAR elevation data or predefined Hydrologic Units (e.g. HUCs) from the National Hydrography Dataset as those approaches utilize surface topography. For this analysis, we were able to utilize the Peconic Estuary groundwater contributing area and subwatersheds that had been delineated by USGS (Schubert 1998). The USGS subwatershed maps were digitized into a geographic information system, so that they could be utilized to spatially summarize the model input data (Figure 2).

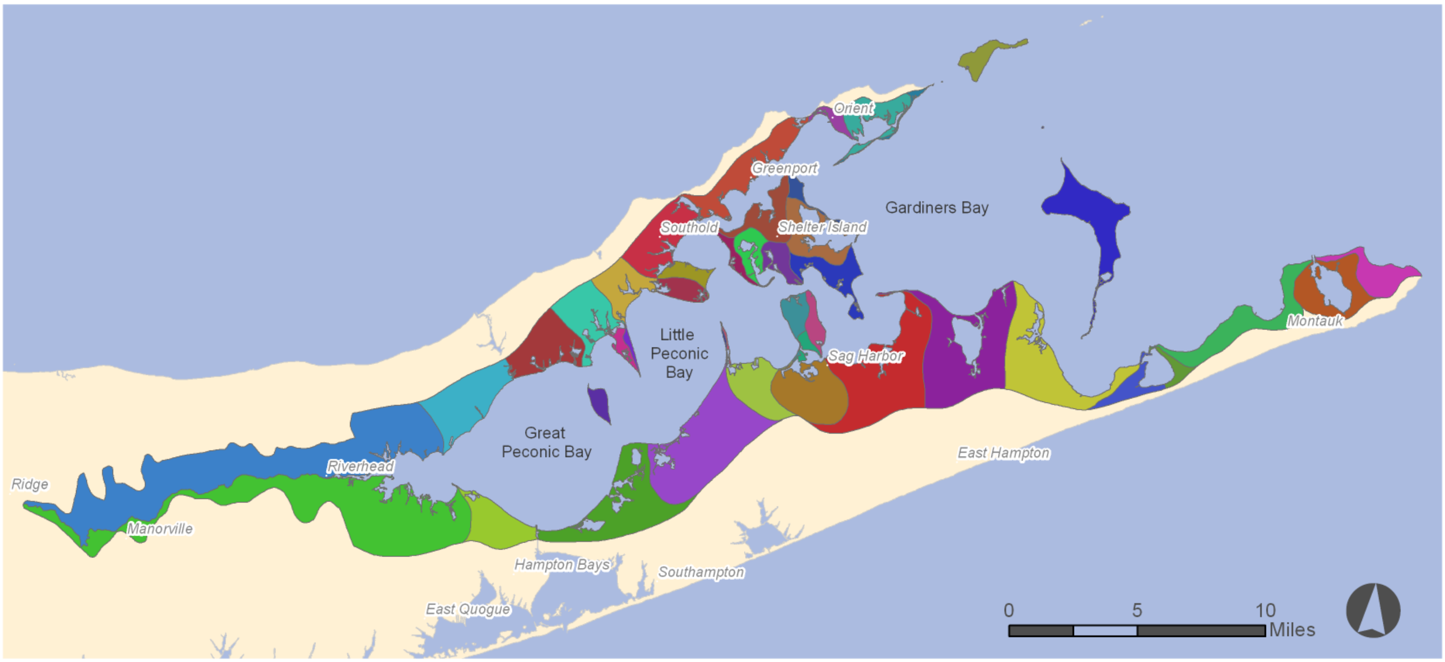


Figure 2. Subwatershed delineations for the Peconic Estuary groundwater contributing areas.

NLM data requirements

The NLM estimates nitrogen load from three major sources: wastewater (sewage treatment plants and on-site systems), atmospheric deposition, and fertilizer (residential, agricultural, and recreational (i.e. golf courses)). For each of these inputs, a great deal of data 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 C and D.

Wastewater inputs

The NLM estimates nitrogen load contributions from both sewage treatment plants discharging to the watershed and from residential on-site septic systems and cesspools. Sewage treatment plants located within the Peconic Estuary were identified using Suffolk County 2013 sewer data layers (Figure 3). The Greenport sewage treatment plant that has an outfall that releases to Long Island Sound was not included in the final results. Data on nitrogen concentration and flow are provided on the US Environmental Protection Agency (EPA) Enforcement and Compliance History Online (ECHO) site for each of these locations, with the exception of Plum Island, which is a small federal plant servicing the national Animal Disease Center. Flow rates and nitrogen concentrations were multiplied and averaged across three years to get a total average annual load for each sewage treatment plant.

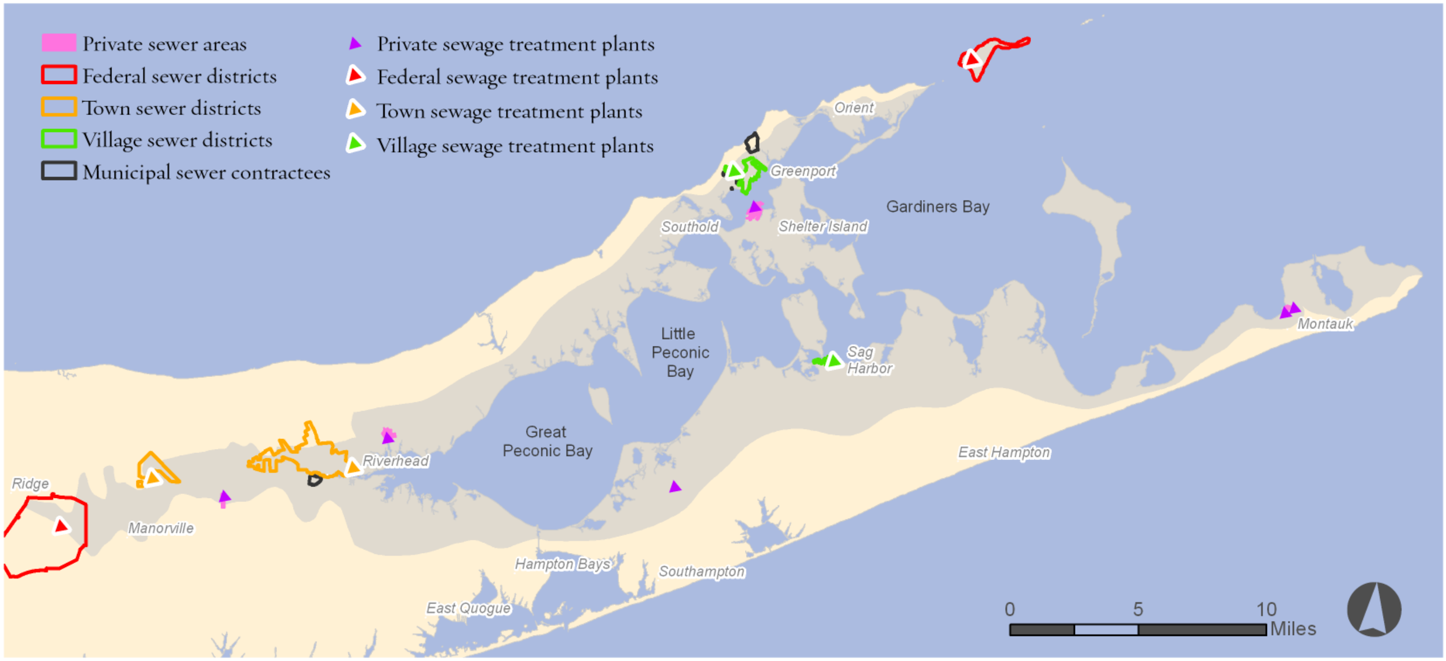


Figure 3. Sewage treatment plants and sewered areas partially or wholly within the Peconic Estuary boundary (source: Suffolk County Dept. of Economic Development & Planning 2013).

To estimate loading from septic systems and cesspools, we first needed to calculate the number of unsewered residences. This was accomplished using 2013 residential parcel data and sewer district boundaries obtained from Suffolk County. Property class codes that identify the type of residence (single family, two family, apartment, etc.) were used to estimate the total number of unsewered residences by subwatershed. It is somewhat difficult to know whether these unsewered residences are serviced by a septic system or cesspool. For the purposes of the model, it was assumed that any unsewered residence constructed before 1973 has its waste handled by a cesspool rather than a septic system because residences constructed after 1973 are required by the County to install septic systems. This year-built information, unfortunately, was only consistently tracked by the Town of Southampton in the parcel data, and so this cesspool rate (53%) estimate was applied across the study area.

The model applies per person nitrogen loading rates and percent removal rates by standard septic systems and cesspools (see Appendix D). It should be noted, however, that NLM's previously determined 35% reduction by leaching fields is likely high. Other experts suggest this removal rate should be in the order of 10-20% (Newsday 2007), meaning the results of NLM underestimate the total wastewater nitrogen load.

For population information, we obtained US Census 2010 data to determine the average number of people per household, which was adjusted with data on seasonal influx at the town level to get a more accurate estimate of average household size by subwatershed. The data on number of residences using septic systems or cesspools was multiplied with average household size to get a total population on septic systems or cesspools per subwatershed.

It is also important to note that NLM and other models of its type do not consider non-residential unsewered areas in order to avoid double counting the nitrogen load. For example, when a resident uses a restroom at a local restaurant this is assumed to replace the usage at that person's home. However, if there are businesses that attract large numbers of people from outside the watershed or if there are other uses that generate significant non-human nitrogen concentrated wastewater, the model will likely underestimate this contribution. These non-residential unsewered loads are important when considering the localized effects of different wastewater treatment upgrade alternatives.

Atmospheric deposition inputs

Atmospheric nitrogen deposition data assumptions have two main components: rates of deposition and a summary of the land cover types upon which the nitrogen is deposited. Atmospheric deposition rates were obtained from the National Atmospheric Deposition Program's (NADP) Cedar Beach monitoring location in Southold, the only site within the study area. We averaged the five most recent years of data (2007-2011). However, because the Cedar Beach location only monitors wet deposition, these rates were combined with data from the four nearest locations from the Clear Air Status and Trends Network (CASTNET) database showing dry deposition. The CASTNET data was averaged across the four locations and over the same period (2007-2011) and added to the NADP data 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 NLM assigns different transport rates to different land cover types depending on the amount of nitrogen that is transported from the surface to the vadose zone and eventually to the aquifer. 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). The NLM therefore relies on the best available land cover data to summarize by subwatershed. While the 2006 National Land Cover Dataset was the most recent dataset with full coverage of the region, it was determined that this was not high enough resolution (30 meters) for the purposes of this analysis. Instead, a higher resolution dataset that was created in 2003 by the USGS for the Peconic Estuary Program was selected. This also included a high resolution impervious surfaces layer, which was used instead of generalizing imperviousness by land use/cover type, which is the model default.

Fertilizer inputs

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. Combined these provide a value of the total nitrogen load entering the system. Fertilizer use is categorized as agricultural, residential (lawns), and recreational (golf courses). Many land cover datasets, including the one used in this study, do not classify different types of agriculture, which often are fertilized at different rates. With the input of Cornell Cooperative Extension we concluded that this level of classification was an important addition to the analysis. Cornell Cooperative Extension helped in providing a digitized map of agricultural lands by type (crops, greenhouse/nurseries, tree fruits, sod, pasture, vineyards) using satellite imagery and local knowledge. This data layer was then merged with the base land cover layer to create a more robust dataset. As a check on reliability, we compared the Cornell Cooperative Extension data with the model assumptions and found that, in general, the model default rates for agricultural fertilizer were applicable to the Peconic Estuary, with the exception of pasture and vineyards. Based on Cornell Cooperative Extension's input, we did not consider pasture as fertilized land, and vineyards were included but with a much lower application rate than the other agricultural land use types (see Appendix D).

Determining the total golf course area was made possible by Suffolk County's parcel data and the appropriate land use codes representing both public and private golf courses. This was further integrated into the land cover dataset in order to ensure that forested or built areas of golf course parcels were not included in the total calculation of fertilized area. The base model fertilizer rates for golf courses were assumed to be reasonable for the Peconic Estuary.

Lawn areas are typically more difficult to calculate because they are not captured explicitly in land cover or parcel data and would require advanced remote sensing or manual digitization to create a spatial dataset. In lieu of this information, the NLM makes an assumption of average lawn size per residence of 0.05 hectares (0.12 acres) based on Koppelman

1978's *The Long Island comprehensive waste treatment management plan*. We concluded that this was a reasonable estimate, given that the median parcel size within the study area is 0.2 hectares (0.49 acres). This average was multiplied by the total number of residential parcels to arrive at a total lawn area for a particular subwatershed. The total lawn area per subwatershed was further multiplied by the percent of homes assumed to use fertilizer (based on Long Island Sound Study 2006 and Koppelman 1978) and the NLM lawn fertilizer application rates to compute the total nitrogen load entering each subwatershed from residential fertilizer.

Results

The NLM was run for the forty-three Peconic Estuary subwatersheds and the final outputs were summarized by contributing source. Figure 4 shows the absolute and relative quantities for the estuary as a whole, and Table 1 lists the absolute and relative quantities per subwatershed. The nitrogen loads were also normalized by subwatershed area, referred to as nitrogen *yield*, for comparing across subwatersheds of differing sizes. The final loads calculated account for all transport or losses as nitrogen passes through the system, including uptake by plants and soils, denitrification in the aquifer, losses in septic tanks and leaching pits, and gaseous losses of fertilizer based on the research studies behind the NLM.

Our analysis found that the predominant source of nitrogen entering the Peconic Estuary from the land is on-site wastewater. As shown in Figure 4, our analysis ascribes 43% of nitrogen loading to septic systems and cesspools for the Peconic Estuary as a whole. Nineteen of the subwatersheds showed a contribution from septic systems and cesspools of 50% or greater, with four subwatersheds showing a contribution of over 75%. Sewage treatment plants accounted for only 13% of the wastewater load, and 6.6% of the total land-based nitrogen load. Atmospheric deposition and fertilizer account for the other half of the land-based nitrogen load and were 24% and 26.4% of the total respectively, with agriculture being the most significant (17%) of the three types of fertilizer inputs modeled (Figure 4). Three subwatersheds on the North Fork had contributions of greater than 50% from agricultural fertilizer applications. It is worth noting that these summaries do not take into account direct atmospheric deposition to the water surface, which adds an additional nitrogen load to the estuary of 972,147 kg N per year based on a Peconic Estuary boundary that extends in a straight line from the eastern tip of Plum Island to Montauk Point (See Figure 1).

	kg N yr^{-1}
Atmospheric deposition	**64,233**
Wastewater	**132,453**
septic systems/ cesspools	114,737
sewage treatment plants	17,717
Fertilizer	**70,415**
lawns	15,350
golf courses	10,590
agriculture	44,475
TOTAL	**267,101**
Subwatershed area (ha)	44,083
Yield	6.1

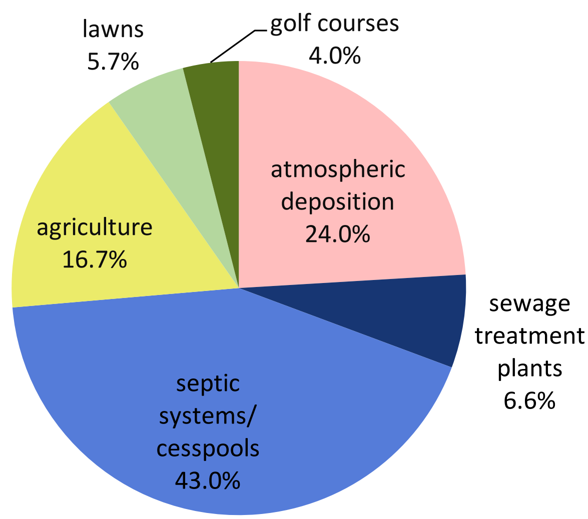


Figure 4. Total nitrogen loading to the Peconic Estuary (does not include direct deposition to the water surface).

Table 1 shows the nitrogen loads to receiving waters of the Peconic Estuary by subwatershed. The percentages indicate relative contributions by source type. Yield is equivalent to the total load per area of each subwatershed. See Figure 5 for subwatershed codes.

sub watershed	Atmospheric		Wastewater				Fertilizer						Total	Yield
			STPs		septics/cesspools		agriculture		lawns		golf			
	(kg N yr^{-1})		(kg N yr^{-1})		(kg N yr^{-1})		(kg N yr^{-1})		(kg N yr^{-1})		(kg N yr^{-1})		(kg N yr^{-1})	(kg N yr^{-1} ha^{-1})
FB1	9397	18%	15119	29%	11747	22%	12617	24%	1670	3%	2363	4%	**52913**	8.7
FB2	6922	41%	624	4%	8174	49%	34	0%	968	6%	0	0%	**16723**	3.4
GI	1839	98%	0	0%	29	2%	0	0%	5	0%	0	0%	**1872**	1.4
NF0	2191	11%	0	0%	5779	29%	10200	52%	620	3%	842	4%	**19632**	13.5
NF10	470	19%	0	0%	1835	73%	0	0%	217	9%	0	0%	**2522**	7.7
NF11	1075	16%	0	0%	1981	30%	3444	51%	210	3%	0	0%	**6710**	9.3
NF12	96	14%	0	0%	526	78%	0	0%	52	8%	0	0%	**674**	10.5
NF13	212	15%	0	0%	1061	77%	0	0%	110	8%	0	0%	**1383**	9.4
NF14	1524	14%	0	0%	4345	40%	4566	42%	461	4%	3	0%	**10899**	10.8
NF15	1669	14%	0	0%	4410	36%	4912	40%	470	4%	736	6%	**12197**	10.8
NF4	133	57%	0	0%	88	38%	0	0%	11	5%	0	0%	**231**	2.9
NF5	844	16%	0	0%	337	6%	4056	77%	50	1%	0	0%	**5286**	8.1
NF6	279	14%	0	0%	958	48%	624	32%	117	6%	0	0%	**1978**	10.5
NF7	1862	22%	0	0%	4454	53%	839	10%	832	10%	367	4%	**8355**	7.0
NF8	1703	16%	0	0%	6009	56%	2293	22%	652	6%	0	0%	**10658**	9.7
NF9	402	17%	0	0%	1808	75%	0	0%	199	8%	0	0%	**2409**	8.7
PI	483	100%	0	0%	0	0%	0	0%	0	0%	0	0%	**483**	1.4
RI	254	92%	0	0%	20	7%	0	0%	3	1%	0	0%	**276**	1.5
SF0	1399	28%	0	0%	3185	64%	0	0%	400	8%	0	0%	**4985**	5.3
SF1	2752	24%	0	0%	5269	47%	0	0%	632	6%	2639	23%	**11293**	5.9
SF10	3924	41%	456	5%	4173	44%	0	0%	724	8%	211	2%	**9488**	3.4
SF11	4069	25%	0	0%	10720	65%	94	1%	1700	10%	19	0%	**16602**	6.1
SF12	2910	31%	0	0%	5566	60%	0	0%	855	9%	9	0%	**9339**	4.5
SF13	468	67%	0	0%	210	30%	0	0%	18	3%	0	0%	**696**	1.8
SF14	228	82%	0	0%	46	16%	0	0%	6	2%	0	0%	**279**	1.6
SF15	1778	39%	809	18%	1721	37%	0	0%	265	6%	30	1%	**4602**	3.7
SF16	1445	29%	0	0%	2548	52%	0	0%	392	8%	542	11%	**4927**	5.1
SF17	952	93%	0	0%	64	6%	0	0%	12	1%	0	0%	**1028**	1.5
SF2	4122	27%	32	0%	9004	58%	796	5%	1164	8%	392	3%	**15511**	5.4
SF3	21	100%	0	0%	0	0%	0	0%	0	0%	0	0%	**21**	1.3
SF4	39	100%	0	0%	0	0%	0	0%	0	0%	0	0%	**39**	1.4
SF5	1277	22%	0	0%	2989	51%	0	0%	362	6%	1288	22%	**5916**	6.7
SF6	479	34%	0	0%	823	58%	0	0%	112	8%	0	0%	**1414**	4.2
SF7	368	26%	0	0%	941	66%	0	0%	122	9%	0	0%	**1430**	5.4
SF8	186	13%	0	0%	1139	78%	0	0%	131	9%	0	0%	**1457**	12.1
SF9	2007	22%	0	0%	6128	68%	0	0%	792	9%	50	1%	**8978**	6.7
SI1	1046	25%	677	16%	1730	42%	0	0%	300	7%	389	9%	**4142**	6.0
SI2	296	19%	0	0%	474	31%	0	0%	69	5%	684	45%	**1523**	7.6
SI3	955	43%	0	0%	1079	49%	0	0%	160	7%	27	1%	**2222**	3.3
SI4	855	74%	0	0%	267	23%	0	0%	38	3%	0	0%	**1160**	1.8
SI5	508	26%	0	0%	1258	64%	0	0%	188	10%	0	0%	**1955**	5.7
SI6	527	27%	0	0%	1230	64%	0	0%	176	9%	0	0%	**1932**	5.4
SI7	269	28%	0	0%	610	63%	0	0%	86	9%	0	0%	**964**	5.4
Total	**64233**	**24%**	**17717**	**7%**	**114737**	**43%**	**44475**	**17%**	**15350**	**6%**	**10590**	**4%**	**267101**	**6.1**

Table 1. Nitrogen loads to receiving waters of the Peconic estuary by subwatershed.

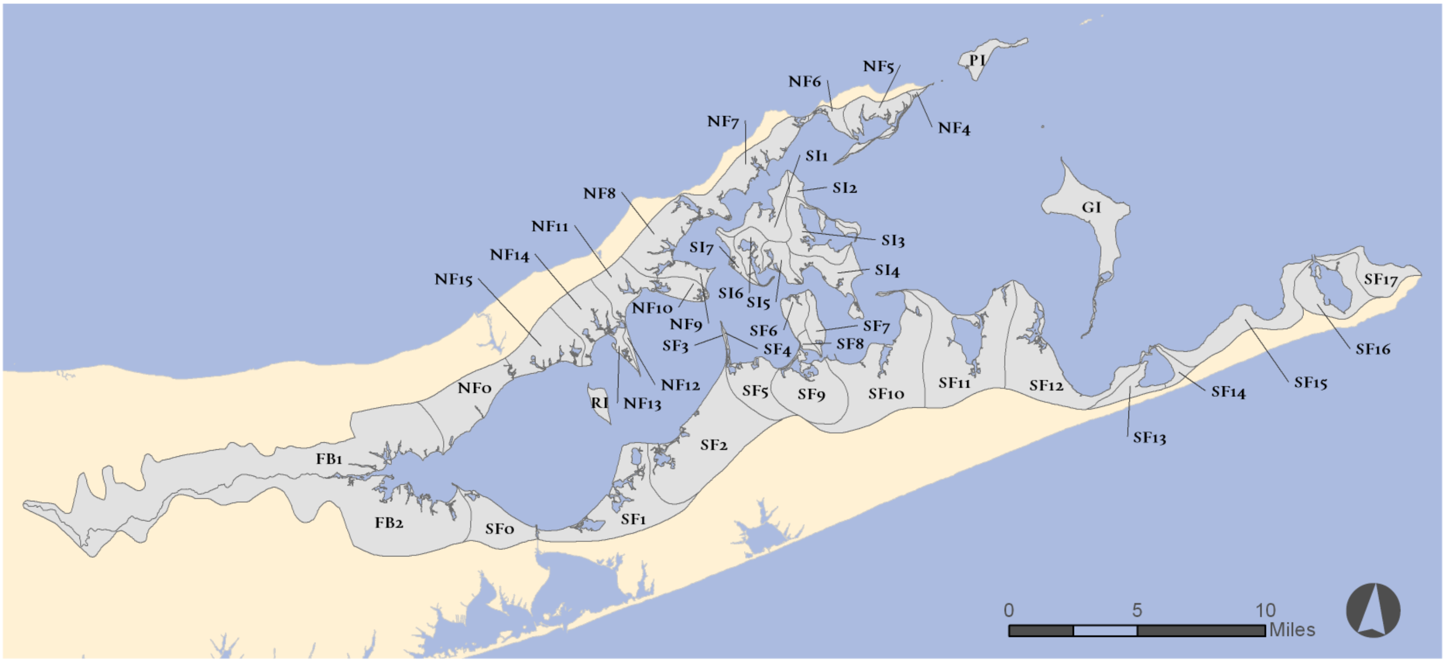


Figure 5. Peconic Estuary subwatershed code key.

The results of this analysis reveal that, while wastewater is the primary land-derived source of nitrogen, there is significant variation among different subwatersheds of the estuary, and therefore any policies to address nitrogen impacts should consider strategies at a finer spatial resolution when possible. Figure 6 depicts the same results from Table 1 geographically, with the size of each pie chart adjusted to reflect the total load from that subwatershed compared to the loads from other subwatersheds. In most subwatersheds (twenty-five), on-site wastewater systems are the primary contributor of nitrogen. The only major wastewater treatment plant that contributes to the estuary is the Riverhead sewage treatment plant (STP), accounting for 27% of the nitrogen loading in the northern Flanders Bay subwatershed (FB1).

Wastewater was not the primary source of nitrogen in all subwatersheds. Agricultural fertilizer is the main source in a few subwatersheds in Great Peconic Bay and Little Peconic Bay on the North Fork and around Long Beach Bay. The other exceptions were small subwatersheds that are largely unpopulated, and therefore mostly subject to atmospheric deposition of nitrogen. These included areas such as Montauk Point, Gardiners Island, and southeast Shelter Island. Golf courses were also a significant contributor in a few subwatersheds such as Noyack Bay, southeast Great Peconic Bay, and northeast Shelter Island. While the nitrogen load of residential lawn fertilizer was overall more significant than golf courses, the contribution from lawn fertilizer did not stand out in any particular subwatershed. The distribution of lawn fertilizer loads among subwatersheds correlates to the on-site wastewater load as both depend on the number of residences in the subwatershed, and the load from on-site wastewater sources is significantly higher than the load from lawn fertilizer on average per residence. This is about a 7.5:1 ratio of nitrogen loading from septic systems/cesspools to lawn fertilizer for the Peconic Estuary as a whole.

See Appendix A for site-specific nitrogen load maps.

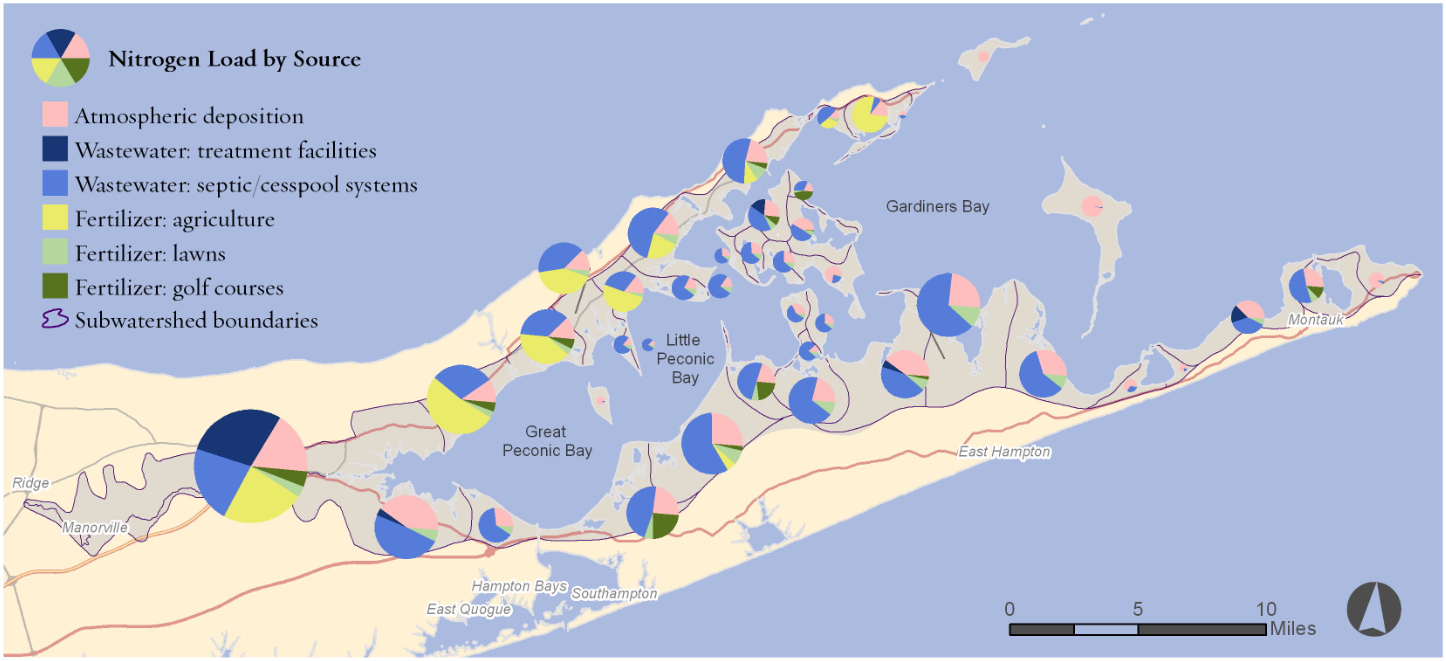


Figure 6. Nitrogen load by source for the 43 subwatersheds of the Peconic Estuary. This map excludes direct deposition to the water surface. The size of each pie chart indicates the relative size of loading compared to other subwatersheds.

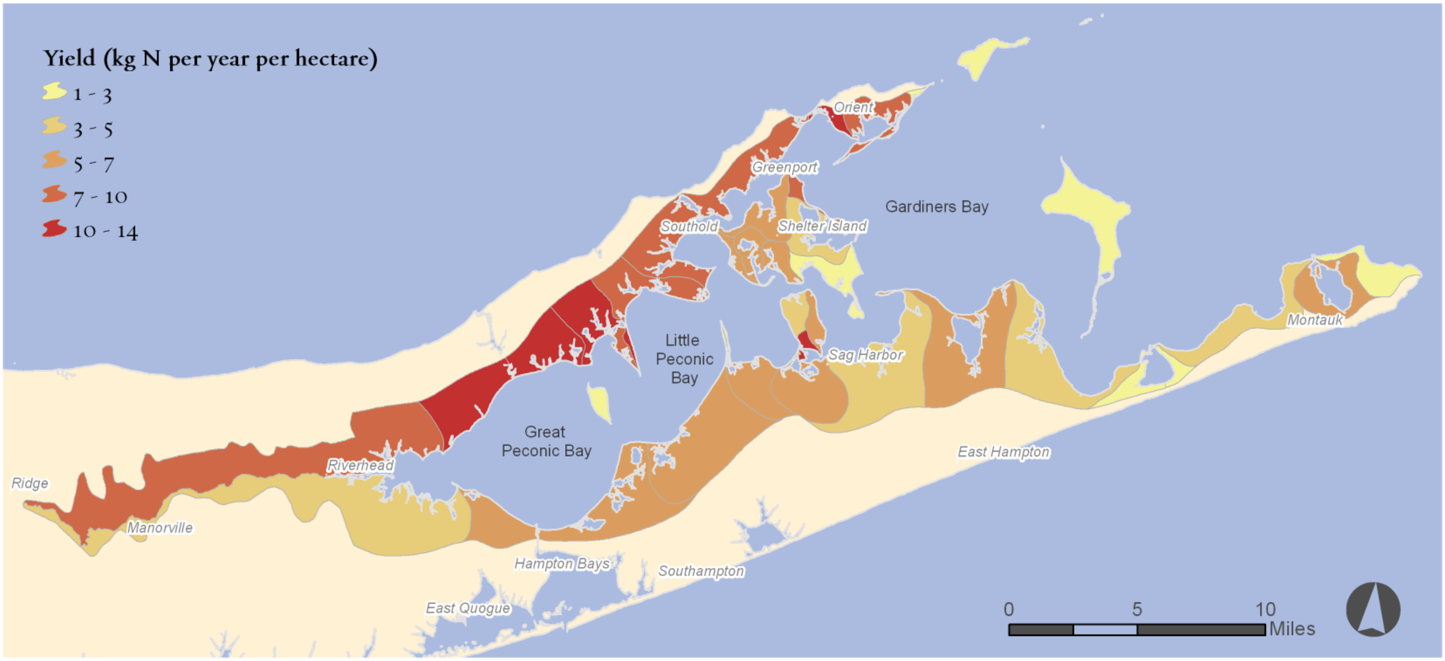


Figure 7. Subwatershed nitrogen yield in kilograms nitrogen load per unit hectare of subwatershed area.

Since total nitrogen loads are determined, to a significant degree, by the geographic size of the subwatershed, it is also important to consider nitrogen yield, which is the total load normalized by area (Figure 7). The patterns in nitrogen yield are largely driven by the agricultural lands on the North Fork, which are less common on the South Fork and elsewhere in the estuary. This is particularly true of the northern shore of Great Peconic Bay. Other types of fertilizer inputs are generally not significant enough in any one particular area on their own to drive the differences in nitrogen yield. This is also the case with atmospheric deposition, which is generally uniform throughout the estuary. Densely populated areas in small subwatersheds, however, can lead to on-site wastewater systems driving the nitrogen yield patterns. This is the case around Orient and North Haven, which have relatively high septic system loads within a small subwatershed area.

Model sensitivity

While the Nitrogen Loading Model has been validated in a number of locations, it is a relatively simple linear model used to produce estimates of nitrogen load by source. Many of the parameter assumptions require averages over time and space to produce a single output of nitrogen load. Accordingly, to assess the reliability of our findings based on the model, we explored the model's sensitivity to certain assumptions, particularly those with the greatest uncertainty.

Lawn fertilizer

We took a closer look at the estimates of lawn area as these are almost never provided in a spatial data layer. As noted, for inputs to the model, we used an average lawn size of 0.05 hectares (0.12 acres) from Koppelman 1978. The median parcel size in the Peconic Estuary is 0.2 hectares (0.49 acres), so we effectively assumed that, on average, one-quarter of a residential parcel is lawn. As a secondary approach, we calculated an upper bound on the potential lawn area by calculating the total residential land use and eliminated any land cover types that would clearly not be considered lawn such as impervious surfaces/building footprints, water, wetlands, forests, agriculture, or barren lands. This secondary approach would still yield a significant overestimate of total lawn area as the land cover dataset's minimum mapping unit would not account for other non-lawn land cover that are at a finer resolution than the data. Nonetheless, it is still useful in setting an upper bound of potential lawn area. Using this secondary approach, the total lawn acreage is 3.3 times as large as the base assumption we used in the model, which means we would be assuming over three-quarters of a typical parcel is lawn. If 49% of that total lawn area is fertilized (the assumption from the 2006 Long Island Sound Study report that we used in the model), this results in a lawn nitrogen load of 50,654 kg N per year as compared with 15,350 kg N per year with the base model assumption that we used. This would equate to about a 2.25:1 ratio of nitrogen loading from septic systems/cesspools to lawn fertilizer estuary-wide.

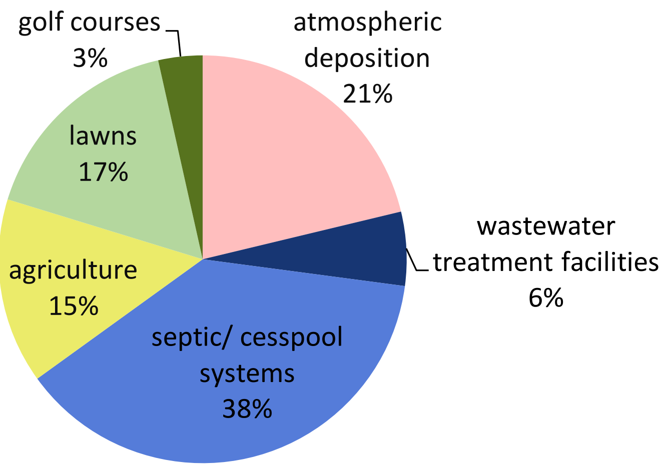


Figure 8. Percentages of nitrogen load by sources with modified lawn assumptions (upper bound).

On-site wastewater systems

There is also uncertainty about the percent of on-site wastewater systems that are septic systems versus cesspools as there is no database that tracks this information. As noted, we assumed that all homes built in 1973 or earlier have cesspools, but the owners of older buildings may have installed septic systems as upgrades. Additionally, there was only year built information for the Town of Southampton, which meant we applied the same assumption across all subwatersheds.

The wastewater load is less sensitive to the model assumption of cesspools versus septic systems because it does not change the total load leaving homes within the Peconic Estuary, but does change the amount of nitrogen that is removed before encountering the aquifer. As previously mentioned, we assumed 53% of on-site systems were cesspools based on year built information from the Town of Southampton. This differs substantially from the default 9% cesspool rate from Valiela *et al.* 1997 using data from Waquoit Bay in Cape Cod. Using the 9% cesspool rate, as compared with our 53% model assumption, decreases the on-site wastewater load from 114,737 kg N per year to 93,588 kg N per year, a reduction of 18.4% in the nitrogen load from on-site wastewater systems.

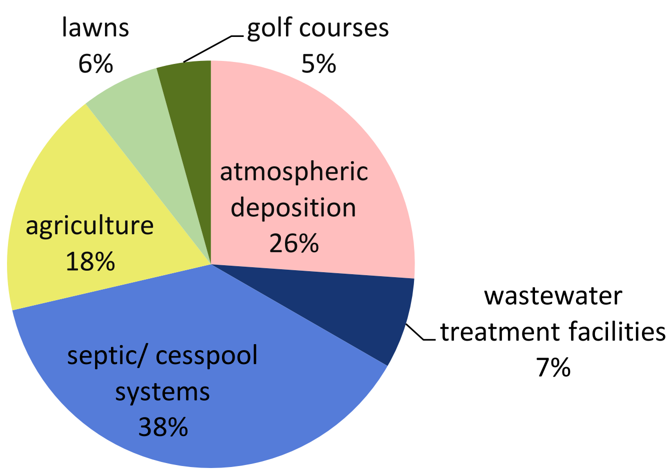


Figure 9. Percentages of nitrogen load by source using the NLM default model cesspool assumption (9% cesspool rate).

Summary

The results produced in the NLM model for the Peconic Estuary indicate that on-site septic systems and cesspools are the primary land-based sources of nitrogen to the Peconic Estuary. Further investigation into the subwatersheds of the estuary clearly show, however, that there is significant variation in the relative impact that on-site systems contribute and that potential reduction strategies should be spatially explicit and at a finer scale when feasible. Fertilizer inputs, from agriculture in particular, as well as atmospheric deposition, also play significant roles and should not be ignored in any attempt to reduce the total nitrogen load from land-based sources. Further, direct atmospheric deposition to the water surface is very large, and its impact should be explored further given different flushing rates in the estuary. Technological changes (e.g. upgrades of septic systems, sewer expansions, fertilizer efficiency improvements), as well as land cover/ land use changes (e.g. urbanization, natural/agricultural land protection) should also be explored in detail to better understand potential future loading scenarios and to inform policy or land management decisions.

References

Bowen, J.L., J.M. Ramstack, S. Mazzilli and I. Valiela (2007). NLOAD: an interactive, web-based modeling tool for nitrogen management in estuaries. Ecological Applications, 17(5) Supplement.

Bowen, J. L. and I. Valiela (2004). Nitrogen loads to estuaries: Using loading models to assess effectiveness of management options to restore estuarine water quality. Estuaries 27: 482-500.

Cloern, J.E. (2001). Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210, 223-253.

Deegan, L.A., D.S. Johnson, R.S. Warren, B.J. Peterson, J.W. Fleeger, S. Fagherazzi and W.M. Wollheim (2012). Coastal eutrophication as a driver of salt marsh loss. Nature 490: 388-392

Long Island Sound Study (2006). Public Perception Survey of Long Island Sound Watershed Residents. New York: Stony Brook University. November 16. Final Report.

Kinney, E.L. and I. Valiela (2011). Nitrogen loading to Great South Bay: land use, sources, retention, and transport from land to bay. Journal of Coastal Research, 27(4) 672–686.

Koppelman, L.E. (1978). The Long Island comprehensive waste treatment management plan. Volume II: Summary Documentation. Nassau-Suffolk Regional Planning Board. Hauppauge, New York, USA.

Latimer, J.S. and M. Charpentier (2010). Nitrogen inputs to seventy-four southern New England estuaries: Application of a watershed nitrogen loading model. Estuarine, Coastal and Shelf Science, 89(2010) 125-136.

Schubert, Chris E. (1997). Areas Contributing Ground Water to the Peconic Estuary, and Ground-Water Budgets for the North and South Forks and Shelter Island, Eastern Suffolk County, New York. USGS Water-Resources Investigations Report, 97-4136.

Smith, J. (2007, March 12). Cesspools on LI: The Threat to our Water. Newsday. 67(90): A4-A5, A14-A15.

Stinnette, I. (2014). Nitrogen Loading to the South Shore, Eastern Bays, NY: Sources, Impacts and Management Options (Master's thesis). Stony Brook University: School of Marine and Atmospheric Sciences. Stony Brook, NY.

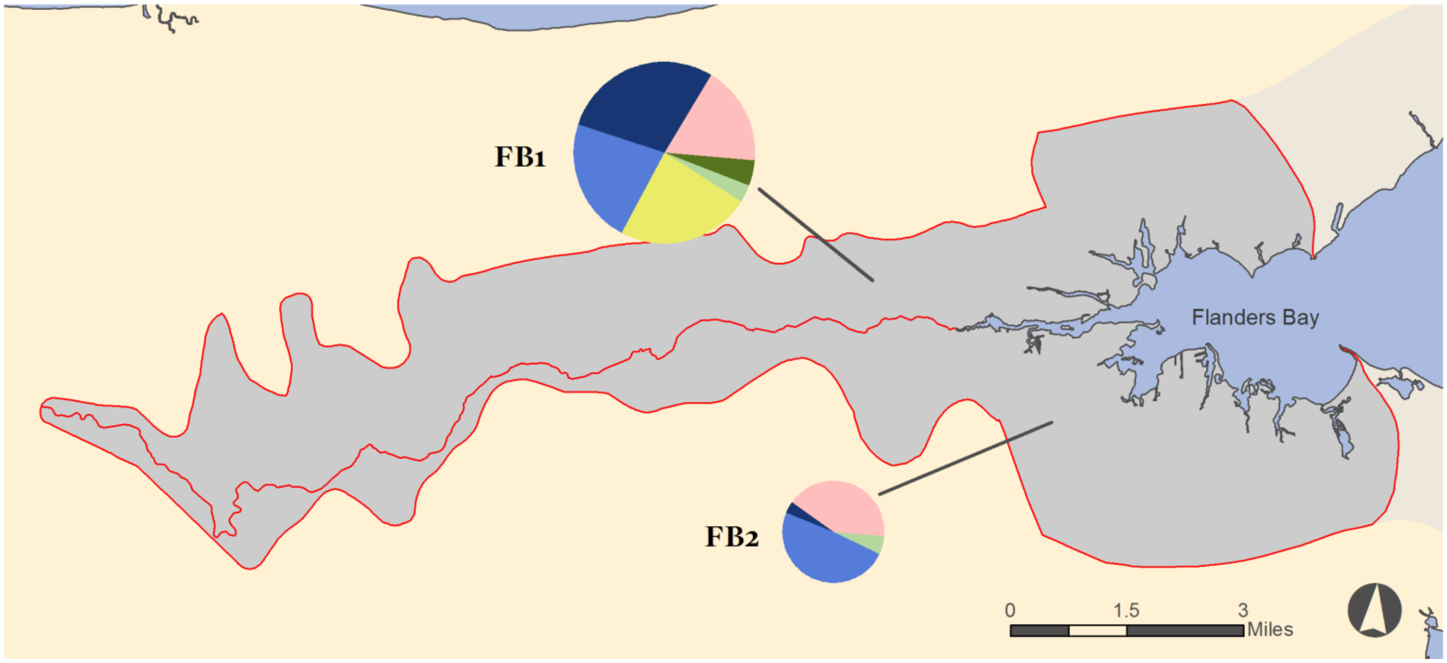
Valiela I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley and C. H. Sham (1997). Nitrogen loading from coastal watersheds to receiving estuaries: New method and application. Ecological Applications, 7 358-380.

Valiela, I., M. Geist, J. McClelland, and G. Tomasky (2000). Nitrogen loading from watersheds to estuaries: verification of the Waquoit Bay nitrogen loading model. Biogeochemistry, 49, 277–293.

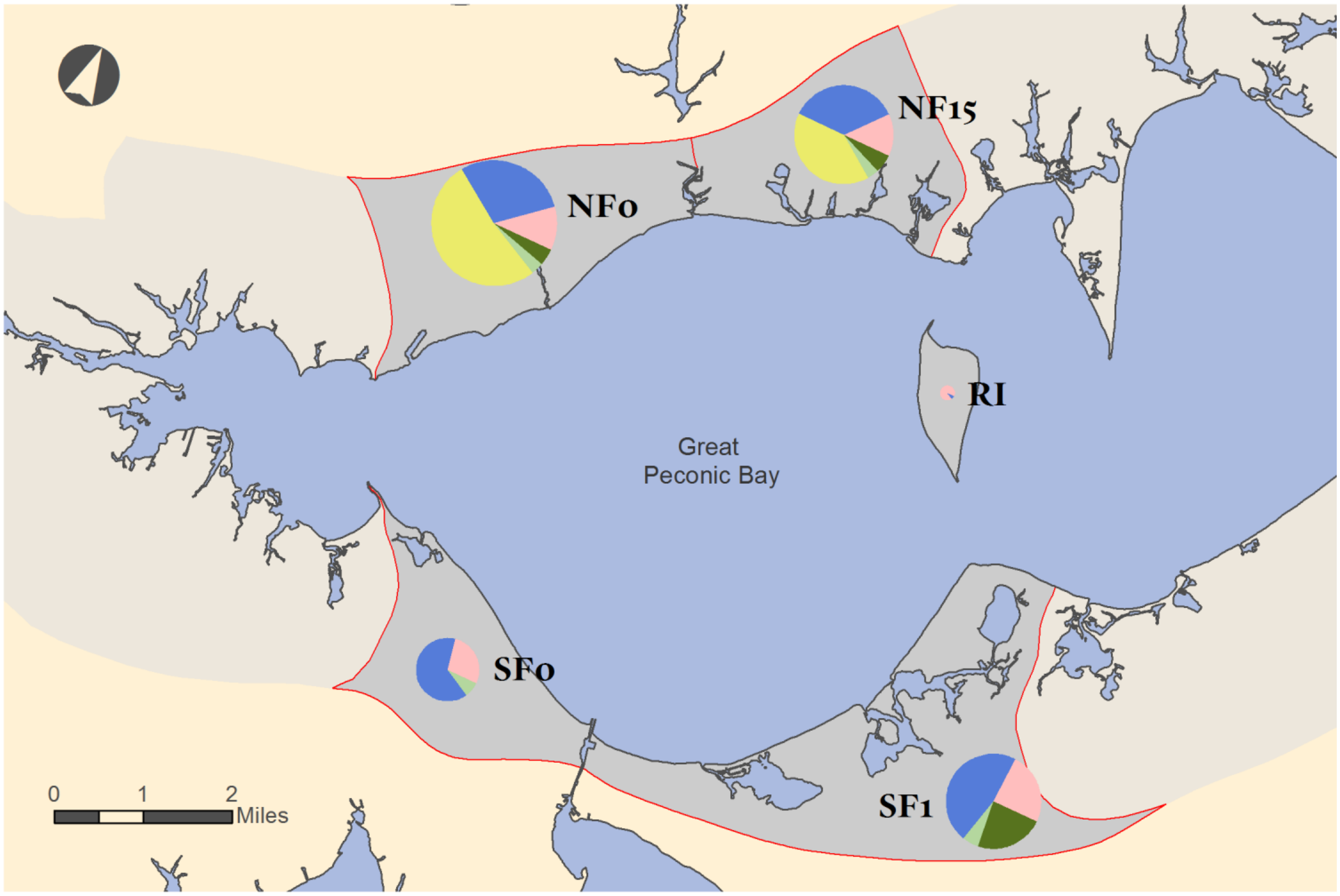
Walker, H. (2014, May 7). Personal communication.

Woods Hole Group, Inc. (2014). Southern New England and New York Seagrass Research Towards Restoration – Phase II report (in production).

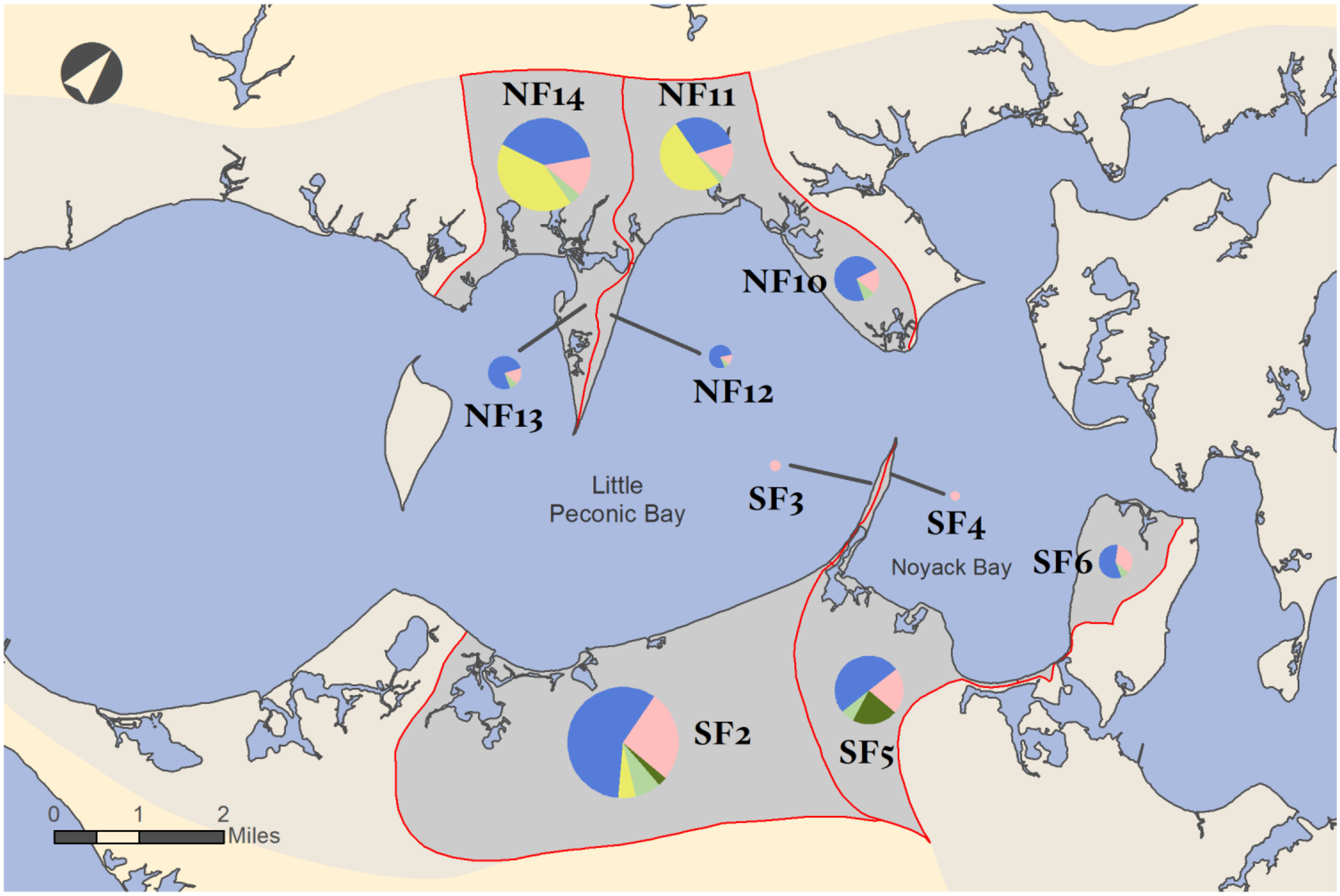
APPENDIX A – Nitrogen loading figures by subregion



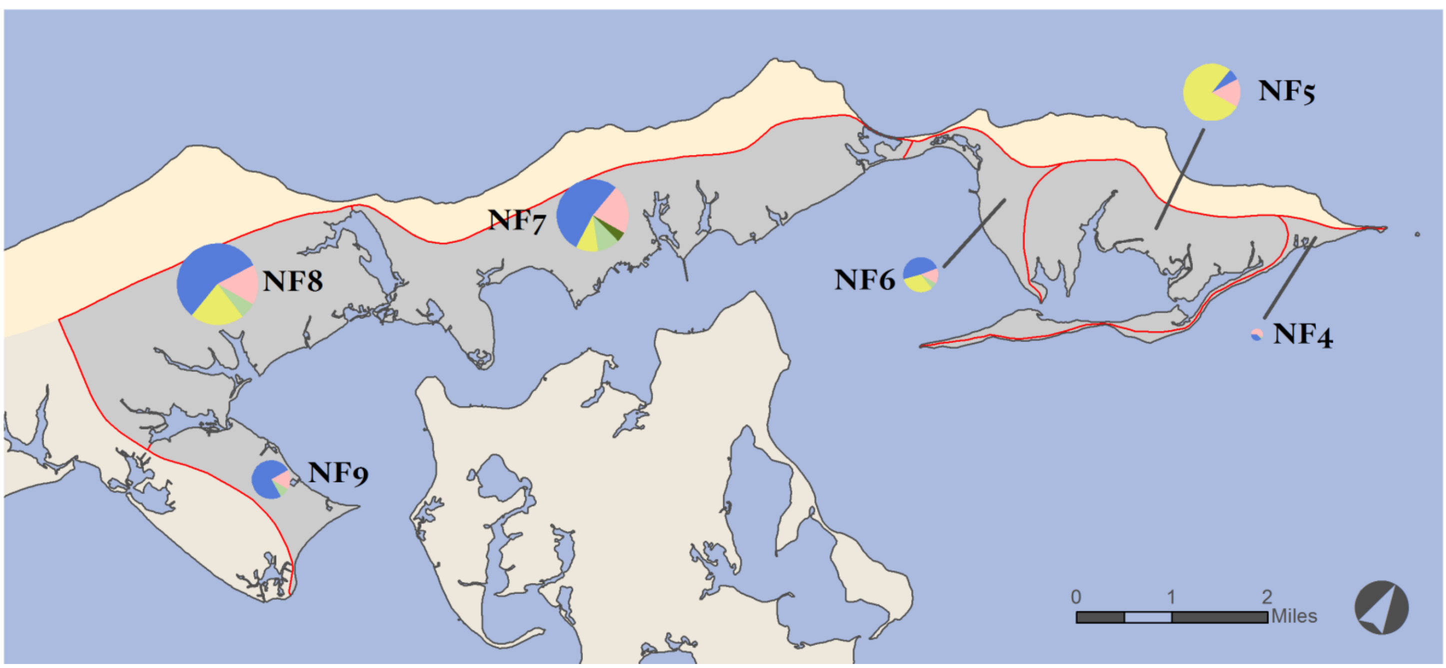
Flanders Bay



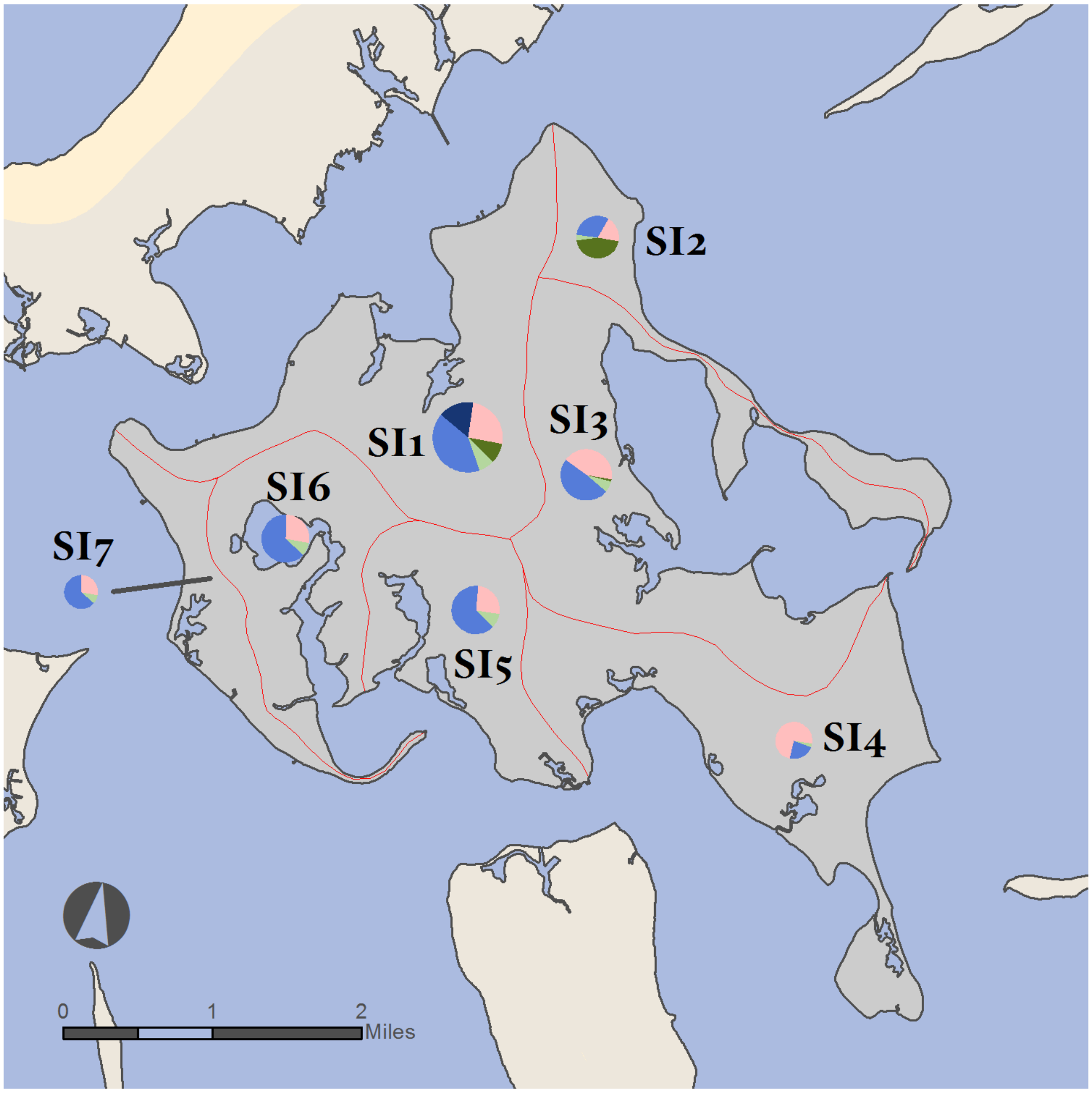
Great Peconic Bay



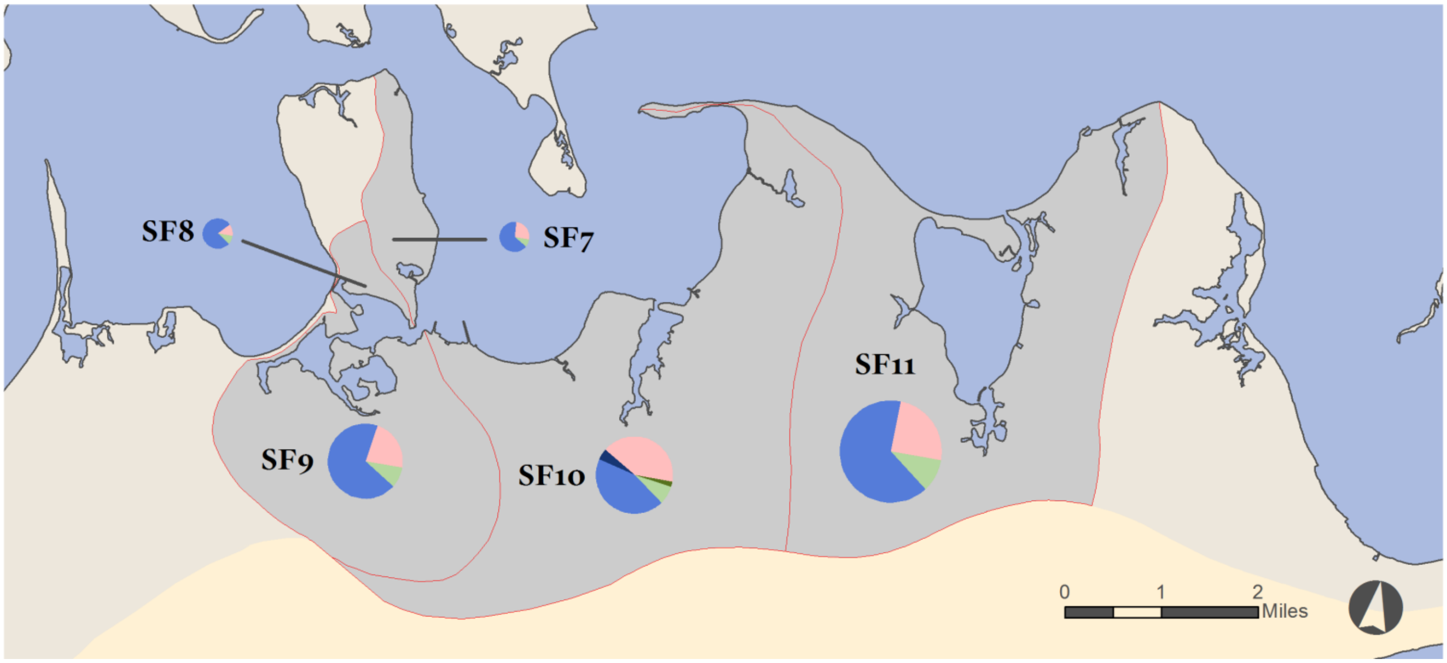
Little Peconic Bay / Noyack Bay



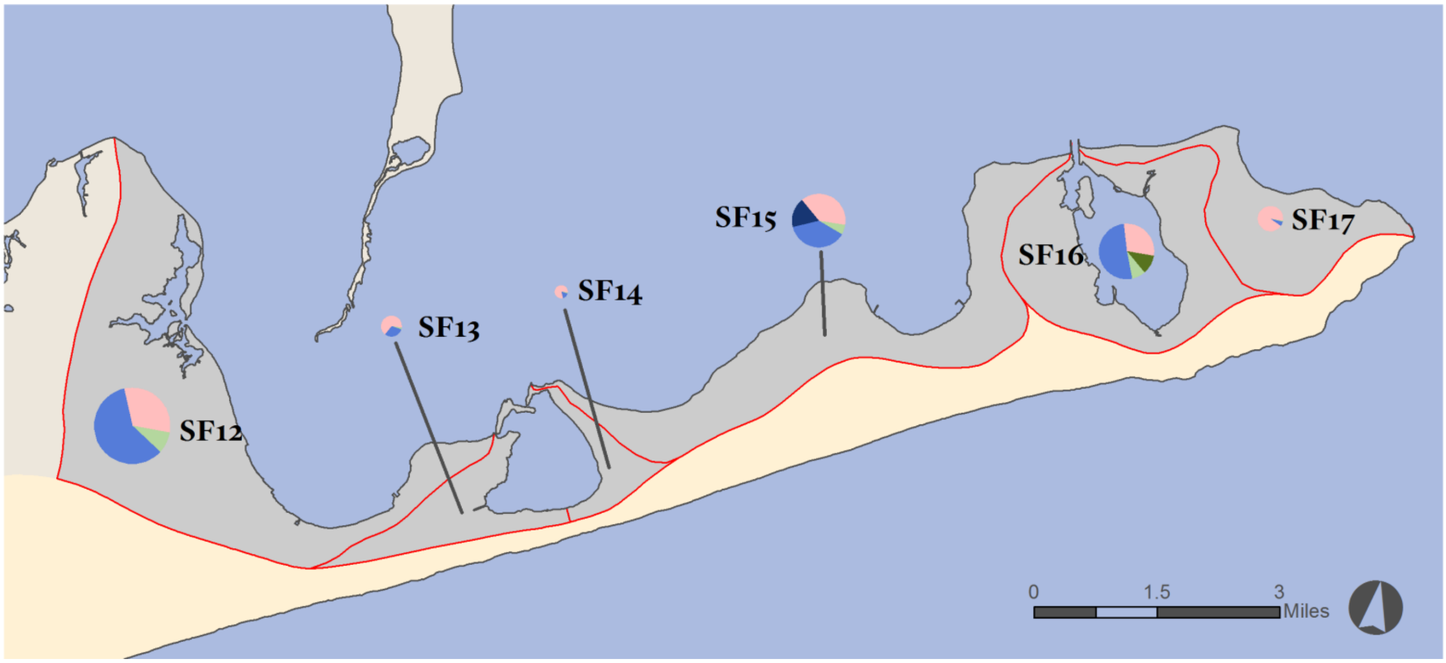
Southold Bay / Orient



Shelter Island



Sag Harbor / Three-Mile Harbor



Napeague Bay / Montauk

APPENDIX B – Data Sources

Source	Name
U.S. Geological Survey	Peconic Estuary Program Land Cover 2003
	Peconic Estuary Program Impervious Surfaces 2003
Suffolk County -	Land Use 2013
Dept. of Economic Development & Planning	Sewer district boundaries and sewage treatment plants 2013
	Building footprints 2013
U.S. Census	Population statistics 2010
National Atmospheric Deposition Program	Cedar Beach wet N deposition rates
U.S. EPA	CASTNET (Clean Air Status and Trends Network) - dry N deposition rates
	ECHO (Environmental Compliance History Online) - sewage treatment plant N flow rates

APPENDIX C – Base NLM 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 44% 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 49% of houses fertilizing lawns 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.

Nitrogen to and through vadose zone and aquifer:

Via nitrogen percolating diffusely from watershed surface:

j. (sum of a though i) x 39% not lost in vadose zone x 65% not lost in aquifer

Via wastewater from

k. 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 65% not lost through leaching field x 66% not lost in plumes x 65% not lost in aquifer.
l. 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 65% not lost in aquifer.

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

Nitrogen loading to estuary:

Sum of j + K+ l +m

*For atmospheric deposition, all land considered agricultural was used in the calculation. For fertilizer, however, 'pasture land' was not included as application rates would be negligible. All other agricultural land use types assumed the base average fertilizer rate, with the exception of vineyards which utilizes a much lower level of fertilizer. See parameters below.

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

APPENDIX D – 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. Unless footnoted these are the NLOAD model defaults, utilized in Kinney and Valiela (2011) and Latimer and Charpentier (2010).

Total atmospheric deposition (wet and dry)[1]	15.1 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		22%
% atmos N transported from freshwater ponds		44%
% atmos N transported from Impervious surfaces (roof/driveway)		38%
Fertilizer N applied to lawns[2]	104 kg N/ha	
Fertilizer N applied to agriculture	136 kg N/ha	
Fertilizer N applied to vineyards[3]	8.41 kg N/ha	
Fertilizer N applied to rec/golf courses[2]	115 kg N/ha	
Average lawn area	0.05 ha	
% of homes that use fertilizer[4]		49%
% 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[5]		53%
Per capita human N excretion rate	4.8 kg N/pp/yr	
% N transported from septic tank		94%
%N transported through leaching field		65%
% waste transported from septic plumes		66%
% watershed N transported from vadose zone		39%
% N transported from aquifer		65%

[1] Average from NADP Cedar Beach monitoring location and supplemented with regional CASTNET data to account for dry deposition.
[2] Valiela *et al*. 1997
[3] Communications with Cornell Cooperative Extension, April 2013.
[4] LISS Study 2006
[5] From 'year built' information from Town of Southampton- GIS Dept.