Southern New England and New York Seagrass Research Towards Restoration – Phase II

Prepared For:
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April 2014

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1.0 INTRODUCTION

The coastal waters of Southern New England and New York have lost extensive areas of seagrass habitat. The cause of this decline is multifaceted and based within a series of multiple stressors. These include the effects associated with increasing and chronic excess nutrient (primarily nitrogen) loads in combination with other environmental stressors such as thermal stress, changes in landscape, and possibly climate change (Latimer and Rego 2010, Moore et al. 2012, Touchette et al. 2003). The famous wasting disease event of the late 1930s resulted in a widespread loss of eelgrass in this region. Brown tides caused by blooms of the alga *Aureococcus anophagefferens* in the Long Island area first appeared in 1985 and have periodically resulted in significant losses of eelgrass[1]. Despite the recent absence of disease and brown tides in some areas, efforts to restore seagrass habitats have had limited to no success. As a result, seagrass habitat generally remains in decline throughout the region. The loss of seagrass may be linked to major declines in both finfish and shellfish populations, cascading to declines in economic and recreational fisheries (Hughes et al. 2002).

Research focused on understanding the relationships between multiple stressors and the health of seagrass communities is ongoing. Efforts to quantify nutrient inputs and to determine thresholds associated with seagrass response have been continuing for decades and collectively have found seagrasses to be sensitive to relatively small increases in nutrient inputs (Latimer and Rego 2010, Hauxwell et al. 2001. The aim of this second phase of The Nature Conservancy's (TNC) Seagrass Research and Restoration Initiative (Seagrass Initiative) is to evaluate anthropogenic sources of stress to seagrass habitats in Southern New England and New York, in context with site-specific physical characteristics and to study a series of specific estuaries where restoring enabling conditions will most likely preserve extant seagrass habitat or support recovery of lost habitat. Previous work associated with this project (Phase I) studied actual stressor-response characteristics through *in situ* field sampling and mesocosm experiments within the same region (Short et al. 2012). The mesocosm experiments applied different light, sediment, nutrient, and temperature conditions to a group of ten (10) populations of eelgrass (*Zostera marina*) within the New England/New York region. This work, coupled with a parallel study of population genetics yielded information on relative genetic diversity and resilience to multiple stressors among the populations studied. This information is important to the success of future seagrass restoration because the limited resources available to restore seagrasses need to be based on an optimized approach where the likelihood of success is maximized.

The primary activities associated with this project have been focused on: (1) collection of existing data (nutrient loads, flushing rates, water temperature, sediment characteristics, and historical eelgrass distribution), (2) the development of decision criteria for the selection of embayments to analyze in further detail (described herein), (3) developing additional watershed-estuarine nitrogen load models, and (4) making predictions of future

[1] http://commcgi.cc.stonybrook.edu/am2/publish/General_University_News_2/Damaging_Brown_Tide_Re-emerges_across_entire_South_Shore_of_Long_Island.shtml

conditions and associated risks associated with eelgrass preservation and restoration among 16 selected embayments within the study area.

This report provides an overview of project goals and objectives, methods applied to calculate nitrogen loads and the prediction of future environmental conditions in a series of selected embayments, and recommendations associated with future efforts to restore seagrass habitat (and the overall functionality of estuarine ecosystems) in the selected embayments.

2.0 PROJECT GOALS AND OBJECTIVES

The overarching goal of the Seagrass Initiative is to identify the genetic diversity of eelgrass throughout Southern New England and New York, improve understanding of the interactive effects of multiple stressors on eelgrass, and apply this information to inform and promote enabling conditions for healthy seagrass meadows and other important estuarine habitats.

The objective of this phase (Phase II) is to collect and augment site-specific data on nitrogen loads, benthic conditions, historical extent of seagrass habitats, and predict how future conditions (effects of nitrogen loads and climate change) may influence, and guide, protection and restoration strategies in long-term planning.

3.0 PROJECT METHODS

One goal the Seagrass Initiative Technical Team (the Project Team) established was to select embayments within the project study area spanning Long Island to Cape Cod in the states of New York, Connecticut, Rhode Island, and Massachusetts to apply more detailed analysis of nitrogen loading rates, estuarine physics, and sediment types. An additional set of embayments were chosen to include in a parallel analysis of the potential effects of climate change (i.e., thermal stress and sea level rise). These embayments were to be distributed among the four states in the study area and represent systems that currently support seagrass communities or those where seagrass habitat has been lost. The selection process for these embayments began with the collection and evaluation of existing information within the study area. Existing data associated with a total of 170 embayments and subembayments were collected, transformed into a spatially-explicit form (i.e., GIS shapefiles and Google Earth KZM files), and ranked by susceptibility to the effects associated with nutrient enrichment (eutrophication) and physical environmental conditions (e.g., water residence time). The Project Team, with the assistance of Woods Hole Group, evaluated these ranked embayments and established a series of selection criteria. These criteria were related to existing and historical seagrass habitat, the relative abundance of site-specific data, and the current level of susceptibility of seagrass communities to multiple stressors. The Project Team ultimately selected 10 key embayments to further analyze (see sections 3.3 and 3.4 below). Some of these embayments are comprised of subembayments which increased the total number to 18.

Woods Hole Group applied the watershed nitrogen load model (NLM) developed by Valiela et al. (1997) to the contributing watersheds of all 20 subembayments. Sources of watershed areas are described in Appendix III. Inputs for the NLM were collected from a variety of readily available sources (NYS GIS Clearing House, CT DEEP, RIGIS, MASS GIS, U.S. Census Bureau, and others). Sources and values of these input data are listed and described in Appendix I. The outputs of the NLM are described below and normalized to watershed and estuarine areas.

The methods associated with Section 4.2 (Climate Change Analysis) are based on multiple regressions of historical data from within the study area. The predictions of future water temperatures (a known environmental stressor) are based on the response (if any) of estuarine water temperatures to changes in local meteorological conditions. The effects of sea level rise are predicted within the context of thresholds associated with water depth, light attenuation, and compensation points related to light saturating conditions.

The following sections (3.1 through 3.4) provide more detail and discussion on the methods that have been applied to data collection, site selection, nitrogen load calculations, and climate change analysis.

3.1 DATA COLLECTION AND COMPILATION

Woods Hole Group collected and reviewed estuarine areas, volumes, flushing times, nitrogen loading rates, sediment organic matter content, and eelgrass areas for a total of 170 estuarine systems in the study area.

Nitrogen loads were reported for 74 estuaries within the study area by Latimer and Charpentier (2010). Additional nitrogen loads were reported by Nixon et al. (1995), the Massachusetts Estuary Project (MEP), Valiela et al. (2000), Kinney and Valiela (2011), Brawley (2002), and EPA Region 2. Water residence time values were published by Abdelrhman (2005) and the MEP (UMASS Dartmouth technical partner).

Data associated with levels of organic matter in estuarine sediments were obtained from the USDA-NRCS as subaqueous soils and the USGS as total organic carbon (TOC). The NRCS subaqueous soils consist of classifications akin to those established for terrestrial soils. These classifications are sometimes applied to sea grass and other benthic habitat studies. Currently, however, the areal coverage of subaqueous soils is limited to the Rhode Island coastal ponds. Wider areas of coverage are anticipated in the coming years. The USGS TOC data is available for most of Long Island Sound but limited to main stem portions of estuarine systems within the study area. Figures 1 and 2 show the areal coverage of both subaqueous and TOC data, respectively.

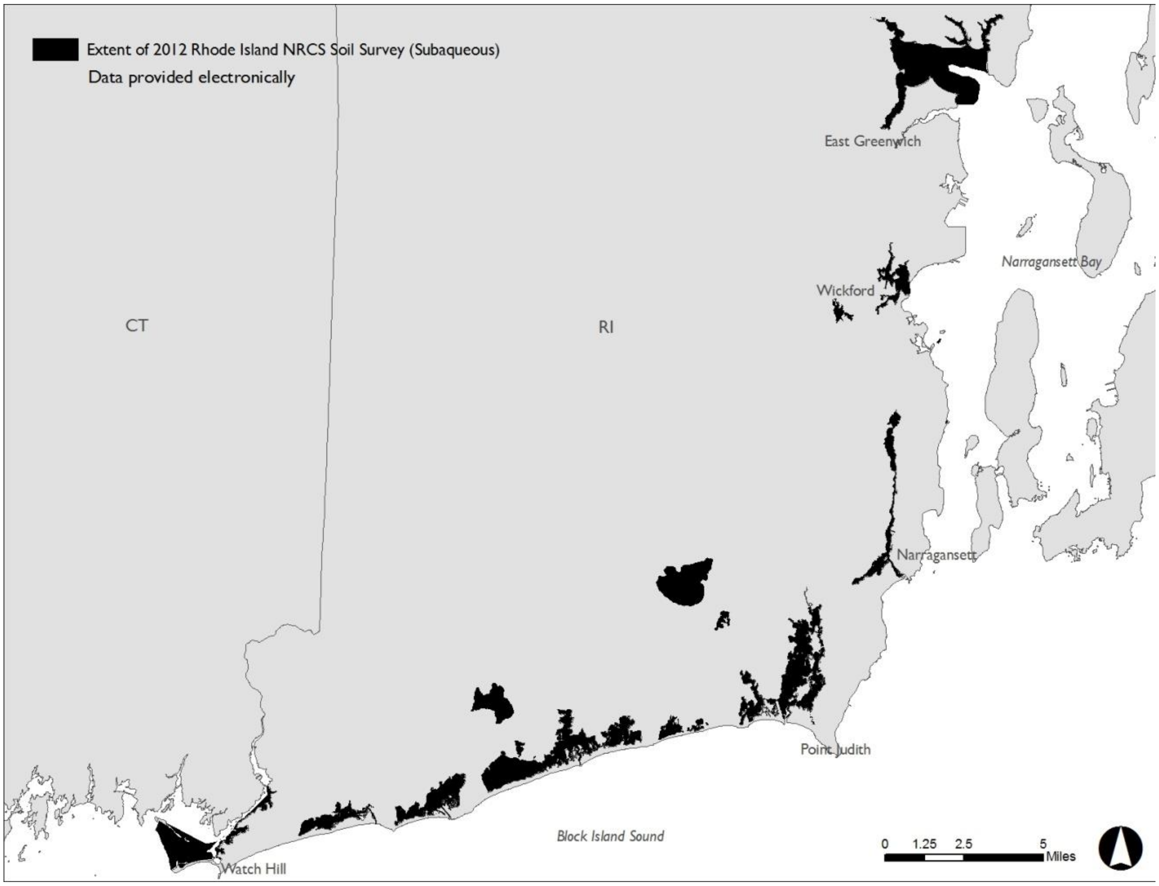

Figure 1. Geographical extent of subaqueous soils data coverage (NRCS).

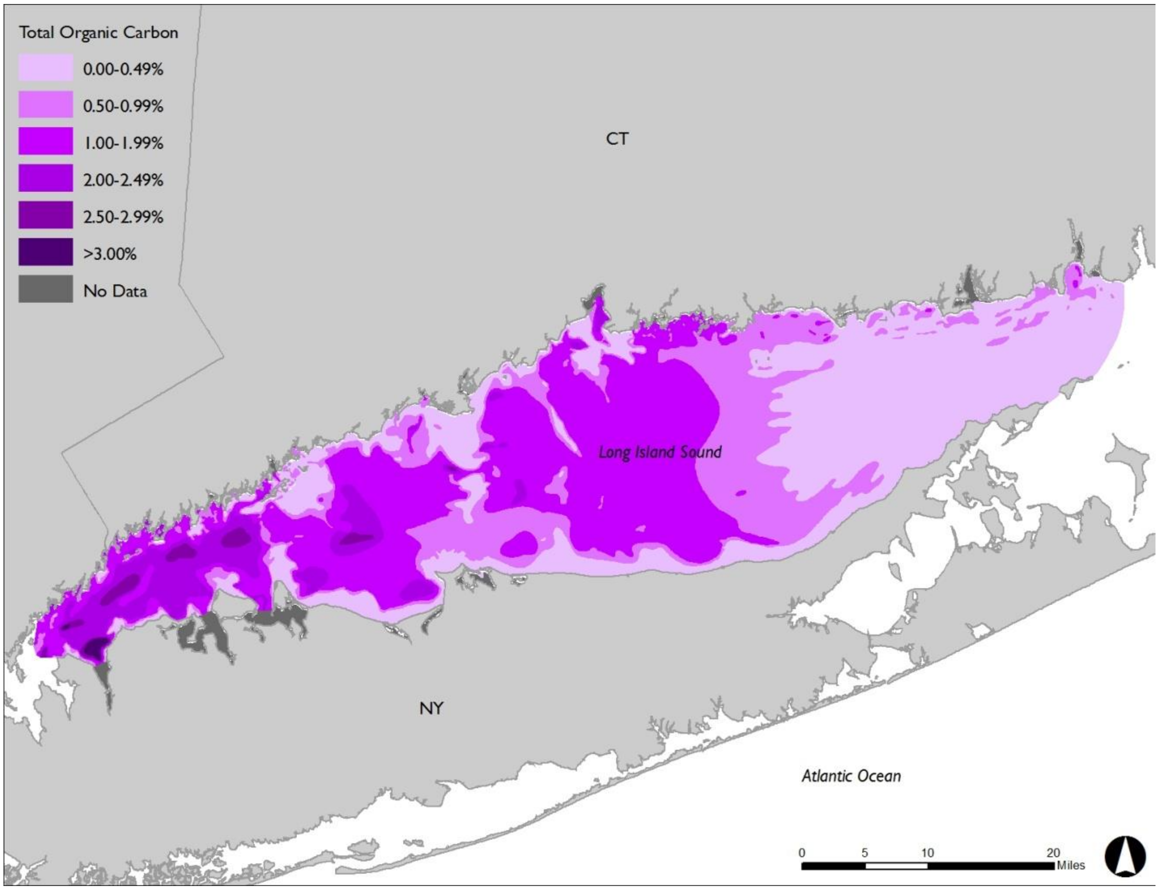

Figure 2. Geographical extent and reported values of sediment total organic carbon (TOC) (USGS).

3.2 SPECIFIC SITE SELECTION PROCESS

Woods Hole Group provided a breakdown of all the estuaries within the project area where data were collected and ranked them based on the susceptibility of seagrass habitat to nitrogen loads and water residence times. Following the review and evaluation of additional criteria (genetics, resilience to multiple stressors, proximity to salt marsh habitat, watershed condition) by the Project Team, TNC provided a final table of candidate embayments to conduct additional nitrogen load calculations and future conditions analysis. Table 1 shows the selected embayments including those which are coincident with parallel studies by Dr. Jamie Vaudrey (University of Connecticut, Avery Point).

Table 1. List and partial characteristics of embayments selected by the TNC Project Team for further analysis (NLM and future conditions)[2].

State	Site Name (Embayments)	Eelgrass Present	Eelgrass Historic	Unique Genetics (Short et al)	Resilience to Stressors (Short et al)	Adjacent Saltmarsh	Develop NLM	Future Scenarios Modeling
NY	Fishers Island (Barleyfield Cove, East Harbor, Chocomount Cove, West Harbor, Hay Harbor)	**X**	**X**	**X**	-	**X**	**X**	**X**
NY	Wading River	**X**	-	-	-	**X**	**X**	-
NY	Northport/Huntington Bays/Harbors	-	-	-	-		**X**	**X**
NY	Nissequogue River	-	-	-	-	**X**	**X**	**X**
NY	Peconic Bays (Great & Little)	**X**	**X**	-	-	**X**	-	**X**
CT	Duck Island (Menunketesuck River, Patchogue River)	**X**	**X**	**X**	**Low**	**X**	-	**X**
CT	Ram Island (Mystic Harbor, Palmer Cove)	**X**	**X**	**X**	**Low**	**X**	**X**	**X**
CT	Hotchkiss Beach (Stony Creek)	**X**	**X**	-	-	**X**	**X**	**X**
CT	Saugatuck River	-	**X**	-	-	**X**	**X**	-

[2] Additional criteria associated with the selection of these embayments included a composite index (0-100) established by The Nature Conservancy Project Team and reported flushing times and nitrogen loads (where available).

State	Site Name (Embayments)	Eelgrass Present	Eelgrass Historic	Unique Genetics (Short et al)	Resilience to Stressors (Short et al)	Adjacent Saltmarsh	Develop NLM	Future Scenarios Modeling
CT	Quiambog Cove	X	X	-	-	-	-	X
CT	Mumford Cove (Upper & Lower)	X	X	-	-	X	-	X
CT	Stonington Harbor	X	X	-	-	X	-	X
CT/RI	Little Narragansett Bay (LNB, Pawcatuck River, Wequetequock)	X	X	-	-	X	-	X
RI	Greenwich Bay	-		-	-	-	-	X
RI/MA	Mount Hope Bay	-		-	-	-	-	X
MA	Taunton River	-		-	-	-	-	X
MA	Nasketucket Bay	-	X	-	-	-	X	X
MA	Wareham River	X	X	-	-	-	X	X
MA	Little Buttermilk Bay	-	X	-	-	-	X	-
MA	Buttermilk Bay	-	X	-	-	-	-	X

3.3 NITROGEN LOAD ANALYSIS

The purpose of this task was to determine the feasibility of creating nutrient loading models for the set of embayments identified by the Project Team (some previously identified by Short et al. [2012] as supporting *Z. marina* populations that are relatively resilient to multiple stressors). Short et al. (2012) determined the resilience of *Z. marina* to multiple stressors based on genetic, population, and plant tolerance studies. Their study included field surveys, genetic evaluations, and mesocosm experiments on a subset of 10 populations within the study area. They concluded that the following populations were most resilient to the multiples stressors of high temperature, low light availability, and poor sediment characteristics: Great South Bay (NY_11), Prudence Island (RI_3), Ninigret Pond (RI_10), and Southway/Monomoy Island (MA_2). Nitrogen loading estimates currently exist for all of these systems, except for Southway/Monomoy. As described above, the Project Team evaluated existing data and preliminary stressor susceptibility rankings to come up with a prioritized list of embayments for additional nitrogen load analysis. Woods Hole Group assessed the feasibility of running these analyses and applied a nitrogen loading model to the entire set of embayments.

An acceptable, verified, peer-reviewed approach to modeling nitrogen loads to the embayments in this study is to apply the nitrogen loading model (NLM, Valiela et al. 1997) which is described at http://nload.mbl.edu. Dr. John Brawley (Woods Hole Group) was among contributing developers of this model and has applied it to several coastal watersheds in Massachusetts (Brawley 2002). In a recent study, NLM was the model applied by Dr. Jim Latimer (EPA) and colleagues to 74 estuarine watersheds in southern New England (Latimer and Charpentier 2010) and results were used to compare loads to eelgrass losses (Latimer and Rego 2010). It should be noted that there are several similar watershed load models and some of these are described and provided at the NLM website. The Woods Hole Group, in consultation with the Project Team, applied the original NLM model to the selected embayment watersheds for consistency with other previous and current projects of similar nature.

The NLM model is based on an algorithm that accounts for all significant sources and pathways of nitrogen delivery to coastal waters via watersheds. Uncertainty based on the inputs and transformations within NLM is estimated to be about 38% (Collins et al. 2000), based on standard deviation associated with 8 of the 16 input variables (standard error of the mean was reported as 12-14%). Nitrogen inputs include atmospheric deposition, domestic wastewater, and fertilizer application to agriculture and turf (including lawns). The model takes into consideration processes that intercept watershed nitrogen, including assimilation by vegetation, adsorption to soils, volatilization of ammonia, and denitrification. The amount of nitrogen entering the watershed and the portion of that which reaches the aquifer below depends on the types of land uses present in the watershed. The algorithm considers the following general land use types: residential areas, impervious surfaces, unfertilized turf, golf courses, agriculture, freshwater ponds and marshes, and forested areas. The model inputs applied to the selected embayment watersheds (this project) are listed in Appendices I and II. For more detailed descriptions of the characteristics of these land use categories and loss terms associated with them, vadose and saturated aquifer zones see Valiela et al. (1997), Brawley (2002), Latimer and Charpentier (2010), Collins et al. (2000) and others.

Sources for embayment and watershed boundaries, buildings, impervious surfaces, land use, eelgrass, sewered areas, wetlands, and population (occupancy rates) are summarized in Appendix III.

The Project Team selected 10 general estuarine areas culminating in a total of 20 watersheds where NLM was to be applied. Section 4.1 describes the results of the NLM modeling work to these watersheds, including a summary of inputs and loads by source category, and any caveats associated with the modeling process. Figure 3 shows the locations of the watersheds modeled. Some of the study locations are composed of several sub-watersheds which are not visible due to the scale of Figure 3.

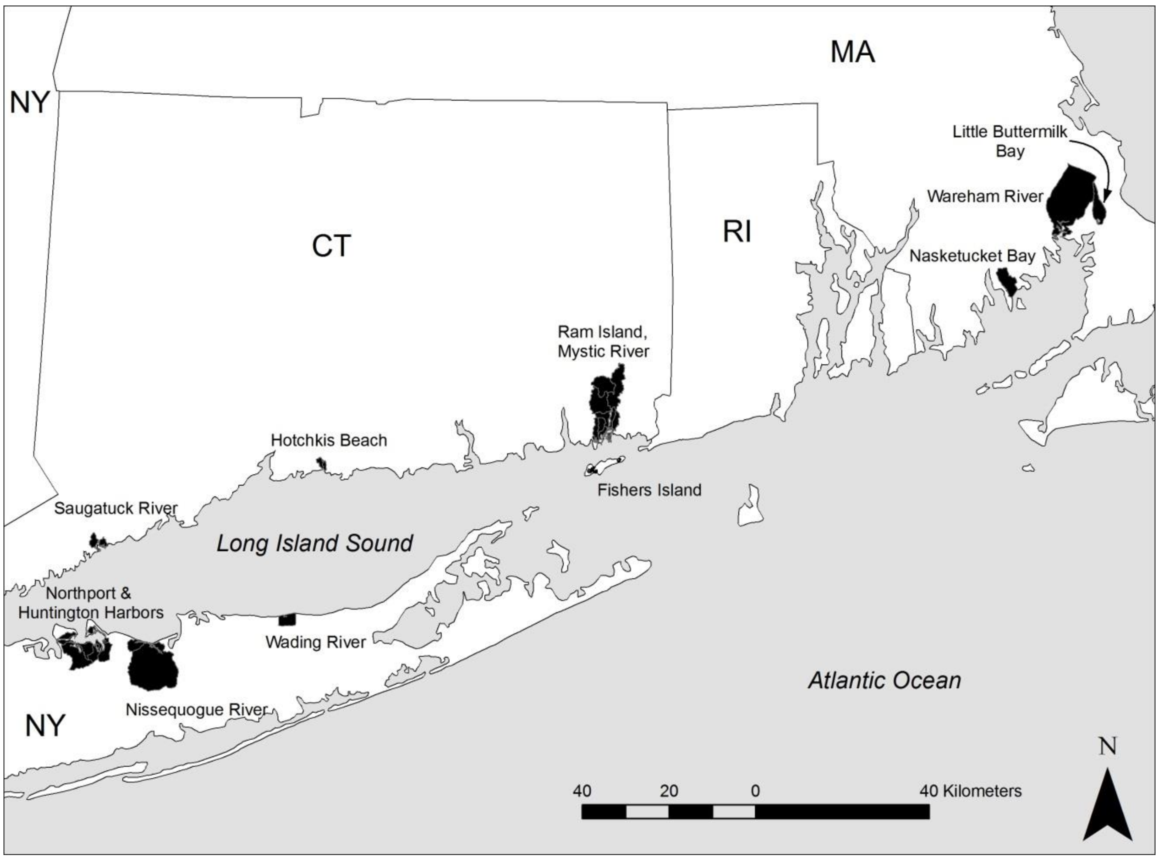

Figure 3. The project study area showing locations of watersheds where nitrogen load models were applied.

For systems with wastewater treatment facilities within the watershed area, the 3-5 year average total Nitrogen (kg N yr^{-1}) output of the facility was computed. This average total N added to the NLM output parameter "Total wastewater N delivered to estuary (kg N yr^{-1})". Data for average total N were acquired from the Enforcement and Compliance History Online (ECHO, http://echo.epa.gov/) and from contact with state authorities. Wastewater treatment facilities are located within the watersheds of 5 study locations:

Wareham River, Saugatuck River, Wareham, Ram Island, and Northport & Huntington Harbors.

3.4 CLIMATE CHANGE ANALYSIS

Z. marina habitats in the New York/New England region are potentially at risk due to the effects associated with climate change. Poor survivability has been demonstrated to be related to thermal stress (sometimes coupled with nitrate toxicity) and the loss of saturating light conditions, which can be a result of sea level rise.

Water temperature - Changes in future conditions determine the long-term effectiveness of restoration practices. Several studies have demonstrated the sensitivity of *Z. marina* to elevated water temperatures (reaching and exceeding 23^{o} to 27^{o} C). Thermal tolerance thresholds have been shown to differ among populations due to acclimation and variations in resilience (Short et al. 2012). Although few studies have quantified the actual relationship between frequency and duration of warm water events and stress levels in *Z. marina*, it is known that mean temperatures in excess of 25^{o} C for periods of weeks results in reduced vigor and increased mortality (Bintz et al. 2003, Johnson et al. 2003, Touchette et al. 2003, Moore et al. 2012, and Short et al. 2012). Periodic phenomena such as spring-neap tide cycles (see Figure 4 below) and the North Atlantic Oscillation (NAO) can have measurable effects on embayment water temperatures and the frequency and duration of extreme events. These were included in our statistical modeling approach (see below).

A statistical approach was followed that can be used to simulate daily seasonal environmental conditions in the estuary under a range of scenarios for climate change. The approach applied by Wagner et al (2011) was explored, where statistical models were used in this manner to forecast estuarine water temperatures. This approach involved two steps. First, historical data were used to develop a statistical model relating temperature in the estuary to regressors like boundary water temperature, air temperature, tidal volumes, and solar irradiance. Second, the analogue of a weather generator (Wilks 2012) that was used to simulate the behavior of these regressors under alternative scenarios of climate change was developed. Weather generators are commonly used to study the impacts of climate change on agriculture (where, as here, the occurrence and duration of extreme weather is of primary interest).

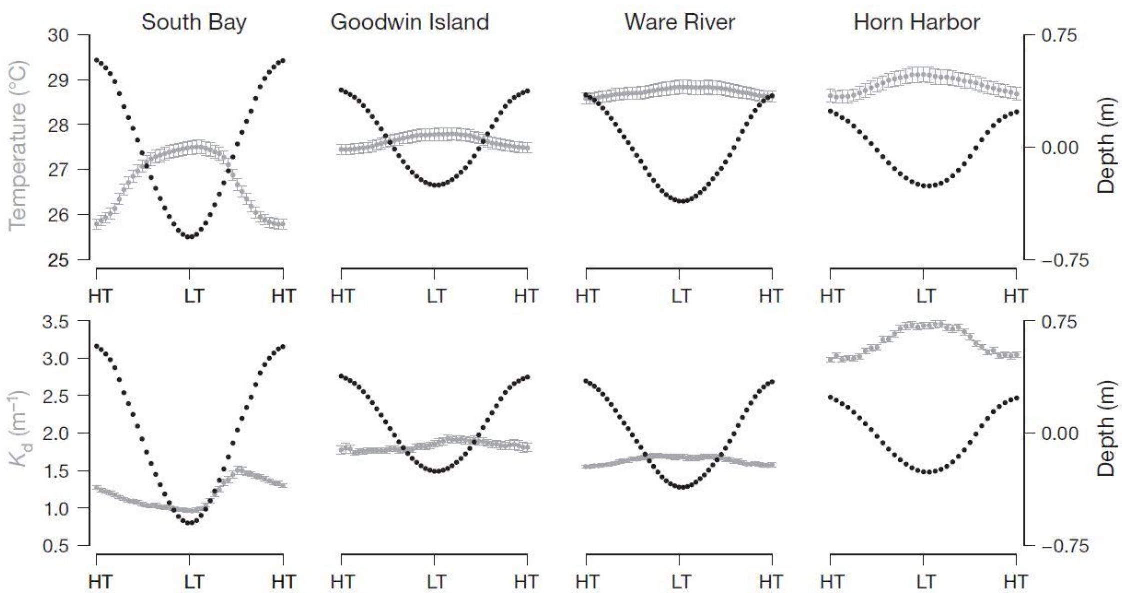

Figure 4. Graphical relationships between tidal amplitude, water temperature, and light extinction coefficient in a series of Maryland and Virginia estuaries (from Moore et al. 2012).

The weather generator was then used to simulate forcing that was applied to the estuary models to simulate environmental conditions – including the occurrence and duration of extreme conditions – under alternative climate change scenarios. It is important to stress that the embayment models are meant to simulate quantities like maximum daily temperature, number of days with maximum temperature exceeding a given level, etc. These may be more important to *Z. marina* than daily mean temperature because means do not adequately describe ecological responses to variable conditions.

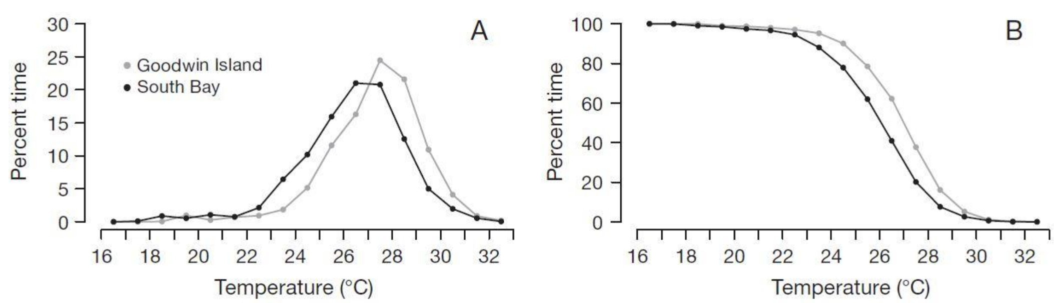

Figure 5. Frequency distributions and cumulative frequency distributions for water temperature at Goodwin Island and South Bay (VA and MD, respectively). From Moore et al. (2012).

Sea Level Rise – Sea level rise may have undesirable influences on *Z. marina* populations that exist at elevations that are near their light compensation points; where small decreases in the frequency and duration of saturating light may result in unsustainable conditions. The degree to which light attenuation affects existing and historical seagrass habitats was evaluated in context with depth and observed light extinction coefficients.

Nutrient Loading – Near-future predictions of changes in nutrient loads to the embayments selected in this study can be made based on existing and likely future management plans. For example, water bodies that have been identified by the Environmental Protection Agency (EPA) and the states as impaired due to nutrient enrichment have, or will have, total maximum daily loads (TMDLs) developed. The TMDLs provide quantitative targets of future nutrient loads. Some municipalities have developed management plans for future nutrient reductions. These may include specific proposed timelines for the implementation of reduction practices such as centralized wastewater and inlet widening. Sediment quality is directly linked to nutrient input and water exchange (flushing rates). Estimates of future nutrient loads will allow for determining probabilities of changes in sediment quality.

The results of these studies are provided as probabilities associated with future conditions (e.g., probability distributions of water temperature metrics). The goal is to make this approach transferable such that it can be extended to other embayments. The results of these assessments, including all models developed to support this task, were provided to TNC in GIS and Google Earth formats.

4.0 PROJECT RESULTS

The following sections summarize the results of the nitrogen load modeling using NLM on the 18 individual estuarine systems within the study area.

4.1 NITROGEN LOAD ANALYSES

Summary: The NLM was applied to 20 coastal watersheds to calculate total nitrogen loads to their receiving coastal waters. Appendix I is a list of the values applied to the model input parameters. Table 2 provides a summary of areal loads to each embayment. Detailed descriptions of these loads (e.g., by source) are described below.

Table 2. Summary of embayment areas, calculated nitrogen loads, and normalized areal nitrogen loads to the 20 embayments in this study.

Estuarine Area	Sub-Embayment	Estuary Area (m^2)	Total N delivered to Estuary (kg N y^{-1})	N Load per estuarine area (g m^{-2} y^{-1})
Fishers Island	East Harbor	157,218	1206	4.50
	Hay Harbor	239,271	533	2.23
	Chocomount Cove	217,200	225	1.04
	Barleyfield Cove	113,500	133	1.17
	West Harbor	404,561	1,229	3.04
Hotchkiss Beach	Hotchkiss Beach	243,172	6,705	27.57
Little Buttermilk Bay	Little Buttermilk Bay	409,125	8,995	21.99
Nasketucket Bay	Nasketucket Bay	2,981,211	10,109	3.39
Nissequogue River	Nissequogue Main	715,020	164,935	230.67
	Nissequogue West	254,610	22,531	88.49
Northport – Huntington Harbors	Centerport Harbor	516,689	24,983	48.35
	Huntington Bay	4,818,258	16,934	3.51
	Huntington Harbor	1,411,499	93,983	66.58
	Lloyd Harbor	2,237,267	4,015	1.79
	Northport Bay	7,111,428	9,272	1.30
	Northport Harbor	2,315,250	25,647	11.08
Ram Island	Ram Island	5,608,890	49,237	8.78
Saugatuck River	Saugatuck River	2,038,712	170,702	83.73
Wading River	Wading River	36,815	30,609	831.43
Wareham River	Wareham River	3,682,964	64,814	17.60

4.1.1 New York

4.1.1.1 Fishers Island

Five embayments were studied on Fishers Island (NY): Hay Harbor, West Harbor, Chocomount Cove, Barleyfield Cove, and East Harbor (Figure 6). Watersheds associated with these embayments were delineated based on local topography because groundwater levels were not available for analysis. Currently there are no wastewater treatment facilities within the Fishers Island watershed.

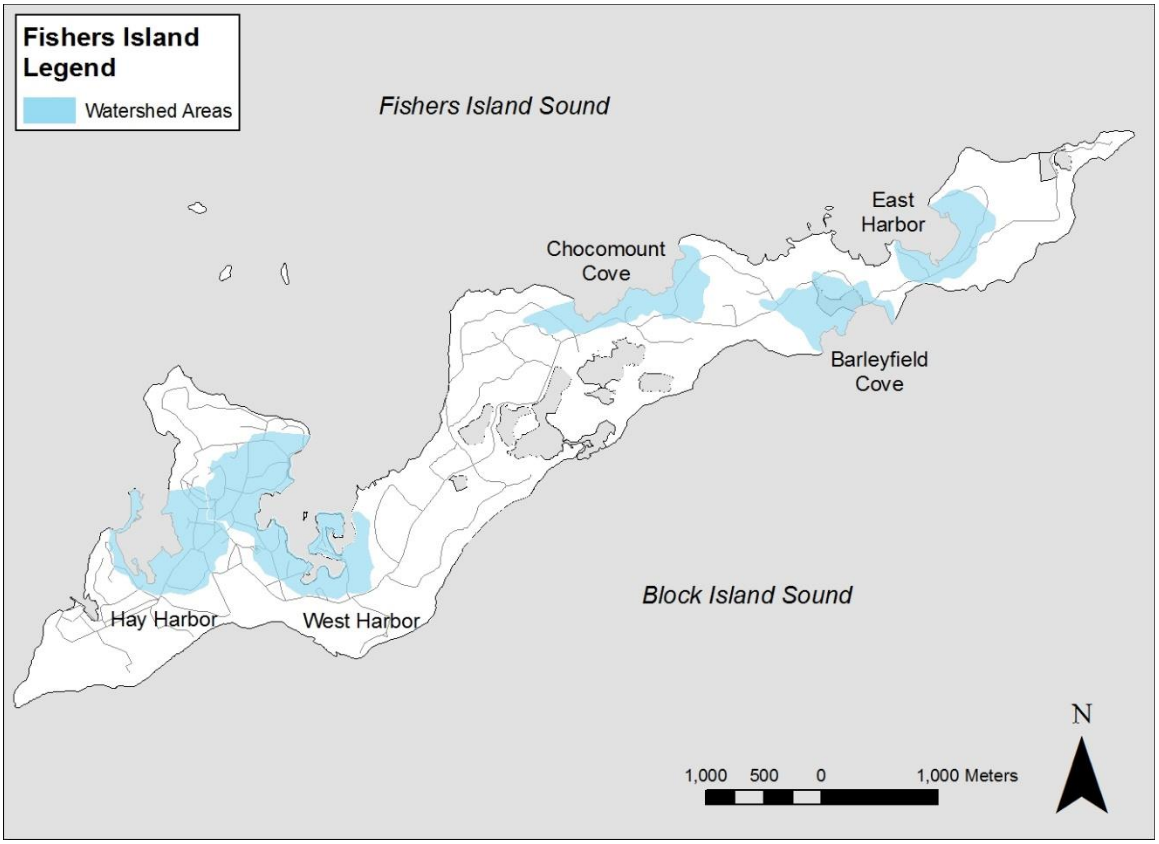

Figure 6. Map of Fishers Island embayments and watersheds (Hay Harbor, West Harbor, Chocomount Cove, Barleyfield Cove, and East Harbor).

4.1.1.1.1 Hay Harbor

Hay Harbor is located on the southwestern end of Fishers Island. It has an estuarine area of 23.93 ha and the watershed is 49 ha (watershed:estuary ratio of 2.03). A summary of selected land use inputs to the NLM are shown in Table 3. The results of the NLM are shown in Table 4 and Figures 7 and 8. Although the areal rate of nitrogen delivery to Hay Harbor is relatively low (2.23 g m^{-2} y^{-1}), 78% of the load is attributed to septic wastewater which may be managed to further reduce land-derived nitrogen input.

Table 3. Watershed area and selected land use areas in Hay Harbor watershed.

Land Use Category	Area (ha)
Watershed area	48.52
Land area	48.29
Area of freshwater ponds	0.23
Number of buildings	120
Buildings within 200m of shore	69
Total area of impervious surfaces	6.76
Area of natural vegetation	33.45
Area of wetlands	2.08
Area of other agriculture	0
Area of golf courses	0
Area of parks and athletic fields	0

Table 4. Total nitrogen loading to Hay Harbor (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	81	15%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	413	78%
Fertilizer: agriculture	-	0%
Fertilizer: lawns	39	7%
Fertilizer: golf courses	-	0%
Total	533	

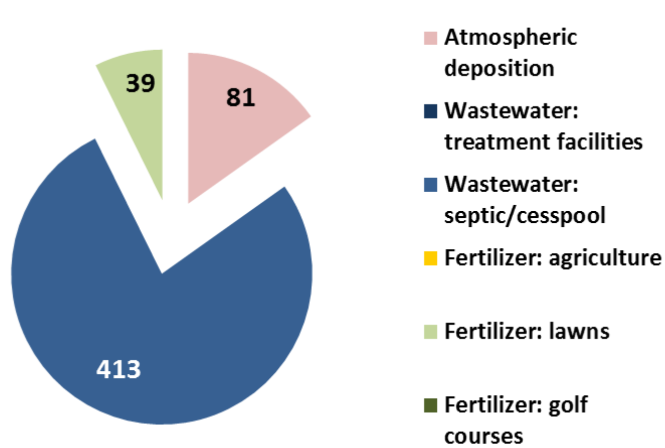

Figure 7. Total nitrogen load (kg) by source to Hay Harbor.

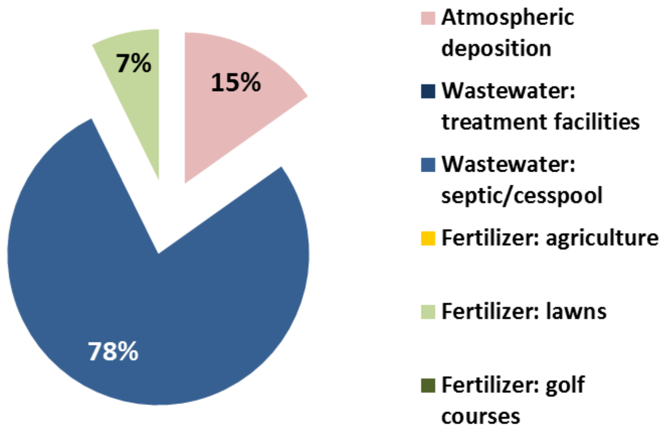

Figure 8. Total nitrogen load (%) by source to Hay Harbor.

4.1.1.1.2 West Harbor

West Harbor is located immediately east of Hay Harbor, along the southwestern end of Fishers Island. It has an estuarine area of 16 ha and the watershed is 93 ha (watershed:estuary ratio of 2.29). A summary of selected land use inputs to the NLM are shown in Table 5. The results of the NLM are shown in Table 6 and Figures 9 and 10. Like neighboring Hay Harbor, the areal rate of nitrogen delivery to Hay Harbor is relatively low (3.04 g m^{-2} y^{-1}), 80% of the load is attributed to wastewater which may be managed to further reduce land-derived nitrogen input.

Table 5. Watershed area and selected land use areas in West Harbor.

Land Use Category	Area (ha)
Watershed area	92.58
Land area	92.58
Area of freshwater ponds	0
Number of buildings	276
Buildings within 200m of shore	184
Total area of impervious surfaces	14.52
Area of natural vegetation	58.54
Area of wetlands	3.63
Area of other agriculture	0
Area of golf courses	0
Area of parks and athletic fields	2.09

Table 6. Total nitrogen loading to West Harbor (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	155	13%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	985	80%
Fertilizer: agriculture	-	0%
Fertilizer: lawns	89	7%
Fertilizer: golf courses	-	0%
Total	1,229	

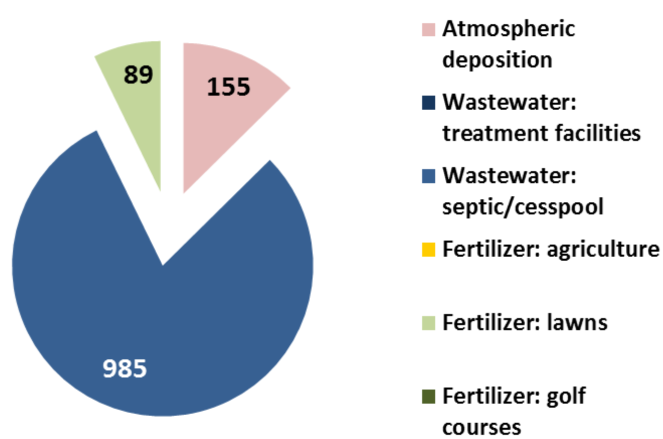

Figure 9. Total nitrogen load (kg) by source to West Harbor.

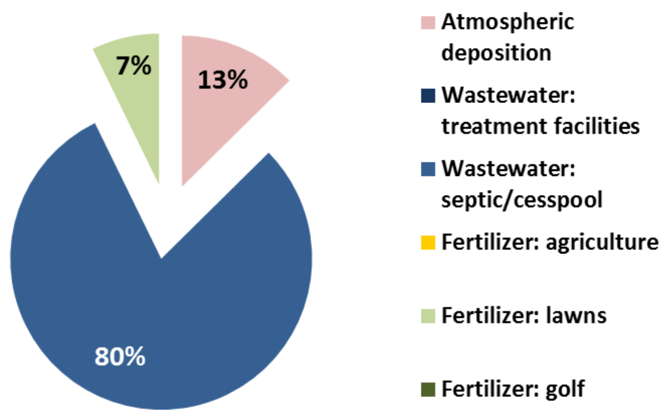

Figure 10. Total nitrogen load (%) by source to West Harbor.

4.1.1.1.3 Chocomount Cove

Chocomount Cove is located on the northwestern side of Fishers Island. It has an estuarine area of 21.72 ha and the watershed is 40 ha (watershed:estuary ratio of 1.84). A summary of selected land use inputs to the NLM are shown in Table 7. The results of the NLM are shown in Table 8 and Figures 11 and 12. Although the areal rate of nitrogen delivery to Chocomount Cove is very low (1.04 g m^{-2} y^{-1}), 68% of the load is attributed to septic wastewater which may be managed to further reduce land-derived nitrogen input.

Table 7. Watershed and selected land use areas in Chocomount Cove.

Land Use Category	Area (ha)
Watershed area	39.87
Land area	39.87
Area of freshwater ponds	0
Number of buildings	40
Buildings within 200m of shore	35
Total area of impervious surfaces	2.46
Area of natural vegetation	35.27
Area of wetlands	0.14
Area of other agriculture	0
Area of golf courses	0
Area of parks and athletic fields	0

Table 8. Total nitrogen loading to Chocomount Cove (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	58	26%
Wastewater: treatment facilities	0	0%
Wastewater: septic/cesspool	154	68%
Fertilizer: agriculture	0	0%
Fertilizer: lawns	13	6%
Fertilizer: golf courses	0	0%
Total	225	

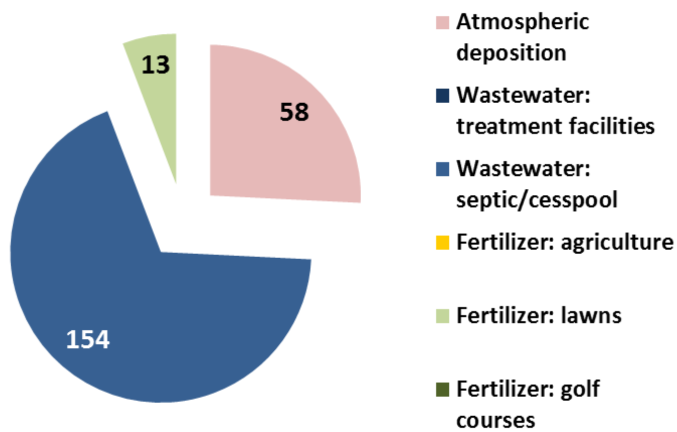

Figure 11. Total nitrogen load (kg) by source to Chocomount Cove.

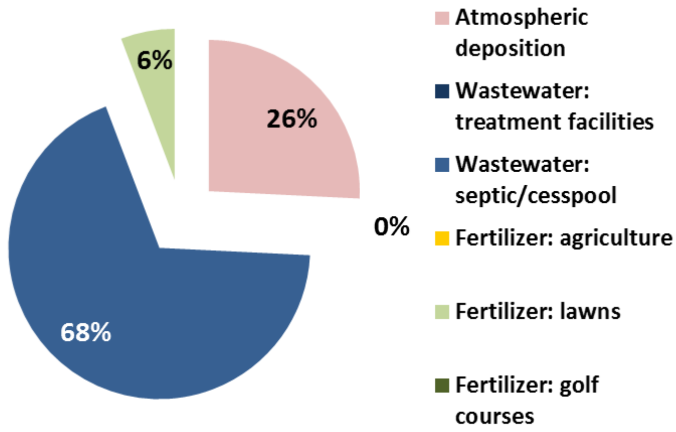

Figure 12. Total nitrogen load (%) by source to Chocomount Cove.

4.1.1.1.4 Barleyfield Cove

Barleyfield Cove is located on the northeastern side of Fishers Island. It has an estuarine area of 11.35 ha and the watershed is 33.52 ha (watershed:estuary ratio of 2.95). A summary of selected land use inputs to the NLM are shown in Table 9. The results of the NLM are shown in Table 10 and Figures 13 and 14. Although the areal rate of nitrogen delivery to Chocomount Cove is very low (1.04 g m^{-2} y^{-1}), 68% of the load is attributed to septic wastewater which may be managed to further reduce land-derived nitrogen input.

Table 9. Watershed and selected land use areas in BarleyField Cove.

Land Use Category	Area (ha)
Watershed area	33.52
Land area	33.52
Area of freshwater ponds	0
Number of buildings	21
Buildings within 200m of shore	11
Total area of impervious surfaces	1.83
Area of natural vegetation	24.24
Area of wetlands	3.38
Area of other agriculture	0
Area of golf courses	0
Area of parks and athletic fields	3.02

Table 10. Total nitrogen loading to Barleyfield Cove (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	55	41%
Wastewater: treatment facilities	0	0%
Wastewater: septic/cesspool	71	53%
Fertilizer: agriculture	0	0%
Fertilizer: lawns	7	5%
Fertilizer: golf courses	0	0%
Total	133	

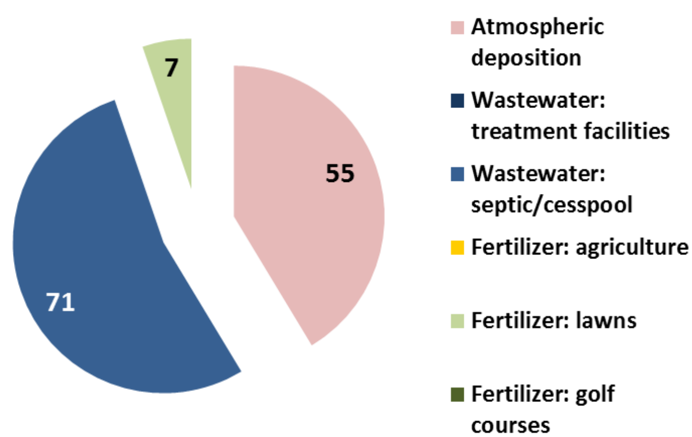

Figure 13. Total nitrogen load (kg) by source to Barleyfield Cove.

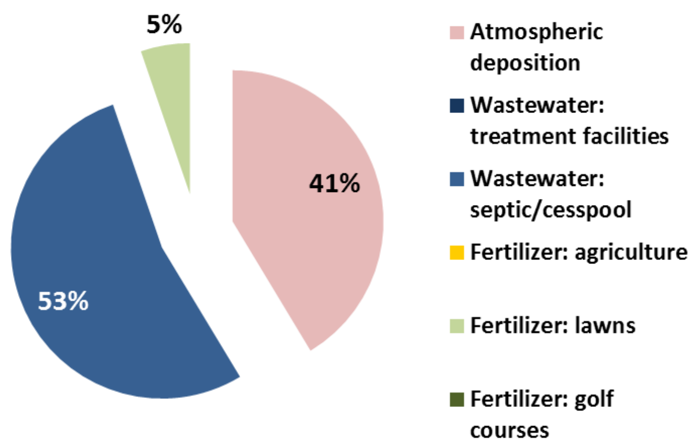

Figure 14. Total nitrogen load (%) by source to Barleyfield Cove.

4.1.1.1.3 East Harbor

East Harbor is located on the northeastern point of Fishers Island. It has an estuarine area of 16 ha and the watershed is 32 ha (watershed:estuary ratio of 2.01). A summary of selected land use inputs to the NLM are shown in Table 11. The results of the NLM are shown in Table 12 and Figures 15 and 16. The nitrogen budget for this embayment is significantly influenced by the presence of a golf course (Fishers Island Club) which, according to model results, contributes 81% of the total nitrogen load of 4.5 g N m^{-2} y^{-1}.

Table 11. Watershed and selected land use areas in East Harbor.

Land Use Category	Area (ha)
Watershed area	31.62
Land area	31.05
Area of freshwater ponds	0.57
Number of buildings	20
Buildings within 200m of shore	16
Total area of impervious surfaces	3.09
Area of natural vegetation	3.85
Area of wetlands	1.75
Area of other agriculture	0
Area of golf courses	21.36
Area of parks and athletic fields	0

Table 12. Total nitrogen loading to East Harbor (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	556	46%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	75	6%
Fertilizer: agriculture	-	0%
Fertilizer: lawns	6	0%
Fertilizer: golf courses	569	47%
Total	1,206	

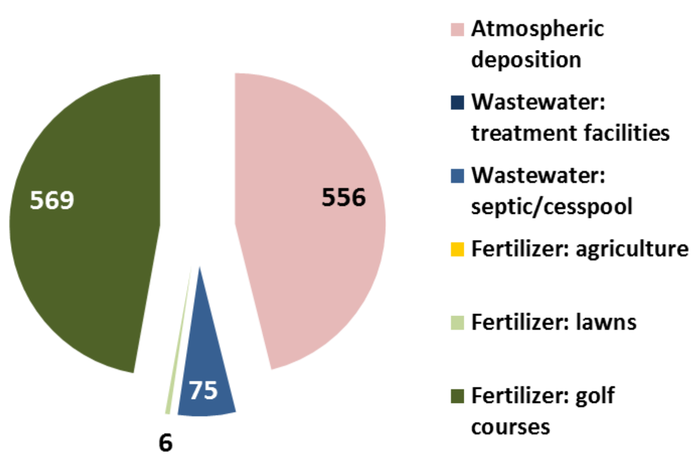

Figure 15. Total nitrogen load (kg) by source to East Harbor.

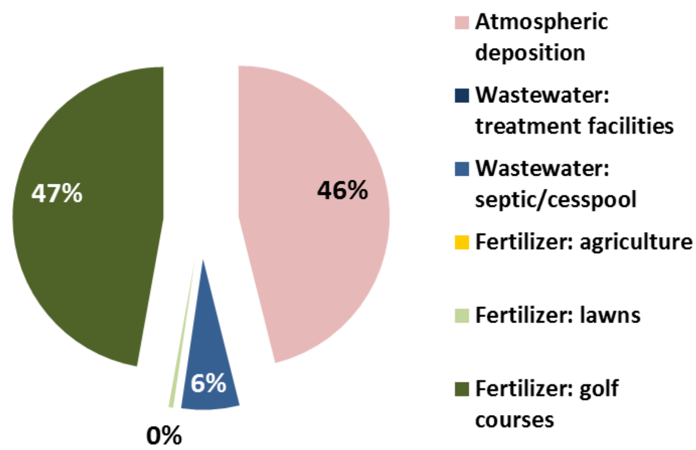

Figure 16. Total nitrogen load (%) by source to East Harbor.

4.1.1.2 Wading River

The Wading River is located on the north shore of Long Island. It is a saltmarsh-dominated estuary with a relatively narrow main channel system. It has an estuarine area of 3.68 ha and the watershed is 3,258 ha (watershed:estuary ratio of 885). A summary of selected land use inputs to the NLM are shown in Table 13. The results of the NLM are shown in Table 14 and Figures 18 and 19. The areal nitrogen load to this system (831.43 g N m^{-2} y^{-1}) is quite high due to the relative size of the watershed and the budget is dominated by wastewater contributions from a relatively dense residential area to the south and east portions of the watershed. There are no wastewater treatment facilities within the Wading River watershed.

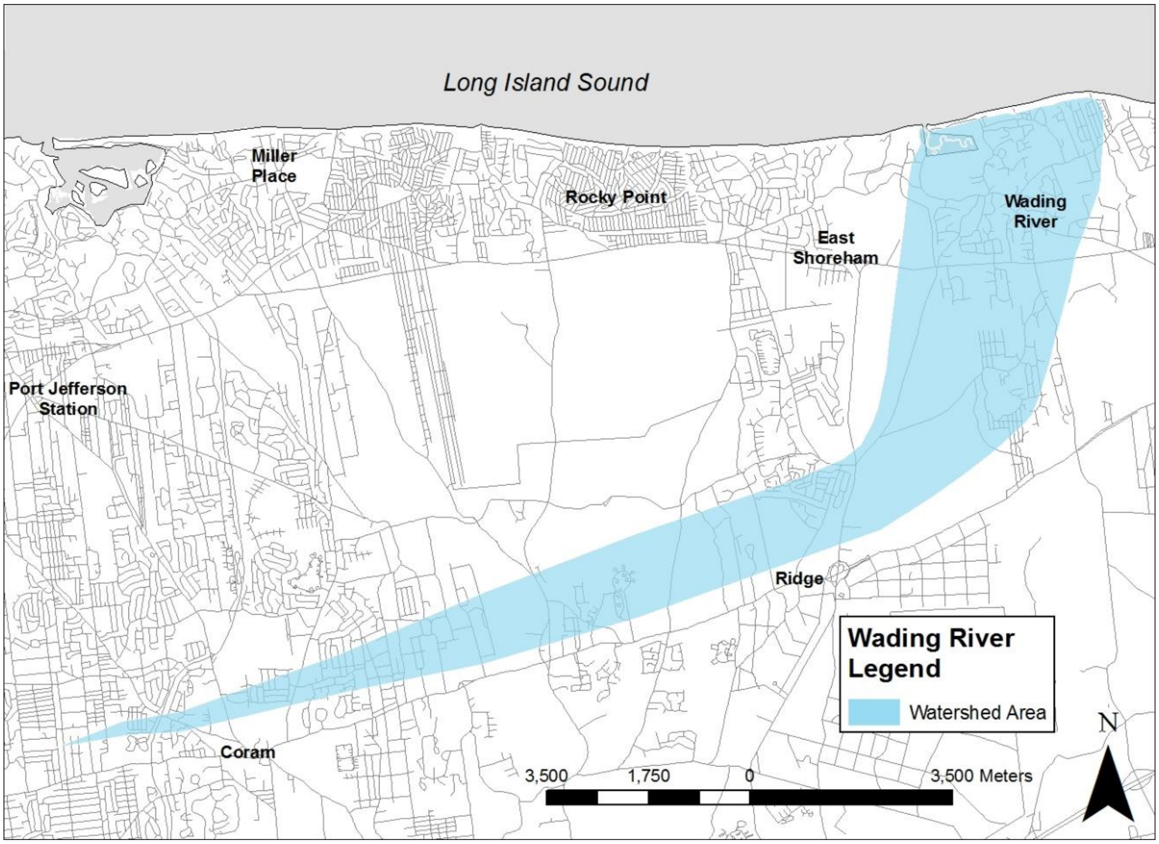

Figure 17. Map of Wading River embayment and watershed.

Table 13. Watershed and selected land use areas in Wading River.

Land Use Category	Area (ha)
Watershed area	3,258.24
Land area	3,234.36
Area of freshwater ponds	23.88
Number of buildings	5,397
Buildings within 200m of shore	12
Total area of impervious surfaces	220.90
Area of natural vegetation	2,355.80
Area of wetlands	69.86
Area of other agriculture	50.94
Area of golf courses	15.87
Area of parks and athletic fields	27.13

Table 14. Total nitrogen loading to Wading River (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	5,387	18%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	21,969	72%
Fertilizer: agriculture	1,080	4%
Fertilizer: lawns	1,750	6%
Fertilizer: golf courses	423	1%
Total	30,609	

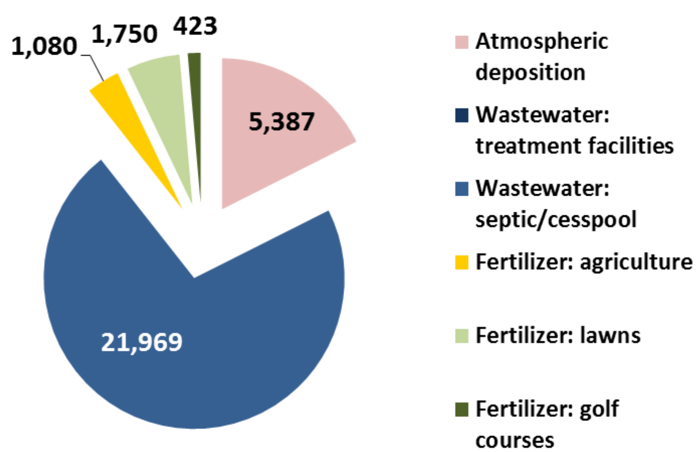

Figure 18. Total nitrogen load (kg) by source to Wading River.

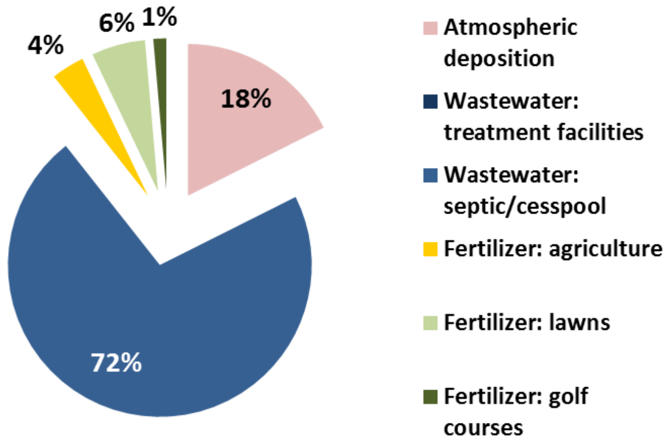

Figure 19. Total nitrogen load (%) by source to Wading River.

4.1.1.3 Northport/Huntington

The Northport/Huntington system (Figure 20) is comprised of 6 individual contributing watersheds associated with 6 (or 7 depending on how the complex is arranged) separate embayments. There are two wastewater treatment facilities within the Northport/Huntington watershed system located in the Northport Harbor and Huntington Harbor watersheds, respectively.

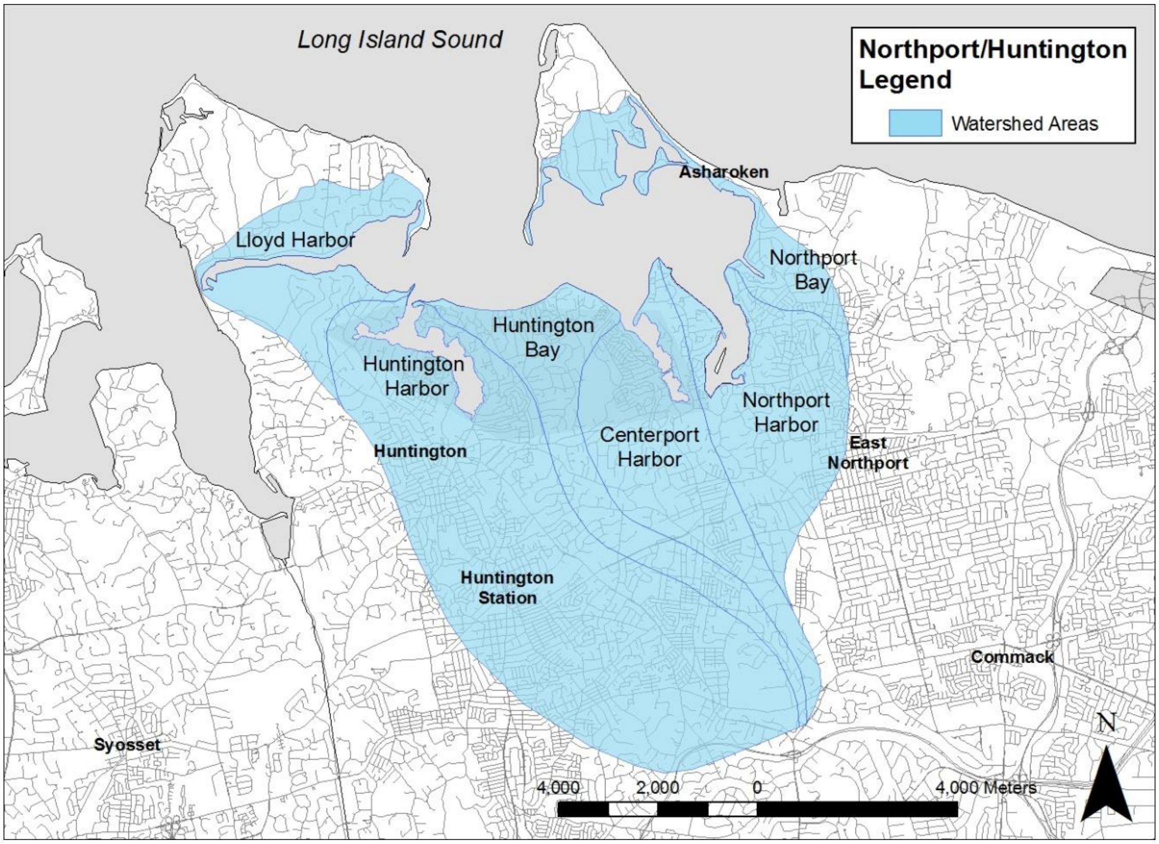

Figure 20. Map of the Northport/Huntington Bay/Harbor complex and associated watersheds.

4.1.1.3.1 Lloyd Harbor

Lloyd Harbor is located on the western side of the estuarine complex. It has a relatively long, narrow main section that extends to the extreme western edge of Lloyd's Neck. It has an estuarine area of 224 ha and the watershed is 636 ha (watershed:estuary ratio of 2.84). A summary of selected land use inputs to the NLM are shown in Table 15. The results of the NLM are shown in Table 16 and Figures 21 and 22. The areal nitrogen load to this system (1.79 g N m^{-2} y^{-1}) is due to the relatively low number of houses and various uses within the watershed. The nitrogen budget is dominated by wastewater contributions (63%) from residential areas near the mouth of the estuary. There are no wastewater treatment facilities within the Lloyd Harbor watershed.

Table 15. Watershed and selected land use areas in Lloyd Harbor.

Land Use Category	Area (ha)
Watershed area	799.6
Land area	798.80
Area of freshwater ponds	0.8
Number of buildings	645
Buildings within 200m of shore	121
Total area of impervious surfaces	49.48
Area of natural vegetation	429.72
Area of wetlands	46.36
Area of other agriculture	0
Area of golf courses	0
Area of parks and athletic fields	240.99

Table 16. Total nitrogen loading, by source, to Lloyd Harbor (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	1,277	32%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	2,529	63%
Fertilizer: agriculture	-	0%
Fertilizer: lawns	209	5%
Fertilizer: golf courses	-	0%
Total	4,015	

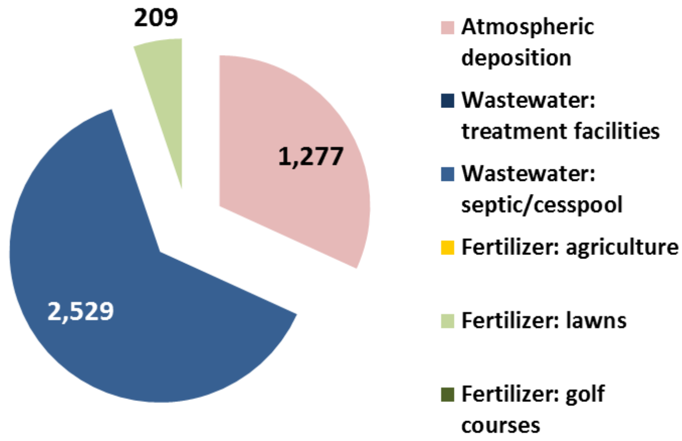

Figure 21. Total nitrogen load (kg) by source to Lloyd Harbor.

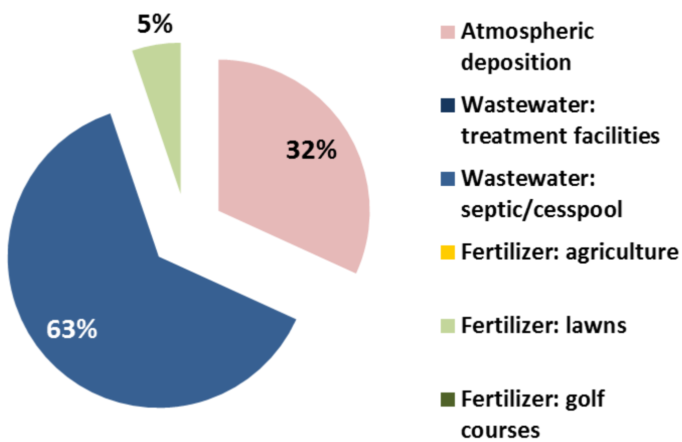

Figure 22. Total nitrogen load (%) by source to Lloyd Harbor.

4.1.1.3.2 Huntington Harbor

Huntington Harbor is adjacent to Lloyd Harbor (immediately south). It has an estuarine area of 141 ha and the watershed is 3,759 ha (watershed:estuary ratio of 26.65). A summary of selected land use inputs to the NLM are shown in Table 17. The results of the NLM are shown in Table 18 and Figures 23 and 24. The areal nitrogen load to this system (66.58 g N m^{-2} y^{-1}) is relatively high and primarily associated with a densely populated watershed (wastewater accounts for 85% of nitrogen input). The total nitrogen load from the Huntington wastewater treatment facility (SPDES NY000021342) based on

2009 NYDEC SPDES documentation is approximately 95 lbs d^{-1} or 15,728 kg N yr^{-1}. This accounts for 33% of the total annual N load to Huntington Harbor (Table 17).

Table 17. Watershed and selected land use areas in Huntington Harbor.

Land Use Category	Area (ha)
Watershed area	3,759.06
Land area	2,226.07
Area of freshwater ponds	7.28
Number of buildings	6,542
Buildings within 200m of shore	451
Total area of impervious surfaces	291.77
Area of natural vegetation	1,225.53
Area of wetlands	7.89
Area of other agriculture	0.68
Area of golf courses	39.78
Area of parks and athletic fields	113.24

Table 18. Total nitrogen load to Huntington Harbor (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	7,270	8%
Wastewater: treatment facilities	15,728	17%
Wastewater: septic/cesspool	64,169	68%
Fertilizer: agriculture	644	1%
Fertilizer: lawns	5,727	6%
Fertilizer: golf courses	445	0%
Total	93,983	

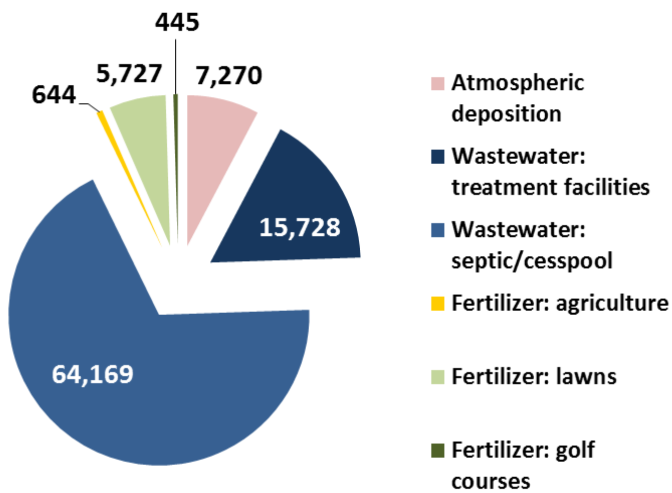

Figure 23. Total nitrogen load (kg) by source to Huntington Harbor.

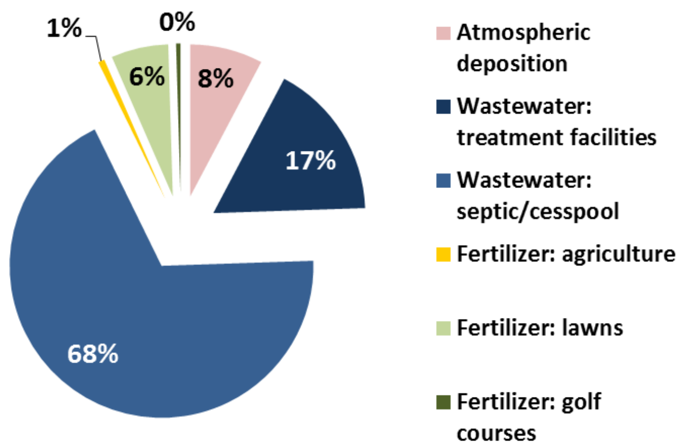

Figure 24. Total nitrogen load (%) by source to Huntington Harbor.

4.1.1.3.3 Huntington Bay

Huntington Bay is the larger, open western portion of the combined Northport/Huntington estuarine system. The Huntington Bay watershed is only one of three that contribute directly to Huntington Bay (Lloyd and Huntington Harbor watersheds comprise the remaining watersheds). It has an estuarine area of 482 ha and the watershed is 951 ha (watershed:estuary ratio of 1.97). A summary of selected land use inputs to the NLM are shown in Table 19. The results of the NLM are shown in Table 20 and Figures 25 and 26. The areal nitrogen load to this system (3.51 g N m^{-2} y^{-1}) is relatively low and primarily associated with wastewater contributions (78% of nitrogen input). There are no wastewater treatment facilities within the Huntington Bay watershed.

Table 19. Watershed and selected land use areas in Huntington Bay.

Land Use Category	Area (ha)
Watershed area	950.96
Land area	946.61
Area of freshwater ponds	4.35
Number of buildings	3,528
Buildings within 200m of shore	326
Total area of impervious surfaces	209.84
Area of natural vegetation	509.27
Area of wetlands	5.32
Area of other agriculture	1.87
Area of golf courses	-
Area of parks and athletic fields	43.91

Table 20. Total nitrogen loading to Huntington Bay (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	1,646	10%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	13,231	78%
Fertilizer: agriculture	40	0%
Fertilizer: lawns	873	5%
Fertilizer: golf courses	1,144	7%
Total	16,934	

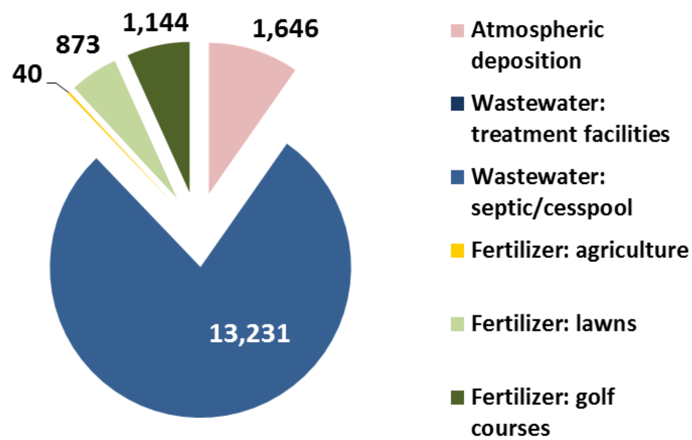

Figure 25. Total nitrogen load (kg) by source to Huntington Bay.

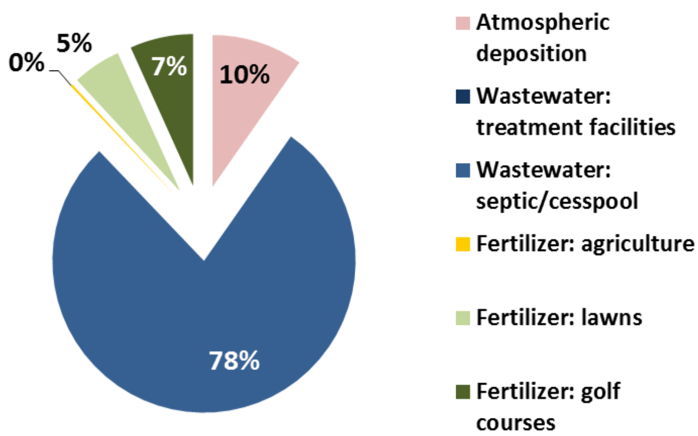

Figure 26. Total nitrogen load (%) by source to Huntington Bay.

4.1.1.3.4 Centerport Harbor

Centerport Harbor is located along the southern portion of this estuarine complex. It has an estuarine area of 52 ha and the watershed is 1,213 ha (watershed:estuary ratio of 23.32). A summary of selected land use inputs to the NLM are shown in Table 21. The results of the NLM are shown in Table 22 and Figures 27 and 28. The areal nitrogen load to this system is 48.35 g N m^{-2} y^{-1} and is relatively high and primarily associated with a densely populated watershed (wastewater accounts for 77% of nitrogen input). There are no wastewater treatment facilities within the Centerport Harbor watershed.

Table 21. Watershed and selected land use areas in Centerport Harbor.

Land Use Category	Area (ha)
Watershed area	1,212.80
Land area	1,208.66
Area of freshwater ponds	4.14
Number of buildings	5,097
Buildings within 200m of shore	544
Total area of impervious surfaces	294.92
Area of natural vegetation	520.07
Area of wetlands	7.20
Area of other agriculture	6.74
Area of golf courses	67.54
Area of parks and athletic fields	57.34

Table 22. Total nitrogen loading to Centerport Harbor (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	2,144	9%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	19,244	77%
Fertilizer: agriculture	143	1%
Fertilizer: lawns	1,652	7%
Fertilizer: golf courses	1,800	7%
Total	24,983	

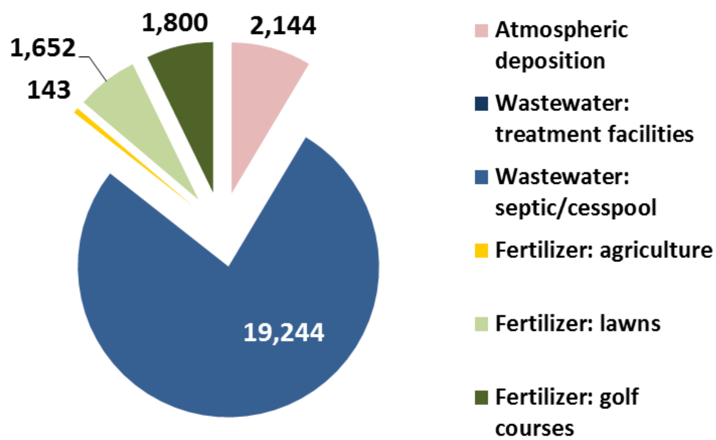

Figure 27. Total nitrogen load (kg) by source to Centerport Harbor.

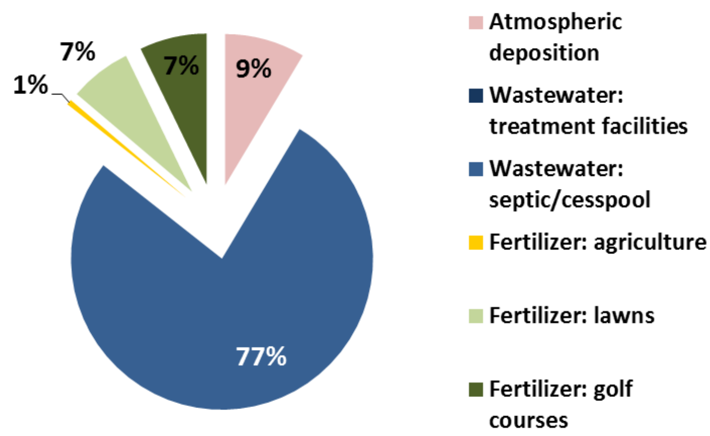

Figure 28. Total nitrogen load (%) by source to Centerport Harbor.

4.1.1.3.5 Northport Harbor

Northport Harbor is located immediately east of Centerport Harbor. It has an estuarine area of 232 ha and the watershed is 1,150 ha (watershed:estuary ratio of 4.96). A summary of selected land use inputs to the NLM are shown in Table 23. The results of the NLM are shown in Table 24 and Figures 29 and 30. The areal nitrogen load to this system (9.08 g N m^{-2} y^{-1}) is moderately high and primarily associated with a densely populated watershed (wastewater accounts for 85% of nitrogen input). The Northport Village wastewater treatment facility (SPDES NY0024881) currently discharges 20 lbs TN d^{-1} (3,311 kg TN yr^{-1}) according to NYDEC[3] (Table 20).

Table 23. Watershed and selected land use areas in Northport Harbor.

Land Use Category	Area (ha)
Watershed area	1,150.07
Land area	1,148.39
Area of freshwater ponds	1.68
Number of buildings	5,033
Buildings within 200m of shore	282
Total area of impervious surfaces	320.29
Area of natural vegetation	500.34
Area of wetlands	5.61
Area of other agriculture	2.23
Area of golf courses	-
Area of parks and athletic fields	68.27

[3] Newsday reports an average daily total nitrogen load of 18.5 lbs/day. See: http://www.newsday.com/long-island/towns/northport-gets-1-5m-grant-for-sewer-plant-1.5533620

Table 24. Total nitrogen loading to Northport Harbor.

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	2,111	8%
Wastewater: treatment facilities	3,311	13%
Wastewater: septic/cesspool	18,546	72%
Fertilizer: agriculture	47	0%
Fertilizer: lawns	1,632	6%
Fertilizer: golf courses	-	0%
Total	25,647	

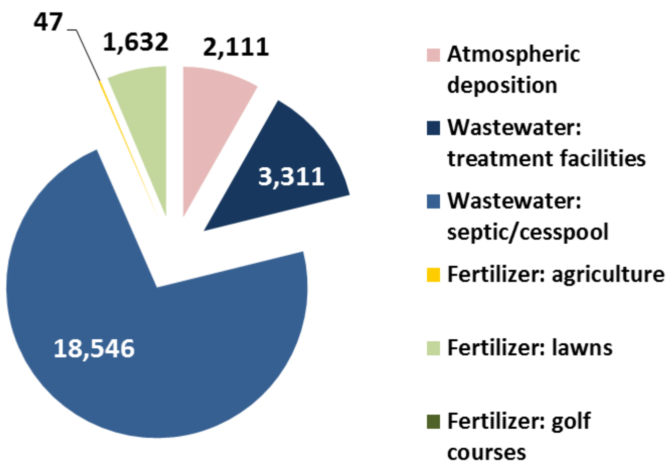

Figure 29. Total nitrogen load (kg) by source to Northport Harbor.

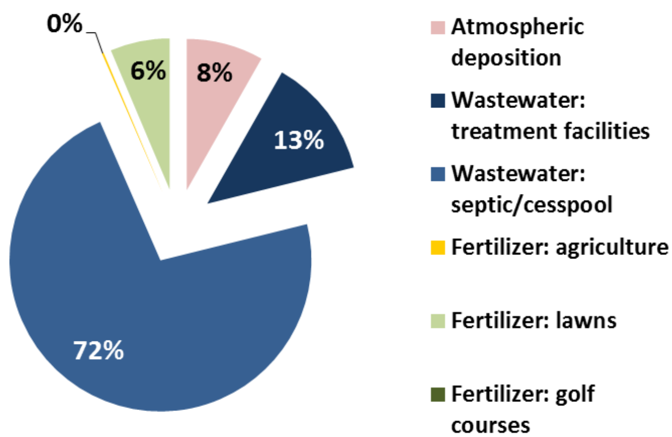

Figure 30. Total nitrogen load (%) by source to Northport Harbor.

4.1.1.3.6 Northport Bay

Northport Bay is located in the northeastern portion of the Northport/Huntington estuarine complex. Like the Huntington Bay watershed, it contributes part of the total inputs to the wider bay system. It has an estuarine area of 711 ha and the watershed is 562 ha (watershed:estuary ratio of 0.79). A summary of selected land use inputs to the NLM are shown in Table 25. The results of the NLM are shown in Table 26 and Figures 31 and 32. The areal nitrogen load to this system (1.30 g N m^{-2} y^{-1}) is relatively low and primarily due to a low number of houses contributing wastewater compared to the overall watershed size (wastewater accounts for 82% of nitrogen input). There are no wastewater treatment facilities within the Northport Bay watershed.

Table 25. Watershed and selected land use areas in Northport Bay.

Land Use Category	Area (ha)
Watershed area	561.67
Land area	560.86
Area of freshwater ponds	0.81
Number of buildings	1,875
Buildings within 200m of shore	502
Total area of impervious surfaces	127.30
Area of natural vegetation	265.47
Area of wetlands	30.75
Area of other agriculture	-
Area of golf courses	-
Area of parks and athletic fields	43.59

Table 26. Total nitrogen loading to Northport Bay.

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	1,042	11%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	7,622	82%
Fertilizer: agriculture	-	0%
Fertilizer: lawns	608	7%
Fertilizer: golf courses	-	0%
Total	9,272	

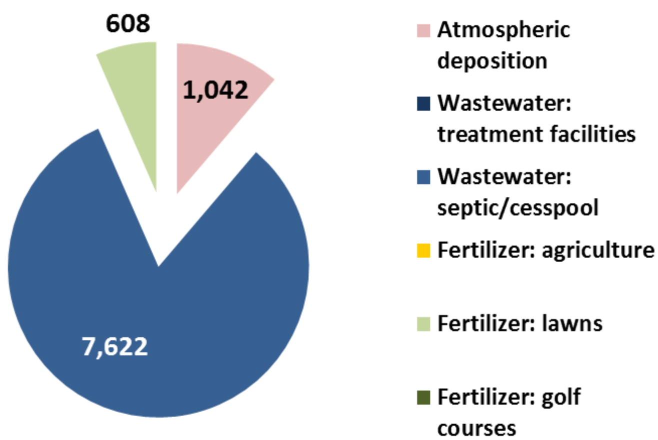

Figure 31. Total nitrogen load (kg) by source to Northport Bay.

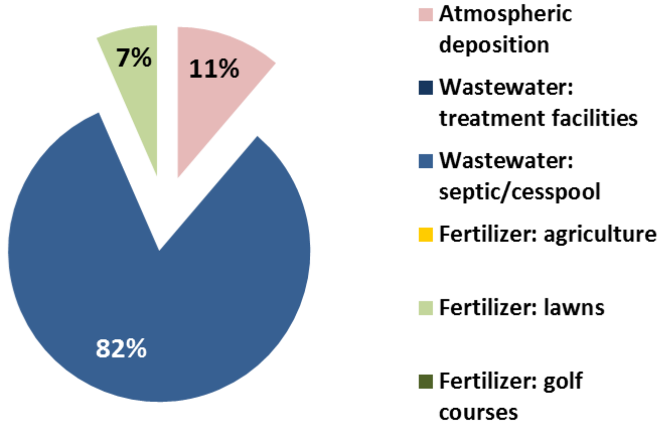

Figure 32. Total nitrogen load (%) by source to Northport Bay.

4.1.1.4.1 Nissequogue River Main Branch

The Nissequogue River is located on the north shore of Long Island (Figure 33). There are two estuarine systems within the Nissequogue area: the main branch and the west branch. The main branch has an estuarine area of 72 ha and the watershed is 11,836 ha (watershed:estuary ratio of 164). A summary of selected land use inputs to the NLM are shown in Table 27. The results of the NLM are shown in Table 28 and Figures 34 and 35. The areal nitrogen load to this system (230.67 g N m^{-2} y^{-1}) is significantly high and primarily due to the high watershed:estuary ratio and a densely populated watershed (wastewater accounts for 75% of nitrogen input). There is one wastewater treatment facilities within the Nissequogue watershed: Kings Park STP (NY0023311). This treatment facility underwent improvements to increase its tertiary treatment capacity from 0.6 to 1.2 million gallons per day. The TMDL wasteload allocation for nitrogen at this facility is 26 lbs/day (base load is estimated at 134 lbs/day)[4]. The outfall of this facility is in Smithtown Bay and, therefore, it does not discharge into the Nissequogue River (according to NY DEP).

[4] http://longislandsoundstudy.net/wp-content/uploads/2010/03/2006_tracking_report.pdf

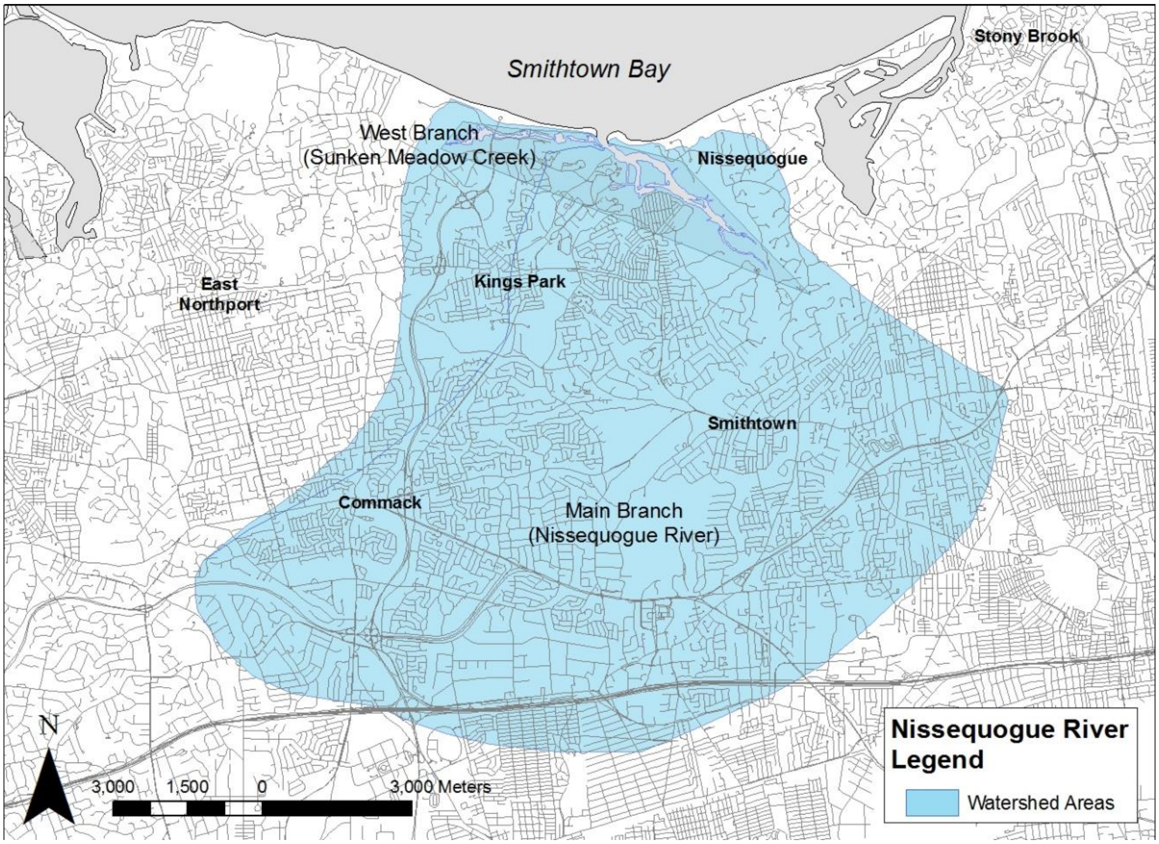

Figure 33. Map of Nissequogue River embayments and watersheds.

Table 27. Watershed and selected land use areas for Nissequogue River (Main).

Land Use Category	Area (ha)
Watershed area	11,835.50
Land area	11,781.04
Area of freshwater ponds	54.46
Number of buildings	32,160
Buildings within 200m of shore	270
Total area of impervious surfaces	3,797.23
Area of natural vegetation	4,286.98
Area of wetlands	413.74
Area of other agriculture	84.98
Area of golf courses	155.32
Area of parks and athletic fields	1,434.79

Table 28. Total nitrogen loading to Nissequogue River (Main).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	24,281	15%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	124,291	75%
Fertilizer: agriculture	1,801	1%
Fertilizer: lawns	10,423	6%
Fertilizer: golf courses	4,139	3%
Total	164,935	

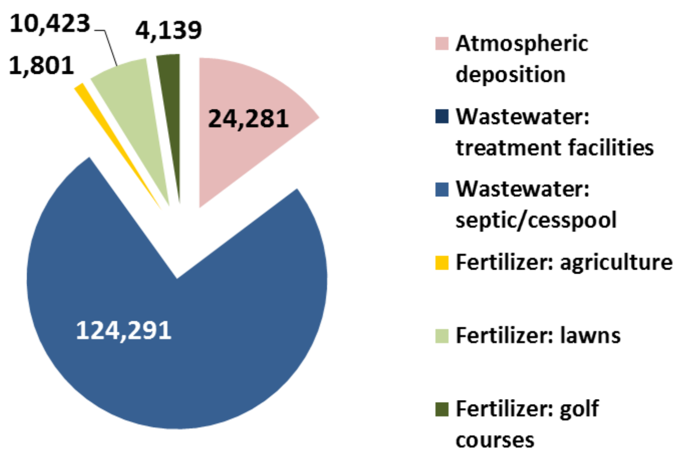

Figure 34. Total nitrogen load (kg) by source to Nissequogue River (Main).

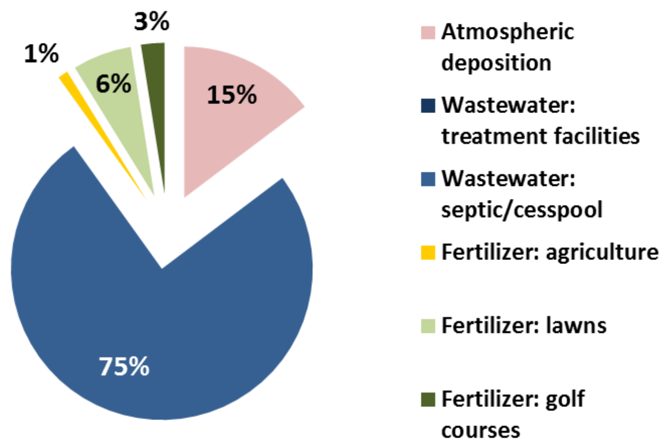

Figure 35. Total nitrogen load (%) by source to Nissequogue River (Main).

4.1.1.4.2 Nissequogue West

This section of the Nissequogue system extends westward from the mouth of the combined estuarine system. It has an estuarine area of 25 ha and the watershed is 1,503 ha (watershed:estuary ratio of 60.12). A summary of selected land use inputs to the NLM are shown in Table 29. The results of the NLM are shown in Table 30 and Figures 36 and 37. The areal nitrogen load to this system (25.11 g N m^{-2} y^{-1}) is somewhat high and primarily associated with contributions from wastewater, atmospheric deposition, and a golf course.

Table 29. Watershed and selected land use areas for Nissequogue River West.

Land Use Category	Area (ha)
Watershed area	1,503.07
Land area	1,500.58
Area of freshwater ponds	2.49
Number of buildings	4,609
Buildings within 200m of shore	17
Total area of impervious surfaces	372.92
Area of natural vegetation	607.03
Area of wetlands	41.78
Area of other agriculture	3.40
Area of golf courses	13.57
Area of parks and athletic fields	231.43

Table 30. Total nitrogen loading to Nissequogue River West (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	2,830	13%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	17,772	79%
Fertilizer: agriculture	72	0%
Fertilizer: lawns	1,495	7%
Fertilizer: golf courses	362	2%
Total	22,531	

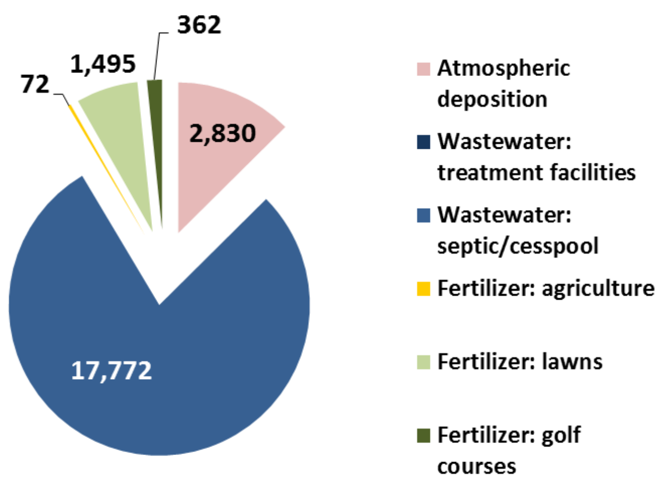

Figure 36. Total nitrogen load (kg) by source to Nissequogue River West.

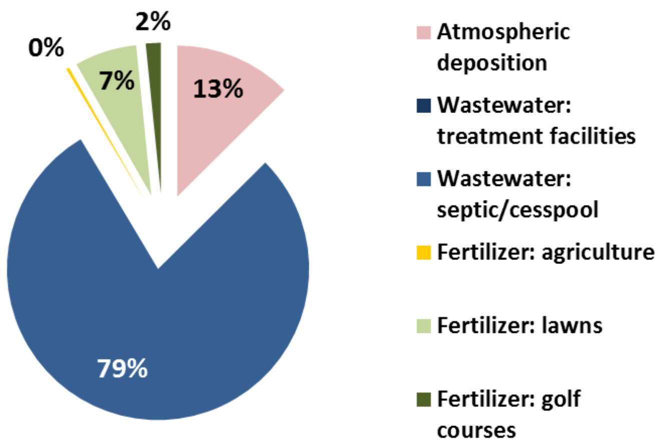

Figure 37. Total nitrogen load (%) by source to Nissequogue River West.

4.1.2 Connecticut

4.1.2.1 Ram Island[5]

Ram Island is located along the eastern Connecticut coast (Figure 38). Although it is comprised of an irregularly joined system of embayments, it is treated as one unit for the purpose of nitrogen load assessment. It has a combined estuarine area of 561 ha and the watershed is 8,826 ha (watershed:estuary ratio of 15.74). A summary of selected land use inputs to the NLM are shown in Table 31. There is one wastewater treatment facility that discharges in to the receiving waters of this estuary – the Stonington-Mystic Water Pollution Control Facility (WPCF)(Permit ID - CT0100544). Three years of total nitrogen discharge data (2010 – 2012) were provided by the CT DEP and the resulting average load was calculated to be 5,002 kg yr^{-1}. These point source loads were added to the NLM predicted watershed loads. The results of the NLM are shown in Table 32 and Figures 39 and 40. The areal nitrogen load to this system (8.78 g N m^{-2} y^{-1}) is moderately high and primarily associated wastewater, atmospheric deposition, and agriculture inputs.

[5] The building data within the sewered area in the northern portion of this watershed (Ledyard, CT) remains unaccounted for. It is approximately 10% of the total sewered area (1% of total watershed area), and no more than 5% of the total sewered buildings within it. If the data become available this section will be updated accordingly.

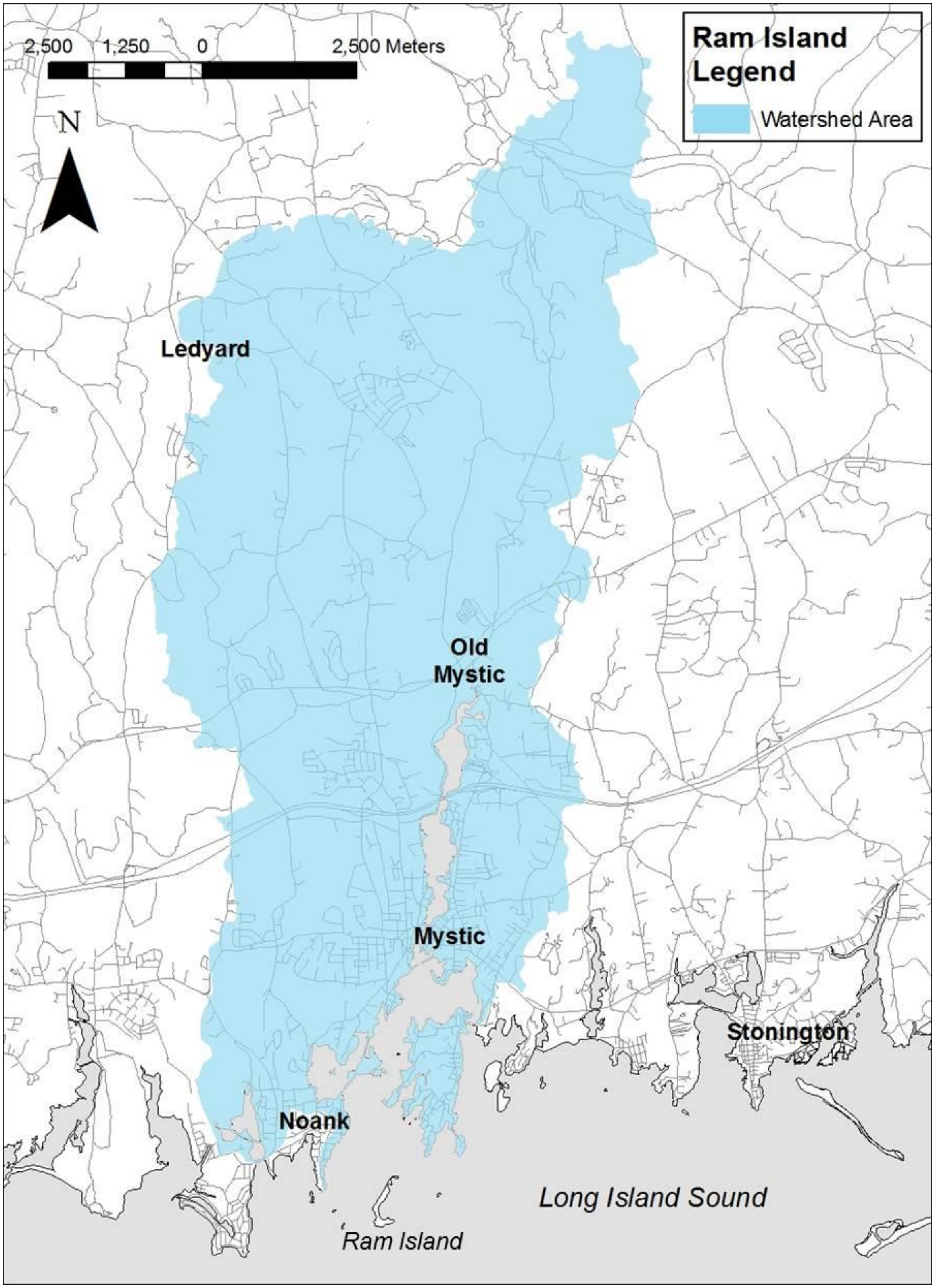

Figure 38. Map of Ram Island regional embayments and watersheds.

Table 31. Watershed and selected land use areas for Ram Island.

Land Use Category	Area (ha)
Watershed area	8,826.17
Land area	8,730.45
Area of freshwater ponds	95.72
Number of buildings	5,747
Buildings within 200m of shore	1,028
Total area of impervious surfaces	661.06
Area of natural vegetation	6,394.59
Area of wetlands	591.35
Area of other agriculture	433.56
Area of golf courses	0
Area of parks and athletic fields	4.32

Table 32. Total nitrogen loading to Ram Island embayments (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	15,578	32%
Wastewater: treatment facilities	5,002	10%
Wastewater: septic/cesspool	17,599	36%
Fertilizer: agriculture	9,194	19%
Fertilizer: lawns	1,864	4%
Fertilizer: golf courses	-	0%
Total	49,237	

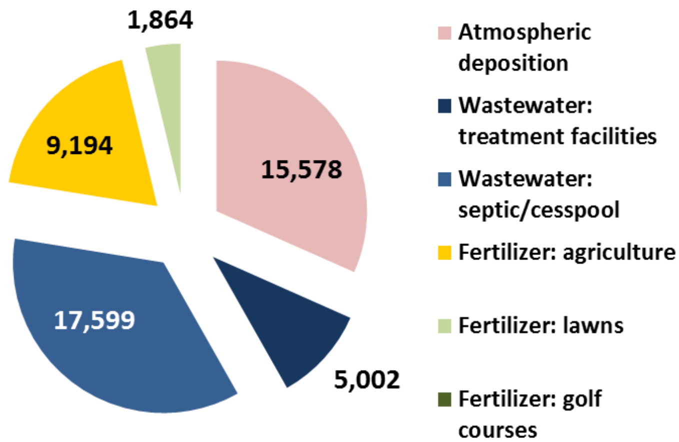

Figure 39. Total nitrogen load (kg) by source to Ram Island embayments.

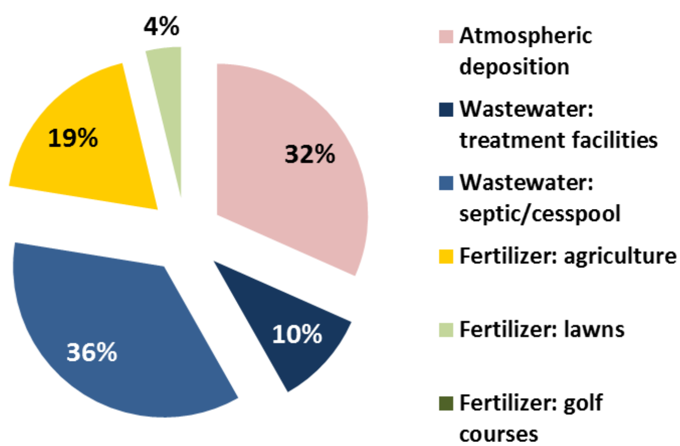

Figure 40. Total nitrogen load (%) by source to Ram Island embayments.

4.1.2.2 Hotchkiss Beach (Stony Creek)

Hotchkiss Beach (Figure 41) is a saltmarsh-dominated estuarine system on Connecticut's eastern Long Island Sound coast. It has an estuarine area of 24 ha and the watershed is 389 ha (watershed:estuary ratio of 16.01). A summary of selected land use inputs to the NLM are shown in Table 33. The results of the NLM are shown in Table 34 and Figures 42 and 43. The areal nitrogen load to this system (27.57 g N m^{-2} y^{-1}) is relatively high and primarily associated with a densely populated watershed (wastewater accounts for 80% of nitrogen input). There are no wastewater treatment facilities within the Hotchkiss Beach watershed.

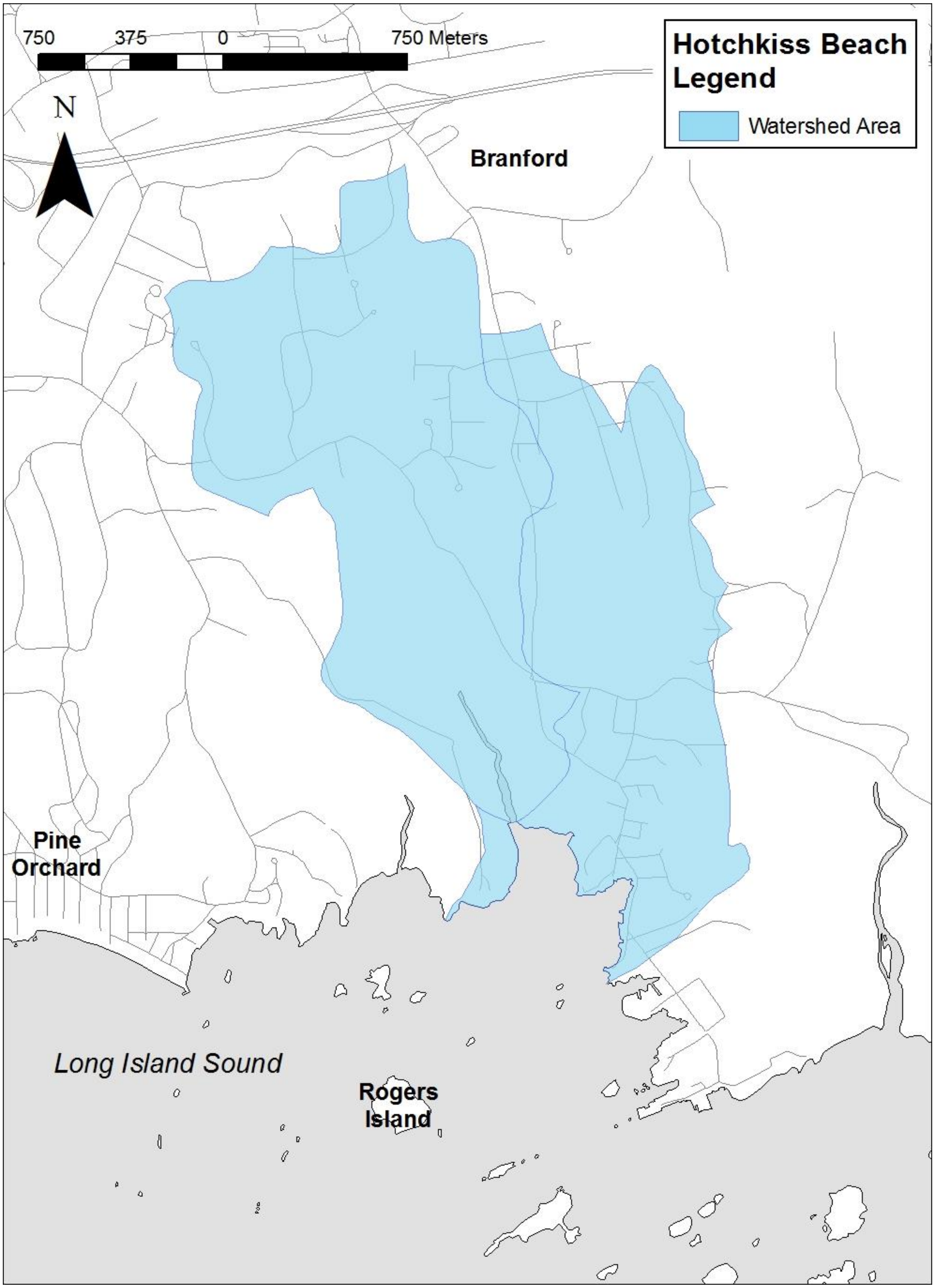

Figure 41. Map of Hotchkiss Beach embayment.

Table 33. Watershed and selected land use areas for Hotchkiss Beach.

Land Use Category	Area (ha)
Watershed area	389.23
Land area	387.74
Area of freshwater ponds	1.49
Number of buildings	1,462
Buildings within 200m of shore	234
Total area of impervious surfaces	33.95
Area of natural vegetation	191.93
Area of wetlands	47.20
Area of other agriculture	6.57
Area of golf courses	0
Area of parks and athletic fields	0.49

Table 34. Total nitrogen loading to Hotchkiss Beach.

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	740	11%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	5,349	80%
Fertilizer: agriculture	140	2%
Fertilizer: lawns	476	7%
Fertilizer: golf courses	-	0%
Total	6,705	

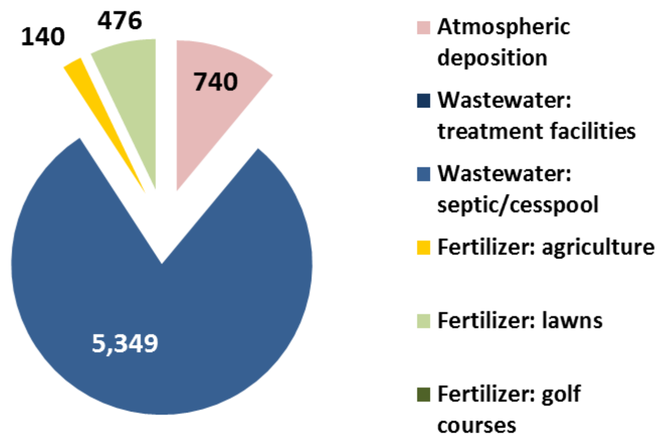

Figure 42. Total nitrogen load (kg) by source to Hotchkiss Beach.

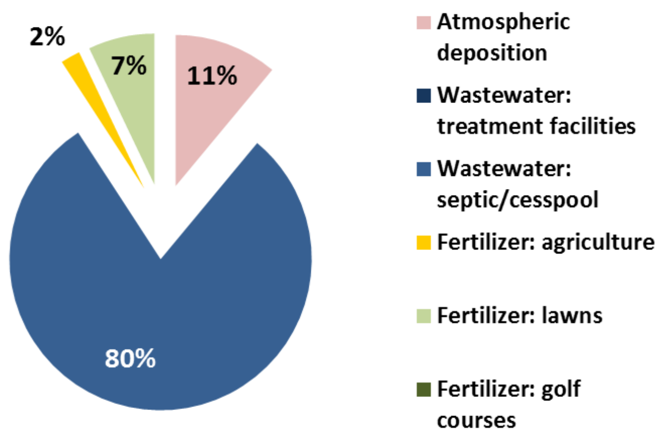

Figure 43. Total nitrogen load (%) by source to Hotchkiss Beach.

4.1.2.3 Saugatuck River

The Saugatuck River is located in western Long Island Sound (Westport, Connecticut). The contributing watershed is relatively complex as there are several main tributaries that span a range of geologic substrate and land uses. A previous study of nitrogen loads to the main stem of the Saugatuck River was conducted by HDR-HydroQual, Inc. (2011). The total nitrogen load to a point in the estuary near the crossing of Metro North rail line (East and West Ferry Lanes, Westport, CT) was calculated through a reputable land use loading modeling approach: GWLF. The total load to the Saugatuck Harbor estuary is reported as the sum of the load reported by HDR-HydroQual (2011) and the results of the NLM application to the lower Saugatuck River/Harbor watershed(s). A summary of selected land use inputs to the NLM are shown in Tables 35 and 36. The results of the NLM are shown in Table 37 and Figures 46 and 47.

The lower Saugatuck River watershed has one waste water treatment facility (WWTF) point source located just south of the I-95 bridge along the eastern shore of the estuary. Three years of effluent load monitoring data (2010 – 2012) were provided by the CT DEP. The mean daily load was calculated to be 34.33 lbs d^{-1}. This value is very close to the load reported by the LISS for 2009 (38 lbs d^{-1}). This equates to approximately 5,684 kg yr^{-1} (see Table 37). The total combined nitrogen load to the Saugatuck River system (including the harbor) comes to 170,702 kg yr^{-1} which results in an annual areal load of 83.73 g TN m^{-2}. This is a relatively high loading rate and is well above the areal loading rates that eelgrass can survive within (see Section 4.1.4). It should be noted that recent improvements in the WWTF (2008) have resulted in loads approximately 60% lower than the TMDL waste load allocation for this facility.

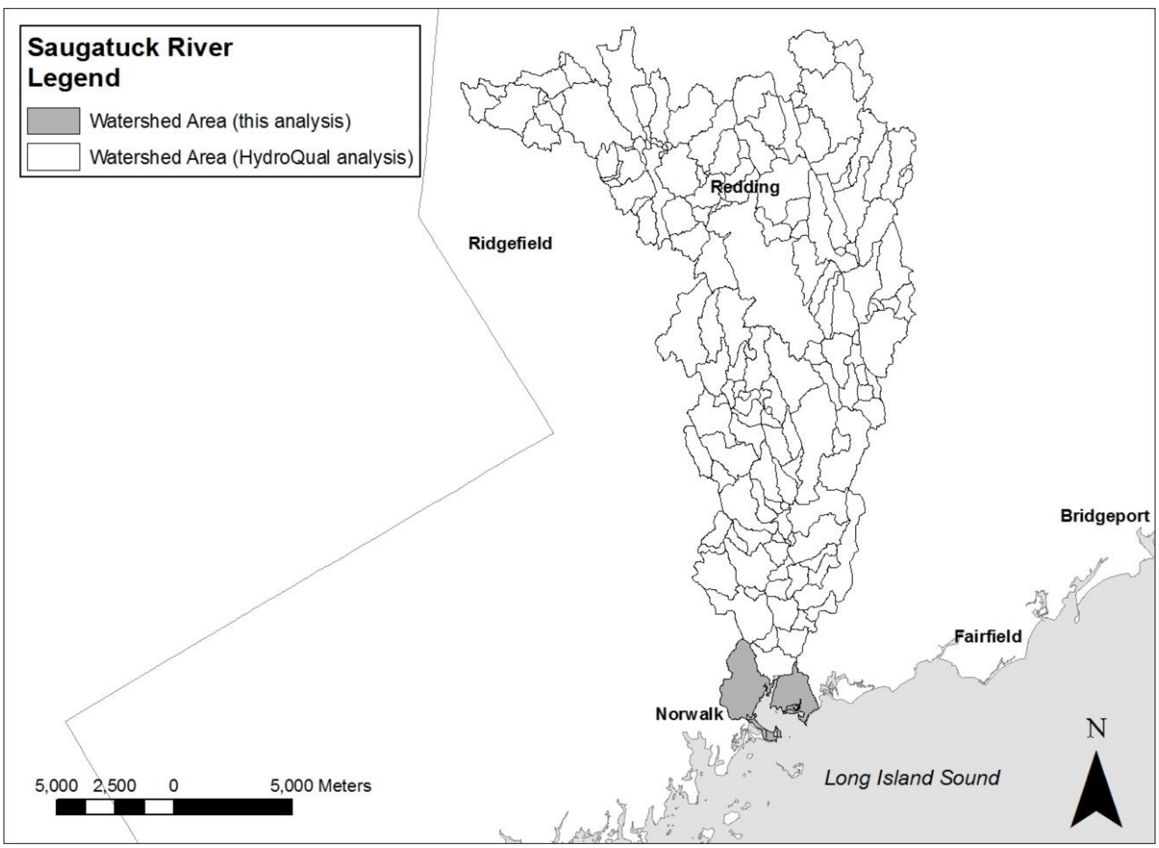

Figure 44. Map of upper watershed areas (unshaded polygons) previously modeled by HDR, Inc. (HDR HydroQual 2011). Lower Saugatuck River watershed (shaded area along coast) is shown in Figure 45.

The Westport Water Pollution Control Plant (WPCP) is located in the Saugatuck River (lower) watershed, and has a 3-year (2010 – 2012) average total N output of 804.5 kg N yr^{-1}. This number was added directly to the NLM output in Table 33.

Table 35. Total nitrogen load (kg/yr) by source to upper Saugatuck River (HDR HydroQual 2011).

TN load (kg/yr)	Aspetuck	Little River	Saugatuck Reservoir	Downstream Saugatuck River	West Branch	Upstream Saugatuck River	Westport
Hay or Pasture	698	260	115	116	164	455	23
Cropland	47	23	6	28	16	23	83
Forest	352	103	165	115	181	347	74
Wetland	34	5	16	9	12	21	1
Transition	467	135	63	230	274	757	228
Low-Intensity Development	219	60	34	145	197	171	426
High-Intensity Development	1,828	293	552	1,576	1,918	902	4,436
Erosion from Stream Bank	70	6	12	23	34	51	88
Groundwater	24,133	7,563	5,019	7,040	9,605	17,044	12,633
Septic Systems	11,209	2,141	4,344	6,121	7,671	10,270	13,916
Total Load	39,056	10,588	10,327	15,403	20,071	30,042	31,909
Total Load				**157,396**			

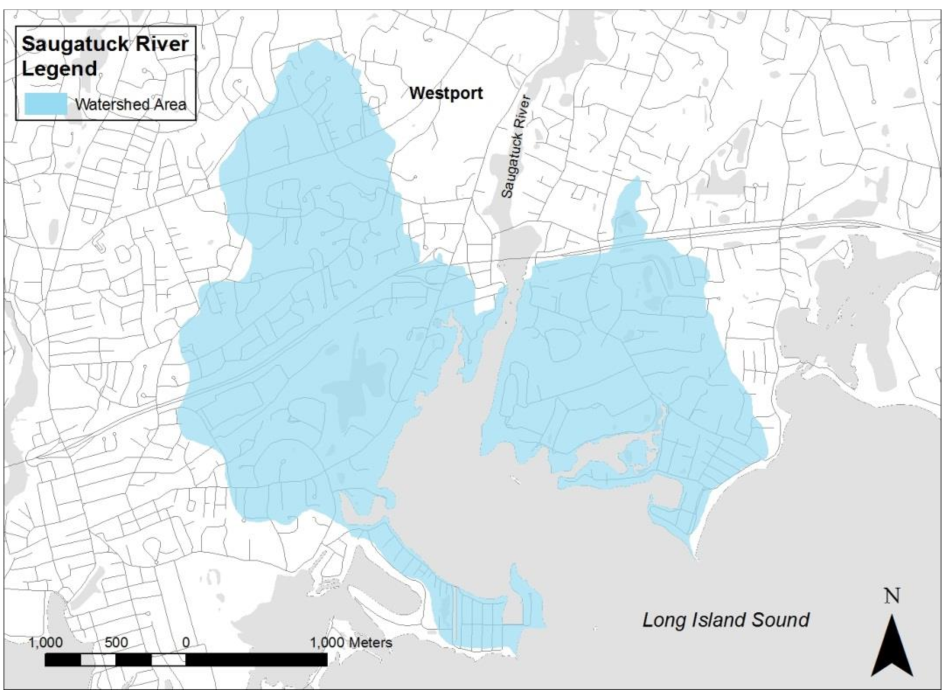

Figure 45. Map of lower (estuarine portion) of the Saugatuck River embayment and watersheds.

Table 36. Watershed and selected land use areas associated with the lower Saugatuck River embayment.

Land Use Category	Area (ha)
Watershed area	747.88
Land area	746.49
Area of freshwater ponds	1.39
Number of buildings	2,074
Buildings within 200m of shore	982
Total area of impervious surfaces	224.93
Area of natural vegetation	747.88
Area of wetlands	22.30
Area of other agriculture	0
Area of golf courses	49.55
Area of parks and athletic fields	0.37

Table 37. Total nitrogen loading to lower Saugatuck River.

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	1,676	9%
Wastewater: treatment facilities	5,684	31%
Wastewater: septic/cesspool	8,831	49%
Fertilizer: agriculture	-	0%
Fertilizer: lawns	672	4%
Fertilizer: golf courses	1,321	7%
Total	18,184	

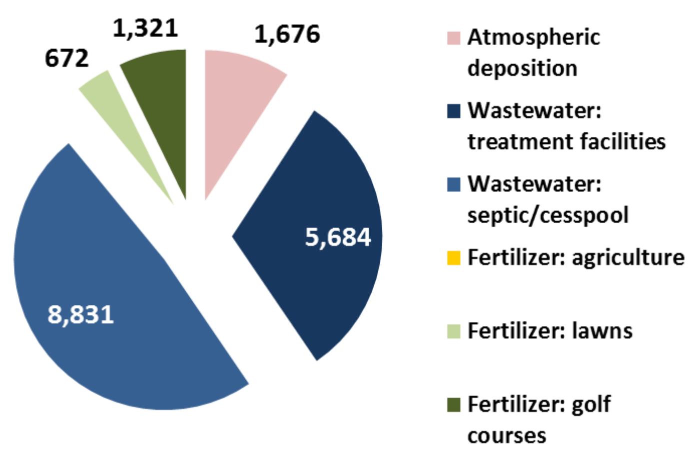

Figure 46. Total nitrogen load (kg) by source to lower Saugatuck River.

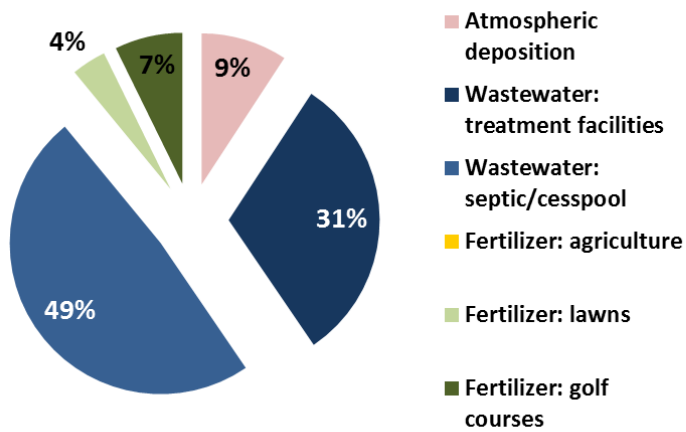

Figure 47. Total nitrogen load (%) by source to lower Saugatuck River.

4.1.3 Massachusetts

4.1.3.1 Nasketucket Bay

Nasketucket Bay is located in Buzzards Bay (MA). It is a relatively open estuarine system comprised of salt marsh and rocky coastal features. It has an estuarine area of 298 ha and the watershed is 1,445 ha (watershed:estuary ratio of 4.85). A summary of selected land use inputs to the NLM are shown in Table 38. The results of the NLM are shown in Table 39 and Figures 49 and 50. The areal nitrogen load to this system (3.39 g N m^{-2} y^{-1}) is relatively low and primarily associated with nearly equal contributions from agriculture, wastewater, and atmospheric deposition. There are no wastewater treatment facilities within the Nasketucket River watershed.

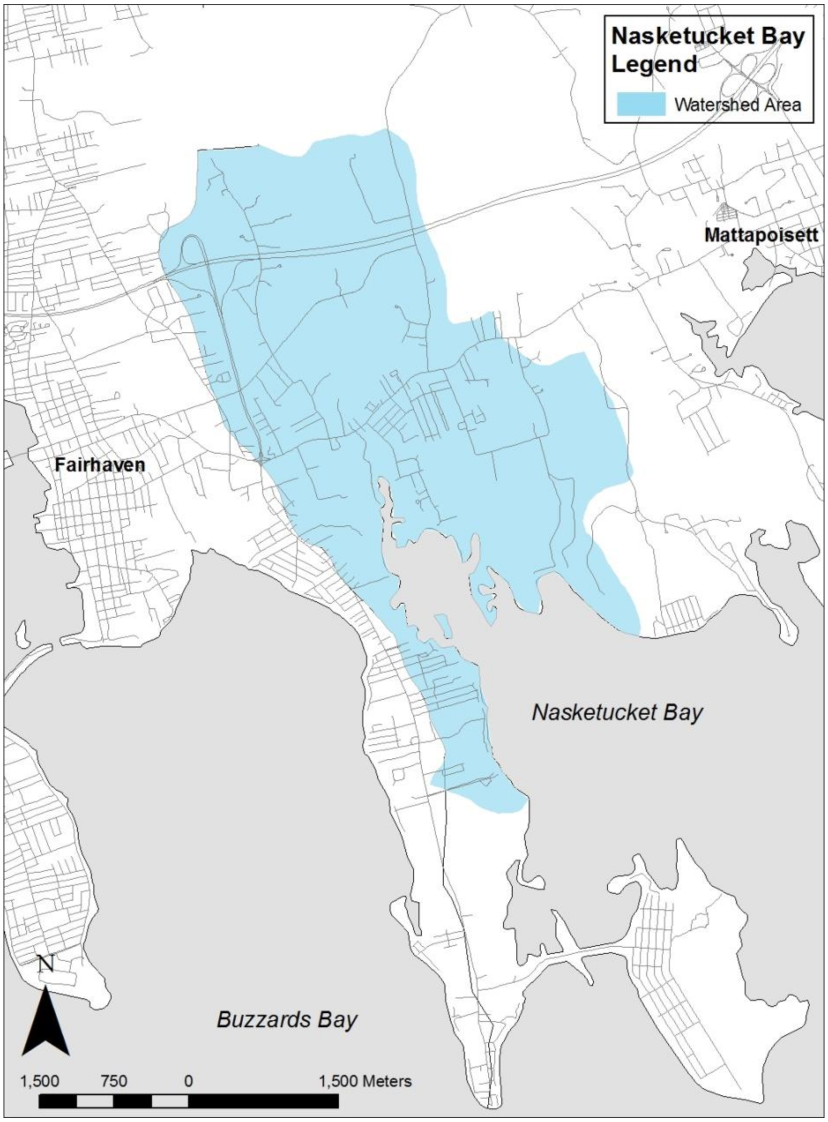

Figure 48. Map of Nasketucket Bay and watershed.

Table 38. Watershed and selected land use areas for Nasketucket Bay.

Land Use Category	Area (ha)
Watershed area	1,445.04
Land area	1,440.32
Area of freshwater ponds	4.72
Number of buildings	1,058
Buildings within 200m of shore	177
Total area of impervious surfaces	168.28
Area of natural vegetation	753.26
Area of wetlands	251.89
Area of other agriculture	135.74
Area of golf courses	0
Area of parks and athletic fields	13.38

Table 39. Total nitrogen load to Nasketucket Bay (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	2,982	29%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	3,846	38%
Fertilizer: agriculture	2,933	29%
Fertilizer: lawns	350	3%
Fertilizer: golf courses	-	0%
Total	10,111	

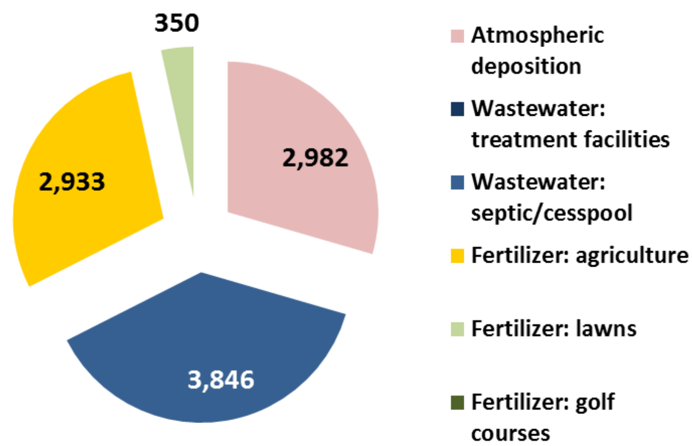

Figure 49. Total nitrogen load (kg) by source to Nasketucket Bay.

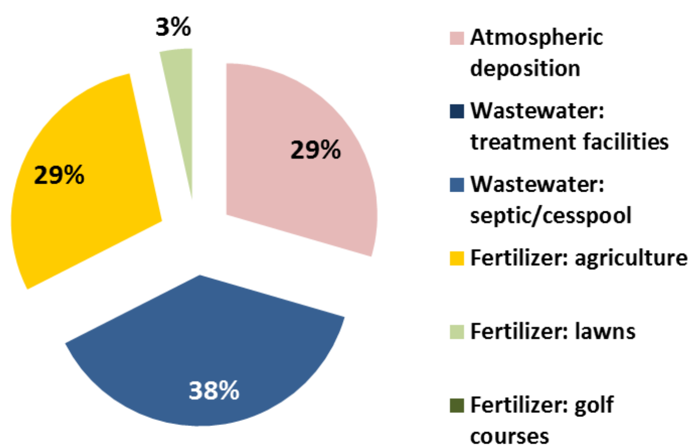

Figure 50. Total nitrogen load (%) by source to Nasketucket Bay.

4.1.3.2 Wareham River

The Wareham River is located near the head of Buzzards Bay (Figure 51). It has an estuarine area of 368 ha and the watershed is 11,380 ha (watershed:estuary ratio of 30.90). There is one WWTF that contributes treated effluent to the Wareham River (via the Aqawam River tributary). This WWTF (MA0101893) has been under scrutiny by local stakeholders due to frequent permitted discharge violations and some discrepancies in EPA reported load summaries[6]. Total nitrogen loads associated with this treatment facility are approximately 9,300 kg yr^{-1}. A summary of selected land use inputs to the NLM are shown in Table 40. The results of the NLM are shown in Table 41 and Figures 52 and 53. The areal nitrogen load to this system (17.60 g N m^{-2} y^{-1}) is moderately high and primarily associated with nearly equal contributions from agriculture, wastewater, and atmospheric deposition.

[6] According to the Buzzards Bay NEP: "The average daily nitrogen loading for the period July 2005 to December 2006 (roughly the period of the MEP water quality and loading analysis) was 56.17 lbs per day lbs per day (20,502 pounds per year, = 9,302 kg). For the period June 2009 to June 2010, daily load averaged 45.80 pounds per day, which totaled 16,717 pounds annually (7,585 kg)." For their summary of TN loads from this facility the Buzzards Bay NEP assumed the 2005-2006 mean values and these are applied in this study. Please see: http://www.buzzardsbay.org/wareham-river-subwatershed.htm.

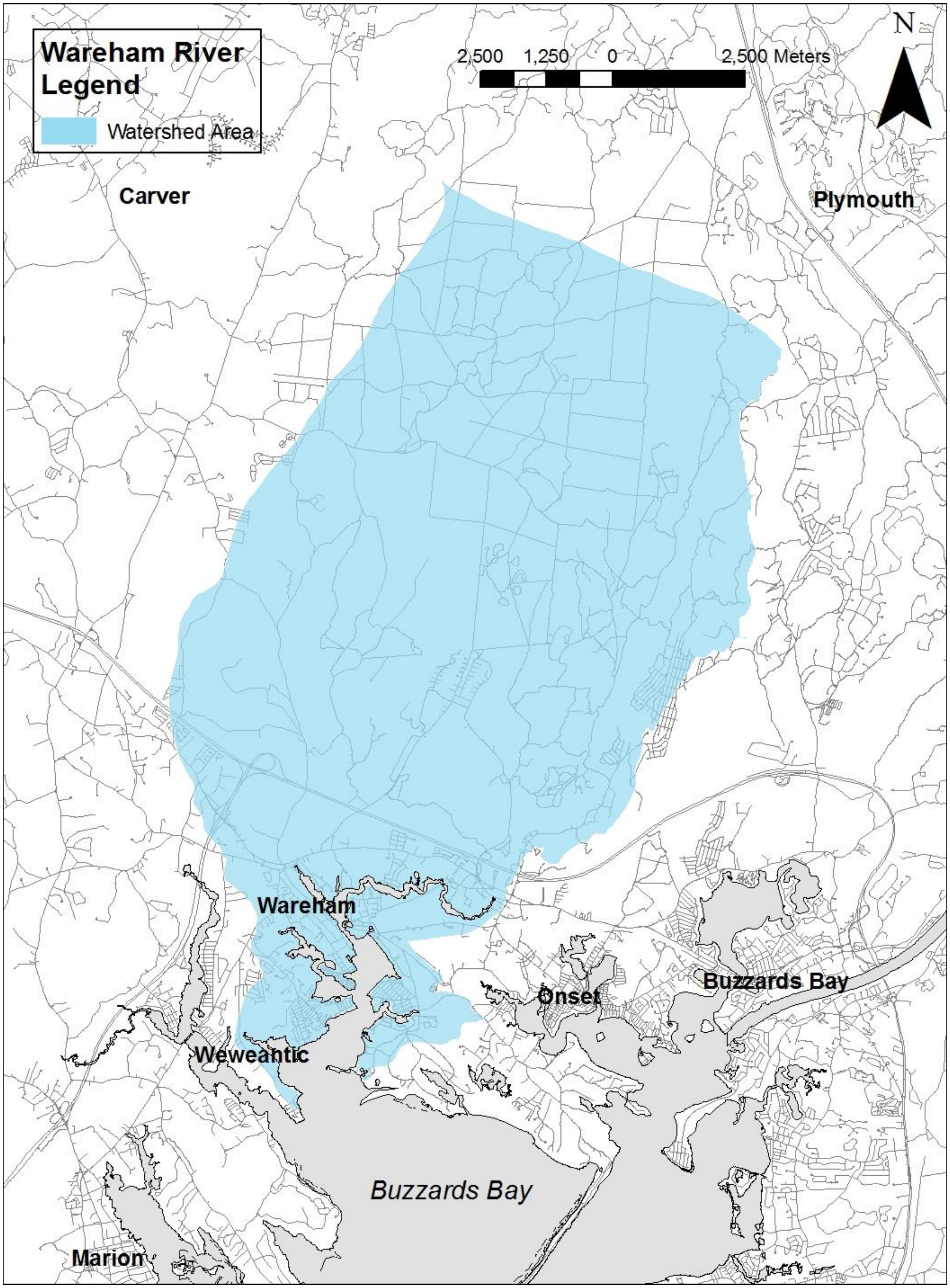

Figure 51. Map of the Wareham River estuary and watershed.

Table 40. Watershed and selected land use areas for the Wareham River estuary.

Land Use Category	Area (ha)
Watershed area	11,379.93
Land area	10,723.68
Area of freshwater ponds	656.25
Number of buildings	5,273
Buildings within 200m of shore	1,056
Total area of impervious surfaces	913.00
Area of natural vegetation	7,288.29
Area of wetlands	584.42
Area of other agriculture	3.72
Area of golf courses	0
Area of parks and athletic fields	45.40

Table 41. Total nitrogen loading to the Wareham River estuary (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	19,793	31%
Wastewater: treatment facilities	9,300	14%
Wastewater: septic/cesspool	18,194	28%
Fertilizer: agriculture	15,798	24%
Fertilizer: lawns	1,730	3%
Fertilizer: golf courses	-	0%
Total	64,815	

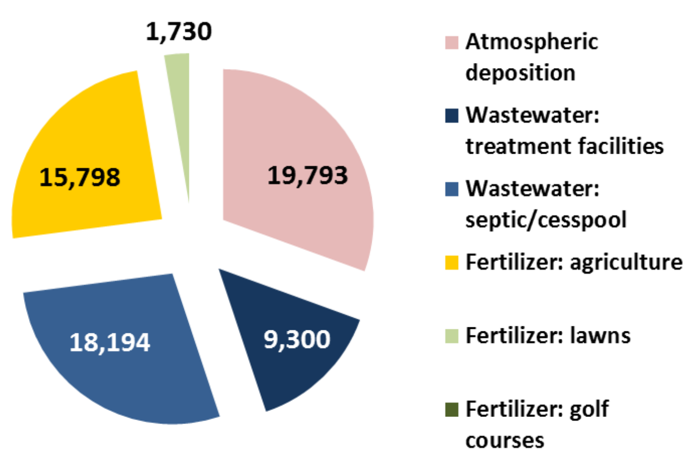

Figure 52. Total nitrogen load (kg) by source to the Wareham River estuary.

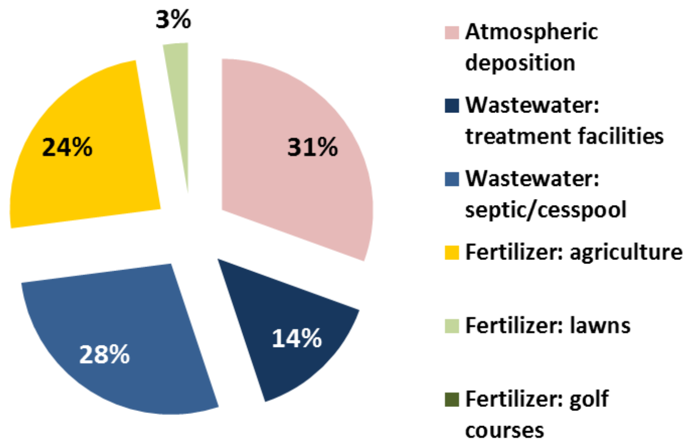

Figure 53. Total nitrogen load (%) by source to the Wareham River estuary.

4.1.3.3 Little Buttermilk Bay

Little Buttermilk Bay is located near the head of Buzzards Bay and is part of a combined estuarine system with Buttermilk Bay. It has an estuarine area of 41 ha and the watershed is 1,593 ha (watershed:estuary ratio of 38.94). A summary of selected land use inputs to the NLM are shown in Table 42. The results of the NLM are shown in Table 43 and Figures 55 and 56. The areal nitrogen load to this system (21.99 g N m^{-2} y^{-1}) is relatively high and primarily associated with a densely populated, large watershed (wastewater and atmospheric deposition accounts for 47% and 32% of nitrogen input, respectively). There are no wastewater treatment facilities within the Little Buttermilk Bay watershed.

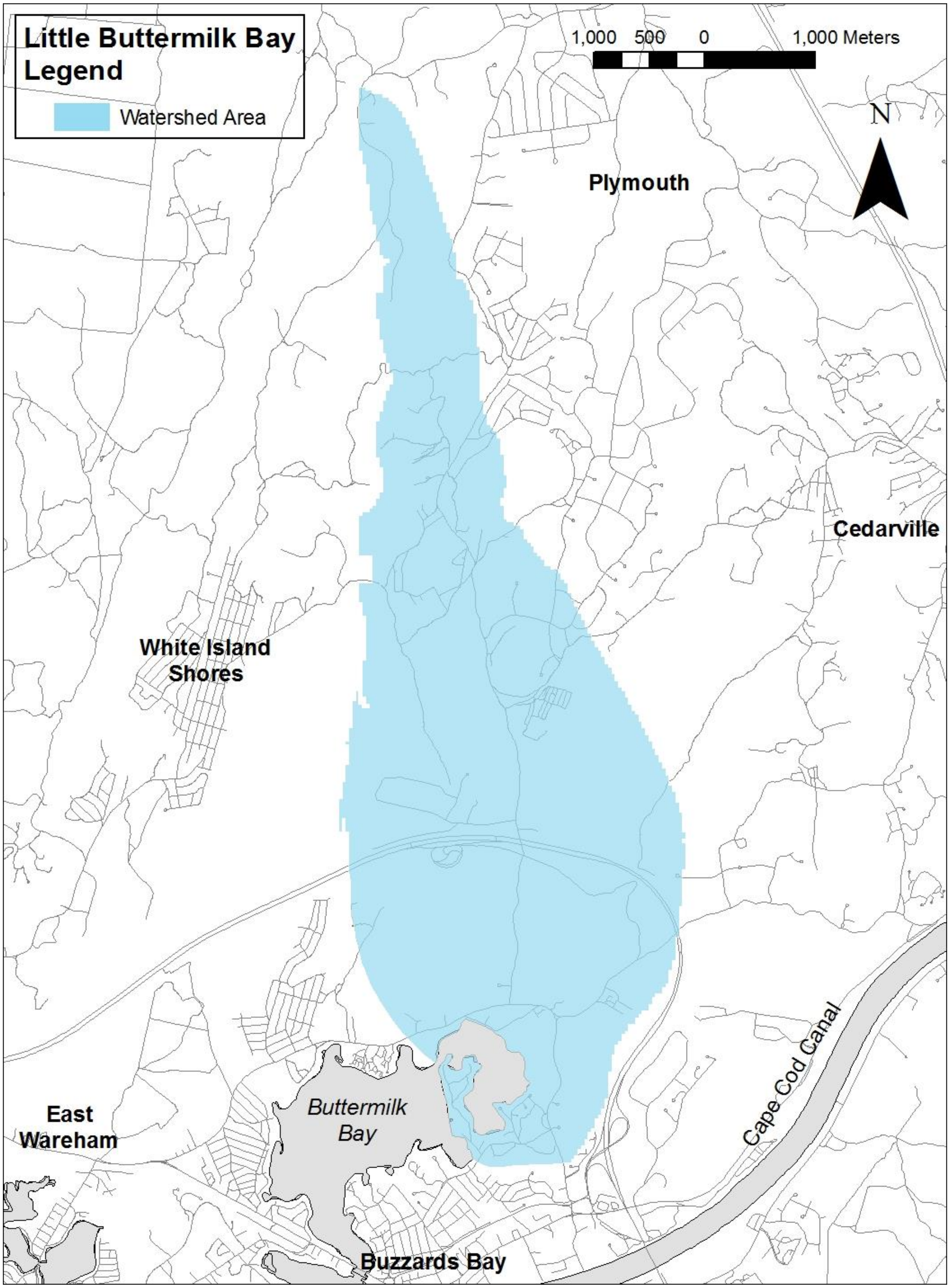

Figure 54. Map of Little Buttermilk Bay and watershed.

Table 42. Watershed and selected land use areas associated with Little Buttermilk Bay.

Land Use Category	Area (ha)
Watershed area	1,592.95
Land area	1,469.13
Area of freshwater ponds	123.82
Number of buildings	1,158
Buildings within 200m of shore	155
Total area of impervious surfaces	116.30
Area of natural vegetation	1,026.93
Area of wetlands	79.98
Area of other agriculture	4.28
Area of golf courses	11.76
Area of parks and athletic fields	0.58

Table 43. Total nitrogen loading to Little Buttermilk Bay (kg, %).

Source	Total Nitrogen Load (kg)	Total Nitrogen Load (%)
Atmospheric deposition	2,920	32%
Wastewater: treatment facilities	-	0%
Wastewater: septic/cesspool	4,185	47%
Fertilizer: agriculture	1,465	16%
Fertilizer: lawns	376	4%
Fertilizer: golf courses	49	1%
Total	8,995	

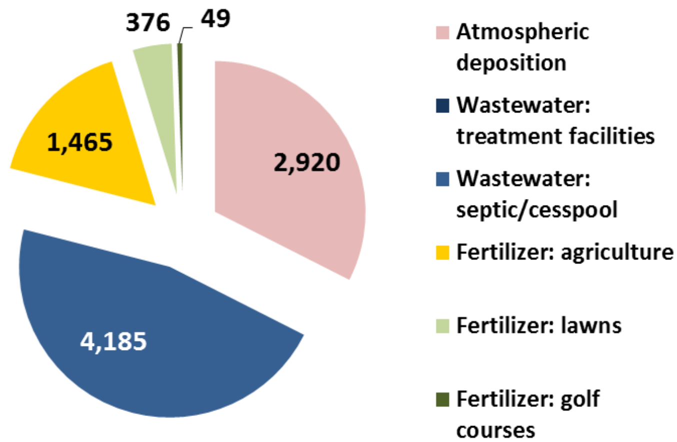

Figure 55. Total nitrogen load (kg) by source to Little Buttermilk Bay.

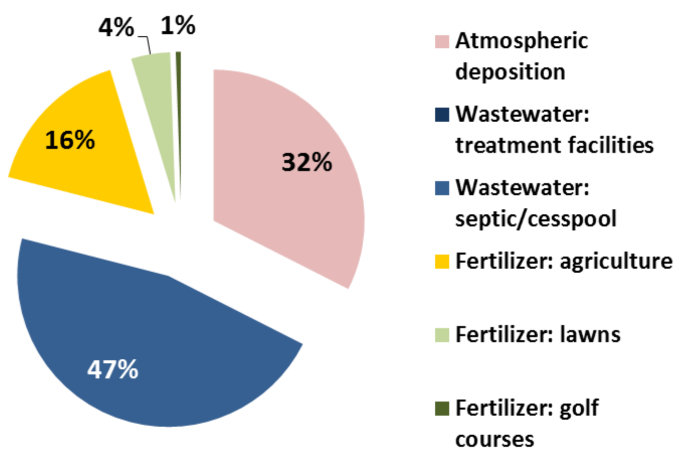

Figure 56. Total nitrogen load (%) by source to Little Buttermilk Bay.

The resulting modeled nitrogen loads to all of the embayments are depicted in the context of geographical locations and magnitudes in Attachment 2.

4.1.4 Synthesis of Nitrogen Loads to Receiving Waters

The nitrogen loads estimated for each of the project embayments can be put into context with important ecological thresholds that have been recently proposed by investigators. Hauxwell et al. (2003) reported the onset of *Z. marina* decline at about 3 g TN m^{-2} y^{-1}

with total disappearance at about 6 g TN m^{-2} y^{-1}. This range is lower than, but is consistent with, several other studies that, together, have suggested an overall range of 3 to 10 g TN m^{-2} y^{-1} where rapid widespread decline and disappearance of *Z. marina* occurs (Brawley 2002, Latimer and Rego 2010). Tables 40 and 41 summarize the level of reduction (kg and %) that would be necessary to meet a few reported areal TN load (to embayment) thresholds associated with *Z. marina* for each of the embayments in this study.

Table 44. Summary of areal TN loads and resulting reductions (kg TN) required to meet specific eelgrass loading thresholds (3, 5, and 10 g TN m^{-2} y^{-1}).[7]

System	Embayment	Existing Total N load to embayment (g m^{-2} y^{-1})	Reduction (kg y^{-1}) necessary to meet 3 g TN m^{-2} y^{-1}	Reduction (kg y^{-1}) necessary to meet 5 g TN m^{-2} y^{-1}	[8]Reduction (kg y^{-1}) necessary to meet 10 g TN m^{-2} y^{-1}
Fishers	East Harbor	4.50	236	(79)	(865)
	Hay Harbor	2.23	(184)	(663)	(1,859)
	Chocomount Cove	1.04	(424)	(857)	(1,938)
	Barleyfield Cove	1.17	(208)	(435)	(1,004)
	West Harbor	3.04	16	(793)	(2,816)
Hotchkiss Beach	Hotchkiss Beach	27.57	5,975	5,488	4,273
Little Buttermilk Bay	Little Buttermilk Bay	21.99	7,769	6,951	4,905
Nasketucket Bay	Nasketucket Bay	3.39	1,163	(4,800)	(19,706)
Nissequogue	Nissequogue Main	230.67	162,790	161,360	157,785
	Nissequogue West	88.49	21,767	21,258	19,985
Northport - Huntington	Centerport Harbor	48.35	23,433	22,399	19,816
	Huntington Bay	3.51	2,460	(7,189)	(31,311)
	Huntington Harbor	66.58	89,748	86,925	79,867
	Lloyd Harbor	1.79	(2,714)	(7,200)	(18,415)
	Northport Bay	1.3	(12,125)	(26,390)	(62,051)
	Northport Harbor	11.08	18,703	14,073	2,500
Ram Island	Ram Island	8.78	32,419	21,202	(6,843)
Saugatuck River	Saugatuck River	83.73	164,585	160,508	150,314
Wading River	Wading River	831.43	30,499	30,425	30,241
Wareham River	Wareham River	17.60	53,771	46,405	27,991

[7] A negative values (shown within parentheses) represents the additional load capacity (kg TN y^{-1}) for each threshold. For example, an increase of 79 kg TN y^{-1} to Hay Harbor would result in a normalized areal load of 5.0 g TN m^{-2} y^{-1}.

[8] Latimer and Rego (2010) suggest that the majority of Z. marina decline and disappearance occurs between 5 and 10 g TN m^{-2} y^{-1}. However, other studies suggest that the onset of stress from excessive nitrogen loading begins to occur around 3 g TN m^{-2} y^{-1}.

Table 45. Summary of % load reductions necessary (from previous table) to meet specific eelgrass loading thresholds (3, 5, and 10 g TN m^{-2} y^{-1}).[9]

System	Embayment	Existing total N load to embayment (g m^{-2} y^{-1})	% Reduction necessary to meet 3 g TN m^{-2} y^{-1}	% Reduction necessary to meet 5 g TN m^{-2} y^{-1}	% Reduction necessary to meet 10 g TN m^{-2} y^{-1}
Fishers	East Harbor	4.50	33%	-	-
	Hay Harbor	2.23	-	-	-
	Chocomount Cove	1.04	-	-	-
	Barleyfield Cove	1.17	-	-	-
	West Harbor	3.04	1%	-	-
Hotchkiss Beach	Hotchkiss Beach	27.57	89%	82%	64%
Little Buttermilk Bay	Little Buttermilk Bay	21.99	86%	77%	55%
Nasketucket Bay	Nasketucket Bay	3.39	12%	-	-
Nissequogue	Nissequogue Main	230.67	99%	98%	96%
	Nissequogue West	88.49	97%	94%	89%
Northport - Huntington	Centerport Harbor	48.35	94%	90%	79%
	Huntington Bay	3.51	15%	-	-
	Huntington Harbor	66.58	95%	92%	85%
	Lloyd Harbor	1.79	-	-	-
	Northport Bay	1.3	-	-	-
	Northport Harbor	11.08	73%	55%	10%
Ram Island	Ram Island	8.78	66%	43%	-
Saugatuck River	Saugatuck River	83.73	96%	94%	88%
Wading River	Wading River	831.43	100%	99%	99%
Wareham River	Wareham River	17.60	83%	72%	43%

[9] Negative values that represent no reduction necessary have been omitted so that this table only depicts necessary load reductions.

Based on the thresholds described above (and later in Section 5) the susceptibility of *Z. marina* to stresses associated with nitrogen over enrichment can be qualitatively ranked. Table 46 applies nitrogen loading rates and water residence time (where available) to rank susceptibility: by order of magnitude greater than lowest threshold of TN load (3 g m^{-2} y^{-1}) and water residence times of 3-5 days (low), 5-9 days (medium), and >9 days (high).

Table 46. Summary and comparison of nitrogen loads

System	Embayment	N Load per estuarine area (g m^{-2} y^{-1})	Water residence time (d)[10]	Susceptibility to nitrogen load
Fishers	East Harbor	4.50	-	Low
	Hay Harbor	2.23	-	Low
	Chocomount Cove	1.04	-	Low
	Barleyfield Cove	1.17	-	Low
	West Harbor	3.04	-	Low
Hotchkiss Beach	Hotchkiss Beach	27.57	-	High
Little Buttermilk Bay	Little Buttermilk Bay	21.99	-	High
Nasketucket Bay	Nasketucket Bay	3.39	-	Low
Nissequogue	Nissequogue Main	230.67	4.3	Extremely High
	Nissequogue West	88.49	-	High
Northport - Huntington	Centerport Harbor	48.35	1.80	High
	Huntington Bay	3.51	5.65	Low
	Huntington Harbor	66.58	2.49	High
	Lloyd Harbor	1.79	3.33	Low
	Northport Bay	1.3	4.12	Low
	Northport Harbor	11.08	2.18	Moderately High
Ram Island	Ram Island	8.78	-	Moderately High
Saugatuck River	Saugatuck River	83.73	4.16	High

[10] See Attachment I for additional estimates of residence times in the region. Missing data indicated by (-).

System	Embayment	N Load per estuarine area (g m^{-2} y^{-1})	Water residence time (d)[10]	Susceptibility to nitrogen load
Wading River	Wading River	831.43	-	Extremely High
Wareham River	Wareham River	17.60	4.3	Moderately High

4.2 CLIMATE CHANGE ANALYSES

The purpose of this section is to provide insight on how climate change could influence the relative success of restoration and preservation efforts of *Z. marina* populations within the embayments selected under Project Task 4 (Table 1 and Table 47). Intuitively, increases in mean atmospheric temperatures, due to the insulating effects caused by heat trapping gases, will have an associated result of increasing mean water temperatures. The extent of this increase will likely vary interannually, by season, and specific location. The effects of increases in water temperature include thermal stress to *Z. marina* and other marine macrophytes and secondary effects such as increased system metabolism which, in many cases, is currently fueled by nutrient enrichment. Therefore, warmer temperatures can have multiple influences on the survival of *Z. marina* and its overall habitat.

In addition, sea level rise (SLR) continues to increase as thermal expansion of ocean waters, combined with melting of glacial ice. Two effects of SLR on *Z. marina* habitat include increased light limitation (especially among beds that occupy marginal areas and depths) and a decrease in overall habit availability. Both of these effects are site-specific and dependent upon embayment hypsography and water quality.

Our approach to addressing the potential impacts of climate change to the project area, and the specific estuaries of interest, is focused on two types of analysis. First, a statistical approach was developed to predict the changes in the frequency of thermal stress events that can be linked to IPCC model predictions of increased mean air temperatures (e.g., 2050, 2100). For this real water and air temperature data collected from a set of estuaries within the study area were applied. Since tidal characteristics and solar radiation also influence local water temperatures, we have included data on these variables for each of the candidate estuaries to determine their relative importance. The goal of this effort is to determine the response of water temperature “exceedances” of thermal thresholds associated with *Z. marina* survival as a response to changes in climate (temperature). Second, the estuaries within the study area were characterized based on SLR with respect to their potential susceptibility to incremental increases in sea level along with existing and future water quality characteristics (e.g., the degree of eutrophication and associated stressors). This approach considers the general relationships of minimum light saturation requirements of *Z. marina* (e.g., H_{sat}) and tidal amplitude (and depth) as modeled by Koch and Beer (1996) and others.

Table 47. Areal and tidal characteristics of all embayments within this study.[11]

State	Site Name (Embayments)	Watershed Area (m^2)	Embayment Area (m^2)	Watershed -Estuarine area ratio	Mean Tidal Amplitude (ft)	Mean Tidal Amplitude (m)
NY	Fishers Island (East Harbor)	316,235	157,218	2.01	2.34	0.71
NY	Fishers Island (West Harbor)	925,770	404,561	2.29	2.34	0.71
NY	Fishers Island (Chocomount Cove)	398,700	217,200	1.84	2.34	0.71
NY	Fishers Island (Barleyfield Coved)	335,200	113,500	2.95	2.34	0.71
NY	Fishers Island (Hay Harbor)	485,162	239,271	2.03	2.34	0.71
NY	Wading River	32,582,400	36,815	885.03	2.34	0.71
NY	Northport/Huntington (Centerport Harbor)	12,128,000	516,689	23.47	7.27	2.22
NY	Northport/Huntington (Huntington Bay)	9,509,600	4,818,258	1.97	7.03	2.14
NY	Northport/Huntington (Huntington Harbor)	22,333,500	1,411,499	15.82	7.03	2.14
NY	Northport/Huntington (Lloyd Harbor)	7,996,000	2,237,267	3.57	7.03	2.14
NY	Northport/Huntington (Northport Bay)	5,616,700	7,111,428	0.79	7.27	2.22
NY	Northport/Huntington (Northport Harbor)	11,500,700	2,315,250	4.97	7.27	2.22
NY	Nissequogue River (Main)	118,355,000	715,020	165.53	7.15	2.18
NY	Nissequogue River (West)	15,030,700	254,610	59.03	7.15	2.18
NY	Peconic Bays (Great & Little)	332,558,814	149,037,705	2.23	2.45	0.75
CT	Duck Island (Menunketesuck River, Patchogue River)	65,523,300	470,153	139.37	4.22	1.29
CT	Ram Island (Mystic Harbor, Palmer Cove)	88,261,737	5,608,890	15.74	2.34	0.71

[11] Sources of information: Red=J. Latimer (EPA); Blue=Calculated from HUC12 shapefiles (USGS); Green=Recorded directly from NOAA Tides and Currents (nearest station); Purple=Calculated from NOAA model predicted tides.

State	Site Name (Embayments)	Watershed Area (m^2)	Embayment Area (m^2)	Watershed -Estuarine area ratio	Mean Tidal Amplitude (ft)	Mean Tidal Amplitude (m)
CT	Hotchkiss Beach (Stony Creek)	3,892,285	243,172	16.01	6.00	1.83
CT	Saugatuck River	7,478,845	2,038,712	3.67	7.07	2.15
CT	Quiambog Cove	19,529,287	294,077	66.41	2.34	0.71
CT	Mumford Cove (Upper & Lower)	9,716,363	1,928,245	5.04	2.56	0.78
CT	Stonington Harbor	13,663,953	1,593,116	8.58	2.34	0.71
CT/RI	Little Naragansett Bay (LNB, Pawcatuck River, Wequetequock)	481,665,269	2,924,345	164.71	2.70	0.82
RI	Greenwich Bay	54,852,754	12,043,644	4.55	4.17	1.27
RI/MA	Mount Hope Bay	104,534,861	38,917,633	2.69	4.36	1.33
MA	Taunton River	122,255,596	12,221,222	10.00	4.68	1.43
MA	Nasketucket Bay	14,450,371	2,981,211	4.85	3.93	1.20
MA	Wareham River	113,799,317	3,682,964	30.90	3.60	1.10
MA	Little Buttermilk Bay	15,929,517	409,125	38.94	3.60	1.10
MA	Buttermilk Bay	43,175,388	2,160,319	19.99	3.60	1.10

4.2.1 Analysis of Water Temperature

"For the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected."[12]

The Intergovernmental Panel on Climate Change (IPCC) has released a series of reports that document a range of predicted global temperature increases based on peer-reviewed, scientifically defensible atmospheric models. Although these results have been challenged in the political realm, they are the most robust predictions of climate change currently available from trusted sources. There is inherent error in predictive models, particularly when deterministic approaches are applied. Therefore, predictions are often reported in ranges of likely results (based on several modeling approaches) and expert opinion is used to distil results into "most likely" values. The predicted ranges of global temperature increases over the next 36 to 86 years are illustrated below in Figure 57 and Table 48.

[12] IPCC Fourth Assessment Report: Climate Change 2007 (Climate Change 2007: Working Group I: The Physical Science Basis).

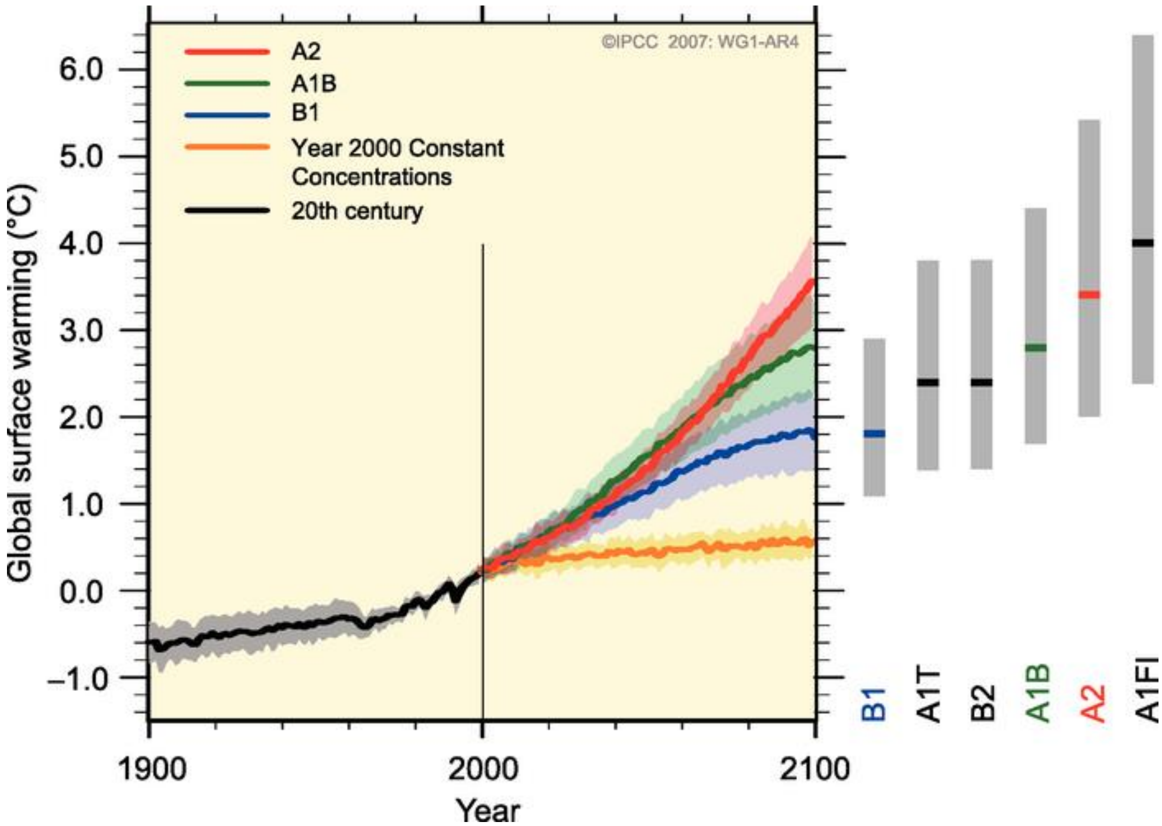

Figure 57. Multi-model global averages of surface warming (relative to 1980–1999) for a series of models (IPCC 2007).[13]

[13] Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. From: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-spm-5.html.

Table 48. Projected global average surface warming and sea level rise at the end of the 21st century.[14]

	Temperature Change (°C at 2090-2099 relative to 1980-1999)		Sea Level Rise) (m at 2090-2099 relative to 1980-1999) Model-based range excluding future rapid dynamical changes in ice flow
Case	**Best estimate**	**Likely range**	
Constant Year 2000 concentrations	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

The goal of the following analysis is to explore the impact of an increase in average air and ocean temperatures on the statistical properties of estuarine temperature – specifically, on the frequency of hourly exceedances of estuarine temperature of 25°C[15]. To do so, the general approach of Wagner *et al*. (2011) was followed. This involves two steps. In the first step, historical data are used to develop a regression model relating hourly estuarine temperature to hourly air and ocean temperatures (and possibly other regressors). In the second step, the fitted regression model is forced by hourly air and ocean temperatures simulated from a model incorporating a specified increase in their means. The values of hourly estuarine temperature simulated in this way can then be used to characterize the impact of increased air and ocean temperatures on the frequency of water temperature exceedances of 25°C or other statistical properties of future water temperatures.

Continuous water temperature data were collected from several sources (National Estuarine Research Reserve System, Dr. Jamie Vaudrey). It is important to apply high resolution temperature data in this analysis because we are interested in determining the response of the frequency of high temperature (thermal stress) events that may occur for only a short period per tidal cycle or day (e.g., perhaps 1 to 4 hours per day). These

[14] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth System Models of Intermediate Complexity and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs). Year 2000 constant composition is derived from AOGCMs only. From: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html.

[15] This temperature threshold is somewhat vague because, although there have been studies to determine temperature stress in mesocosms, water temperature varies on tidal and diel cycles (daily). Therefore, the response to temperature stress can be cumulative over times that vary by embayment. Nevertheless, 25°C to 28°C comes up as a typical threshold range in the literature.

discreet events may be of greater ecological importance than just looking at mean daily, weekly, monthly, or seasonal water temperatures or discreet observation at different frequencies. Continuous water temperature data were not available for all of the embayments selected by the TNC Project Team to conduct site-specific statistical modeling. In fact, of the continuous water temperature data collected, many sets remain unused due to significant gaps and other inconsistencies. Part of this project includes the contribution of water temperature data loggers (e.g., Onset Hobo sondes) that can be strategically placed in additional estuaries of interest where the following statistical modeling approach can be applied to gain site-specific information on susceptibility to future increases in water temperature.

The analysis outlined here was based on data from 10 August through 30 September (2012) in at 4 sites: Branford Harbor, Clinton Harbor, Cold Spring Harbor, and Mattituck. The data used for this analysis were contributed by Dr. Jamie Vaudrey at UCONN (Avery Point). The period is limited to this time period because, for the most part, the data loggers were run from August through the following June or July with significant interruptions that occurred during the mid-summer. The exception was the data set used from Mattituck (not specifically listed for this project but within the area) where data were available from May through September. The analysis focused on the period of highest water temperatures and this period covers a total of 1248 hours. However, missing data reduced this number to just over 1000 hours. In addition to estuarine temperature, these data included ocean temperature from a buoy located in Long Island Sound, air temperature, and tidal height. Standard model screening resulted in the following fitted models for the 4 sites:

Branford Harbor: $W_t = -14.4 + 1.55 O_t + 0.09 A_t - 0.08 T_{t-8}$

Clinton Harbor: $W_t = -19.9 + 1.82 O_t + 0.02 A_t - 0.09 T_{t-4}$

Cold Spring Harbor: $W_t = -9.2 + 0.52 O_{t-4} + 0.04 A_t - 0.12 T_t$

Mattituck: $W_t = -9.3 + 1.38 O_t + 0.04 A_{t-1} - 0.7 T_{t-4}$

where W_t is water temperature in the estuary in hour *t*, O_t is ocean temperature in hour t, A_t is air temperature in hour *t*, and T_t is tidal height in hour *t*.

The values of R^2 for the fitted models were:

Branford Harbor: 0.90

Clinton Harbor: 0.88

Cold Spring Harbor: 0.72

Mattituck: 0.89

The time series of observed and fitted values of estuarine temperature are shown in Figure 58. These are in reasonably good agreement. The observed and modeled number of hourly exceedances (out of approximately 1000) by estuarine temperature of 25°C were:

Branford Harbor: observed 422, modeled 310

Clinton Harbor: observed 349, modeled 302

Cold Spring Harbor: observed 351, modeled 303

Mattituck: observed 359, modeled 310

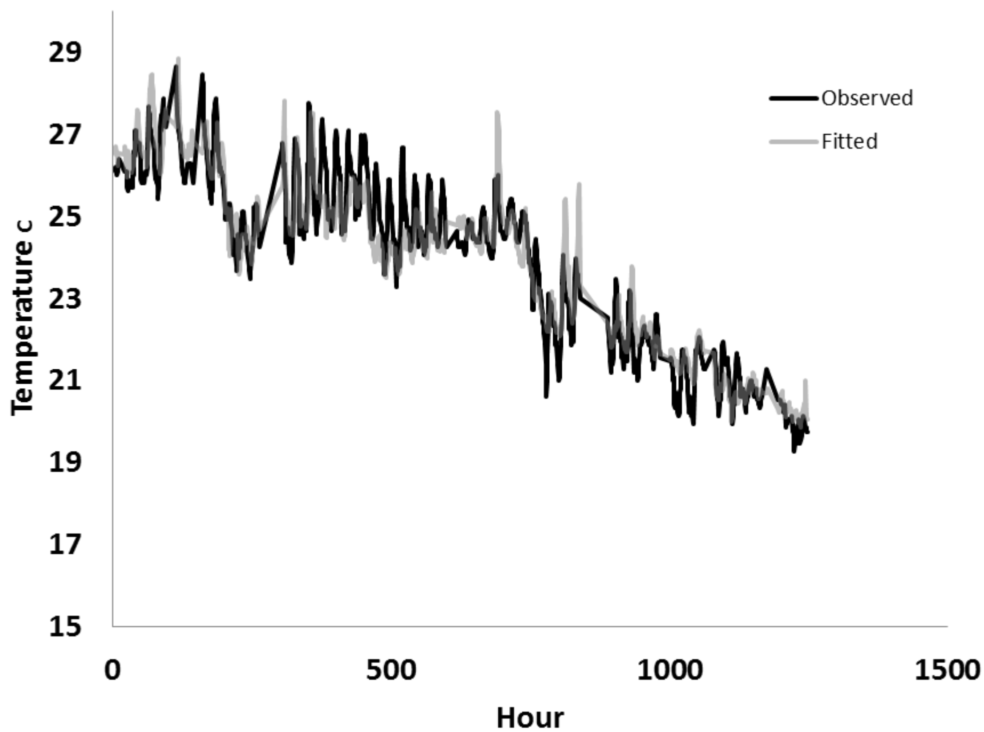

Figure 58. An example of model fit: observed (solid black) and model predicted (gray) output from base run of Mattituck Harbor.

The simulation models of future hourly ocean and air temperatures had the form:

$$O_t = \delta + (\beta_o + \beta_1 t) + \varepsilon_t$$

$$A_t + \delta + (\gamma_o + \gamma_1 t) + \eta_t$$

where δ is a specified future increase in the average ocean and air temperature, $\beta_o + \beta_1 t$ and $\gamma_o + \gamma_1 t$ represent the seasonal trends in ocean and air temperatures, respectively, and the errors ε_t and η_t represent unmodeled variability in hourly ocean and air temperatures, respectively. The seasonal trends in ocean and air temperatures were estimated by fitting linear trend models to the time series of ocean and air temperatures, respectively.

To use this model to simulate hourly air temperatures, it is necessary to specify μ and to simulate a sequence of errors. There are various ways to simulate a sequence of errors that retain the pattern of serial dependence in the observed errors. Here, we used a version of the so-called rotation method described in a different context by DeRuiter & Solow (2008) applied to the residuals from the fitted seasonal trend models. Once a sequence of simulated air temperatures has been formed, it can be used to force the fitted model of estuarine temperatures to produce a simulated sequence from which statistics of interest can be found.

The approach outlined above was used to predict the frequency of exceedance of hourly water temperature of 25°C for different values of δ. The expected number of hours (scaled to 1248) predicted to exceed this threshold for selected values of δ are shown in Table 49 and Figure 59.

Table 49. The expected number of hours (scaled to 1,248) predicted to exceed 25 C for selected values of mean temperature increase from 2012.

δ	Branford	Clinton	Cold Spring	Mattituck
0.5	661	641	541	663
1	805	817	682	813
1.5	855	870	830	862
2	952	972	916	967

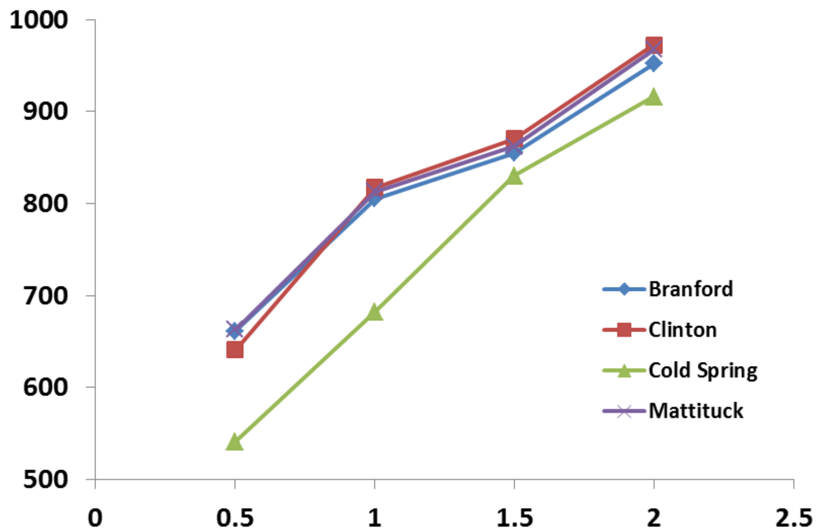

Figure 59. Graphic representation of values shown in Table 46.

What is apparent in Figure 59 is that there is a relatively steep slope associated with increased frequency of temperature threshold exceedances with incremental increases in mean air temperatures. Three of the four embayments studied depict very similar trends with one (Cold Spring Harbor) showing a lower y-intercept. Otherwise, all four slopes are almost indistinguishable. Table 50 illustrates some of the key physical characteristics of these four systems: tidal amplitude, area, and water residence time. Amplitude and area both contribute to water residence time (depth and volume are not included here). That is there is some degree of autocorrelation between these two and water residence time. The response to temperature increase is indistinguishable between Mattituck, Branford, and Clinton, yet Mattituck's residence time is twice greater than the others. Interestingly, Cold Spring Harbor's residence time is within the same range (1.71 d) but its mean tidal amplitude is somewhat greater than the other three. Although we have not presented enough data and model results to explain this further, our results suggest that greater tidal amplitude can be associated with a lower intercept on the temperature response curve, thus a slower response to climate change. Another illustration of this concept is shown in Figure 60 where linear regressions of response in water temperature to increased air temperature are separated by incremental temperature changes (i.e., 0.5, 1.0, 1.5, and 2.0) from the base year of 2012.

Table 50. Mean tidal amplitude, estuarine area, and water residence times for modeled embayments.

Embayment	Mean Tidal Amplitude (ft)	Estuarine Area (km^2)	Water Residence Time (d)
Branford	5.85	1.41	1.08
Clinton	4.55	2.69	0.83
Cold Spring	7.30	1.19	1.71
Mattituck	5.2	0.63	2.55

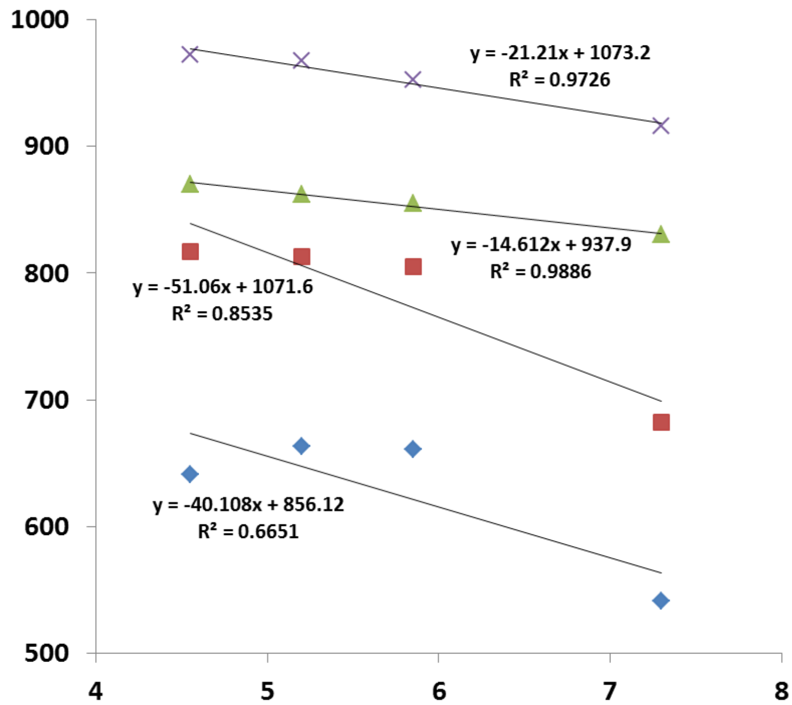

Figure 60. Linear regressions of tidal amplitude (x-axis) against hours of exceeding 25 C (y-axis) for each 0.5-degree increase in air temperature (0.5 to 2.0, bottom to top).

If we treat all the selected model outputs as one set of response variables then the linear regression shown in Figure 61 depicts the trend in response (R^2=0.88). This result suggests that there is on the order of a 210-hour increase in exceedance of the 25 C threshold per degree C increase in mean air temperature for this group of Long Island Sound estuaries. This is about a 40% increase in time (per degree increase) when water temperature will exceed the approximate thermal stress threshold of 25 C. This is a significant impact to existing *Z. marina* populations that are already close to the threshold. The upper and lower bounds of the data may be related to tidal amplitude; however, more study is necessary to sufficiently test this hypothesis. But attain, this relationship to tidal amplitude (which is related to residence time and overall volumetric exchange) is intuitive and it is also apparent in the example shown in Figure 4 (Section 3.4).

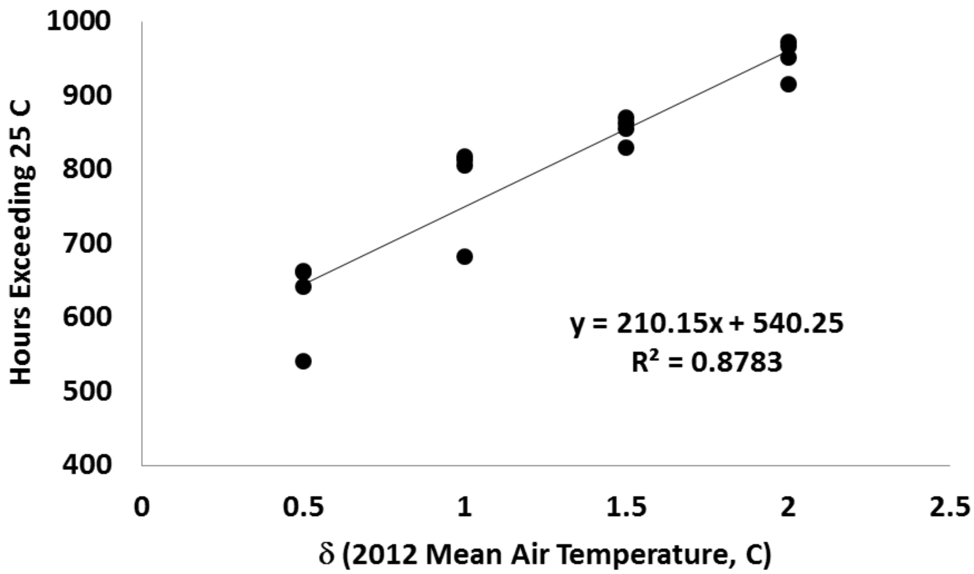

Figure 61. Linear regression between change in mean air temperature and hours of water temperature exceeding 25 C (all four estuaries).

4.2.2 Analysis of Sea Level

Sea level increases associated with changing climate conditions have been predicted to range from 0.2 to 0.6 m (0.66 to 1.97 ft) according to the IPCC. The higher end of this range could be significant enough to have undesirable consequences on mid to low elevation *Z. marina* beds, especially in meso and macrotidal environments and/or estuaries that exhibit poor light penetration due to the effects of eutrophication. The light requirements of *Z. marina* have been studied extensively and specific guidance on criteria associated with light quality in estuarine environments has been established and reviewed by several scientific investigators and coastal managers from Chesapeake Bay to Long Island Sound (Batiuk et al. 2000; Koch 2001; Yarish et al. 2006). A recent review of this subject by Vaudrey (2008) provides an excellent description of *Z. marina* water quality requirements in context with water depth and other important variables. A paper published in 1996 (Koch & Beer 1996) explored whether the much higher tidal range in western Long Island Sound (3 m) compared to that of in eastern Long Island Sound (1 m) Sound could further reduce light availability and, therefore, restrict the vertical distribution of eelgrass. Their conclusion was that indeed the larger tidal range in the western Sound, in combination with poor light availability (due to nutrient enrichment), was responsible for the disappearance of eelgrass beds. Conversely, the upper limit of eelgrass habitat (approximately [MHHW-MLLW)/2) would presumably be raised with increasing sea level. However, the area available for vertical (and horizontal) migration of *Z. marina* is likely limited in most estuaries where coastal development has replaced suitable habitat. Thus, the risk of eelgrass loss in existing beds due to SLR increases with tidal amplitude. Likewise, the likelihood of suitable restoration sites diminishes with increasing sea level in the same regions.

The relationship between minimum light availability and depth is made with the Lambert-Beer equation, a widely applied approach to estimate light availability at depth. The equation uses the light extinction coefficient (K_d) which is usually site-specific and influenced by multiple local water column characteristics (particulate matter, dissolved organics). The following table, developed by Vaudrey (2008) provides an example of the values of K_d that are required to meet two minimum % light requirements of *Z. marina*.

Table 51. K_d (m^{-1}) required for eelgrass growth and survival (15% and 22%).

Depth (m)	15%	22%
0.25	7.6	6.1
0.5	3.8	3.0
0.75	2.5	2.0
1.0	1.9	1.5
1.25	1.5	1.2
1.5	1.3	1.0
1.75	1.1	0.9
2.0	0.9	0.8
2.25	0.8	0.7
2.5	0.8	0.6
2.75	0.7	0.6
3.0	0.6	0.5
3.25	0.6	0.5
3.5	0.5	0.4
3.75	0.5	0.4
4.0	0.5	0.4
4.25	0.4	0.4
4.5	0.4	0.3
4.75	0.4	0.3
5.0	0.4	0.3
5.25	0.4	0.3
5.5	0.3	0.3
5.75	0.3	0.3
6.0	0.3	0.3

As stated above, the effects of SLR on *Z. marina* habitat will likely be greater in areas like western Long Island Sound (west of the Race) where tidal amplitudes are relatively high. The corresponding effects of nutrient enrichment, with typically increase K_d significantly, need to be considered at each estuary of interest. The reduction of nitrogen loads below the approximate threshold of 5 g TN m^{-2} y^{-2} may only provide marginal increases in the likelihood of eelgrass recolonization or restoration in estuaries with large tidal ranges (i.e., western Long Island Sound).

5.0 DISCUSSION OF CURRENT AND FUTURE CONDITIONS

5.1 WATERSHED-DERIVED NUTRIENTS

Nutrient enrichment to receiving estuarine waters is the primary driver responsible for altered, unsuitable environmental conditions for *Z. marina* and other estuarine species of interest. The previous sections provide estimates of existing nitrogen loads to a series of embayments that were selected by the TNC Project Team. These estimates are subject to some degree of uncertainty (inputs and model errors); however, the application of the NLM has been shown to be acceptable by many investigators (Latimer and Rego, 2010; Kinney and Valiela. 2011; J. Vaudrey, *pers. comm*).

Although there are other factors that may significantly contribute to *Z. marina* decline, and hamper restoration efforts, the effect of excess nitrogen load is the primary source of unsuitable conditions in the benthos and throughout the water column. The ranges of target loads that have been assessed by coastal managers throughout this study area (NY, CT, RI, and MA) vary slightly, but the response of *Z. marina* to excess nitrogen follows a very sharp response curve. Figure 58, below, illustrates this sensitivity to nitrogen and confirms that the threshold to declines in *Z. marina* is relatively low and narrow in range. Hauxwell et al. (2003) reported the onset of *Z. marina* decline at about 3 g TN m^{-2} y^{-1} with total disappearance at about 6 g TN m^{-2} y^{-1}. This range is consistent with several other studies that, together, have suggested an overall range of 3 to 10 g TN m^{-2} y^{-1} when declines in *Z. marina* occur. The problem with assuming that the lower end of this threshold is a suitable target for habitat suitability improvements is that eelgrass habitats are often self-maintaining. That is, once a decline starts it may continue without the any additional increase of nutrient load. This has been illustrated in several cases: when the protective properties of roots and canopy are removed the resulting resuspension of sediments, erosion, and shifts in benthic habitat (and biochemistry) can perpetuate additional losses. The shift in baseline conditions may also result in hysteresis where the new alternative stable state may have different “reverse state” thresholds (i.e., nutrient regimes may need to be lower than the assumed “loss” threshold to successfully restore the original habitat. This phenomenon is described in reviews by Scheffer et al. (1994, 2001) and Duarte et al. (2009).

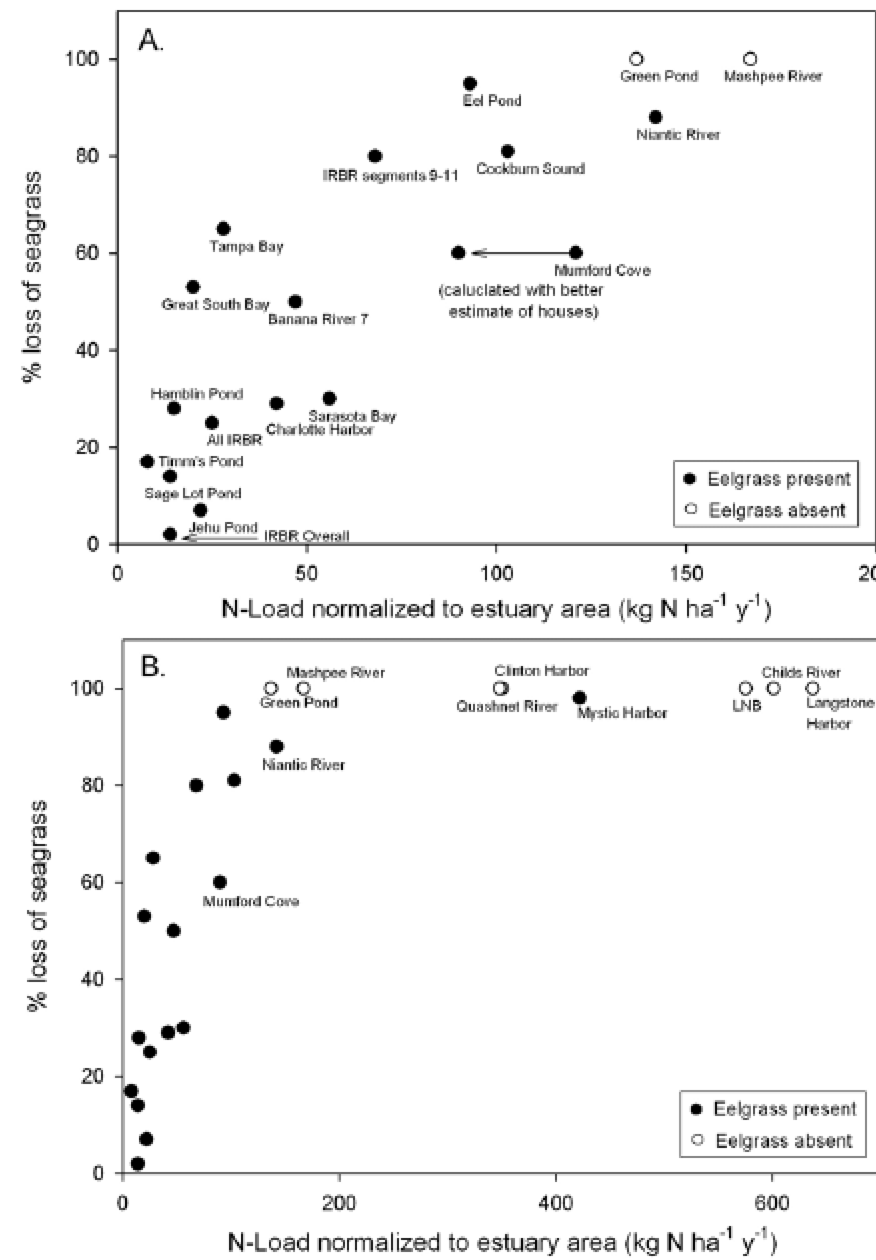

Figure 62. Nitrogen load vs. % eelgrass loss (from Vaudrey 2008).

Table 52 provides a summary of the relative susceptibility to current nitrogen loads and an estimated level of likelihood of achieving reductions that would result in conditions favorable (or nearly favorable) for ecosystem restoration (see Section 6 for more description). Figures 63, 64 and 65 are graphical depictions of this information.

Table 52. Summary of relative susceptibility to current nitrogen loads and probability of attaining sufficient reductions.

System	Embayment	N Load per estuarine area (g m^{-2} y^{-1})	Susceptibility to nitrogen load	Probability of attaining sufficient load reductions
Fishers Island	East Harbor	4.50	Low	Good
	Hay Harbor	2.23	Low	Good
	Chocomount Cove	1.04	Low	Good
	Barleyfield Cove	1.17	Low	Good
	West Harbor	3.04	Low	Good
Hotchkiss Beach	Hotchkiss Beach	27.57	High	Moderate
Little Buttermilk Bay	Little Buttermilk Bay	21.99	High	Moderate
Nasketucket Bay	Nasketucket Bay	3.39	Low	Moderate
Nissequogue River	Nissequogue Main	230.67	Extremely High	Poor
	Nissequogue West	88.49	High	Good
Northport - Huntington	Centerport Harbor	48.35	High	Moderate
	Huntington Bay	3.51	Low	Good
	Huntington Harbor	66.58	High	Moderate/Good
	Lloyd Harbor	1.79	Low	Good
	Northport Bay	1.3	Low	Good
	Northport Harbor	11.08	Moderately High	Moderate/Good
Ram Island	Ram Island	8.78	Moderately High	Moderate
Saugatuck River	Saugatuck River	83.73	High	Poor
Wading River	Wading River	831.43	Extremely High	Poor
Wareham River	Wareham River	17.60	Moderately High	Moderate/Good

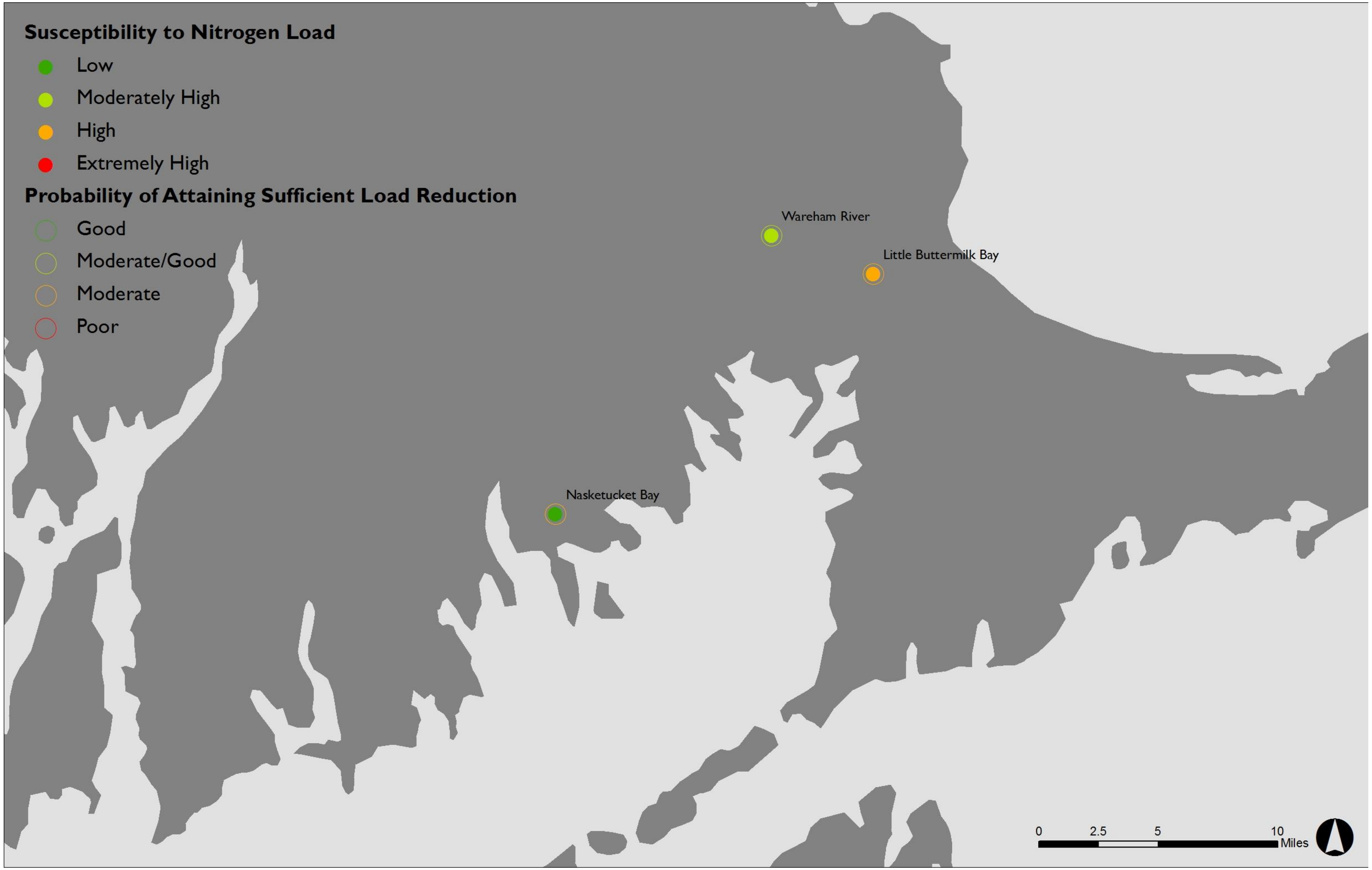

Figure 63. Relative susceptibility to existing watershed nitrogen loads to the embayments (eastern region) listed in Table 46.

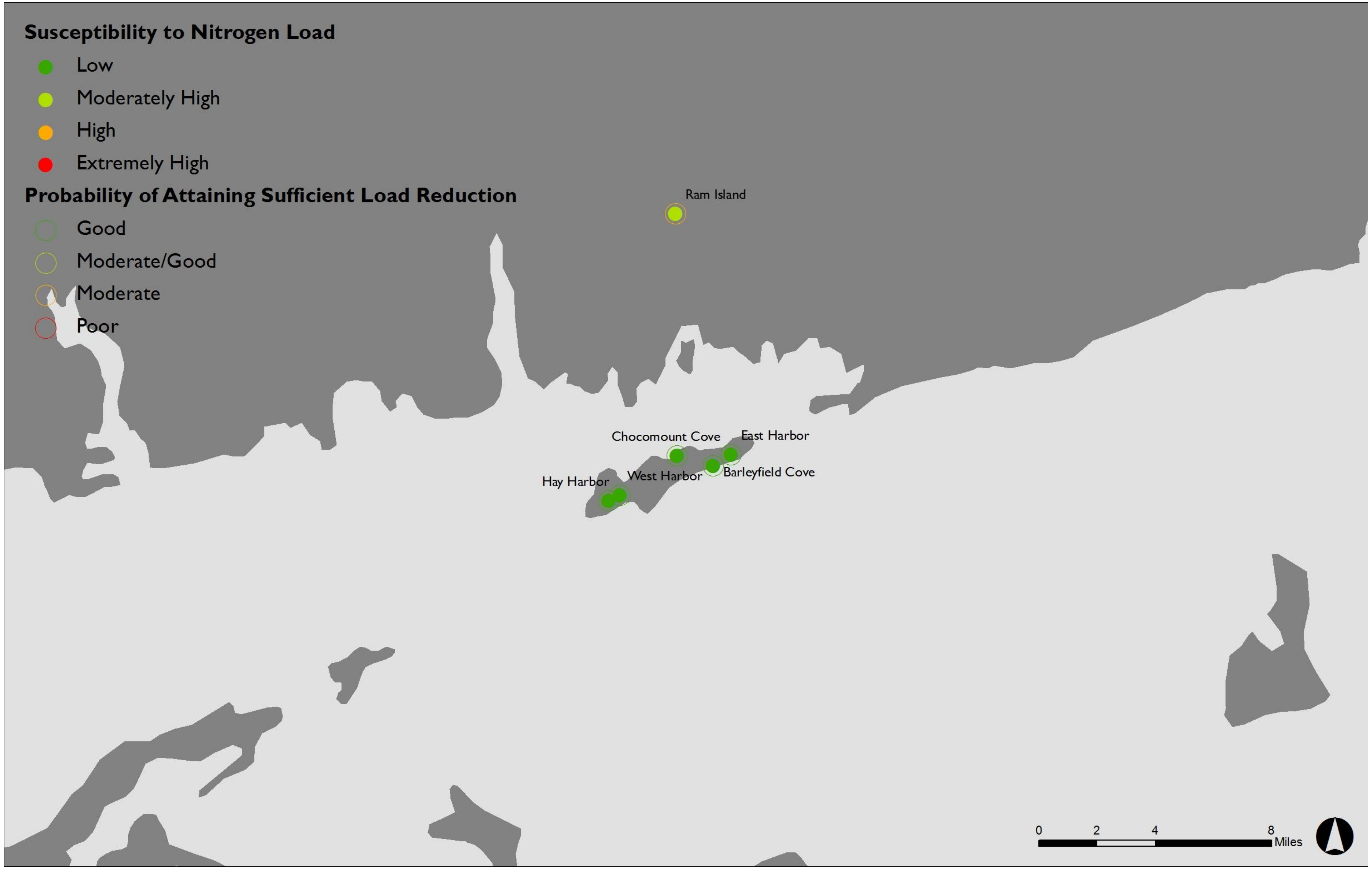

Figure 64. Relative susceptibility to existing watershed nitrogen loads to the embayments (central region) listed in Table 46.

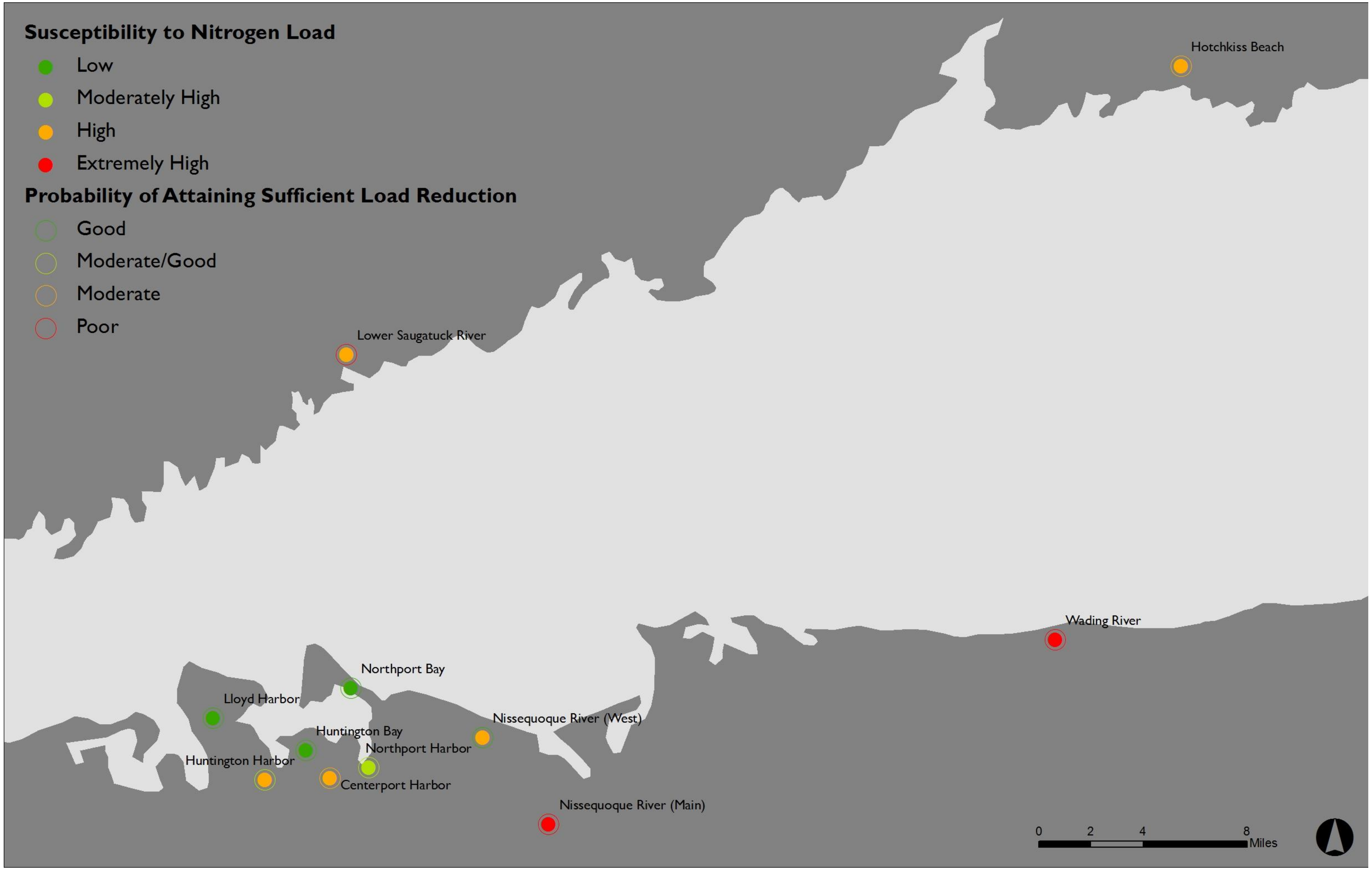

Figure 65. Relative susceptibility to existing watershed nitrogen loads to the embayments (western region) listed in Table 46.

5.2 CLIMATE CHANGE

The results of our statistical model(s) on the potential response to increased air and water temperatures over time (as predicted by IPCC and others) suggest that there is little difference in the overall rate of increase of the frequency of thermal events. We chose 25 C as the threshold associated with thermal stress on *Z. marina* but it is likely that tolerance to high temperatures do vary across populations (Short et al. 2012). But this tolerance has not been thoroughly tested against rigorous frequency-duration scenarios. It may not be necessary to test too much further if the intention of restoration is to apply efforts sufficiently below stressor thresholds. The temperature of 25 C appears to be a consistent value associated with the onset of the effects of thermal stress in multiple studies and through empirical observations.

Since thermal stress may affect most eelgrass populations within a consistent range of frequency and duration, the estuaries and open coastal areas that are most likely to experience greater stress are those with relatively small tidal ranges and poor flushing. Likewise, the associated risk to thermal stress increases with nitrogen load.

The risk associated with increased sea level, as described above, is higher in estuaries with relatively high tidal ranges that are experiencing excess nitrogen loads.

Table 53 provides a summary of nitrogen loads (where modeled), tidal amplitude, and the associated relative risk of climate change due to increases in water temperature and SLR.

Table 53. Nitrogen loads, tidal amplitudes, and relative risks of thermal stress events and reduced light conditions associated with climate change.

State	Site Name (Embayments)	Current Nitrogen Load (g TN m^{-2} y^{-1})	Mean Tidal Amplitude (ft)	Relative Risk to Thermal Stress	Relative Risk to SLR
NY	Fishers Island (East Harbor)	4.50	2.34	High	Low
NY	Fishers Island (West Harbor)	3.04	2.34	High	Low
NY	Fishers Island (Chocomount Cove)	1.04	2.34	High	Low
NY	Fishers Island (Barleyfield Cove)	1.17	2.34	High	Low
NY	Fishers Island (Hay Harbor)	2.23	2.34	High	Low
NY	Wading River	831.43	2.34	High	Medium
NY	Northport/Huntington (Centerport Harbor)	48.35	7.27	High	High
NY	Northport/Huntington (Huntington Bay)	3.51	7.03	Medium	High
NY	Northport/Huntington (Huntington Harbor)	66.58	7.03	High	High

State	Site Name (Embayments)	Current Nitrogen Load (g TN m^{-2} y^{-1})	Mean Tidal Amplitude (ft)	Relative Risk to Thermal Stress	Relative Risk to SLR
NY	Northport/Huntington (Lloyd Harbor)	1.79	7.03	Medium	High
NY	Northport/Huntington (Northport Bay)	1.30	7.27	Medium	High
NY	Northport/Huntington (Northport Harbor)	11.08	7.27	Medium	High
NY	Nissequogue River (Main)	230.67	7.15	High	High
NY	Nissequogue River (West)	88.49	7.15	High	High
NY	Peconic Bays (Great & Little)	-[16]	2.45	High	Medium/Low
CT	Duck Island (Menunketesuck River, Patchogue River)	-	4.22	Medium	Medium
CT	Ram Island (Mystic Harbor, Palmer Cove)	8.78[17]	2.34	Medium	Low
CT	Hotchkiss Beach (Stony Creek)	27.57	6.00	Medium	High
CT	Saugatuck River	83.73	7.07	High	High
CT	Quiambog Cove	-	2.34	High	Medium
CT	Mumford Cove (Upper & Lower)	4.54	2.56	High	Medium
CT	Stonington Harbor	6.62	2.34	High	Low
CT/RI	Little Naragansett Bay (LNB, Pawcatuck River, Wequetequock)	-	2.70	Medium	Low
RI	Greenwich Bay	11.4	4.17	High	High
RI/MA	Mount Hope Bay	57.56	4.36	High	Medium
MA	Taunton River	128.8	4.68	High	High
MA	Nasketucket Bay	3.39	3.93	Medium	Low
MA	Wareham River	17.60	3.60	Medium	Medium
MA	Little Buttermilk Bay	21.99	3.60	High	Medium
MA	Buttermilk Bay	11.78	3.60	High	Medium

Figures 66 through 71 illustrate the relative risks shown in Table 53 (sea level rise and thermal stress events). An assessment of the contribution of the sum of the susceptibility and relative risks described above (and shown in Tables 52 and 53) is summarized in Table 54. The risk to eelgrass habitat associated with nitrogen load, as described above, increases significantly as loads increase beyond 5 to 10 g N m-2 y-1. Embayments with

[16] Currently under review.
[17] Ram Island results partially complete: missing small area of upper watershed load.

current loads exceeding this range are considered medium or high risk, depending on the order of magnitude. Embayments with large tidal amplitudes, such as in western Long Island Sound, may be at greater risk from SLR due to pre-existing poor water quality (low light availability). Mesotidal estuaries may be more resilient to increases in SLR. Risk associated with thermal stress may be lower in embayments with larger tidal amplitudes due to greater mixing with deeper boundary waters.

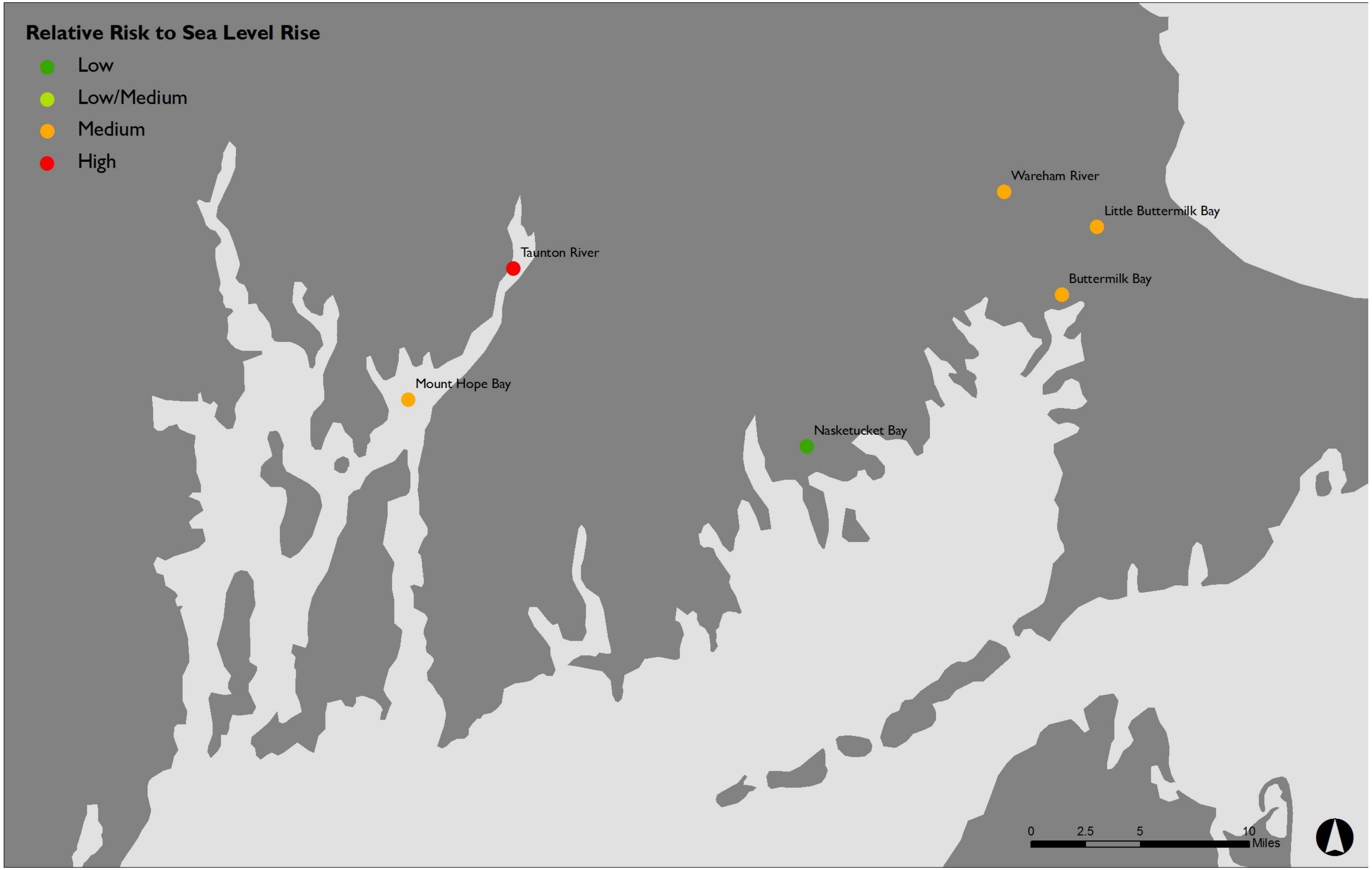

Figure 66. Risk to eelgrass habitat associated with increase in sea level rise (eastern region).

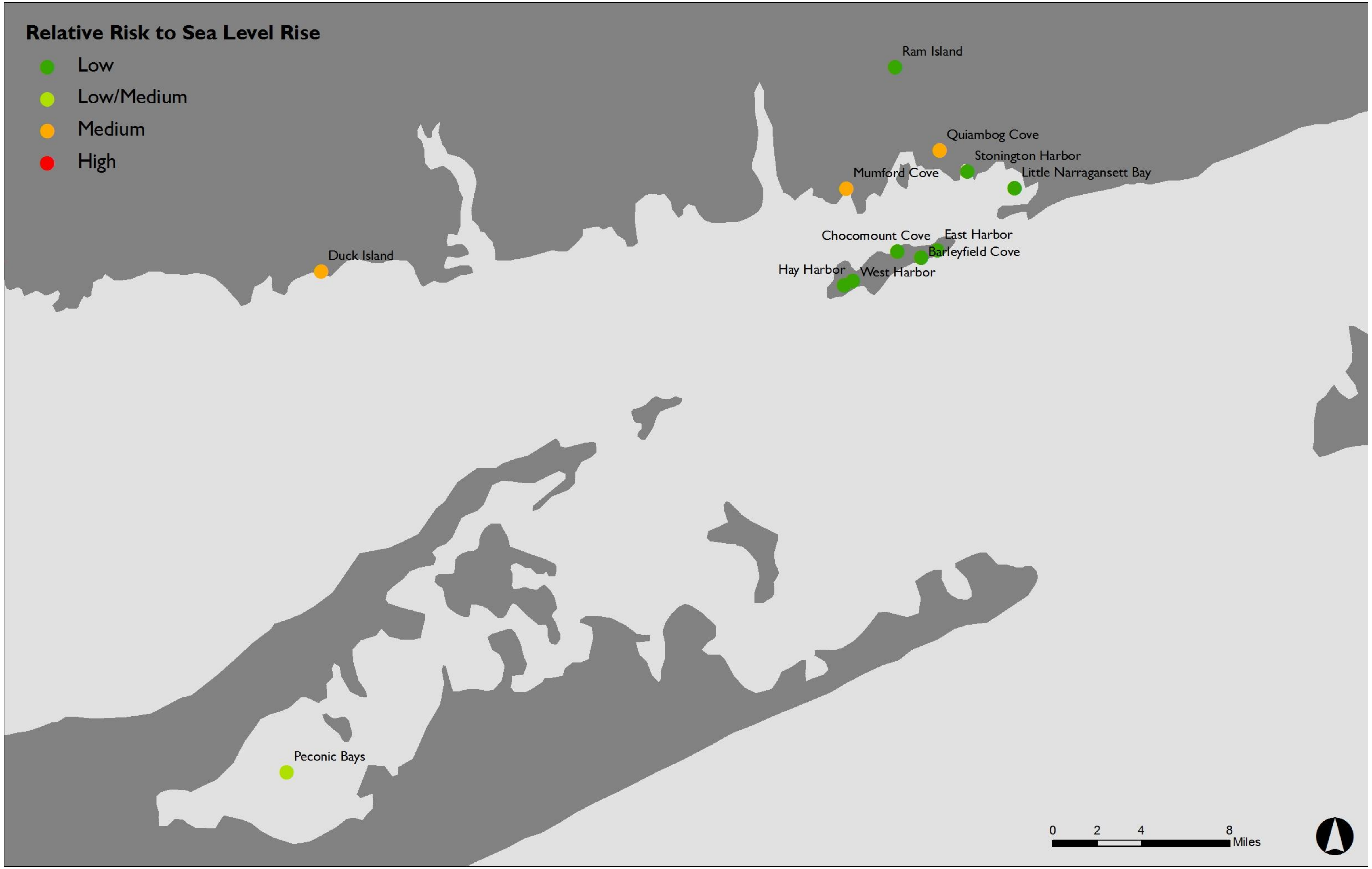

Figure 67. Risk to eelgrass habitat associated with increase in sea level rise (central region).

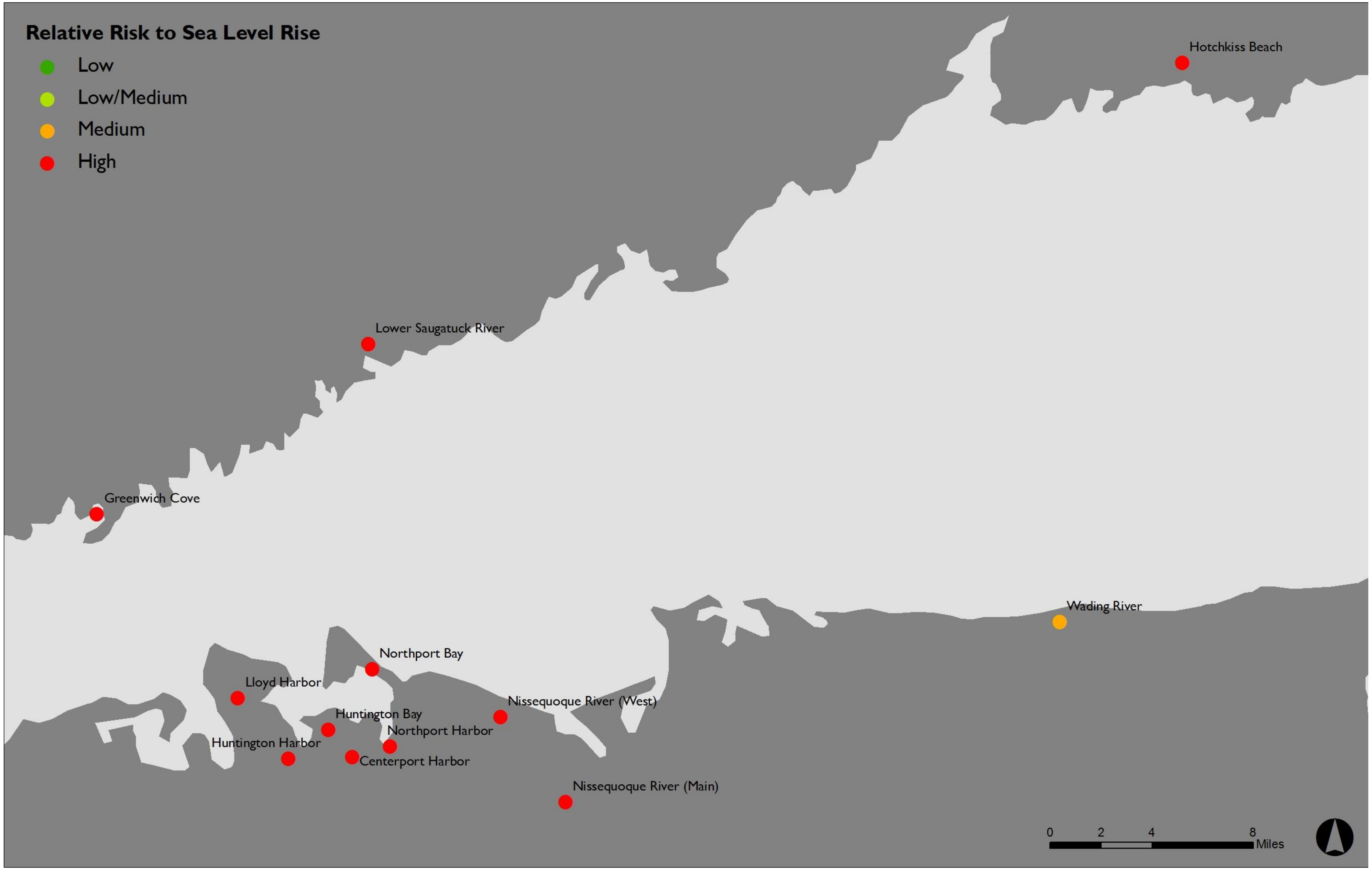

Figure 68. Risk to eelgrass habitat associated with increase in sea level rise (western region).

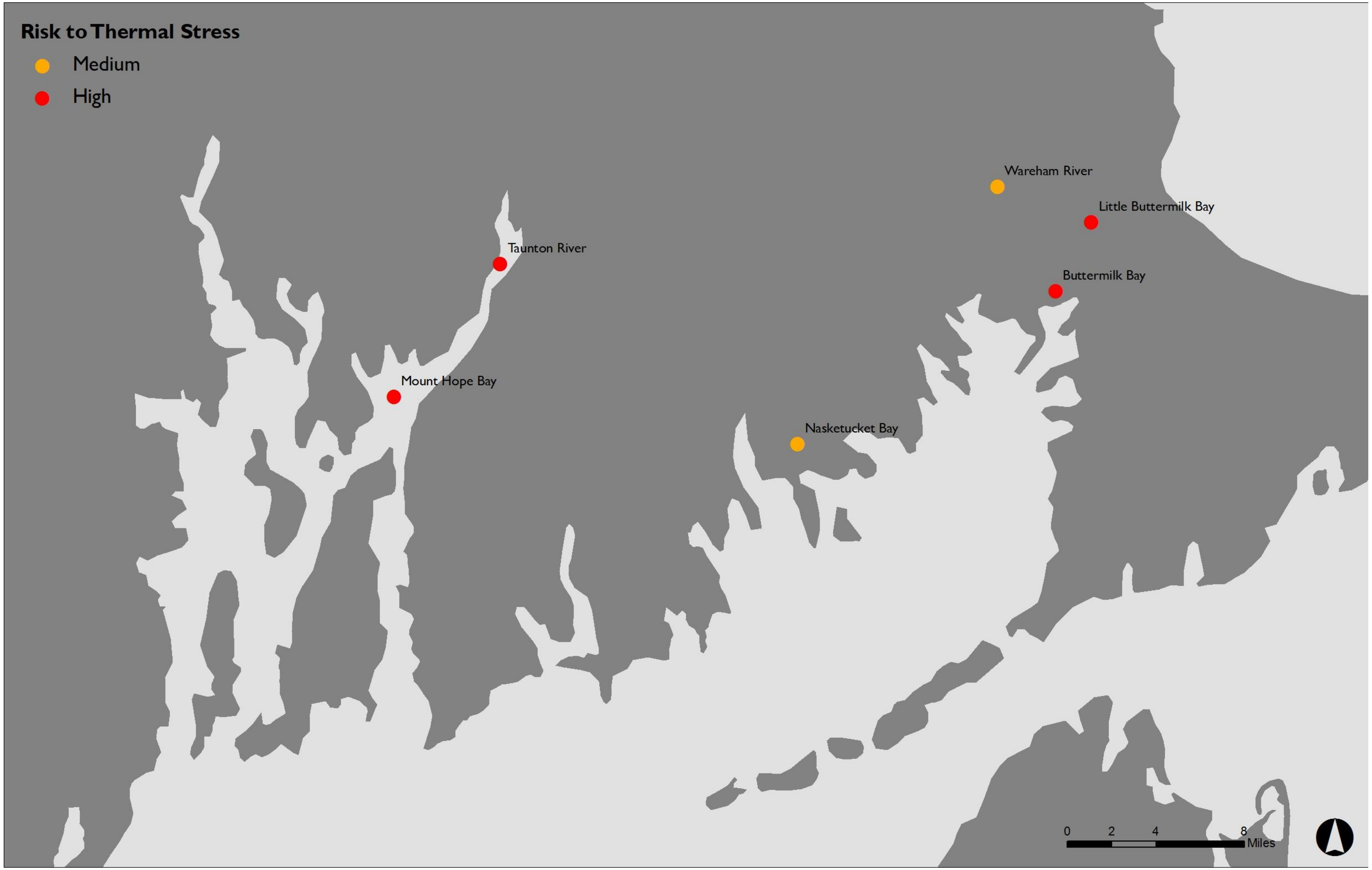

Figure 69. Risk to eelgrass habitat associated with increased frequency of thermal stress (eastern region).

Figure 70. Risk to eelgrass habitat associated with increased frequency of thermal stress (central region).

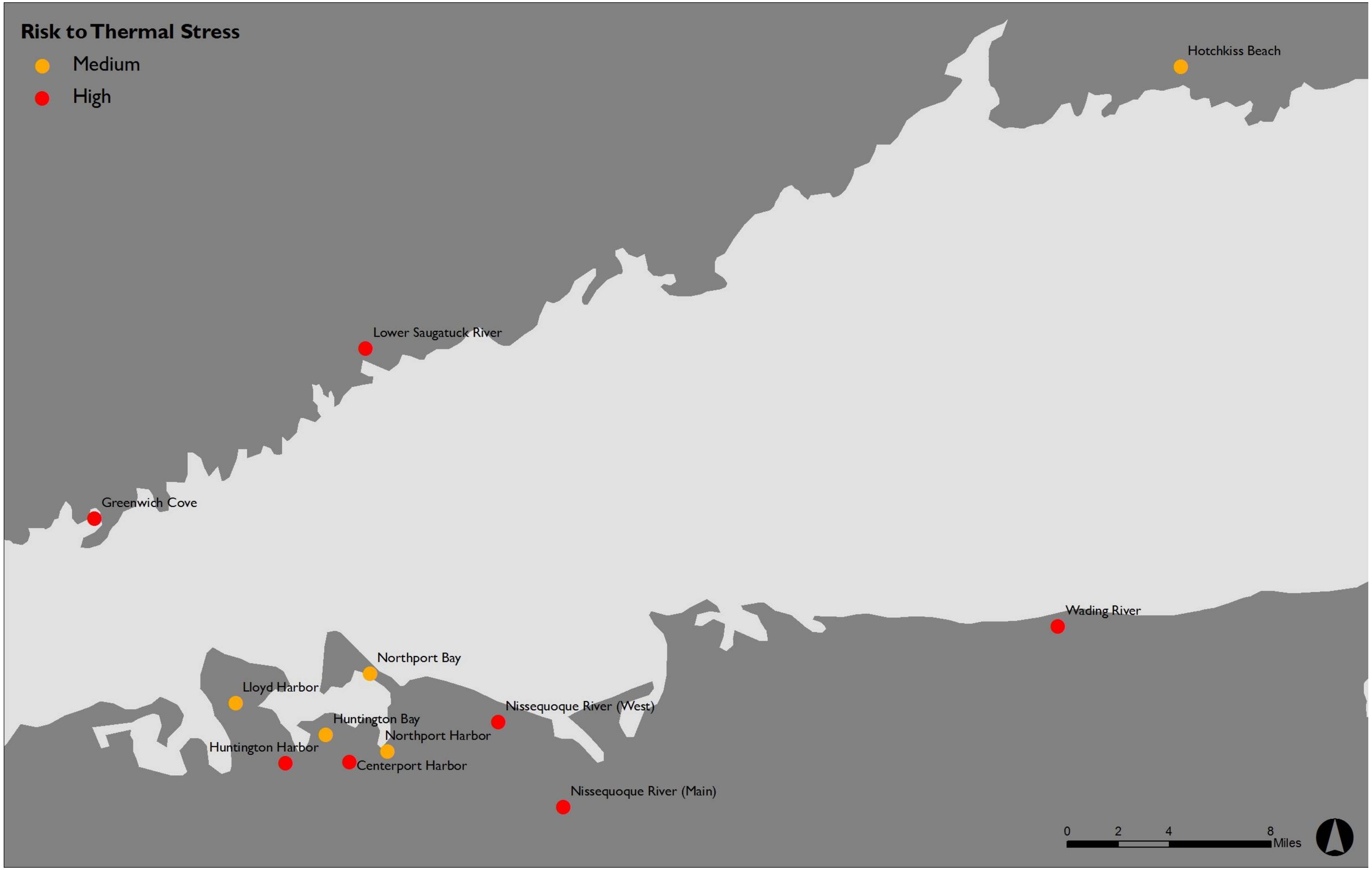

Figure 71. Risk to eelgrass habitat associated with increased frequency of thermal stress (western region).

Table 54. Summary of multiple stressors to *Z. marina* (and whole ecosystem).

State	Site Name (Embayments)	Relative Risk to Nitrogen Enrichment	Relative Risk to Thermal Stress	Relative Risk to SLR	Overall Relative Risk to Stressors
NY	Fishers Island (East Harbor)	Low	High	Low	Low
NY	Fishers Island (West Harbor)	Low	High	Low	Low
NY	Fishers Island (Chocomount Cove)	Low	High	Low	Low
NY	Fishers Island (Barleyfield Cove)	Low	High	Low	Low
NY	Fishers Island (Hay Harbor)	Low	High	Low	Low
NY	Wading River	High	High	Medium	High
NY	Northport/Huntington (Centerport Harbor)	Medium	High	High	Medium
NY	Northport/Huntington (Huntington Bay)	Low	Medium	High	Medium
NY	Northport/Huntington (Huntington Harbor)	Medium	High	High	Medium
NY	Northport/Huntington (Lloyd Harbor)	Low	Medium	High	Medium
NY	Northport/Huntington (Northport Bay)	Low	Medium	High	Medium
NY	Northport/Huntington (Northport Harbor)	Medium	Medium	High	Medium
NY	Nissequogue River (Main)	High	High	High	High
NY	Nissequogue River (West)	Medium	High	High	High
NY	Peconic Bays (Great & Little)	-[18]	High	Medium	Medium
CT	Duck Island (Menunketesuck River, Patchogue River)	-	Medium	Medium	Medium
CT	Ram Island (Mystic Harbor, Palmer Cove)	Medium[19]	Medium	Low	Medium
CT	Hotchkiss Beach (Stony Creek)	Medium	Medium	High	Medium
CT	Saugatuck River	High	High	High	High

[18] Currently under review.
[19] Ram Island results partially complete: missing small area of upper watershed load.

State	Site Name (Embayments)	Relative Risk to Nitrogen Enrichment	Relative Risk to Thermal Stress	Relative Risk to SLR	Overall Relative Risk to Stressors
CT	Quiambog Cove	-	High	Medium	Medium
CT	Mumford Cove (Upper & Lower)	Low	High	Medium	Medium
CT	Stonington Harbor	Low	High	Low	Medium
CT/RI	Little Naragansett Bay (LNB, Pawcatuck River, Wequetequock)	-	Medium	Low	Medium
RI	Greenwich Bay	Medium	High	High	Medium
RI/MA	Mount Hope Bay	High	High	Medium	High
MA	Taunton River	High	High	High	High
MA	Nasketucket Bay	Low	Medium	Low	Low
MA	Wareham River	Medium	Medium	Medium	Medium
MA	Little Buttermilk Bay	Medium	High	Medium	Medium
MA	Buttermilk Bay	Low	High	Medium	Medium

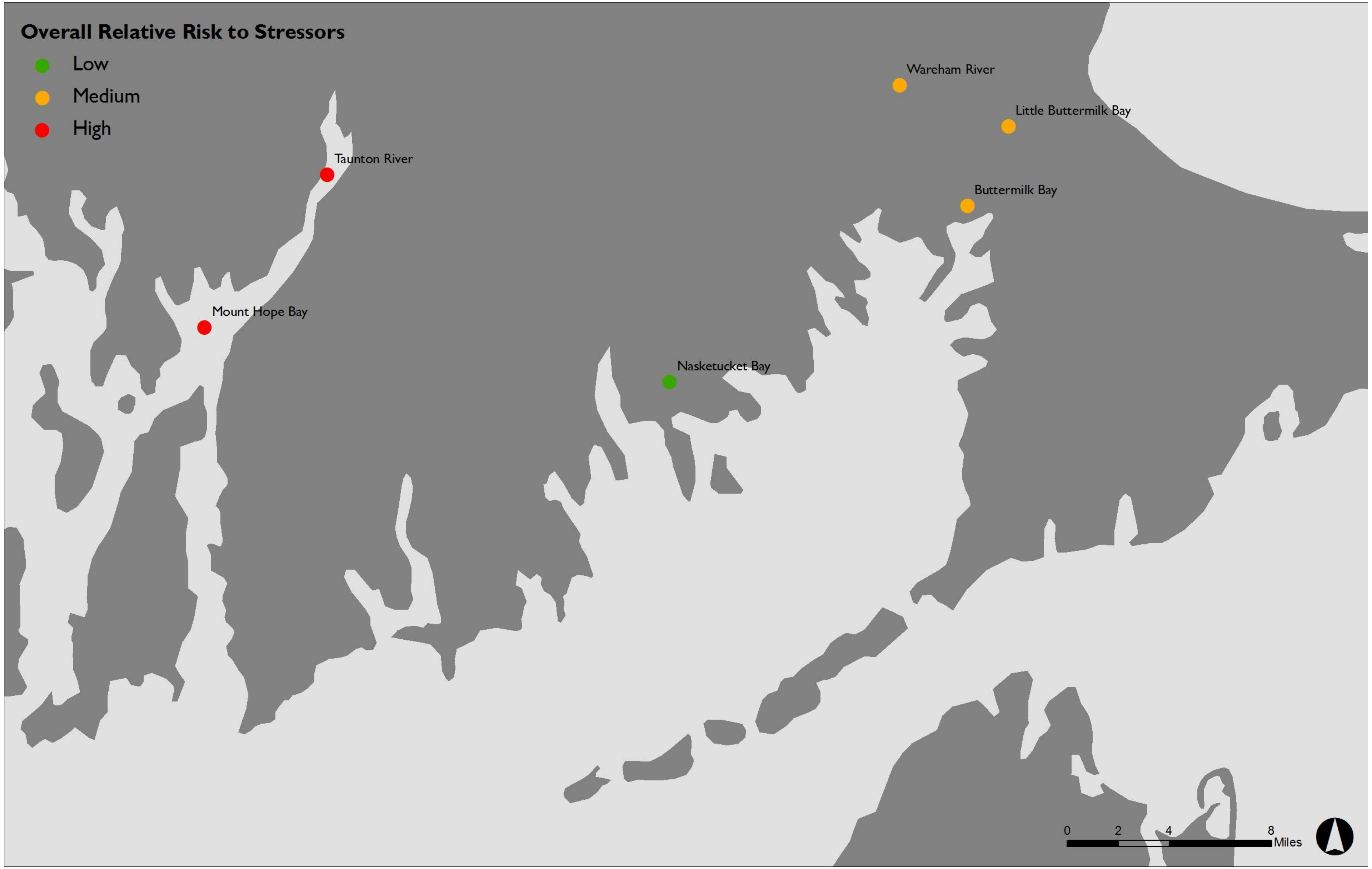

Figure 72. Overall relative risk (eastern region).

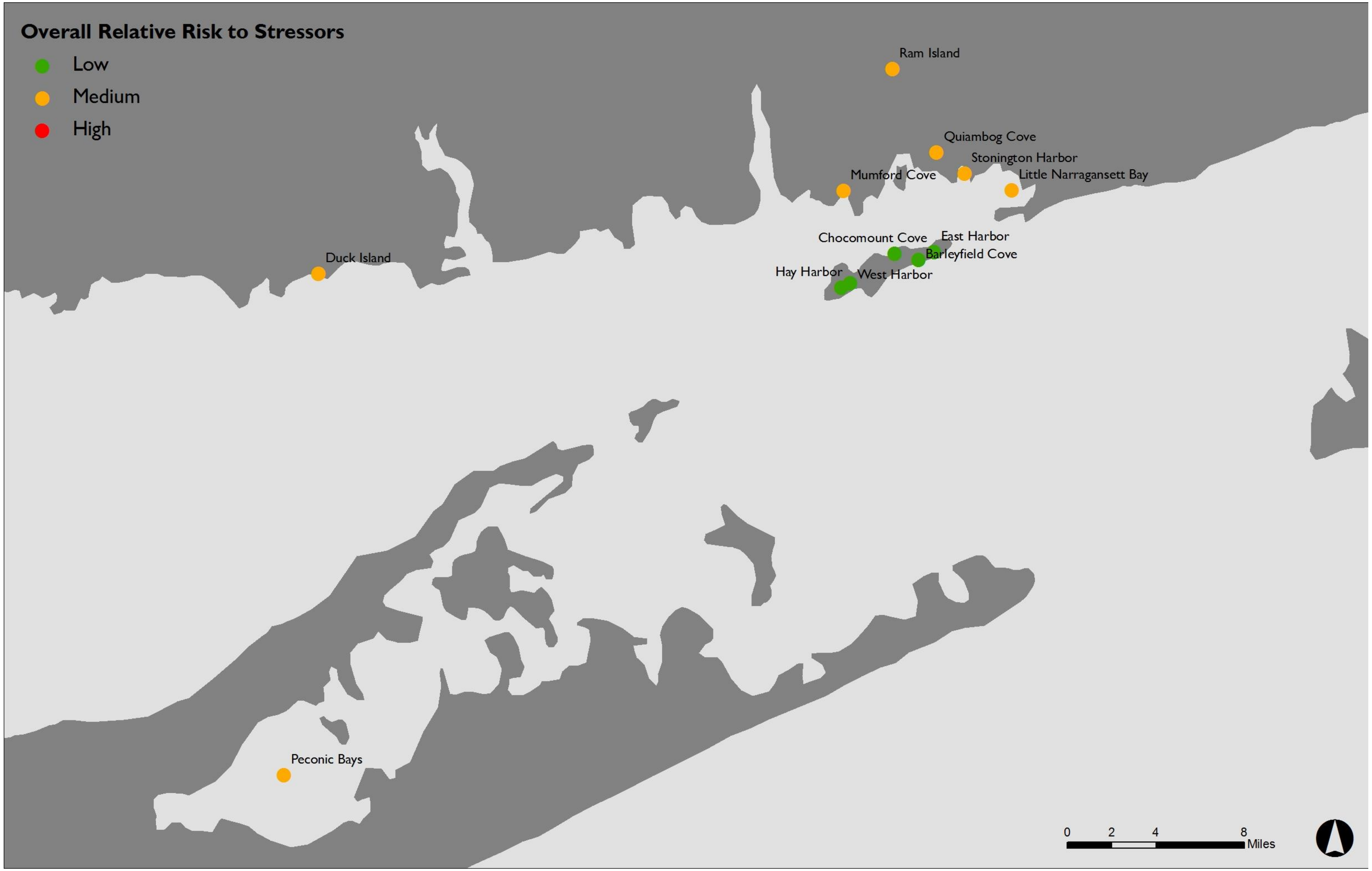

Figure 73. Overall relative risk (central region).

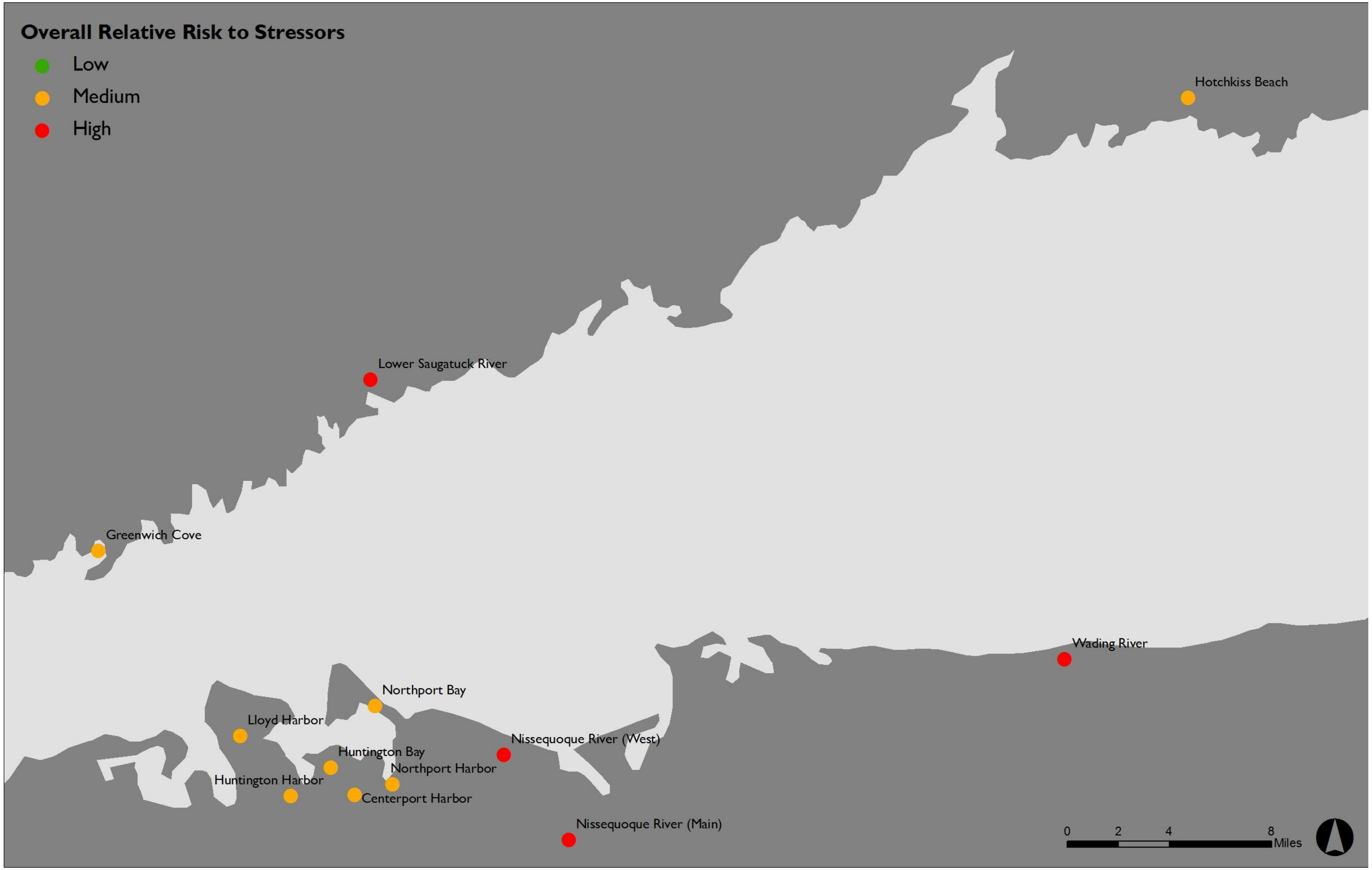

Figure 74. Overall relative risk (western region).

5.3 OTHER

There is always the possibility, if not likelihood, that top-down pressures may lead to, or exacerbate, recent losses of eelgrass beds in New York, New England, and the Canadian Maritimes. Recent papers have been published that identify the invasive European Green Crab (*Carcinus maenas*) as a suspected contributor to significant, rapid losses of *Z. marina* beds (Malyshev and Quijon 2011). Although more monitoring and research is necessary to improve estimates of green crab influences on *Z. marina*, studies to date suggest that these non-native crabs exert significant damage through burrowing, seeking food (juvenile bivalves), and even direct feeding on basal meristems of *Z. marina*[20]. The concentrations of green crabs in many estuaries in the region far exceed other species and have been reported up to 5 crabs per square meter (de Rivera et al. 2005). There is now a swelling of interest in controlling *C. maenas* due to their primary diet of juvenile clams, particularly soft shell clams (*Mya arenaria*) where widespread crashes of the soft shell clam industry in Maine has occurred, purportedly due to the predation by green crabs.

6.0 RECOMMENDATIONS AND DATA NEEDS

In this section are recommendations for improving environmental conditions to support sea grass habitat and other valued ecological services in the embayments within this study. These recommendations follow an evaluation of the relative susceptibility or vulnerability of each of the selected embayments to existing and future ecological stressors and the likelihood that these can be attenuated through management decisions. This section also identifies data and/or other supporting information that is either missing or would be required to further enhance this study.

The direct effects of climate change are undoubtedly uncontrollable in the near-term, particularly since the projected changes have not yet been fully experienced and the forecasts cover periods of decades and centuries. However, the forecasts of both temperature and sea level rise can be applied to decisions related to restoration. That is, estuarine and other coastal systems that are currently stressed and vulnerable to further damage due to climate change may not be good candidates for near-term restorative investments. The climate change forecasts can be applied to managing certain ecological enhancement activities. Some of these include identifying areas where various species may migrate to as conditions change (e.g., low and high salt marsh environments, SAV, and mudflat communities). Certainly, in the northeast U.S., the state of development has imposed great limits to these activities.

What is controllable, to some extent, is nitrogen loading to receiving waters. The majority of the embayments in this study, and throughout the project area, receive the greatest proportion of nitrogen from wastewater sources (septic, cess pool, and treated wastewater). In some cases additional significant loads may come from recreational and agricultural land uses (golf courses and crops) and to some extent, lawn fertilizer applications. These are all controllable to some level through wastewater treatment and sequestration, best management practices (agriculture and recreational facilities), and

[20] http://www.seagrant.umaine.edu/green-crab-summit

municipal or county bylaws to regulate lawn fertilizers. In each watershed different practices can result in different results. For example sewering whole areas and discharging into open waters (e.g., offshore), moving outfall pipes to from embayment to open water (where greater dilution occurs), and implementing (or retrofitting to) advanced wastewater treatment technologies can result in significant load reductions. For agricultural load sources, reviews of farm best management practices and assessing compliance of nutrient and sediment load reduction strategies can result in additional load reductions to receiving waters.

The drivers of cost to reduce nitrogen load through wastewater treatment and other means varies across municipal and regional scales. Briefly, some of these important drivers include the following:

Geology, Soil Type, and Topology

These characteristics have direct influence on the level of cost and effort to design and build the infrastructure necessary to support wastewater transport and treatment. Physical environments vary widely throughout this study area from sandy, unconsolidated glacial aquifers (Long Island, Cape Cod, the Islands) to bedrock and moraine features.

Receiving Waters

Wastewater treatment outfalls are considered point sources of pollutants that require permitting (e.g., NPDES). The existing condition and designated use of receiving waters needs to be considered in the planning of treatment facilities.

Population Density

Capital and operational costs are related to the proximity of wastewater treatment customers to pumping stations and treatment facilities. Population density also drives required capacities necessary to effectively treat and safely discharge treated effluent.

Socio-Economics

Wastewater treatment is expensive and often requires retroactive engineering to older existing infrastructure and the creation of new infrastructure. Ability and willingness to pay for capital and long-term operational costs is often the primary issue associated with decisions to construct these facilities. Thus, the tax base must be high enough to design, permit, construct, and operate wastewater treatment facilities.

The following sections describe each embayment (and their associated subembayments) with respect to the existing nitrogen loads, by source, and what management options may be available to pursue load reduction.

General Data Gaps

Although specific data gaps are noted in the following sections, some areas where data were not obtained include:

1. Infiltration and unsaturated inflow of sewered areas: In several watersheds, especially in Suffolk County (NY) there are small, local-scale wastewater treatment plants that discharge to the unsaturated zone of the local aquifer. The amount of remaining nitrogen that is attenuated through this pathway varies by distance to the saturated zone and sediment type, among other potential factors. This is currently a gap in our understanding of the relative contribution of these local-scale treatment facilities. Infiltration and inflow associated with aging and failing wastewater collection infrastructure flowing into major sewage treatment facilities may also contribute additional nitrogen to receiving waters.

2. Watershed mapping: Several regions of the study area require embayment-scale watershed, or groundwater contributing zone delineation and mapping. For example, USGS HUC boundaries are not always at the desired scale for individual embayment analysis. Also, in areas like Long Island, groundwater travel is of greater importance than surface topography and several embayments on Long Island are not sufficiently delineated using recent USGS groundwater elevation data.

3. Localized sediment conditions: Sediment quality (e.g., percent organic matter) is ecologically important but not often monitored at the scale of small embayments. It is important in terms of determining the potential to sustain desirable habitats such as seagrasses and shellfish. Although there are general relationships between levels of nitrogen enrichment and sediment conditions, site-specific measurements can significantly improve restoration efforts.

4. Agricultural practices: More information on the types of agricultural uses in specific watersheds (contributing zones) is needed for more refined nutrient management planning. This includes site-specific understanding of crops, crop cycling and fallow practices, and fertilizer application rates.

6.1 FISHERS ISLAND EMBAYMENTS (NY)

The five embayments on Fishers Island are in relatively good condition. Existing areal nitrogen loads are at or below thresholds associated with tolerance by *Z. marina*. In East Harbor, however, there has been a notable loss of eelgrass within the central basin between 2002 and 2009. Two-thirds of its watershed is occupied by a golf course that contributes 81% to its total 4.5 g N m^{-2} y^{-1} load. Although on the lower end of the spectrum associated with eelgrass decline, this load may be sufficient enough to perpetually stress the *Z. marina* beds in the vicinity of the harbor. An evaluation of historical and existing water quality (e.g., nutrients, algae, benthic condition, system metabolism) and current fertilizer applications to the golf course would be useful to guide nutrient management in this watershed. Relatively small decreases in golf course fertilizer application could result in a measurable decrease in the total nitrogen load budget.

6.2 WADING RIVER (NY)

The Wading River estuary is a saltmarsh-dominated system with a very high watershed-to-surface water ratio. This is because the estuarine portion of the system is relatively narrow and short, typical of saltmarsh drainage channel systems. The extremely high areal load of nitrogen to this embayment is both an artifact of this topology and the relatively dense residential population within its watershed. Of the 831 g N m^{-2} y^{-2}, 72% is attributed to septic and cesspool wastewater sources. This embayment is probably not well suited for eelgrass habitat anyway due to the vastness of the existing saltmarsh which, although enhances denitrification of land-derived nitrogen, contributes significant amounts of organic matter to surrounding sediments. Tidal energy through its narrow channel may also prevent eelgrass communities from establishing. Despite these conditions, eelgrass was reported to exist in 1873 and 1914[21] though there is no current information on what may have caused its disappearance or its historical abundance.

Monitoring of the saltmarsh community for signs of stress from nitrogen over-enrichment would be a suggested course of action in this system. Investigations by Deegan et al. (2006) suggested that ecological responses in a New England saltmarsh occurred at nitrogen loading rates equivalent to 15–60 g $N{\cdot}m^{-2}{\cdot}yr^{-1}$. These included declines in infauna and mummichog (fish). More recent work by Deegan et al. (2012) demonstrated actual declines in saltmarsh plants and communities associated with prolonged (7 year fertilization) stresses associated with high nitrogen loads. Thus, monitoring of the ecological condition of this saltmarsh-dominated embayment would provide valuable data to assess the degree, if any, of direct stress from the relatively high rate of nitrogen delivery.

6.3 NORTHPORT/HUNTINGTON EMBAYMENTS (NY)

The Northport/Huntington complex of embayments has not supported eelgrass habitat since it was last reported in Huntington Harbor in 1947[22]. Currently, bottom sediments are rich in organic matter (up to 2.5 % in the mouth of the entire embayment and assumed greater in the subembayments). Nitrogen loading rates are relatively high in all of the subembayments with the exception of Lloyd Harbor (1.79 g N m^{-2} y^{-2}) with the vast majority of loading attributed to wastewater inputs. There are two wastewater treatment facilities in this system: Huntington Harbor (SPDES NY0021342) and Northport Harbor (SPDES NY0024881) (see Section 4.1.1). Recent upgrades to the Huntington treatment plant have reduced its nitrogen loading by 67% according to a May 2013 press release[23]. It stated that the upgrade, using biological removal applications, resulted in:

- The amount of nitrogen getting to the sewer plant was reduced by 67 percent
- The amount of sludge produced decreased by 12 percent
- Energy usage to remove nitrogen dropped by 26 percent
- A $68,000 net savings, after taking into account the cost of the system.

[21] New York State Museum and the Brooklyn Botanical Gardens, respectively.
[22] Addy and Johnson, 1947
[23] http://www.huntingtonny.gov/controls/NewsFeed.aspx?FeedID=133

Recent effluent concentration and discharge data have not been accounted for in this report. This should be done to update the estimates of nitrogen load to Huntington Harbor. Since wastewater (septic and WWTF combined) contributions to Huntington Harbor account for almost 85% of the total load, significant improvements to the WWTF may result in enhanced ecosystem function. If all wastewater was removed from the nitrogen load budget it would approach 5 g m^{-2} y^{-1} which could result in a significant increase in the desirable ecosystem attributes such as SAV and greater benthic diversity.

Suffolk County Legislator Spencer has secured $4 million for upgrades to the Northport WWTF[24]. This, combined with other funding, is expected to result in significant reductions of nitrogen to receiving waters. Significant reductions in wastewater contributions to the embayment (currently estimated to be 69% septic and 16% WWTF) could result in major improvements to the ecology of this embayment. The current total areal load is about 11.08 g m^{-2} y^{-1} which is within reach of eelgrass habitat conditions. Significant percent reductions in wastewater load to Centerport Harbor (73% septic wastewater) would be required to reach desirable loads. This complex communicates with Long Island sound quite efficiently such that improvements could be realized with continued efforts to mitigate wastewater contributions.

Figure 75 and 76 depict the sewered areas in the Huntington Harbor and Northport Harbor watersheds.

[24] http://spencer4suffolk.com/content/legislator-spencer-secures-over-4-million-grants-northport-sewer-treatment-plant-upgrades

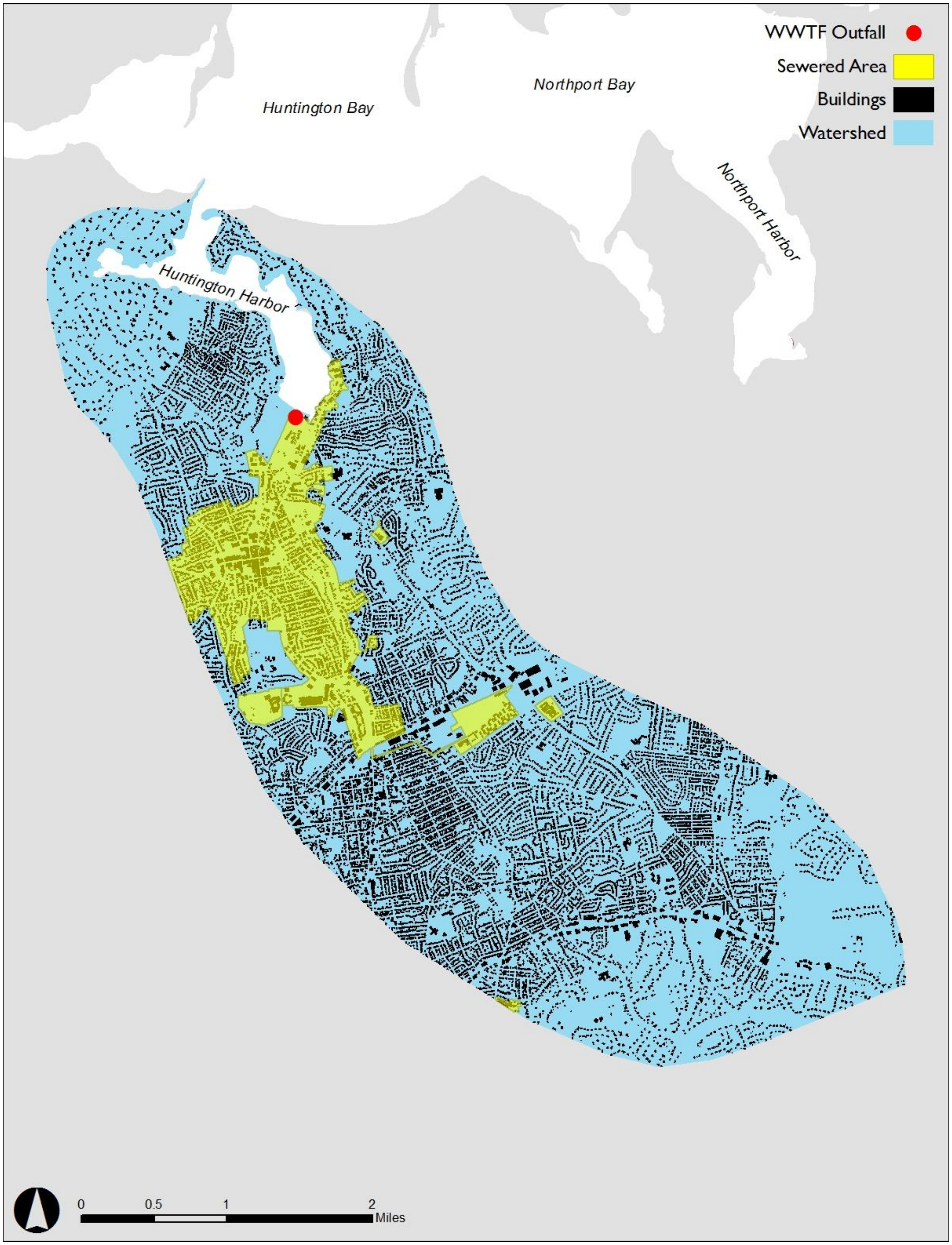

Figure 75. Sewered areas within the Huntington Harbor watershed.

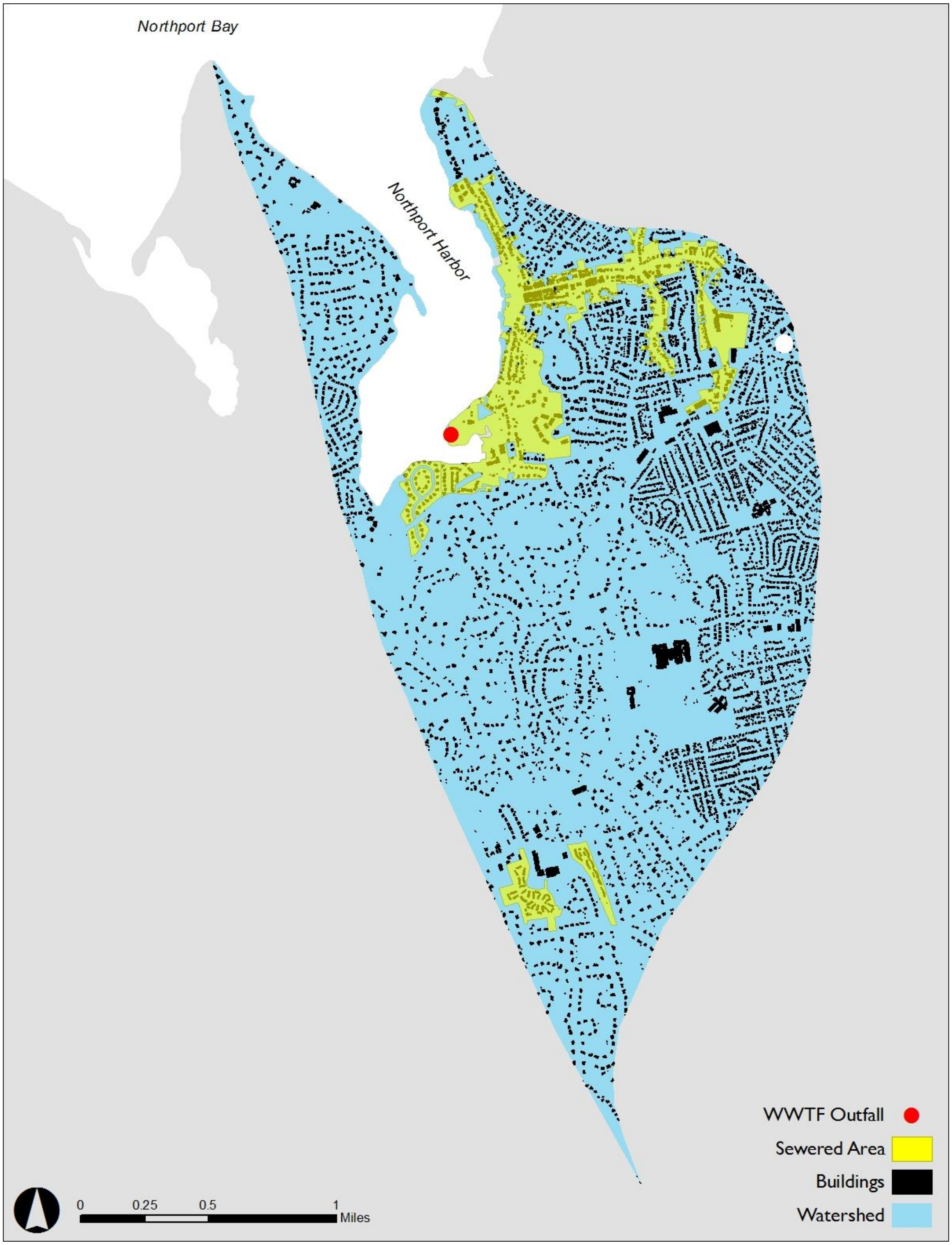

Figure 76. Sewered areas within the Northport Harbor watershed.

6.4 NISSEQUOGUE RIVER (NY)

The Nissequogue River estuary/embayment receives extremely high rates of nitrogen, primarily from wastewater (75%).

6.5 RAM ISLAND AREA (CT)

The Ram Island area of the Stonington/Mystic coastline is a relatively open island coastal feature. The embayment stretches landward where it is more tidally restricted and receives freshwater contributions from the Mystic River and Haley's Brook. Its watershed area is large such that a nearly equal proportion of nitrogen load is associated with atmospheric deposition and wastewater. About 10% of the total nitrogen load is associated with the Stonington-Mystic WPCF (see Figure 77). This treatment facility discharges along the coast, well downstream of the tidally restricted upper portions of the embayment. Some eelgrass has declined in this embayment between 2006 and 2009, mostly in the tidally restricted upper estuary. Additional capacity and extension of the existing sewered area to areas in the northern portion of the watershed (in proximity to the estuary) could significantly reduce existing areal loads (currently greater than 9 g m^{-2} y^{-1}) and result in improved conditions for *Z. marina* habitat and overall ecological function.

NOTE: Data associated with buildings were not received from the town of Ledyard. As a result, the reported nitrogen loading values are currently underestimates. An update of this may decrease the currently reported load from agriculture (19%). It is also worth noting that the land use data applied to this analysis does not break agriculture land use into individual crops or practices.

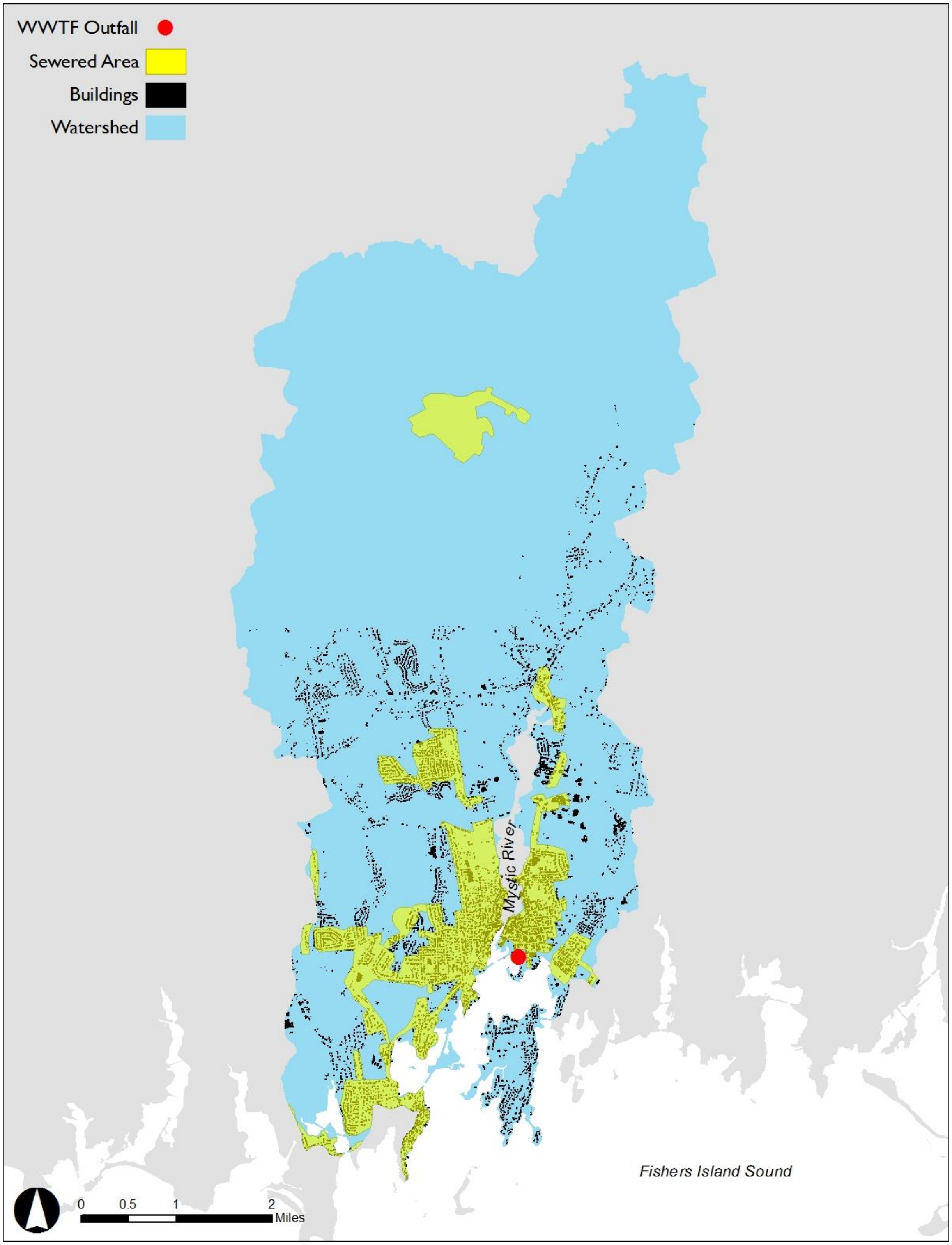

Figure 77. Sewered areas in the Ram Island area watershed.

6.6 HOTCHKISS BEACH (CT)

The Hotchkiss Beach area is an open estuarine environment along the coastal zone with two saltmarsh estuarine systems extending landward to the head of the tide. There are no wastewater treatment facilities within the contributing watersheds and wastewater accounts for 80% of the total nitrogen load (28 g N $m^{-2}y^{-1}$). *Z. marina* has not been reported to have existed along the shoreline of Hotchkiss Beach but was reported to be in Stony Creek, to the east, in 1893[25] and along Hotchkiss Grove, to the west, in 1982[26]. This area is westward of a longitudinal threshold of recent (decades) *Z. marina* habitat. The upper saltmarsh portions of this embayment may not be very well suited for eelgrass habitat due to the reduced conditions and high organics that exist in these ecosystems. Although partially protected by the Thimble Islands, the open shoreline may have fetch significant enough for producing a high energy environment where eelgrass populations may struggle to remain established. Water quality assessments in this area, including benthic sediment characterization, would provide further insight on the suitability for establishing eelgrass habitat at this location and/or the benefits of reducing nitrogen loads from existing (and future) wastewater sources.

6.7 SAUGATUCK RIVER ESTUARY (CT)

The Saugatuck River Estuary (Saugatuck Harbor) is tidal from just north of downtown Westport, where it is brackish, to its relatively wide mouth to Long Island Sound. The watershed is large and extends into the rocky terrain of Aspetuck Valley. The total areal nitrogen load to the tidal region of the embayment is 84 g N m^{-2} y^{-1}. This rate is high enough to result in rich organic benthic muds that extend nearly to its boundary with Long Island Sound. Eelgrass was reported to exist in the Longshore area, just west of Cedar Point and Compo Beach in 1947[27]. The wastewater pollution control plant in Westport[28] is located about halfway up the estuary on the eastern shoreline near where I-95 crosses the river. According to recent news sources, there are plans to integrate all of Saugatuck Shores into this facility which will remove significant nearshore sources of wastewater to the lower estuary (Saugatuck Harbor)[29]. However, the upper watershed is estimated to contribute over 90% of the total nitrogen load compared to the lower Saugatuck River watershed. Thus, the WPCP in Westport contributes only 3% of the total existing load to the estuary. Figure 78 depicts the sewered areas within the Saugatuck River watershed (note: no sewered areas north of figure boundary) and the location of the WPCP.

This area is well within western Long Island Sound where eelgrass habitat has not been observed in many decades. Water quality in this portion of the Sound is generally considered poor. There is a TMDL associated with this region with the goal of alleviated hypoxia and anoxia in central Long Island Sound. Improvements in Sound water quality will presumably allow for additional improvements on the local scale (the main sources to the Sound).

[25] U.S. Dept. of Commerce Chart, 1918
[26] Beckley, 1982
[27] Barske, P. pers comm to R. Rozs (CT DEP)
[28] http://www.westportct.gov/index.aspx?page=801
[29] http://westporthistory.org/all-tours/wastewater-treatment-plant-tour/

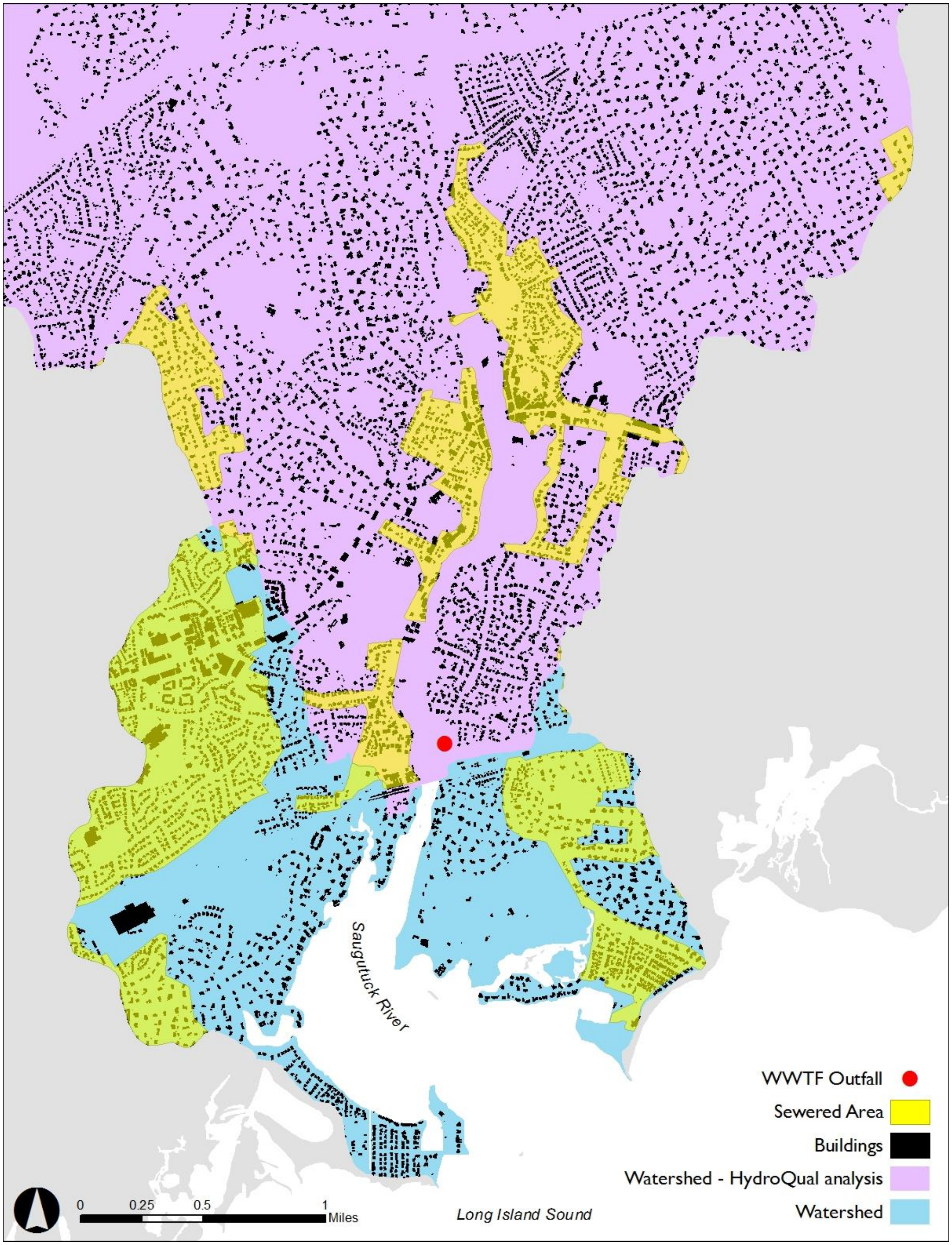

Figure 78. Sewered areas in the Saugatuck River watershed.

6.8 NASKETUCKET BAY (MA)

Nasketucket Bay is located in an open coastline in Buzzards Bay. The head of this embayment is a river fed saltmarsh (Little Bay area) which is rich in organic matter but well flushed. The seaward boundary of this embayment is characterized by Sconticut Neck (a peninsula) and West Island, which is connected to Sconticut Neck via causeway (with culvert to Buzzards Bay). Historical eelgrass surveys indicate broad areas of this habitat extending throughout the central portion of the open waters of the embayment. Masschusetts DEP mapping was either incomplete or had not occurred since 2001.

There are no wastewater treatment facilities within the contributing watershed. Septic wastewater accounts for almost 40% of the total load of 3.4 g N m^{-2} y^{-1}. There are dairy agriculture operations on Sconticut Neck that likely contribute nitrogen to nearby receiving waters through seepage but runoff is likely controlled through BMP (but not confirmed). The 29% of total load attributed to agriculture is defined, by the land use data, as cropland but not by crop type. A breakdown of crop types (e.g., cranberry, corn, fruits) would improve nitrogen management planning. The residential house density on Sconticut Neck is also relatively high but has recently been connected to a treatment facility outside of the watershed. This embayment is currently receiving fairly low areal loads and is well flushed. Reductions of agricultural and unsewered wastewater nitrogen would promote the sustainability of existing eelgrass habitat. Widening of the culvert under the West Island causeway could also increase flushing and enhance eelgrass and general ecosystem health in that area.

6.9 WAREHAM RIVER ESTUARY (MA)

The Wareham River estuary is located near the head of Buzzards Bay just south of the southern entrance to the Cape Cod Canal. The embayment, including the inland saltmarsh and outer harbor area receives about 18 g N m^{-2} y^{-1}. Of this, 28% is attributed to septic wastewater and 14% from a WWTF (Figure 79). The watershed is relatively large compared with the estuary which accounts for the 31% load attributed to atmospheric deposition. Cranberry farming is the dominant source of agricultural nitrogen (24% of total). The total agriculture land use in this watershed is defined as 20% orchard and 80% nursery. Further examination of these classifications is necessary to understand how to manage nitrogen loads from this source of agriculture. This is important because 24% of the total load accounts for approximately 4.32 g m^{-2} y^{-1} and management of this source could be significant for seagrass restoration efforts.

Eelgrass has declined precipitously in this region of Buzzards Bay since the 1980s. The areas of eelgrass near the mouth of Wareham River have been lost but a small region in the middle region of the embayment was remaining in 2010[30].

The sewered area along the western shoreline of the embayment is treated and discharge to receiving waters south of this estuary. The facility on Wareham River treats and discharges wastewater from areas predominantly north of the watershed. Reductions in agricultural fertilizer releases and upgraded WWTF capacity and service would drive

[30] Massachusetts DEP.

areal loads to levels that could sustain eelgrass habitat and a more robust estuarine ecosystem.

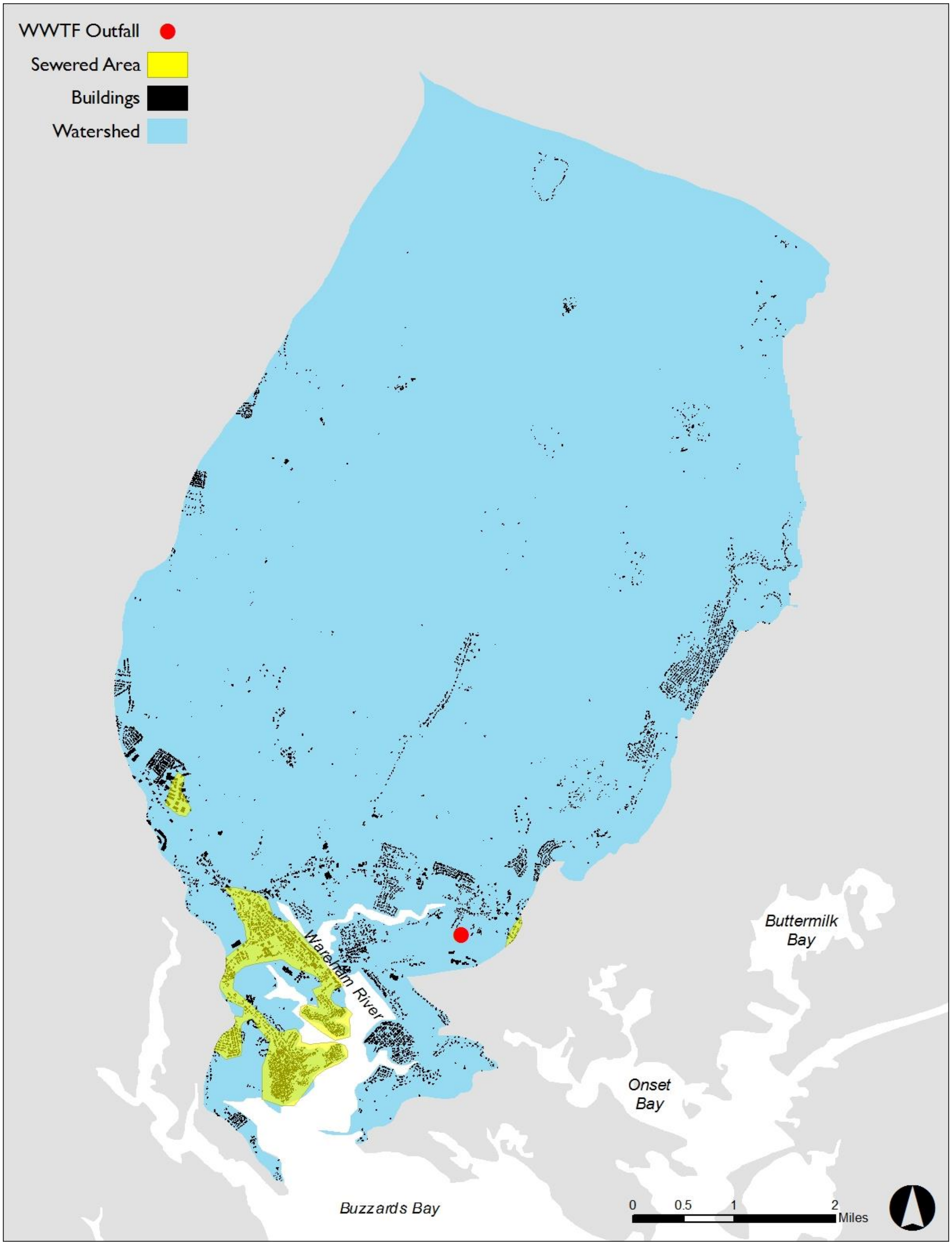

Figure 79. Sewered areas in the Wareham River watershed.

6.10 LITTLE BUTTERMILK BAY (MA)

Little Buttermilk Bay is immediately east of the Wareham River and by 2001 all eelgrass that existed in the bay, and in the adjacent downstream Buttermilk Bay, had vanished. The embayment is poorly flushed, being tidally restricted, and currently receives about 22 g N m^{-2} y^{-1}. The majority of the nitrogen delivered to this embayment is from septic wastewater (47%). The Little Buttermilk Bay watershed is relatively large compared with the estuarine area and this accounts for 32% of the load being attributed to atmospheric deposition. This embayment likely requires significant nitrogen reduction to restore historical eelgrass populations. Target loads should be toward the lower end of published thresholds due to the poorly flushed nature of this system. To accomplish this most of the wastewater nitrogen inputs would need to be removed. Additional reductions in agriculture (currently 16%) inputs would also likely be necessary.

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APPENDIX I.

	Little Buttermilk Bay	Wareham River	Nasketucket River	Ram Island	Hotchkiss Beach	Saugatuck River	Northport-Huntington	Nissequogue	Wading River	Fishers Island	
Average occupancy rate per house[31]	2.50	2.31	2.47	2.07	2.06	2.54	2.64	2.84	3.00	1.97	people per house
Average lawn size	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	ha
Percent of buildings with cesspools	9	9	9	9	9	9	9	9	9	9	percent
Percent of buildings with fertilized lawns	34	34	34	34	34	34	34	34	34	34	percent
Area of roof per building[32]	110	122	157	116	88	128	188	221	180	157	meters square
Area of driveway per building	46	46	46	46	46	46	46	46	46	46	meters square
Area of road as a percent of total watershed	3	3	3	3	3	3	3	3	3	3	percent
Annual precipitation	1130	1130	1130	1130	1130	1130	1130	1130	1130	1130	mm
Recharge from vegetated lands as percent of precipitation	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	percent
Recharge from ponds and wetlands as percent of precipitation	31	31	31	31	31	31	31	31	31	31	percent
N inputs from wet and dry deposition	15	15	15	15	15	15	15	15	15	15	kg per ha per yr
Forest N uptake	65	65	65	65	65	65	65	65	65	65	percent of deposition retained
Vadose N uptake	61	61	61	61	61	61	61	61	61	61	percent of deposition retained
Turf N uptake	62	62	62	62	62	62	62	62	62	62	percent of deposition retained

[31] 2010 Census data.
[32] Calculated from ARC shapefiles.

	Little Buttermilk Bay	Wareham River	Nasketucket River	Ram Island	Hotchkiss Beach	Saugatuck River	Northport-Huntington	Nissequogue	Wading River	Fishers Island	
Recharge from impervious surfaces as percent of precipitation	50	50	50	50	50	50	50	50	50	50	percent of precipitation
N throughput from freshwater ponds to aquifer	44	44	44	44	44	44	44	44	44	44	percent of inputs
N throughput from wetlands to aquifer	22	22	22	22	22	22	22	22	22	22	percent of inputs
N released per person per year	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	kg per cap per yr
Water use	110	110	110	110	110	110	110	110	110	110	m cubed per household
Percent of N inputs released from septic tanks	94	94	94	94	94	94	94	94	94	94	percent of added N released
Leaching field effluent	65	65	65	65	65	65	65	65	65	65	percent of added N released
N released from the plume of the septic system	66	66	66	66	66	66	66	66	66	66	percent of added N released
Evaporation of water used in irrigation	10	10	10	10	10	10	10	10	10	10	percent of water use
Fertilizer applied to lawns	122	122	122	122	122	122	122	122	122	122	kg per ha per yr
Fertilizer applied to golf courses[33]	26.7	26.7	26.7	171	171	171	171	171	171	171	kg per ha per yr
Fertilizer applied to parks and athletic fields[34]	29.3	29.3	29.3	0	0	0	0	0	0	0	kg per ha per yr

[33] For Little Buttermilk Bay, Wareham River, and Nasketucket River: Buzzards Bay N-Load worksheet (buzzardsbay.org/nitrmang/bbnep_nload_littleriver_22dec2010.xlsx).
[34] Ibid.

	Little Buttermilk Bay	Wareham River	Nasketucket River	Ram Island	Hotchkiss Beach	Saugatuck River	Northport-Huntington	Nissequogue	Wading River	Fishers Island	
Gaseous loss of fertilizer	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	percent fertilizer applied
Fertilizer application to cranberry bogs[35]	22.9	22.9	22.9	28	28	28	28	28	28	28	kg per ha per yr
Fertilizer application to other agriculture	136	136	136	136	136	136	136	136	136	136	kg per ha per yr
Denitrification in aquifer	35	35	35	35	35	35	35	35	35	35	percent of N entering the aquifer that is lost

[35] Ibid.

APPENDIX II

Appendix II: Nitrogen Load Model (NLM) Input Values and Units.

NLM Input	Value	Unit
[Rainfall nitrate]	270	ug N per L
[Rainfall ammonium]	920	ug N per L
[Rainfall dissolved organic N]	180	ug N per L
[TDN]	1370	ug N per L
Avg annual rainfall	1130	mm
Wet to total deposition factor	1.25	
Median home size	178	meters square
No. stories /home	2	
House footprint area	89	meters square
Average area of roof	changed for each site based on census data	
Average area of driveway	46.45	meters square
Fertilizer N applied to lawns	122.33	kg per ha per yr
Fertilizer N applied to agriculture	136	kg per ha per yr
Fertilizer N applied to golf courses	171	kg per ha per yr
Fertilizer N applied to parks/athletic fields	0	kg per ha per yr
Average lawn area	0.05	ha
% of homes that use fertilizer	34	percent
Per capita human N exretion rate	4.82	*kg per cap per yr*
People per house	changed for each site based on census data	
# houses in high density residential areas	8	
# houses in medium-high density residential areas	6	
# houses in medium density residential areas	1.33	
# houses in medium-low density residential areas	0.667	
# houses in low density residential areas	0.5	
Note: shaded cells = unconfirmed values, taken from Latimer and Rego (2010)		

APPENDIX III.

<table>
<tr><th>Embayment/Watershed</th><th>Watershed</th><th>Estuary</th><th>Buildings</th><th>Impervious</th><th>Land Use</th><th>Eelgrass</th><th>Sewer</th><th>Wetlands</th><th>Census (2010)</th></tr>
<tr><td>Little Buttermilk Bay</td><td>MassGIS[36]</td><td rowspan="3">MassGIS[37]</td><td rowspan="3">MassGIS[38]</td><td rowspan="3">MassGIS[39]</td><td rowspan="3">MassGIS[40]</td><td rowspan="3">MassGIS[41]</td><td rowspan="3">MassGIS[42]</td><td rowspan="6">[43]</td><td>US Census[44]</td></tr>
<tr><td>Wareham River</td><td rowspan="2">MassGIS[45]</td><td rowspan="2">MassGIS[46]</td></tr>
<tr><td>Nasketucket River</td></tr>
<tr><td>Saugatuck River</td><td rowspan="3">MAGIC[47]</td><td rowspan="3">USGS[48]</td><td>[49]</td><td rowspan="7">MRLC[50]</td><td rowspan="3">UCONN[51]</td><td rowspan="3">CT DEEP[52]</td><td rowspan="3">CT DEEP[53]</td><td>US Census[54]</td></tr>
<tr><td>Hotchkiss Beach</td><td>[55]</td><td>US Census[56]</td></tr>
<tr><td>Ram Island</td><td>Stonington, CT[57]</td><td rowspan="5">US Census[58]</td></tr>
<tr><td>Nissequogue River</td><td>NRCS[59]</td><td rowspan="4">Suffolk Cty[60]</td><td rowspan="4">Suffolk Cty[61]</td><td rowspan="4">Suffolk Cty[62]</td><td rowspan="4">[63]</td><td rowspan="4">TNC[64]</td><td rowspan="4">USFWS[65]</td></tr>
<tr><td>Northport/Huntington Bays</td><td>NYDEC[66]</td></tr>
<tr><td>Wading River</td><td>USGS[67]</td></tr>
<tr><td>Fishers Island</td><td>USGS[68]</td></tr>
</table>

36 http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/, EDITED using data from Joe Costa (email sent 10/17/13)
37 http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
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42 http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/mwraservice.html
43 Included in Land Use files
44 http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk
45 http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/
46 http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/census2010.html
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48 USGS HUC-12 data.
49 https://geopower.jws.com/westport/DataPage.jsp#-& Nathaniel Asare <NAsare@norwalkct.org>
50 http://www.mrlc.gov/nlcd2006.php
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55 Brian Dooley <brian@ne-geo.com>
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57 Bowne, Andrew <abowne@groton-ct.gov>, http://gis.stonington-ct.gov/mapxpress/, Marc Tate <GIS@northstoningtonct.gov>
58 http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk
59 NRCS HUC12 watershed clipped to elevation data (**note**: revised will be associated with USGS 2010 Groundwater Investigations)
60 From Suffolk County GIS (Coastline).
61 https://gisportal.suffolkcountyny.gov/gis/home/item.html?id=39afea11b528424eb9a189cc69ae9982
62 https://gisportal.suffolkcountyny.gov/gis/home/search.html?q=land%20use&t=content&start=1
63 TBD.
64 Stephen Lloyd <slloyd@TNC.org>
65 http://www.fws.gov/wetlands/data/#36
66 ftp://ftp.dec.state.ny.us/dow/LI_Pathogen_GIS_DATA/27%20shellfishing%20waters/, clipped to elevation data for Lloyd & northport bay. (**note**: revised will be associated with USGS 2010 Groundwater Investigations)
67 Delineated from elevation data; ORIGINALLY from http://www.eeaconsultants.com/news/spring2006/studyareamap.pdf. (**note**: revised will be associated with USGS 2010 Groundwater Investigations)
68 Groundwater contributing zone basemap from ftp://ftp.dec.state.ny.us/dow/LI_Pathogen_GIS_DATA/27%20shellfishing%20waters/; also delineated based on USGS elevation data.