NEW YORK CITY'S IMPACT ON LONG ISLAND SOUND WATER QUALITY TECHNICAL REPORT

Image Credit: New York City in Winter, NASA, International Space Station, 01/09/11. (CC BY-NC 2.0)

Jamie Vaudrey, Ph.D.
Department of Marine Sciences
University of Connecticut
1080 Shennecossett Road
Groton, CT 06340
Jamie.Vaudrey@UConn.edu

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Save the Sound®

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NITROGEN POLLUTION THREATENS LONG ISLAND SOUND'S WATERS

For decades, excess nitrogen entering our coastal waterways devastated the health of Long Island Sound (Latimer et al. 2014). The impacts are clear: low oxygen waters and fish die offs, more algae blooms, murky waters, and coastal marshes with barren, flooded patches. The goals of swimmable and fishable waters are thwarted when low oxygen feeds algae blooms, reduces water clarity and drives out desirable fish. We have reduced human generated ***nitrogen pollution*** over the last 20 years, but must make further reductions to get a healthy Sound that is safe for people and wildlife.

Image credit: *Marsh slump at Barn Island, CT* by Jamie Vaudrey (© All rights reserved). Eroding edge of the marsh, not a normal process.

Image credit: *Menhaden Fish Kill* by Chris Deacutis | IAN (CC BY 2.0). Image was captured on the shores of Narragansett Bay, RI.

Image credit: *Gracilaria* by Jamie Vaudrey (© All rights reserved). Seaweed chokes the bottom in many shallow bays and harbors of Long Island Sound.

HELPFUL TERMINOLOGY

nitrogen – a nutrient critical for growth of plant matter, too much can create problems by stimulating too much growth

hypoxia – low oxygen in the water, not supportive of marine life (< 3mg/L for Long Island Sound)

eutrophication – see "Eutrophication" side bar

watershed – the region or area that ultimately drains to a single waterbody

wastewater – freshwater that has been used. Originates from toilets, showers, sinks, washing machines, manufacturing processes, etc.

wastewater treatment plant (WWTP) – a facility that converts wastewater to effluent that can be reused or discharged to the environment with few adverse effects. These plants have varying levels of treatment. Primary treatment removes solid material, secondary digests organic material and kills pathogenic bacteria (and achieves some nutrient removal), tertiary remove nutrients. At the most advanced stage, the effluent is nearly indistinguishable from drinking water.

Long Island Sound's health is at risk because of the number of people living in the watershed, which is the area of land that drains to the Sound. This watershed reaches into northern New England, including large portions of New York City, Connecticut, Massachusetts, Vermont, and New Hampshire (Figure 1). These states have worked to limit nitrogen input from wastewater treatment plants and other sources, but this reduction is counteracted in part by an ever increasing population, especially in the coastal areas, and to a lesser degree by a changing climate.

In coastal salty waters, nitrogen stimulates growth of the plant-like organisms (Howarth and Marino 2006), both microscopic (phytoplankton) and those visible to the human eye (seaweed). As on land, adding nitrogen fertilizes plant life in our coastal waters, but the amount of nitrogen being added to Long Island Sound is equivalent to or greater than what we would put on an intensely farmed agricultural field[a]. While a little nitrogen is beneficial to coastal waters, too much nitrogen changes the ecosystem – fueling the growth of nuisance and toxic algae blooms; creating low oxygen dead zones where fish can't survive; and killing the coastal marshes that provide important wildlife habitat and protect coastal communities from extreme storms – a process called ***eutrophication*** (Long Island Sound Study 2014).

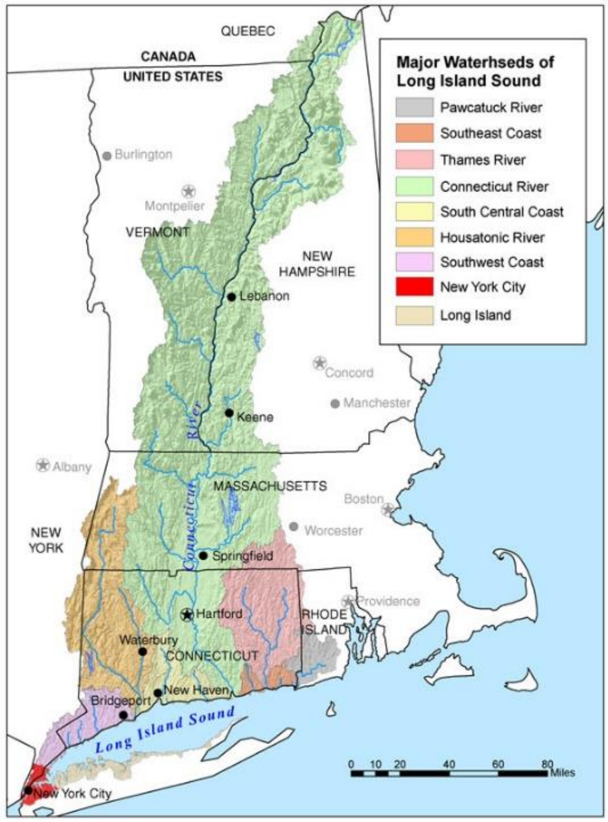


Figure 1: The Long Island Sound watershed covers more than 16,800 square miles in six states and is home to ~9 million people. Image credit: USGS, https://nh.water.usgs.gov/project/ct_atlas/n_model.htm.

LONG ISLAND SOUND'S HEALTH IS AT RISK BECAUSE OF THE NUMBER OF PEOPLE LIVING IN THE WATERSHED

Image credit: *New York City Day 1: Uptown and Downtown* by Adinda Uneputty (CC BY-NC-ND 2.0)

[a] *USEPA estimates fertilization rate of agricultural crops throughout the U.S. to be ~80 pounds nitrogen per acre as of 2011, a rate which has remained at roughly this same level since 1994 (USEPA 2015). Estimates of loads to Long Island Sound developed for this report (Vaudrey et al. 2016) equate to ~84 pounds nitrogen per acre of Long Island Sound, though loads will be higher near the shoreline, where nitrogen enters the system.*

EUTROPHICATION AND HYPOXIA

Nitrogen entering coastal waters fuels the growth of phytoplankton and seaweed, which form the basis of a food web that ultimately feeds animals like oysters and fish (Zhang et al. 2010). However, over-fertilization causes huge amounts of phytoplankton and seaweed to grow (Figure 2).

While phytoplankton and seaweed produce oxygen during the day, they are also respiring and using oxygen, both during the day and the night. A large mass of phytoplankton or seaweed can use all of the oxygen in the water overnight, leaving no oxygen for the fish to breath. As the phytoplankton and seaweed die, the decomposition of that organic matter also uses oxygen. This process, called eutrophication, results in hypoxia (low oxygen) in the bottom water of Long Island Sound and in many of the small bays and harbors along the margin of the Sound (Conley et al. 2009; Vaudrey et al. 2015).

Hypoxia can lead to a shift in the types of plants and animals found in an area (Howell and Simpson 1994; Varekamp et al. 2004); only those who can tolerate periods of low or no oxygen remain in the area. Eutrophication coupled with warming temperatures and acidification of the waters due to climate change exacerbates these changes; both the number of different types of sea life and the total number of individuals can decrease (Conley et al. 2009).

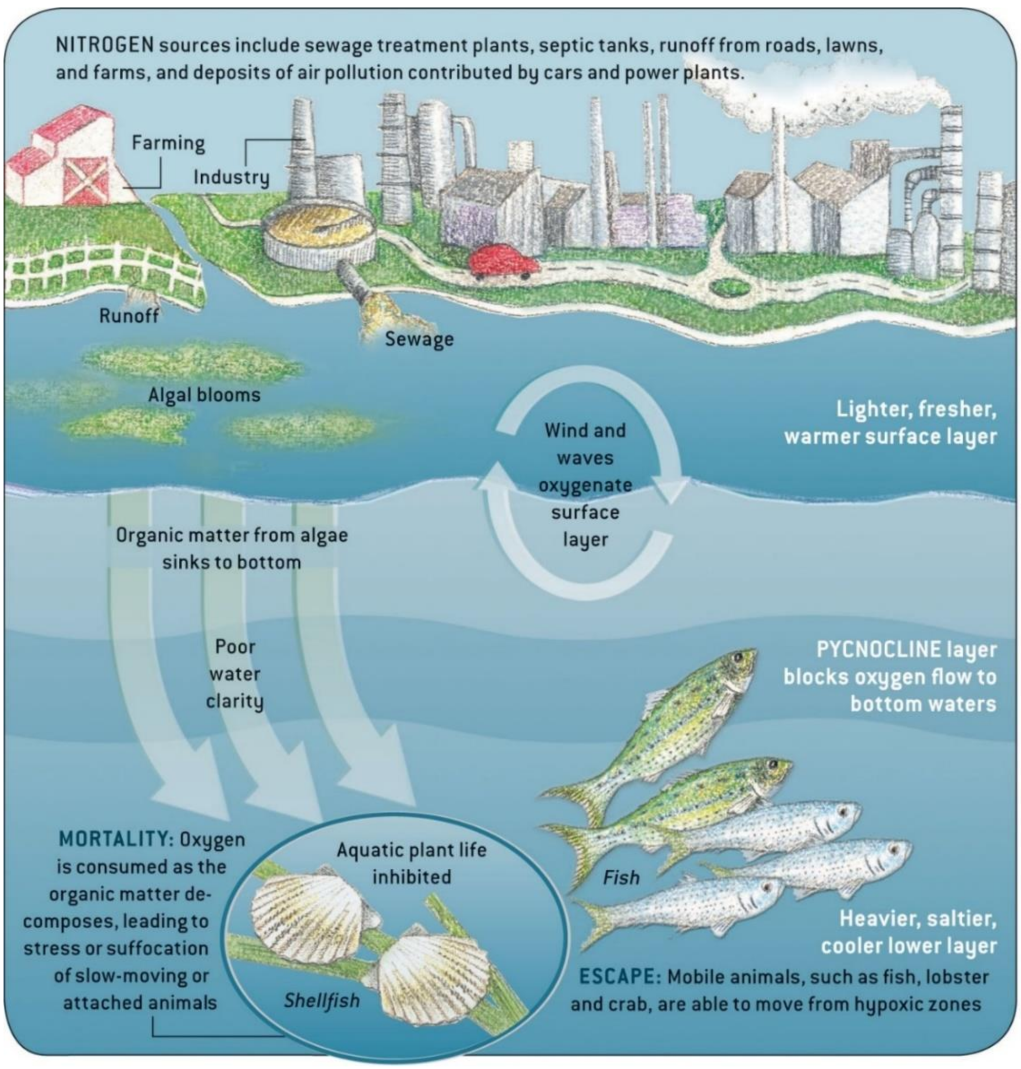


Figure 2: Hypoxia in Long Island Sound – a symptom of eutrophication. Image credit: Long Island Sound Study (2010b).

Unacceptably low levels of oxygen in the waters, or ***hypoxia***, occurs every summer as a result of the level of eutrophication in Long Island Sound. Today, the East River and the western half of Long Island Sound is hypoxic (Figure 3). A comprehensive look at historic oxygen data collected by New York City Department of Environmental Protection (NYCDEP) and their predecessors demonstrates hypoxia in the East River dating back to 1920 (Parker and O'Reilly 1991). Nassau County and New York City monitoring data show hypoxia spreading as far as Cold Spring Harbor and becoming a near annual summertime event in the early 1980s. In fact, the 1980s saw the spread of hypoxia into the Western and Central Basins of Long Island Sound (Parker and O'Reilly 1991). Looking further back in time (1000 years), Long Island Sound summertime hypoxia did not occur until the 1800s, with a second ecosystem shift indicating worsening conditions in the 1970s (Varekamp et al. 2004).

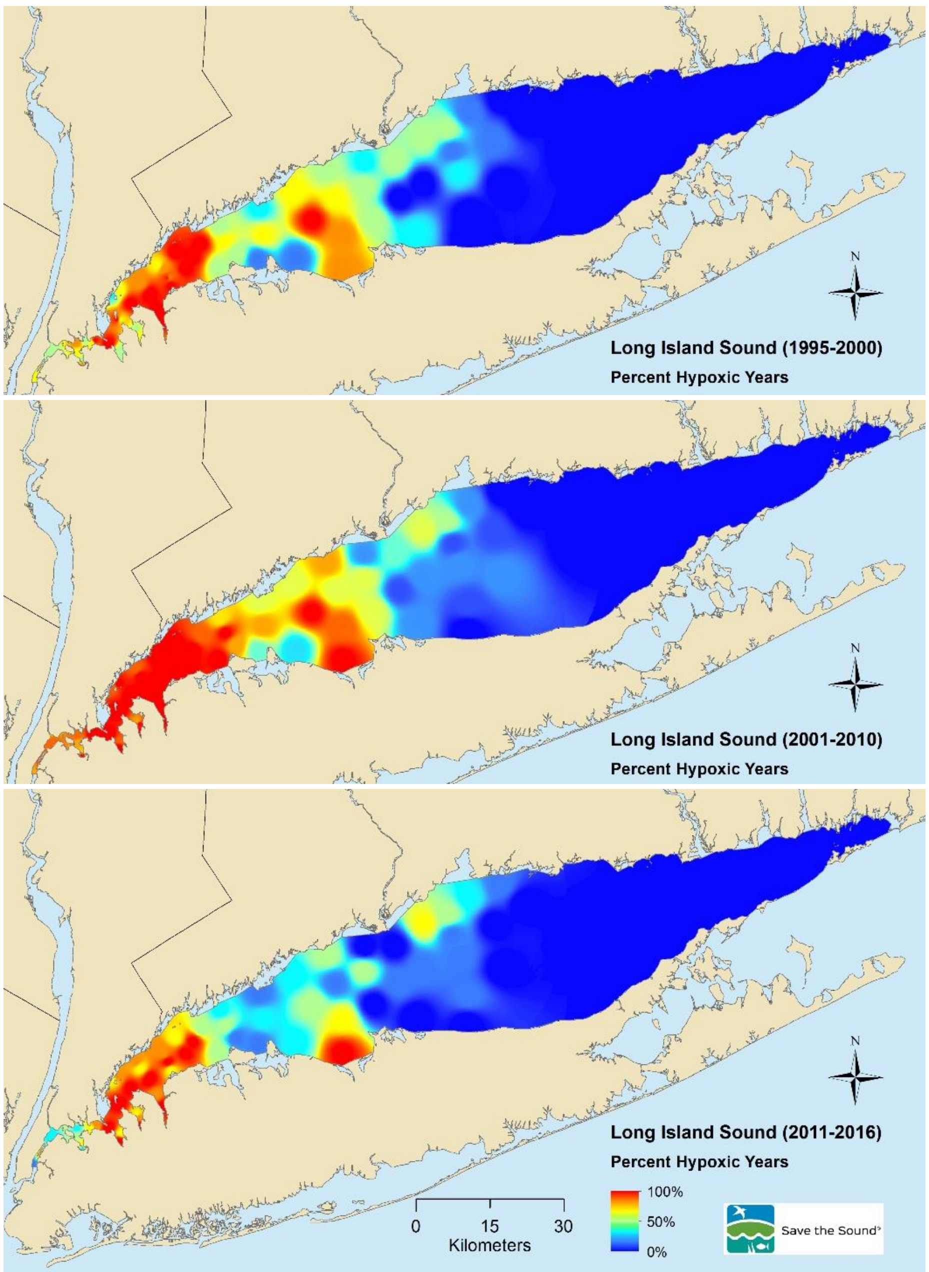


Figure 3: Frequency of hypoxic (very low oxygen, < 3 mg/L) conditions in Long Island Sound from 1991-2011. Red indicates higher frequency, blue is lower frequency. Image credit: Save the Sound, with data from CTDEEP, NEIWPCC IEC, NYCDEP.

In response to the increasing occurrence of hypoxia in Long Island Sound, Connecticut Department of Environmental Protection (now CT Department of Energy and Environmental Protection, CTDEEP) began an extensive monitoring program in 1987 encompassing most of Long Island Sound, to supplement the ongoing monitoring of the East River and adjacent Long Island Sound by NYCDEP. The good news is that the area of hypoxia in the Sound may have decreased by roughly half of what it was in 1987; we need a few more years of monitoring to confirm this decrease because it varies widely year-to-year (Figure 4).

CTDEEP research assistants aboard the research vessel John Dempsey deploy a rosette sampler to collect water quality samples. *Photo* by Lloyd Langevin, courtesy of CTDEEP.

Even with these reductions in area, hypoxia continues to be an annual occurrence in the East River and Western Sound. Investments in upgrades to wastewater treatment plants that discharge to the Sound over the last 20 years have driven this reduction. However, the overall hypoxic area of ~95 square miles in 2017 is still much larger than in 1920, when hypoxia was found only in the 11.5 square miles of the East River.

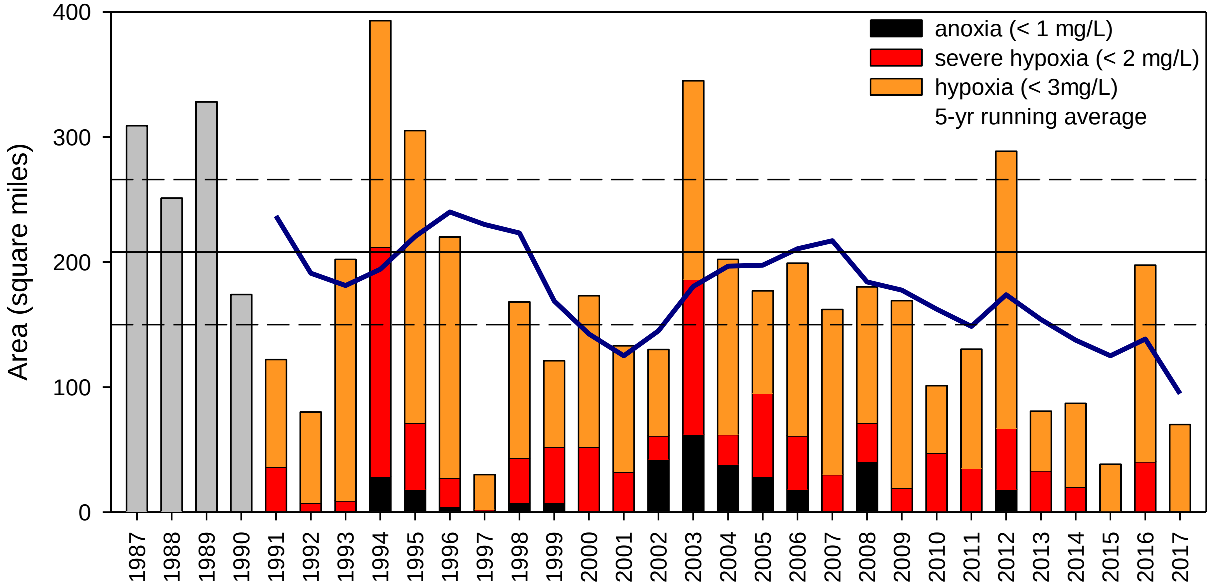


Figure 4: Area of hypoxia in Long Island Sound (data from: Long Island Sound Study 2017). The bars show the area of hypoxia by year with colors differentiating sub-areas of severe hypoxia and anoxia (no oxygen). The grey bars show only hypoxia, severe hypoxia and anoxia were not mapped in these years. Hypoxia varies year-to-year based on differences in climactic factors including wind speed, temperature and river discharge. When the blue line dips below the bottom dashed line, the reduction from the early 1990s average (solid black line) is considered significant (J. Ammerman, LISS, pers. comm.). Since 2014, the area of hypoxia has been lower than this criterion. See Appendix I for details on the calculations and alternate estimates. Image credit: J. Vaudrey.

Image credit: *[Brooklyn Bridge Park](#)* by Jeffrey Bary (CC BY 2.0). A view of New York Harbor and Manhattan, with the salt marsh located at the end of Pier 1 in the foreground.

Image credit: *Artificial oyster reef creation off Governor's Island* by USACE NY. (CC BY 2.0)

Image credit: *czma eelgrass* by NOAA's National Ocean Service (CC BY 2.0). Underwater photo of eelgrass and scallops.

Eutrophied systems ***can recover*** and Long Island Sound is on that road to recovery. But rehabilitation of an ecosystem takes time, sometimes decades (Diaz 2001; Duarte et al. 2009). The key is to identify the main causes and work to reduce those sources. In some cases, restoration efforts will be needed to bring back critical habitats like tidal marshes, seagrass beds, and oyster reefs. These habitats are part of a vibrant and diverse Long Island Sound, and once reestablished, can also help to maintain water quality. Efforts to restore these habitats are already underway, but to ensure their continued success and to expand these habitats throughout Long Island Sound, further reductions in nitrogen inputs are needed.

The Value of Long Island Sound

Long Island Sound provides a number of ecosystem services, defined as ***the benefits people obtain from ecosystems*** (Millenium Ecosystem Assessment 2005). In 2015, an economic valuation of Long Island Sound and its' watershed estimated the Long Island Sound's natural capital equated to $17 billion to $37 billion every year (Kocian et al. 2015). These services are evaluated for a number of habitats, including: beaches, coastal wetlands, cultivated lands, estuaries, forests, fresh water, freshwater wetlands, grasslands, and seagrass. This type of valuation includes estimates for both materials (freshwater, food, raw materials), impacts on the human economy (housing market, tourism, waste treatment), impacts on the natural world (pollination, soil formation, climate stability, habitat and nursery for wildlife), and intrinsic values (cultural and artistic inspiration, science and education, aesthetic information, recreation).

Figure 5: The area of each block represents the fraction of the $17 to $37 billion attributed to a particular ecosystem service. Abbreviations in the figure include M: Moderation of Extreme Events = 1.3%, W: Waste Treatment = 1.3%. <1% is attributed to: S: Soil Formation, H: Habitat and Nursery, A: Aesthetic Information, E: Energy and Raw Materials. Image credit: Vaudrey, modeled after Figure 11 in the Kocian et al. (2015) report.

NEW YORK CITY'S CONNECTION TO LONG ISLAND SOUND

Light illustrates the dense populations around Long Island Sound. Image credit: *Atlantic Coast* by NASA, International Space Station, 09/20/13. (CC BY-NC 2.0)

Long Island Sound and the New York / New Jersey Harbor are two of the most urbanized estuaries in our country (USEPA OW and USEPA ORD 2007), with the Harbor also influencing Western Long Island Sound. Approximately ***9 million people live in the Long Island Sound watershed*** (Long Island Sound Study 2017), with roughly 4 million of those people located in New York State and 1.7 million in the Connecticut coastal region (Vaudrey et al. 2016). This large coastal population has a direct impact on the water quality of Long Island Sound and other local ocean waters.

While New Yorkers often identify the Hudson River and New York Harbor as their emblematic waterways, as a city, they are intimately connected to Long Island Sound by the East River. In fact, the East River receives 60% of the wastewater flowing out of New York City, carrying with it a large burden of nitrogen pollution (Figure 6).

Figure 6: The New York City wastewater treatment plants that impact Long Island Sound and the areas they serve (their "sewershed"). These wastewater plants handle 60% of NYC's wastewater. Image credit: Save the Sound.

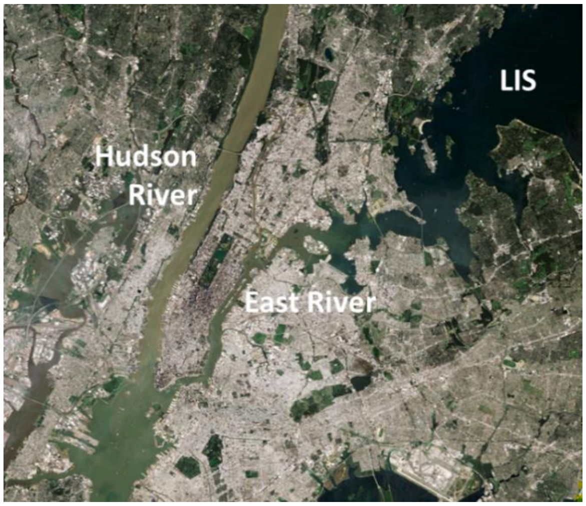


Figure 7: Hudson River after Tropical Storm Irene. Sediment plume exiting the Hudson River on August 31, 2011, following Tropical Storm Irene's landfall in New York on August 28, 2011. The sediment can be seen traveling via the East River into Long Island Sound. Image credit: Robert Simmon (USGS and NASA 2011).

The connection between Long Island Sound and the waters surrounding New York City is made clear by a satellite photo taken three days after Tropical Storm Irene made landfall in New York (Figure 7). The Hudson River was full of sediment washed off the land by heavy flooding in its watershed, which reaches into the Catskills and Adirondack Mountains in upstate New York. This sediment load in the Hudson River acts as a tracer of where the water goes, illustrating the connection to Long Island Sound by the muddy water visible in the East River and travelling into Long Island Sound.

New York City residents benefit directly from a healthy Long Island Sound. The most popular beach in the City is Orchard Beach, situated right on Long Island Sound in Pelham Bay Park, the Bronx. While there are many consumption advisories related to eating fish caught in the waters around New York City (New York State Department of Health 2017), healthy and delicious seafood from Long Island Sound is delivered fresh to City markets and restaurants daily, including the famed Long Island Sound oyster. The East River is a popular waterway for residents and tourists searching out the best views of the Manhattan skyline on the Circle Line or other boats. Many waterfront communities in Queens and the Bronx enjoy marinas and neighborhood swimming spots on the Sound such as Douglaston Manor Beach in Queens and the Mayhem Beach Club in the Bronx. All residents of the eastern United States rely on a healthy Long Island Sound for the critical role it plays as a breeding ground for fish on the eastern seaboard. The ability to interact and enjoy the bounty of our natural resources in multifaceted ways requires good water quality, achieved by reducing nitrogen inputs to these coastal waters.

Image credit: *orchard beach-13* by Dan DeLuca. (CC BY 2.0)

PUTTING LONG ISLAND SOUND ON A NITROGEN DIET

When a waterway is receiving too much of any one pollutant, the U.S. Environmental Protection Agency (USEPA) can put it on a diet for that pollutant. These water pollution "diets" are called Total Maximum Daily Loads (TMDLs). For the Long Island Sound TMDL, the goal was to achieve a reduction in nitrogen entering the Sound sufficient to improve water quality to a state where all of Long Island Sound is swimmable and fishable. Elimination of hypoxia throughout the Sound is used as the metric to measure progress towards this goal.

New York State Department of Environmental Conservation (NYSDEC) and Connecticut Department of Energy and Environmental Protection (CTDEEP) created a nitrogen TMDL for Long Island Sound in 2000 with a target of a 58.5% reduction from 1990 levels for nitrogen leaving wastewater treatment plants and a similar level of reduction for other sources in the watershed (NYSDEC and CTDEP 2000). Reductions required throughout the watershed leveraged already existing programs designed to lower nitrogen loads; the majority of new efforts to curb nitrogen fell to the wastewater treatment plants.

SOURCES OF NITROGEN POLLUTION

Nitrogen entering coastal waters originates from three sources: human sanitary waste from sewer and septic systems (even well-functioning sewer and septic systems contain nutrients); fertilizer applied to lawns, parks, and agricultural fields; and the atmosphere (rain, snow, and dust) (Figure 8). Nitrogen travels to coastal waters carried by direct discharges from wastewater treatment plants and the storm drain system. Groundwater carries nitrogen from septic systems, fertilizers, and atmospheric sources, draining directly to coastal waters or to freshwater streams and rivers which eventually make their way to the coast. In addition to atmospheric sources falling on the land, rain and dust carrying nitrogen also settle directly onto the surface of Long Island Sound.

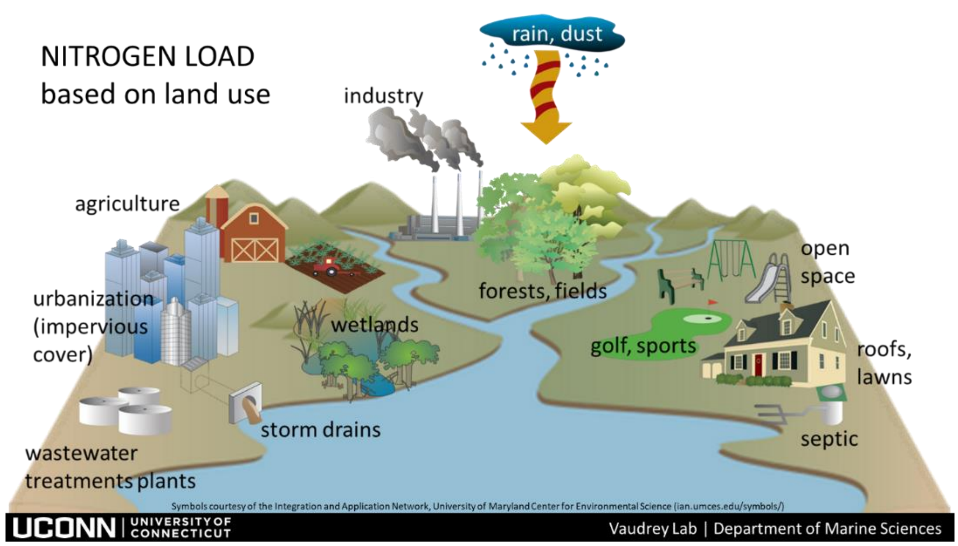


Figure 8: Nitrogen sources in watersheds. Nitrogen applied to the land travels through the groundwater to local streams and rivers or directly to coastal waters. Point sources, or pipes which convey water directly to a river or coastal waters, carry effluent from wastewater treatment plants, storm water systems, and in some cases, the two are combined into CSOs. Image credit: Vaudrey (Vaudrey et al. 2015).

LOCATION MATTERS

Within the Long Island Sound watershed, nitrogen input from the East River and the Connecticut River dominate the load to the edge of the coastal waters (Figure 9, left panel). However, Long Island Sound communicates with the ocean at both its' eastern and western ends.

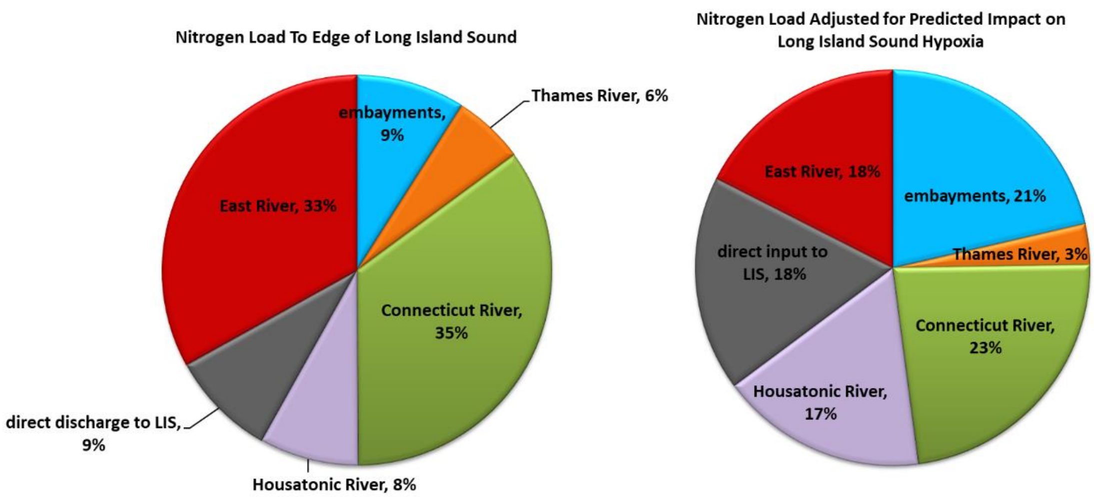


Figure 9: Sources of Nitrogen Loads to Long Island Sound (Vaudrey et al. 2016)[a]. (Left panel) Contribution from various sources for the amount of nitrogen entering Long Island Sound. (Right panel) Nitrogen load adjusted to show the impact of loads from various sources on water quality in Long Island Sound, as shown in Figure 10 (Long Island Sound Study 2010a; NYSDEC and CTDEP 2000). See Appendix II for more information on the data and calculations.

The East River, a tidal strait, connects the Hudson River to Long Island Sound; due to riverine and tidal movement of water, it can also flow south into the Upper Bay of New York Harbor (Figure 7). The Connecticut River, with a similar load of nitrogen to Long Island Sound, flushes with the ocean through the open eastern end of Long Island Sound. The impact on water quality of various management zones in the Long Island Sound watershed (Figure 10) multiplied by the load to the edge of Long Island Sound yields an estimate of the relative contribution of the various loads to Long Island Sound water quality (Figure 9, right panel).

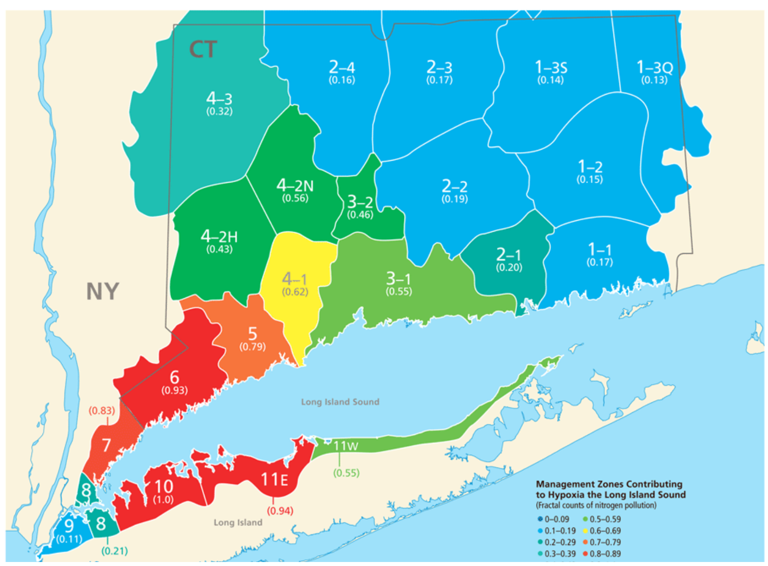
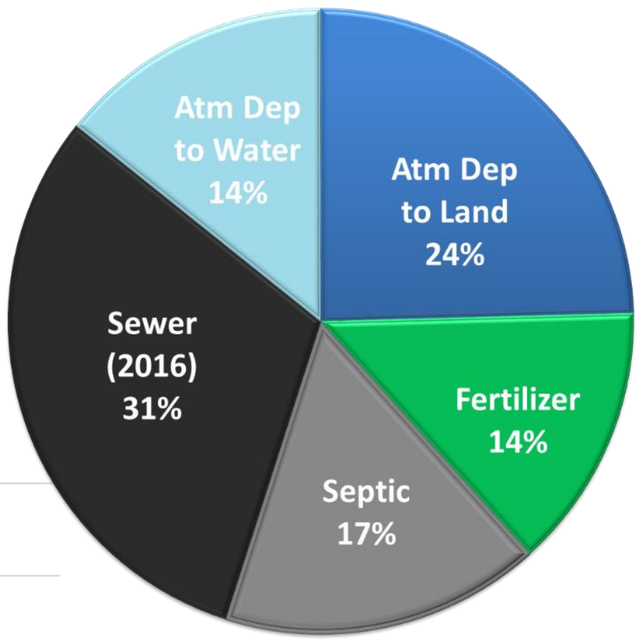


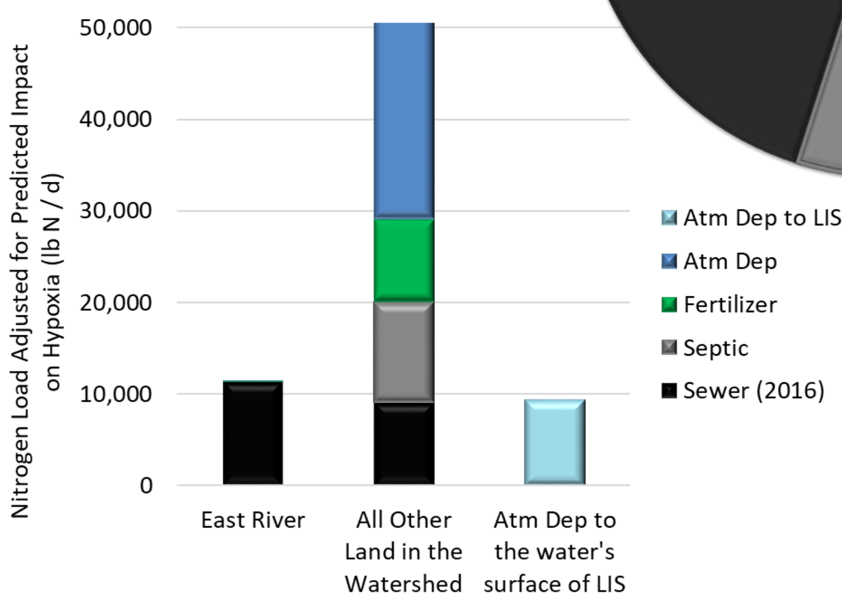
Figure 10: Management Zones Contributing to Hypoxia in the Long Island Sound. For each management zone, the fractional impact of the nitrogen load is shown in parentheses (NYSDEC and CTDEP 2000). Using the eastern portion of the East River as an example (management Zone 8), 21% of the nitrogen load from Zone 8 is considered to have an impact on Long Island Sound hypoxia. The fractional multipliers are based on modeling of water flow and nitrogen cycling in Long Island Sound. Image credit: Long Island Sound Study (2010a).

LONG ISLAND SOUND'S SOURCES OF NITROGEN

Looking at Long Island Sound as a whole, roughly 48% of nitrogen can be attributed to sewer and septic sources (Figure 11, pie chart). Marked contrasts in these sources are seen when we look at the highly urbanized areas of New York City and the coastal areas of the Sound compared with the rest of the Long Island Sound watershed. For the East River, 97% of the nitrogen load is attributed to wastewater treatment plants. This is in stark contrast to the rest of Long Island Sound's watershed (including all areas extending up to Canada), where atmospheric deposition dominates at 47% of the load; septic is 20% and sewer is 17% of the load (Figure 11, middle bar). If we zoom in closer in our inspection and look only at localized coastal watersheds of Long Island Sound's more than 100 bays and harbors not including the East River and other major rivers, septic dominates at 34% with sewer loads coming in at 27%; atmospheric deposition drops down to just 18% of the load. Even well-functioning, nitrogen-removing wastewater treatment plants and septic systems output nitrogen, though plants can often be upgraded to remove more of the nitrogen.

Figure 11: Source of nitrogen loads to Long Island Sound (Vaudrey et al. 2016). Nitrogen loads are adjusted to account for the impact of different entry points into the Sound on water quality. Values are based on wastewater treatment plant nitrogen loads from 2016 and current atmospheric deposition estimates. Septic and fertilizer were determined using the most recent census data (2010) and land cover data (2011). The pie chart shows the sum of all sources presented in the bar chart. See Appendix II for more information on the data and calculations.





NEW YORK CITY'S PROGRESS IN REDUCING NITROGEN POLLUTION

In 2001, the U.S. Environmental Protection Agency approved the 2000 TMDL nitrogen reduction plan for Long Island Sound to address the mounting problems caused by the large amounts of nitrogen entering the Sound (EPA New England and EPA Region 2 2001; NYSDEC and CTDEP 2000). Among other requirements, the plan mandated a 58.5% reduction of nitrogen discharged to the Sound from wastewater treatment plants serving New York City, Long Island, Westchester County and Connecticut, through a phased approach over 15 years, using 1990 levels as the baseline.

As part of an agreement with the NYS Department of Environmental Conservation (NYSDEC) and the NYS Attorney General, the New York City Department of Environmental Protection (NYCDEP) committed to reducing the combined nitrogen discharges from its wastewater treatment plants located along the East River by 58.5% by 2015. Specifically, the plan called for four of the six New York City wastewater treatment plants that directly impact Long Island Sound – Hunts Point, Bowery Bay, Wards Island and Tallman Island in the Upper East River – to be upgraded to treat nitrogen. Newtown Creek and Red Hook in the Lower East River have less of an impact on Long Island Sound (Figure 10); the decision was made to upgrade the other four plants to a degree that the trade equalized load from all six plants would be reduced by the mandated 58.5%.

Four East River plants, upgraded to remove nitrogen, Tallman Island is just out of sight in this photo, located at the "X". Riker's Island is the large island in the middle of the East River with Laguardia Airport just south of the Island. Long Island Sound is to the right (east). Image credit: *2012_03_14_aus-iah-bos_402* by Doc Searls (CC BY 2.0).

In September 2016, New York City reached that goal (Figure 12), after an approved deadline extension. According to NYCDEP reports, the East River wastewater treatment plants have reduced their nitrogen discharge by 60% (NYCDEP 2017). By going above and beyond the required reductions, the East River plants were able to "trade away" their excess reductions to offset shortfalls by wastewater treatment plants in Westchester County that are still working at meeting the 58.5% reduction.

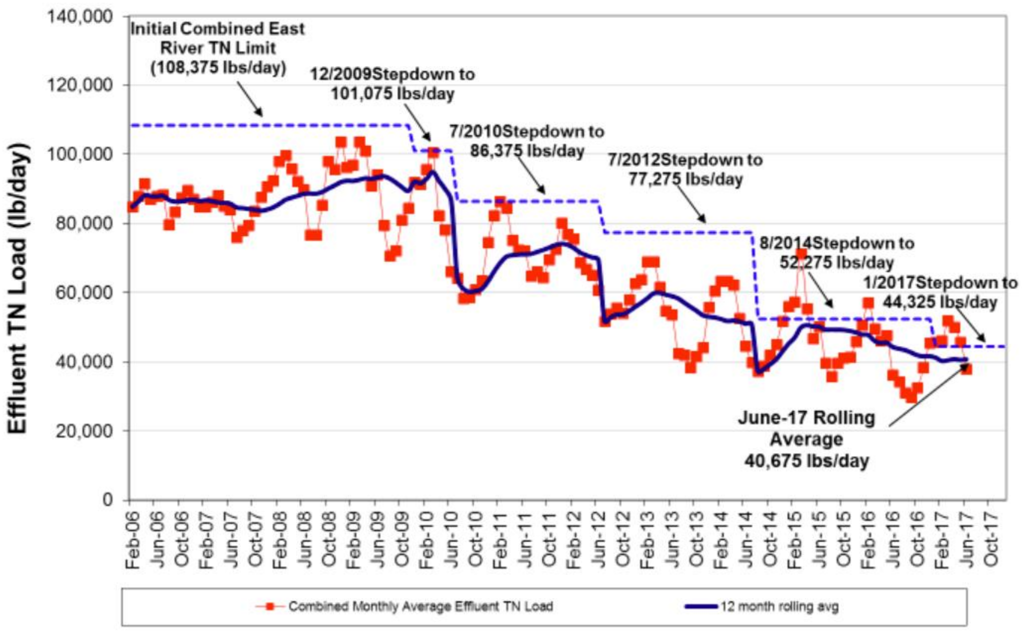


Figure 12: East River wastewater treatment plant's history of progress towards the 2000 TMDL goal of a 58.5% reduction (relative to 1994 levels) of nitrogen in effluent. Each red point is the monthly average load, with the black line showing the rolling average used for assessing compliance with the TMDL. Image credit: NYCDEP (City of New York Department of Environmental Protection Bureau of Engineering Design and Construction 2017).

The nitrogen removal technology installed at the plants converts nitrogen present in wastewater into inert nitrogen gas that is released harmlessly into the atmosphere (NYCDEP 2017). This work required significant upgrades to much of the plants' supporting infrastructure - an investment that not only reduced nitrogen discharges, but also brought the plants into a good state of repair for decades to come.

The capital investments (NYCDEP 2017) made in each plant included:

- $277 million at the Hunts Point Wastewater Treatment Plant
- $388 million at the Wards Island Wastewater Treatment Plant
- $209 million at the Tallman Island Wastewater Treatment Plant
- $161 million at the Bowery Bay Wastewater Treatment Plant

The important investment made by New York City in improving the wastewater treatment technology at these four plants supports improving water quality today and for generations to come. The reduction in nitrogen pollution that has been achieved is critical to supporting the abundant and diverse sea life of Long Island Sound, a source of livelihood, food and enjoyment for millions of people.

WHAT'S NEXT?

ADDITIONAL STRESSORS

Adding to the challenge of restoring Long Island Sound to acceptable nitrogen and oxygen levels are other stressors, including rising population and climate change.

Population projections for New York City predict an increase from 8.2 million people in 2010 to 9 million in 2040 (City of New York and Department of City Planning 2013). The East River receives all of the wastewater generated by the Bronx, which has a projected increase of 194,000 people. The projection for Manhattan, with ~70% of the area draining to the East River, indicates an increase of 160,000 people. The northern half of the boroughs of both Queens and Brooklyn also discharge to the East River. Their increases across the whole borough are projected at 163,000 for Queens and 288,000 for Brooklyn. ***This addition of ~500,000 people to the sewershed of the East River between 2010 and 2040 puts an ever-increasing burden on the wastewater treatment plants.*** This in turn increases the amount of nitrogen delivered to Long Island Sound. To achieve a Long Island Sound and East River free of hypoxia and other water quality issues, our nitrogen reduction plans must anticipate this increasing load. Coupled with the impacts of climate change, this increasing nitrogen load delivered to the wastewater plants will have an even greater impact on water quality.

Image credit: Building Construction, NYC by Sharon Mollerus (CC BY 2.0).

The extent and duration of hypoxia in Long Island Sound is controlled by total nitrogen loads (especially the spring loads), summer wind speed, spring chlorophyll *a* and maximum river discharge (Lee and Lwiza 2008). While physical factors such as wind speed and river flow contribute to the onset of hypoxia (Swanson et al. 2016; Welsh and Eller 1991), ***nitrogen inputs are the only component we can control***. Rising water temperatures and changes in how freshwater is delivered to Long Island Sound, both in timing and intensity of storm events and river flow, is related to changes in the climate (Goldenberg et al. 2001; Voiland and Simmon 2013). These changes to freshwater delivery may result in stronger

Housatonic River. Image credit: *It was rushing sooo fast* by criana (CC BY-NC-ND 2.0).

stratification[b] and changes in river flow, both of which can cause hypoxia to last longer and be more intense (O'Donnell et al. 2014; Wilson et al. 2015; Wilson et al. 2008).

Ocean acidification is also driven by climate change, with increasing carbon dioxide in the atmosphere resulting in corresponding increases in marine waters (Keeling et al. 2010; Pörtner 2012). Coupled with increasing temperature, this increased carbon dioxide in our oceans and coastal waters leads to more acidic waters. Both acidity and hypoxia are exacerbated by large nutrient loads, making our waters both lower in oxygen and more acidic (Baumann and Smith 2017; Breitburg et al. 2015). Hypoxia and ocean acidification act synergistically to make conditions worse, changing the community of sea life to organisms that can tolerate these lower oxygen and higher acidity conditions (Gobler and Baumann 2016).

The influence of these stressors on the Sound work counter to the goals of the nitrogen reduction plan, exacerbating hypoxic conditions and resulting in unacceptably low oxygen levels. The result is loss of coastal marshes[c] that once protected shoreline communities from storms and flooding (Basso et al. 2015), persistent low oxygen dead zones where fish cannot survive (Howell and Simpson 1994), and the overgrowth of seaweed and phytoplankton blooms (Vaudrey et al. 2015).

Lesser Yellowlegs pair at Nike School salt marsh by Christopher Eliot (CC BY 2.0).

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[b] *Stratification refers to fresher (often warmer) water floating on top of saltier (often colder) water. The surface water forms a "cap" on top of the bottom water, inhibiting the transfer of material (including oxygen) between the two layers. Stratification can be strong, as when freshwater sits over salty ocean water; or can be weak, as when slightly salty water sits over saltier water. Intense wind and seasonal changes in temperature can aid with mixing of the two layers until there is no difference in the saltiness or temperature, termed destratifcation.*

[c] *A recent analysis of marsh extent in Long Island Sound found a decline in coverage of 33% from the 1880s to the 1970s, with a slight increase of 3% between the 1970s and 2000s. When evaluated by state, New York lost 19% and Connecticut gained 8% between the 1970s and 2000s, with gains due in part to restoration efforts (Basso et al. 2015). The decline from the 1880s is consistent with the timing of increasing human impact in Long Island Sound (Varekamp et al. 2004).*

SEWER PLANTS ARE STILL THE TOP CONTRIBUTORS OF NITROGEN

Even with the most recent upgrades to the wastewater treatment plants throughout the Long Island Sound area, nitrogen inputs impacting water quality are still dominated by this sewer source which contributes about 33% of the total load when adjusted for the impact of various sources on Long Island Sound water quality (Figure 11). Even after achieving the 58.5% reduction of nitrogen leaving wastewater plants, the East River wastewater treatment plants alone account for ***18% of the total nitrogen load*** to Long Island Sound, or ***56% of the sewer load*** originating from all sources in the Long Island Sound watershed (Figure 11). While great progress has been made reducing the nitrogen leaving wastewater treatment plants around the Sound, including New York City, additional reductions in the load are needed to further improve water quality. Reductions in loads to the East River are integral to this process.

The East River receives wastewater effluent from six treatment plants servicing the Bronx and portions of Manhattan, Queens, and Brooklyn (Figure 6). Taking into account the adjustment factors to estimate impact of nitrogen loads on Long Island Sound water quality (Figure 10), the Newtown Creek and Wards Island plants account for 56% of the trade equalized nitrogen load (Figure 13). To further reduce nitrogen entering the Sound, New York City needs to continue to focus on its wastewater treatment plants and look for further reductions they can achieve in the six wastewater treatment plants that impact the Sound.

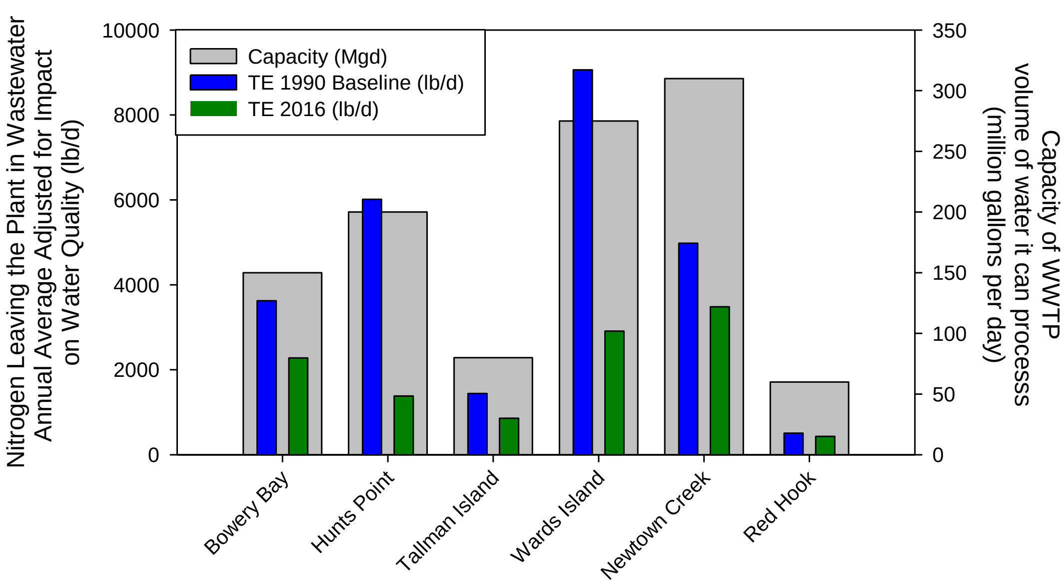

Figure 13: Load of nitrogen to the East River from wastewater treatment plants. Nitrogen in effluent adjusted for impact on Long Island Sound water quality for the six wastewater treatment plants in the East River sewershed as reported by the plants for 2016 versus the baseline of 1990. The nitrogen load was adjusted using the fractional impact of nitrogen loads on hypoxia in Long Island Sound as shown in Figure 10; this adjustment is termed trade equalized (TE) (Long Island Sound Study 2010a; NYSDEC and CTDEP 2000). Image credit: J. Vaudrey.

The table below shows the enforceable effluent limits for each of the East River wastewater treatment plants, as defined in their State Pollutant Discharge Elimination System (SPDES) permits (available at: http://www.dec.ny.gov/permits/6054.html). Newtown Creek's nitrogen concentration in effluent is substantially higher than the four upgraded plants (Bowery Bay, Hunts Point, Tallman Island, Wards Island). Red Hook's permit lists no data for nitrogen. Higher nitrogen concentrations in effluent indicate the potential for additional nitrogen removal.

Wastewater Treatment Plant	SPDES #	SPDES Permit Expiration Date	Total Flow Limitation, 12-month rolling average (MGD)	Nitrogen, TKN (as N), annual average (lbs/d)	Nitrogen as Ammonia (NH_3), monthly average (mg/L)	Nitrogen as TKN, annual average (mg/L)
Bowery Bay	NY0026158	10/31/2020	150	32,000	14	25.6
Hunts Point	NY0026191	10/31/2020	200	24,000	n.a.	14.4
Tallman Island	NY0026239	10/31/2020	80	15,000	16	22.5
Wards Island	NY0026131	10/31/2020	275	46,000	13	20.0
Newtown Creek	NY0026204	10/31/2020	310	n.a.	41	n.a.
Red Hook	NY0027073	10/31/2020	60	n.a.	n.a.	n.a.

n.a. indicates data were not provided for this parameter in the SPDES

Image credit: *Bowery Bay Wastewater Treatment Plant Tour of New Odor Mitigation* by Costa Constantinides (CC BY 2.0).

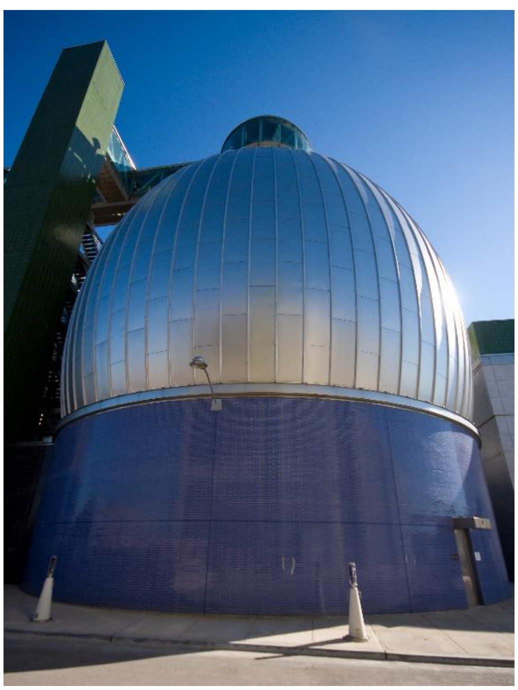

Image credit: *Newtown Creek Digestor Eggs* by Garrett Ziegler (CC BY-NC-ND 2.0)

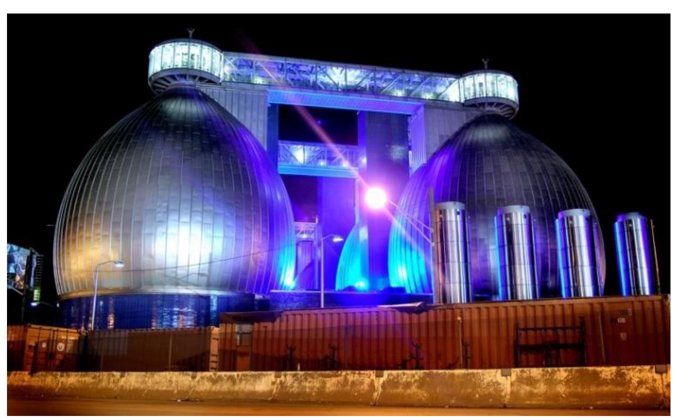

Image credit: *Purple Digester Eggs.jpg* by Victoria Belanger (CC BY-NC-ND 2.0)

EPA'S CALL FOR NEW REDUCTIONS

The target set for reducing nitrogen from wastewater treatment plants was met by Connecticut in 2015 and by New York State in 2016. After reviewing the response in the Sound, USEPA called for continuing efforts to reduce nitrogen, as detailed in the Long Island Sound Nitrogen Strategy issued in 2015 (USEPA Region 1 and USEPA Region 2 2015a; USEPA Region 1 and USEPA Region 2 2015b). This new guidance document moves beyond wastewater treatment plants, recommending a more holistic approach to addressing the nitrogen pollution problem. The four central recommendations are:

1. Complement Long Island Sound TMDL nitrogen management initiatives to address other eutrophication-related impacts; for instance, involving smaller communities in addressing their local problems and bioextraction.
2. Convert the current nutrient criteria from a narrative which describes the desired goal (i.e. eliminate hypoxia) to numeric criteria (i.e. nitrogen in the water cannot exceed X mg per liter).
3. Customize the numeric criteria for each of three watershed groupings:
    a. Coastal watersheds that directly drain to embayments or nearshore waters.
    b. The three large rivers that drain into the Sound – the Connecticut River, Housatonic River and Thames River.
    c. Western Long Island Sound coastal watersheds with large, direct discharging wastewater treatment plants (includes plants located in portions of New York City, Westchester County, Nassau County).
4. Continue to support monitoring, modeling, and researching the link between nitrogen loading and bottom-water dissolved oxygen conditions in the open waters of the Sound.

As noted in the cover letter accompanying the Long Island Sound Nitrogen Strategy, "Despite this progress, there is more to do" (USEPA Region 1 and USEPA Region 2 2015a). Improving water quality in Long Island Sound, reducing the area of hypoxia, and providing habitats supportive of a diverse and vibrant community of sea life requires a continuing commitment to reduce nitrogen inputs to the Sound.

Bioextraction, harvesting nitrogen from the sea as a byproduct of aquaculture. Charles Yarish, professor of ecology and evolutionary biology looks over a line of kelp as it is being harvested by the Thimble Islands Oyster Company from Long Island Sound near Branford on May 22, 2013. Image credit: Peter Morenus/UConn Photo.

Monitoring water quality. Image credit: Save the Sound.

SUMMARY

- New York City succeeded in meeting its target to reduce nitrogen pollution entering Long Island Sound from East River wastewater treatment plants. This tremendous investment in the health of the Sound (1.035 billion dollars) will pay dividends in clean water and a vibrant ecosystem.
- The hypoxic zone in Long Island Sound is now smaller, but still there, stretching from the East River past the coasts of Westchester and Nassau County in the hot summer months.
- New York City remains one of the top contributors of nitrogen to the Sound. Six city wastewater treatment plants still account for 97% of New York City's nitrogen contribution to Long Island Sound.
- New York City WWTPs should investigate ways to optimize nitrogen reduction at the four recently upgraded plants, targeting the seasons immediately before and during the months when hypoxia occurs.
- Additional methods should be investigated for improving water quality in the bays and harbors that line the East River and the Sound. Many if not all of these waterways are stressed from high nitrogen and bacteria loads [31, and this report]. Communities can be engaged through local water monitoring and projects designed to reduce local pollution sources and restore natural habitats.
- Longer term solutions to reducing the overall impact of New York City wastewater on the environment must be considered. For example, the redirection of Boston's wastewater outfall into the ocean versus into the inner harbor has improved water quality dramatically in Boston Harbor.

Hell Gate Bridge, crossing the East River. Image credit: *Hellgate Pano* by Robert (CC BY-NC-ND 2.0).

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APPENDIX I – HYPOXIC AREA

Data for hypoxic area were obtained from the Long Island Sound Study (Long Island Sound Study 2017). In a report to the Long Island Sound Management Committee on October 17, 2017, Dr. Jim Ammerman, LISS Science Coordinator, included the following information on area of hypoxia:

"The average size of the maximum summertime extent of hypoxia (DO ≤ 3.0 mg/L) from 1987–2000 was 208 square miles. Based on the last 20 years of interannual variability, a 28 percent reduction would be necessary to achieve a "measurable reduction," defined as the ability to statistically differentiate (either by regression or by ANOVA) that a change has occurred with 95 percent confidence after 20 years (in 2035). We chose areal extent from the available hypoxia metrics tracked by LISS (areal extent, duration) because this metric is most closely correlated to the severity of impact and is the least environmentally variable of the metrics." (slide 14, Ammerman 2017)

To verify these statistics, the following calculations were preformed:

The average of hypoxic area for years 1987 to 1999 was 208 square miles. The average of hypoxic years for 1987 to 2000 is 205 square miles; Dr. Ammerman evaluated this time period. For the following calculations, the period of 1987-1999 was used.

To evaluate the level of areal extent which can be considered significantly different from 208 ± 106 square miles (average for 1987-1999 and standard deviation), the standard deviation associated with any given year's hypoxia area is required. The standard deviation of the current and preceding 9 years (10-year average) was calculated for each year from 1996 through 2017. The standard deviation was expressed as a percent of the average. These were averaged over the 1996-2017 period to arrive at an estimated standard deviation of 47% of the value for any given year. When comparing the areal extent to the baseline of 208 ± 106 square miles, the annual value ± 47% of the annual value will be used.

Using a One-way ANOVA, the baseline of 208 ± 106 square miles was compared to estimates of area of hypoxia to locate the value at which we can statistically say the area is different from the baseline. A 10-year running average of 131 square miles or less is statistically significant from the baseline. Using Ammerman's calculation (methods in calculation differed), the 28% reduction (from quote above) equates to 150 square miles or less as statistically significant from the baseline. This value of 150 square miles was used in the report. The figure below shows results with Vaudrey's calculations.

Four of the last five years (2013, 2014, 2015, 2017) have been below the threshold for significance. The 5-year running average appears to be trending downward, reaching areas of hypoxia that are small enough to be statistically significant from the baseline. The 10-year average has not yet reached a size where the reduction in area can be considered statistically significant, though this is not surprising given that this average (2008-2017) includes many years prior to the completion of upgrades to WWTPs, completed in January of 2017.

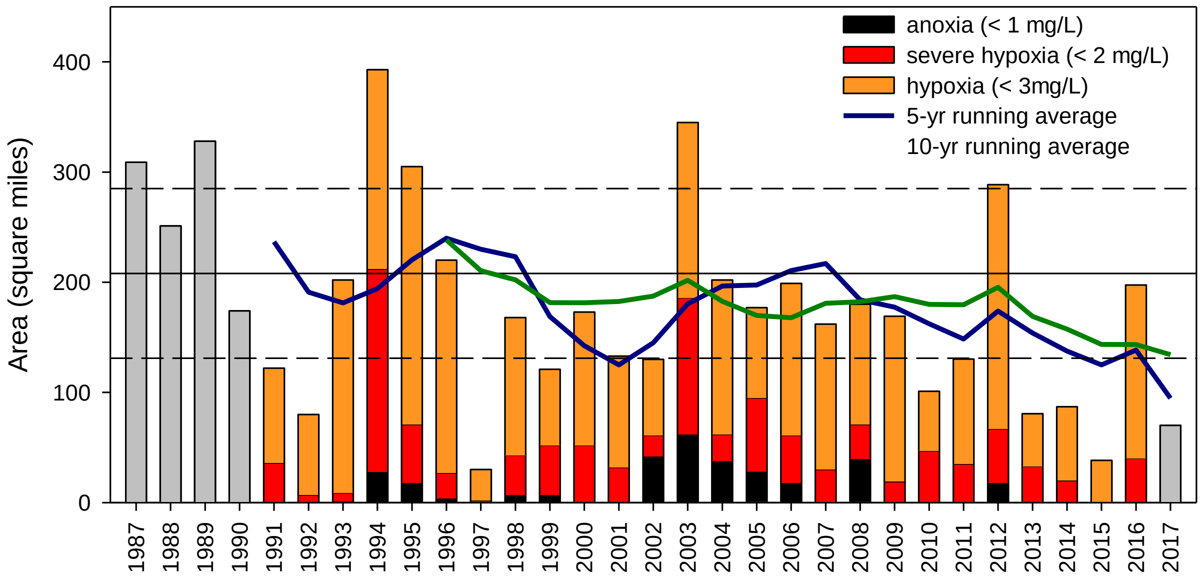

Figure 14: Area of hypoxia in Long Island Sound (Long Island Sound Study 2017). The bars show the area of hypoxia by year with colors differentiating sub-areas of severe hypoxia and anoxia (no oxygen). The grey bars show only hypoxia, severe hypoxia and anoxia were not mapped (years 1987 to 1990) or unavailable at the time of writing (year 2017). Hypoxia varies year-to-year based on differences in climactic factors including wind speed, temperature and river discharge. This version uses Vaudrey's values for statistically significant differences (equivalent to ≤ 131 square miles) and adds in the 10-year running average (green line). The 10-year average has not yet reached a place where it can be considered statistically significant, though this is not surprising given that this average (2008-2017) includes many years prior to the completion of upgrades to WWTPs, completed in January of 2017. Image credit: J. Vaudrey.

Following publishing of the Save the Sound report, the above calculations were re-run (July 2018), using the 1987 to 2000 time frame. The same methods as used above were followed. From a baseline value of 205 square miles ± 96 miles (1987 to 2000), a 10-year running average of 111 square miles or less is statistically significant from the baseline.

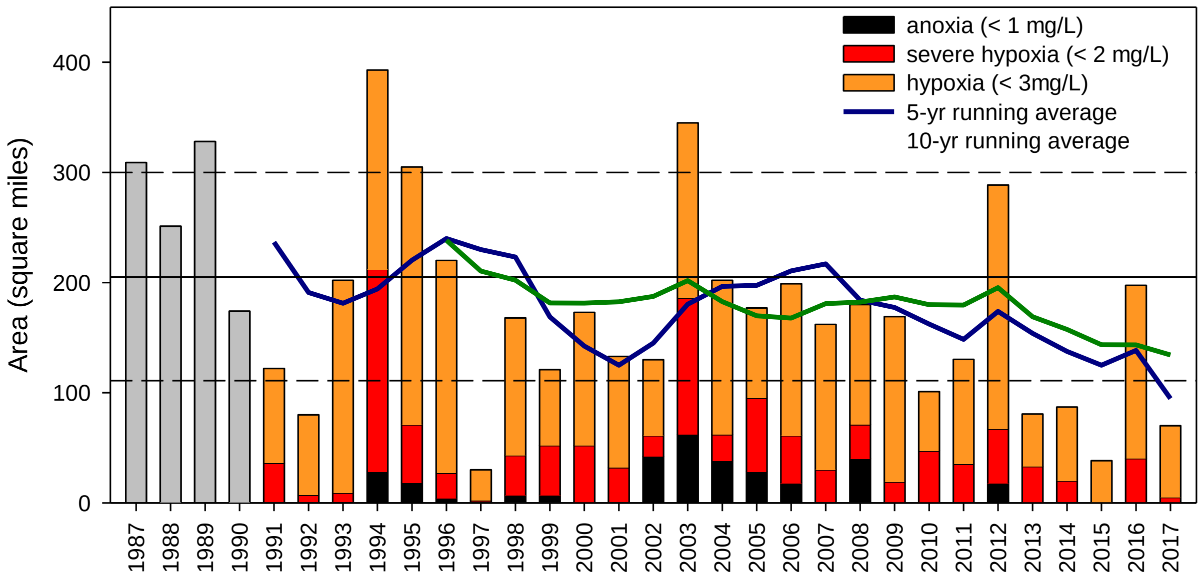

Figure 15: Area of hypoxia in Long Island Sound (Long Island Sound Study 2017). The bars show the area of hypoxia by year with colors differentiating sub-areas of severe hypoxia and anoxia (no oxygen). The grey bars show only hypoxia, severe hypoxia and anoxia were not mapped (years 1987 to 1990). Hypoxia varies year-to-year based on differences in climactic factors including wind speed, temperature and river discharge. This version uses Vaudrey's values for statistically significant differences (equivalent to ≤ 111 square miles) and adds in the 10-year running average (green line). The 10-year average has not yet reached a place where it can be considered statistically significant, though this is not surprising given that this average (2008-2017) includes many years prior to the completion of upgrades to WWTPs, completed in January of 2017. Image credit: J. Vaudrey.

APPENDIX II – SOURCES OF NITROGEN

NITROGEN LOAD TO EDGE OF LONG ISLAND SOUND

The nitrogen load to the edge of Long Island Sound is presented in Figure 9. All other figures use trade equalization to estimate the impact of nitrogen load on the water quality in Western Long Island Sound.

MAJOR RIVERS – TOTAL LOAD TO EDGE OF COASTAL WATERS (NOT TRADE EQUALIZED)

Current estimates of nitrogen load in the Connecticut River, Housatonic River, and Thames River are not easily accessible. The 1990s loads and fraction attributed to sources estimated using the USGS SPARROW model (Moore et al. 2004) were updated to current loads for atmospheric deposition and sewer load from wastewater treatment plants.

A – 1990s load, total	USGS SPARROW Nitrogen Load (kg / y)			
Thames River[a]	2,591,000			
Connecticut River[a]	18,489,000			
Housatonic River[a]	3,880,000			
B – 1990s fractions by source	**Atmospheric Deposition (%)**	**Fertilizer (%)**	**Septic (%)**	**Sewer (%)**
Thames River[a]	50%	19%	16%	15%
Connecticut River[b]	46%	14%	14%	26%
Housatonic River[a]	45%	16%	18%	21%
C – 1990s load by source (= A*B)	**Atmospheric Deposition (kg/y)**	**Fertilizer (kg/y)**	**Septic (kg/y)**	**Sewer (kg/y)**
Thames River	1,295,500	492,290	414,560	388,650
Connecticut River	8,504,940	2,588,460	2,588,460	4,807,140
Housatonic River	1,746,000	620,800	698,400	814,800
D – corrections to 1990s load	**Atmospheric Deposition - 25% reduction (kg/y)**	**Fertilizer - no correction (kg/y)**	**Septic - no correction (kg/y)**	**Sewer - 2016 load, as reported to N trading program (kg/y)**
Thames River	971,625	492,290	414,560	286,421
Connecticut River	6,378,705	2,588,460	2,588,460	1,272,337
Housatonic River	1,309,500	620,800	698,400	396,188

[a] (Moore et al. 2004)

[b] (USGS 2005)

EMBAYMENTS – TOTAL LOAD TO EDGE OF COASTAL WATERS (NOT TRADE EQUALIZED)

Embayment loads were calculated using the Long Island Sound Nitrogen Loading Model (LIS NLM) (Vaudrey et al. 2016). The load from wastewater treatment plants in the LIS NLM is an average of 2011 to 2014 reported loads. These loads were replaced with 2016 reported loads.

Total Load	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
embayments	581,390	744,302	1,041,950	931,637

EAST RIVER – TOTAL LOAD TO EDGE OF COASTAL WATERS (NOT TRADE EQUALIZED)

East River wastewater treatment plant loads from 2016 were used for the sewer fraction. The contribution from atmospheric deposition and fertilizer were determined using the Long Island Sound Nitrogen Loading Model (LIS NLM) (Vaudrey et al. 2016).

Total Load	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
East River	218,769	139,484	0	11,750,643

DIRECT INPUT TO LONG ISLAND SOUND – TOTAL LOAD TO EDGE OF COASTAL WATERS (NOT TRADE EQUALIZED)

Direct input to Long Island Sound includes the reported load from wastewater treatment plants that discharge directly to Long Island Sound and atmospheric deposition to the surface of Long Island Sound. A small amount of fertilizer and septic from eastern Long Island are not included; these are areas that drain directly to Long Island Sound and were not included in the LIS NLM.

The following table provides the values used in the calculation of atmospheric deposition. The area of each zone was calculated by Save the Sound when developing the Long Island Sound Report Card. The nitrogen deposition as kg-N / ha was estimated from the National Atmospheric Deposition Program's map for 2013 to 2015 average wet and dry deposition (NADP 2017). The deposition rate to the neighboring land was used to estimate the load for each zone of Long Island Sound.

	Area (ha)	N dep (kg/ha/y)	N (kg/y)
Western Narrows	4,800	11	52,800
Eastern Narrows	31,100	11	342,100
Western	53,000	10	530,000
Central	136,500	9	1,228,500
Eastern	77,000	8	616,000

The summary for direct loads to Long Island Sound is provided in the table below.

Total Load	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
direct load to LIS	2,769,400	0	0	460,631

NITROGEN LOAD ADJUSTED FOR PREDICTED IMPACT ON LONG ISLAND SOUND HYPOXIA

The "Management Zones Contributing to Hypoxia in the Long Island Sound" (Figure 10) were used to apply a correction to estimate the impact of loads entering in different areas along the coast of Long Island Sound on hypoxia in the Western Sound.

MAJOR RIVERS – TOTAL LOAD CORRECTED FOR IMPACT ON LIS WATER QUALITY

The appropriate TE (trade equalized) factor was applied to each of the major rivers (Figure 10). The factor in the coastal section of the zone was applied to the atmospheric deposition, fertilizer, and septic sources, as these loads are the estimate of what is entering Long Island Sound. The WWTP loads shown in section D of the table below were not treated in this manner, as this list of WWTPs included plants far inland. The TE values calculated for the nitrogen trading program from the reported loads were used, as reported in the CTDEEP database output (includes all plants draining to Long Island Sound with a load greater than 25 lb N / d). The results are shown in section E in the table below.

The following table includes section D from the previous section of this Appendix, which is the load to the edge of Long Island Sound or to the end of the pipe for wastewater treatment plants.

D – Total loads, corrected to 2016 estimates	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
Thames River	971,625	492,290	414,560	286,421
Connecticut River	6,378,705	2,588,460	2,588,460	1,272,337
Housatonic River	1,309,500	620,800	698,400	396,188
E – TE loads, for 2016	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
Thames River	165,176	83,689	70,475	45,541
Connecticut River	1,275,741	517,692	517,692	231,305
Housatonic River	811,890	384,896	433,008	229,241

EMBAYMENTS – TOTAL LOAD CORRECTED FOR IMPACT ON LIS WATER QUALITY

The "Management Zones Contributing to Hypoxia in the Long Island Sound" (Figure 10) were used to apply a correction to estimate the impact of loads entering in different areas along the coast of Long Island Sound on hypoxia in the Western Sound. Embayments located in each zone were identified and the appropriate correction factor was applied.

Total Load	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
embayments	581,390	744,302	1,041,950	931,637
TE loads, for 2016	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
embayments	417,934	506,244	802,063	627,408

EAST RIVER – TOTAL LOAD CORRECTED FOR IMPACT ON LIS WATER QUALITY

The "Management Zones Contributing to Hypoxia in the Long Island Sound" (Figure 10) were used to apply a correction to estimate the impact of WWTP reported loads from 2016. The nitrogen output from Tallman Island WWTP, Bowery Bay WWTP, Hunts Point WWTP, and Wards Island WWTP were multiplied by 0.21. The nitrogen output from Red Hook WWTP and Newtown Creek WWTP were multiplied by 0.11. The total load from atmospheric deposition and fertilizer for the East River were calculated from the LIS NLM which does not differentiate between the two TE zones of the East River. A TE factor of 0.13 was multiplied by these loads.

Total Load	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
East River	218,769	139,484	0	11,750,643
TE loads, for 2016	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
East River	28,440	18,133	0	1,878,651

DIRECT INPUT TO LONG ISLAND SOUND – TOTAL LOAD CORRECTED FOR IMPACT ON LIS WATER QUALITY

Trade equalized factors were applied to the atmospheric deposition and WWTP nitrogen output, based on the zone of Long Island Sound where the load occurred.

	Area (ha)	N dep (kg/ha/y)	N (kg/y)	TE factor	TE N (kgN/y)
Western Narrows	4,800	11	52,800	0.16	8,448
Eastern Narrows	31,100	11	342,100	1.00	342,100
Western	53,000	10	530,000	0.90	477,000
Central	136,500	9	1,228,500	0.50	614,250
Eastern	77,000	8	616,000	0.20	123,200

Total Load	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
direct load to LIS	2,769,400	0	0	460,631
TE loads, for 2016	Atmospheric Deposition (kg/y)	Fertilizer (kg/y)	Septic (kg/y)	Sewer (kg/y)
direct load to LIS	1,564,998	0	0	371,272