

**Application of a Nitrogen Loading Model to the Gargathy Bay watershed,
Accomack County, VA: Implications for Future Development**

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Introduction:

Eutrophication of coastal marine ecosystems is a growing concern for land managers. Coastal water bodies are receiving increased loads of anthropogenic nitrogen as a result of increasing development, population growth and agricultural activity in coastal areas. This nutrient enrichment results in an increase in the rate of supply of organic matter, called eutrophication (Nixon 1995). Eutrophied waters tend to have elevated concentrations of organic matter and phytoplankton, increased biomass of macroalgae and reduced oxygen levels. Thus, water quality is declining in coastal systems experiencing nutrient enrichment.

A study conducted in the coastal bays on Maryland's Eastern Shore found a significant relationship between increased nitrogen loads and increasing concentrations of total nitrogen and chlorophyll-*a* (a proxy for phytoplankton biomass) in the water column (Boynton et al. 1996). The positive relationship between nitrogen loading and chlorophyll-*a* concentrations has strong implications for marine ecosystems, especially coastal lagoons characteristic of Virginia's Eastern Shore. Coastal lagoons tend to be nitrogen-limited systems and large influxes of nitrogen can create conditions favorable for phytoplankton blooms (Taylor et al. 1995). Over time, if nitrogen loading to the lagoons continues the waters can become eutrophied and exhibit symptoms of poor water quality.

Anthropogenic nitrogen enters coastal marine systems from the atmosphere and through freshwater inputs such as runoff from the land, riverine inputs, or as is the case for the lagoons of the Eastern Shore, via groundwater flow. When the dominant freshwater input is groundwater, the water quality of the receiving bay or lagoons is tightly linked to the land use occurring in the watershed (Reay et al. 1992). Driving this link between land use and water quality is the nitrogen load transported in the groundwater from the watershed surface to the receiving water body. Dense agriculture and residential development can be significant non-point sources of nitrogen to groundwater due to fertilization of crops and lawns and leaching of nitrogen from wastewater effluent.

The Eastern Shore of Virginia is an area characterized by minimal development, large-scale agriculture and abundant natural vegetation; however, changes in the landscape are starting to occur as development in the area increases. Accomack County, located on the Eastern Shore, is a predominantly rural county expected to see increasing development in the coming years. One of the county's main concerns is how increasing development will affect the county's resources (Comprehensive Plan 1997). To help County officials understand the link between land use and its potential impacts on water quality and coastal marine ecosystems, a case study was conducted in the Gargathy Bay watershed of Accomack County. By employing a watershed nitrogen loading model, our study evaluated how different land uses in the Gargathy watershed influence the nitrogen

load entering the county's groundwater and subsequently the receiving water bodies, in the present case Gargathy Bay. The following report is a summary of the modeling study and its results, concluding with recommendations for land use planners.

Nitrogen Loading Model (NLM)

A model was used to calculate the annual nitrogen load (kg N y^{-1}) entering Gargathy Bay from the surrounding watershed (Fig. 1). The model, originally developed for Waquoit Bay in Cape Cod, Massachusetts (Valiela et al. 1997) and recently adapted for the Virginia/Maryland Chincoteague Bay (Cole 2005), can be applied to watersheds characterized by rural to suburban land use where the main source of freshwater to the estuary is groundwater. Accomack County has unconsolidated sandy sediments (EPA 1997) which is characteristic of watersheds dominated by groundwater inputs, including Waquoit Bay where the NLM was developed. Given Accomack County's rural landscape, sediment type and freshwater source from groundwater, the NLM is appropriately applied in this region.

The NLM is a tool run in Microsoft Excel that sums up inputs and losses of nitrogen as they traverse through the components of a watershed calculating a final load (kg N y^{-1}) to the base flow groundwater entering the receiving water body. The NLM's simplicity makes it a good choice for public policy and land management because it is relatively easy to apply and does not require significant expenditures of time and money. The model parameters are easy to measure and the mathematics of the NLM are straightforward. Although the nitrogen load values obtained from the NLM are not precise measurements, they provide reliable estimates that can be used to develop land management or zoning policies when calibrated to measured data. The utility and the applicability of the NLM to the Eastern Shore make it an ideal tool for public policy and resource management.

Nitrogen in the model enters the system via three inputs: atmospheric deposition, fertilizer application (both agricultural and residential) and wastewater from septic systems (Fig. 2). An additional input, non-symbiotic nitrogen fixation, was included to account for microbial fixation occurring in the soil (Stanhope 2003). Once the nitrogen inputs reach the watershed surface, they are subject to a series of reductions as they travel through the different land covers and soils (Table 1), the vadose zone and the aquifer (Table 2), eventually arriving at a total nitrogen load entering the receiving water body from the groundwater (Valiela et al. 1997).

Nitrogen inputs (kg ha^{-1}) in the model are deposited onto four different land covers: agriculture, residential turf, natural vegetation and impervious surfaces. Land cover in the Gargathy watershed was determined using GIS ArcMap and datasets from numerous sources including the Regional Earth Science Applications Center (RESAC 2000), the Chesapeake Bay Program, the Virginia Soil and Water Conservation District of Accomack County and WorldView Solution, in addition to aerial digital photographs of the Gargathy watershed and personal observation. Given the dense agriculture in the Gargathy watershed, the modified version of the NLM (Cole 2005) was used because it

specifies agricultural land by major crops. Agricultural land use in Gargathy watershed includes tomatoes, soybeans and corn grown for grain (Virginia Agricultural Statistics 2003, 2004).

Application of the NLM:

The reliability of the model's output was verified by applying the NLM to a small, gauged sub-watershed on Gargathy Creek (Fig. 1) and comparing the modeled nitrogen load to the measurements of Stanhope (2003), who computed annual base flow nitrogen loads for this sub-watershed for 2001-02 through monthly measurements of stream discharge rates and in-stream nutrient concentrations. After establishing the reliability of the model in this sub-watershed, the NLM was applied to the entire watershed for Gargathy Bay to estimate the current annual groundwater nitrogen load to the bay. The model was then manipulated to simulate different land use scenarios such as increased residential and agricultural expansion and increased poultry production, and to project potential changes in the annual nitrogen load to Gargathy Bay and the implications for resultant water quality.

All input values used in the model are specific to Virginia or Accomack County except for parameters measured on a regional basis (i.e. atmospheric deposition). The rate of atmospheric nitrogen deposition was obtained from Meyers et al. (2001) and includes both wet and dry deposition. Wastewater nitrogen inputs were calculated using population and housing densities obtained from the US Census Bureau (TIGER 2000). For all agricultural scenarios, a three-crop rotation of corn followed by winter wheat (as a cover crop) followed by soybeans was assumed (Jim Belote, *personal communication*; Stanhope 2003). Tomato plasticulture was also added to the NLM because of the additional fertilization the crop contributes and its presence in the Gargathy watershed. The area of tomato plasticulture in the watershed was calculated using aerial photos. The nitrogen content in the crops was calculated on a dry matter basis using the Crop Nutrient Calculator from the NRCS website. Agricultural fertilizer nitrogen inputs were calculated using crop-specific fertilization rates (Stanhope, 2003; Virginia Cooperative Extension 2000). Turf fertilization rates used in Valiela et al. (1997) and Cole (2005) were also used in this model. Non-symbiotic nitrogen fixation rates were obtained from references found in the Stanhope thesis (Meisinger and Randall 1991; Castro et al. 2001; Stanhope 2003). The data from Stanhope (2003) and the other sources used in this study focus on the period from 2000 to 2003.

Prior to discussing the modeling results, consideration must be given to the limitations of the model. In general, no matter how complex or simple a model's design, all models are simplifications of natural systems and include some range of error and uncertainty in the calculations. Valiela et al. (1997) estimated that their NLM predicted nitrogen loads within 37-38% of measured loads; therefore, the NLM predictions are interpreted as estimations and not absolute values. Despite the NLM's limitations, several studies including this one have shown the NLM provides reliable estimations comparable to the actual measured loads and is thus a useful management tool for forecasting future scenarios (Heberlig et al. 1997; Valiela et al. 2000).

Results of Model:

The modeled load for the Gargathy sub-watershed was very similar to the measured load. The measured annual nitrogen load for the sub-watershed was 2,149 kg N y⁻¹ (Stanhope 2003); the NLM nitrogen load was 1,954 kg N y⁻¹ (Table 3). The percent error between these two values is only 9%. Such a low percent error is well within the range of 37-38% reported by Valiela et al. (1997) and indicates the NLM can reliably estimate actual nitrogen loads in this Eastern Shore system. The underestimation of the sub-watershed's nitrogen load by the NLM is consistent with another NLM verification study that obtained lower modeled loads compared to actual loads (Heberlig et al. 1997).

Applying the NLM to the entire Gargathy watershed resulted in an annual groundwater nitrogen load of 30,418 kg N y⁻¹ to the receiving Gargathy Bay (Table 4). A large percentage of the nitrogen load, 80%, entering Gargathy Bay was estimated to result from agricultural fertilization. Residential inputs are comparatively small; 3.2% of the annual load was estimated from wastewater and an even smaller percent, 0.6%, was estimated from turf fertilization. In the sub-watershed, inputs from agricultural fertilization were also predicted to be the dominant input (67% of the load); however, residential impacts are more pronounced as wastewater was predicted to contribute almost 7% of the load (Table 3). Atmospheric deposition also appears to be a larger contributor to the annual load in the sub-watershed (~ 14%) compared to the entire Gargathy watershed (9.2%).

Residential Impacts on Nitrogen Loads

Accomack County's 1997 comprehensive plan predicts an annual increase in population of 0.6% and an annual increase in housing density of 2% (Accomack County 1997) over the next 30 years. To determine the impact of increasing residential development the predicted population and housing density increases were used to estimate the change in nitrogen loading from the Gargathy watershed. An increase in Gargathy's population to the 2030 predicted population of 920 people had a minimal impact on the predicted nitrogen load (Table 5). The annual nitrogen load increased by less than 200 kg N y⁻¹ over the 30 year period, increasing from the current 30,418 kg N y⁻¹ to 30,607 kg N y⁻¹. The predicted daily load of nitrogen reaching Gargathy Bay increased from 5.10 mmol N m⁻² d⁻¹ in 2000 to 5.13 mmol N m⁻² d⁻¹ in 2030 (Fig. 3). The slope of the line in Figure 3 indicates that each individual adds about 0.02% to the daily nitrogen load. Overall, the daily loading from residential inputs in this scenario is low.

Population increases bring about changes in land use as areas expand and develop into residential and urban locales to accommodate the increasing population. Accounting for these land use changes is necessary to fully understand the impact of an increasing population and development. Accomack's comprehensive plan identified the pattern of a housing density increase almost three times that of the population increases (Accomack County 1997). As development increases, especially in the northern seaside areas, existing land will undergo a conversion from its current land use, be it agriculture or natural vegetation, to residential land. To capture this land use change, the NLM was run

using three maximum build-out scenarios; the first converting all agricultural land in the Gargathy watershed to residential land, the second converting all natural vegetation in the Gargathy watershed to residential land and finally, converting half of the agricultural land and half of the natural vegetation to residential land. While these scenarios are somewhat extreme, they nevertheless serve to forecast the likely upper limit to nitrogen loading under maximum build-out conditions. We focus our results on the third build-out scenario because it is the most realistic of the three. A total conversion of all agricultural land or all natural vegetation is highly unlikely to occur, at least not within the next 30-year period.

Using the half-and-half build-out scenario, the NLM was run using the housing densities, populations, and turf and impervious surface areas associated with varying densities of residential development, reflected by incorporating different lot sizes into the model from a minimum lot size of a quarter acre to a maximum lot size of 10 acres. The assumption used in each development scenario was that half of the lot would be fertilized turf and half would be impervious surface (houses, driveways, etc). To determine the housing density, the total residential area was divided by the various lot sizes using the assumption of one house per lot on all lots. The population under the different development scenarios was determined by multiplying the number of houses by the average number of people per house (TIGER 2000).

In the Gargathy watershed, if all the residential land in the half-and-half scenario was developed into houses on quarter acre lots the estimated annual groundwater nitrogen load would increase to 62,264 kg N y⁻¹ (Table 6). If the lot sizes increased to one acre, the annual nitrogen load would be 36,493 kg N y⁻¹, a potential increase of 6,075 kg N y⁻¹ above the current annual load. A good baseline for development scenarios is the 10 acre lot size conditions because the housing and population density, and the predicted annual nitrogen load (30,668 kg N y⁻¹) are very similar to the current conditions and load in the Gargathy watershed. The annual load is slightly higher under the 10 acre scenario but that is likely due to the assumption that half of a 10 acre lot is fertilized. Though the level of development in the half-and-half scenario is extreme, it likely brackets the upper end of future build-out scenarios.

Agricultural Impacts on Nitrogen Loads:

Agriculture in the Gargathy watershed is the main nitrogen source to the groundwater. Most of the agricultural nitrogen comes from fertilization of crops and the leaching of excess nitrogen into the groundwater. Nutrient management plans and the use of cover crops have undoubtedly proven successful at reducing nitrogen leaching into the groundwater. In Accomack County, most farmers follow nutrient recommendations given the high cost of fertilizer and the low price of crops (Jim Belote, *personal communication*). Despite the use of nutrient management plans and best management practices, nitrogen still manages to leach into the ground water. Poultry operations are the other agricultural input of nitrogen to the groundwater and they comprise a significant, and increasing, portion of the agricultural land in the county. Given that agriculture is a significant portion of Accomack's landscape and an import industry to the

county, the model was run using various agricultural scenarios to help quantify the impacts of agriculture on the annual nitrogen load to Gargathy Bay.

Accomack County has many poultry operations, so the first model scenario estimated the impact of increasing poultry populations on annual nitrogen loads in the Gargathy watershed. Three assumptions were used for the poultry analysis. The first assumption was that no poultry manure was imported into or exported out of the watershed, based on information obtained from the Virginia Waste Transfer Report (VA DEQ 2002; 2003; 2004). Our second assumption was that producers applied all the poultry manure from their operations on the ground and supplemented crops with synthetic fertilizer when poultry manure alone did not meet crop nutrient needs. Finally, we used Cole's (2005) assumption of six flocks per house per year. Under current conditions in the Gargathy watershed, the model implied no significant impacts from poultry practices since the waste produced was less than total crop fertilizer requirements as there are only around 270,000 birds in the entire watershed each year.

The model was not sensitive to poultry until the number of birds equaled or exceeded 3 million birds per year in the watershed, at which point the waste produced exceeded crop fertilizer requirements. The addition of 3 million birds, the equivalent of adding 20 poultry houses, increased the predicted annual nitrogen load to 30,920 kg N y⁻¹. As the numbers of birds increased, the annual nitrogen load increased reaching a maximum of 147,278 kg N y⁻¹ with 20 million birds, the equivalent of an additional 133 poultry houses in the watershed. A more useful calculation is the daily load of nitrogen reaching Gargathy Bay, which was predicted to be 5.19 mmol m⁻² per day with 3 million chickens; however, that number increased quickly as the number of birds increased reaching a maximum of 24.7 mmol m⁻² per day with 20 million chickens (Fig. 4). The slope of the line in Figure 4 indicates that each individual bird contributes 0.0001% to the daily nitrogen load. A single bird does not contribute an extraordinary amount, but the additive effect of the birds is significant.

The second agricultural scenario estimated the amount of nitrogen an acre of corn, soy and tomato plasticulture leach into the watershed. Given the role of winter wheat as a cover crop, it was not include in the areal leaching analysis. The model was run holding all of the parameters constant and the areal nitrogen release of each crop was evaluated. The areal leaching analysis indicated that one acre of tomato plasticulture leaches the greatest amount of nitrogen. Tomatoes were predicted to leach 433 kg N y⁻¹ compared to 35 and 22 kg N y⁻¹ for corn and soybeans, respectively. One caveat for this analysis is that the NLM is very sensitive to different values for crop nitrogen content. A wide range of values exists in the literature regarding the nitrogen content in crops, and the NLM is sensitive to this range of values. Ultimately, the NRCS calculation tool was used because it provides a reliable, national average of nitrogen crop content.

Implications of the Modeling Work:

To understand the NLM projections, they must be put into the context of their potential impact on water quality. As previously mentioned, a study completed by

Boynton et al. (1996) in the coastal lagoons of Maryland's Eastern Shore found a positive relationship between nitrogen loads and two parameters, measured concentrations of chlorophyll-*a* and total nitrogen in the water. According to this study, the total nitrogen concentrations in the water column increase by $0.53 \mu\text{M}$ for a one unit increase in nitrogen load ($\text{g N m}^{-2} \text{y}^{-1}$), and chlorophyll-*a* concentrations increase by $0.7 \mu\text{g l}^{-1}$ for every one unit increase in nitrogen load (Fig 5; Boynton et al. 1996).

Given the similarities of the Virginia and Maryland coastal bay systems and the lack of biological measurements in Gargathy Bay, these Boynton et al. relationships can be used to estimate the chlorophyll-*a* and nitrogen concentrations that might be expected in Gargathy Bay for our various NLM projections. Our predicted nitrogen load falls in the middle of the estimated loads for the Maryland Bays, suggesting that Gargathy Bay falls in the middle of this regional eutrophication gradient. In other words, Gargathy Bay is not extremely impacted, but it is not pristine either. Currently the annual average chlorophyll-*a* concentration in Gargathy Bay is estimated at $37 \mu\text{g l}^{-1}$. The Maryland coastal bay study reported higher chlorophyll-*a* concentrations, $40\text{-}60 \mu\text{g l}^{-1}$, under higher loading rates, and lower chlorophyll-*a* concentrations $15\text{-}20 \mu\text{g l}^{-1}$ for lower loading rates (Boynton et al. 1996).

The potential impacts of the various projection scenarios on chlorophyll-*a* concentrations can be estimated using the relationship between nitrogen loads and chlorophyll-*a*. Projected increases in the Gargathy Bay population do not significantly change the estimated chlorophyll-*a* concentrations. Land-use changes however, have the potential to be very significant in terms of the predicted increases in chlorophyll-*a* in the system. Under the maximum build-out scenario, a quarter acre lot size would potentially increase chlorophyll-*a* concentrations to $76 \mu\text{g l}^{-1}$, which would be indicative of very eutrophied waters. Even a lot size of one acre could potentially raise chlorophyll-*a* concentrations to $45 \mu\text{g l}^{-1}$, a value that falls on the higher end in the Maryland bays (Boynton et al. 1996; Fig. 5). Similarly, increases in the poultry population could significantly increase chlorophyll-*a* concentrations well above our current estimates.

In addition to increasing phytoplankton biomass, eutrophied systems display a variety of symptoms. Kinney and Roman (1998) found a relationship between increasing nitrogen loads and peak macroalgal biomass in shallow bays in New England (Fig. 6). Though the study focuses on New England estuaries, the implications hold for increased macroalgal biomass in any shallow marine system receiving elevated nitrogen loads, including Gargathy Bay. Nixon et al. (2001) suggest that primary production of shallow marine ecosystems tends to increase with increasing nitrogen input at low rates of loading. However, the study did not relate the primary production to one dominant plant type due to the large variability of plant types that exist in coastal lagoons.

Despite their variations in findings regarding dominant primary producers, the three studies all illustrate that increased nitrogen loading favors primary production in shallow systems and therefore increased supply of organic matter. As the organic matter degrades, oxygen levels in the water could decrease resulting in increasing frequency of hypoxic conditions, and in extreme cases, anoxia or oxygen depletion. The dynamics of

coastal bays and lagoons are complex, and every system will respond differently to increased organic matter. The exact response of Gargathy Bay to increases in organic matter is unknown. Permanent hypoxia or anoxia will probably not occur because of Gargathy Bay's shallow depth, although the exact response will depend on physical factors including tidal excursion and residence time; however, extended frequency of hypoxia during the early morning hours is possible as nitrogen loading increases. Low oxygen levels in the water column can have detrimental effects on the fish, shellfish and other aquatic organisms that inhabit the lagoon.

The groundwater in the Gargathy watershed appears to be receiving moderate nitrogen loads as estimated by the NLM. Overall, in its current state, the Gargathy watershed is a moderately impacted system. Significant changes in land use due to large-scale development or intensified poultry production will likely have negative effects on the water quality of Gargathy's groundwater and coastal bay as shown by the NLM projections. The increased nitrogen loads to the groundwater will translate into more nitrogen entering Gargathy Bay, which could decrease water quality in the bay due to increased algal growth. In addition, increasing nitrogen concentrations in groundwater will have implications for drinking water in the region.

We recommend calibration and application of this nitrogen loading model to other watersheds of Accomack County. By taking advantage of Stanhope's (2003) measured nitrogen loads along the Eastern Shore, we have been able to calibrate the model against measured data, thus ensuring it is producing reliable results. This successful calibration gives us confidence in the modeled estimates of potential nitrogen loads under different land uses. Establishing current loads as a baseline and then running the NLM with different land use scenarios, the County can project the changes in annual groundwater nitrogen loads and use the relationships discussed in this report to determine how the nitrogen loads could affect receiving water bodies. Consideration must be given to the model's limitations when employing the model to make policy and land management decisions. Despite the limitations, however, the model has a great deal of utility for use in policy and land management applications. Specific land use recommendations are not provided because that would require a discussion of political and social issues well beyond the scope of this report. However, intense development and intense poultry production are not recommended in any area of Accomack County due to the estimated increases in groundwater nitrogen loads, which will ultimately adversely affect the water quality of both groundwater and the adjacent coastal bays.

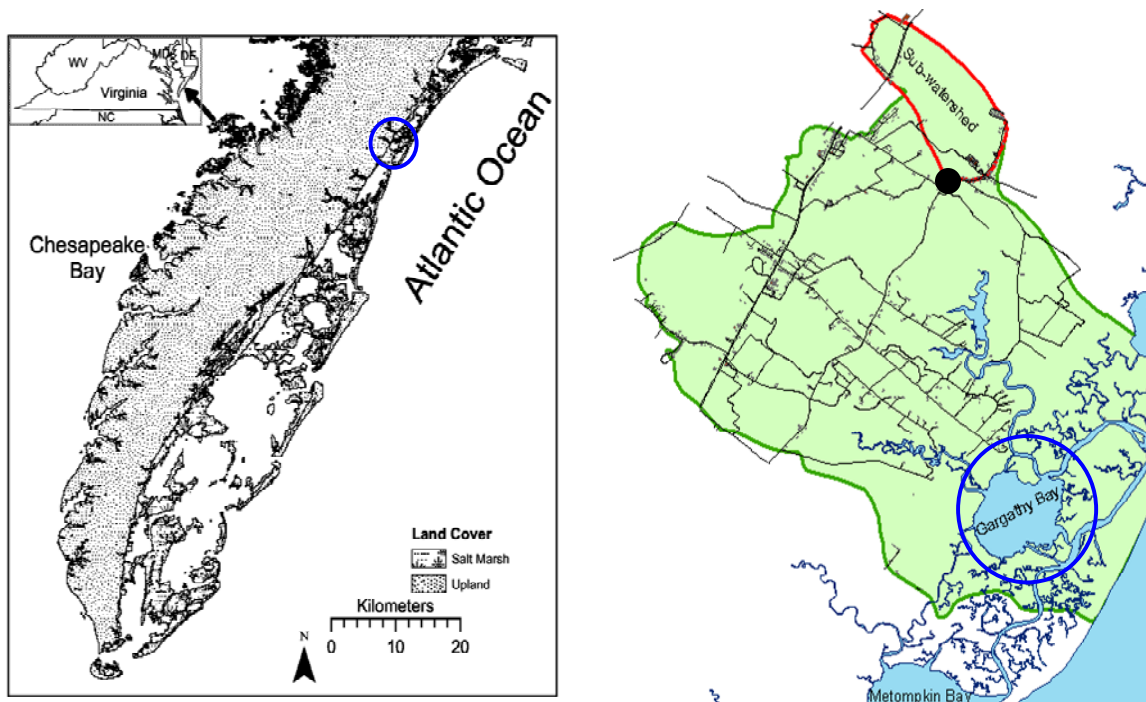


Figure 1: Map of the Eastern Shore of Virginia (reproduced from the Virginia Long-Term Ecological Research program, www.vclter.virginia.edu) and relative location of Gargathy Bay (left) and map of the Gargathy watershed and sub-watershed (right). Point shows the location of Stanhope's (2003) site at which loads were measured.

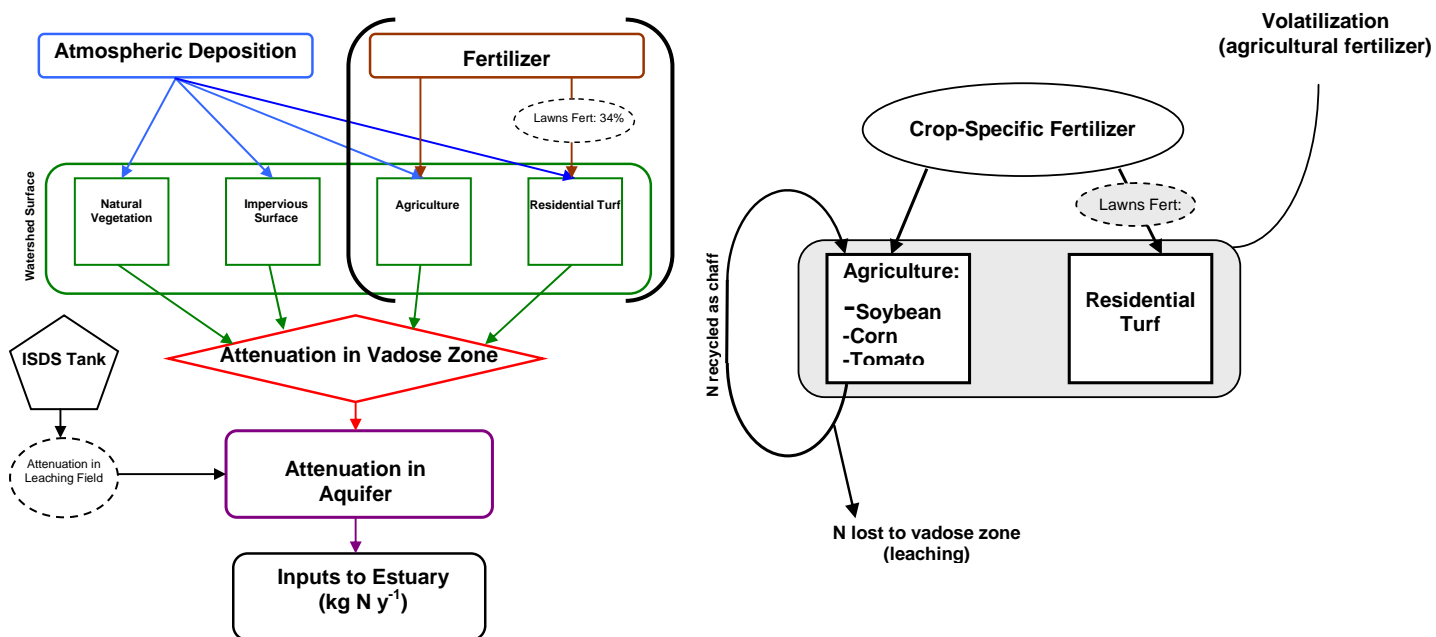


Figure 2: Conceptual diagram (adapted from Valiela et al. 1997 and Cole 2005) of nitrogen as it travels from the watershed to the estuary; diagram on the right details fertilizer application and subsequent nitrogen losses.

NITROGEN INPUT 1: ATMOSPHERIC DEPOSITION		
Type of Land Cover	Watershed component	Percent of nitrogen lost in component
Natural vegetation	Watershed surface/soils	35% lost
Agriculture	Watershed surface/soils	38% lost
Turf	Watershed surface/soils	38% lost
Impervious Surface	Watershed surface/soils	38% lost
NITROGEN INPUT 2: FERTILIZER APPLICATION		
Agriculture	Volatilization	39% lost
	Watershed surface/soils	38% lost
Residential turf (34% of lawns fertilized)	Volatilization	39% lost
	Watershed surface/soils	38% lost
NITROGEN INPUT 3: NON-SYMBIOTIC NITROGEN FIXATION		
Natural Vegetation	Watershed surface/soils	38% lost
Agriculture	Watershed surface/soils	38% lost
Residential Turf	Watershed surface/soils	38% lost
Impervious Surface	Watershed surface/soils	38% lost
NITROGEN INPUT 4: WASTEWATER FROM SEPTIC SYSTEMS		
ISDS Tanks	Septic Tank/Leach Field	30% lost
	Plume Leachate	33% lost

Table 1: Breakdown of the four nitrogen inputs used in the NLM and the percentage of nitrogen lost at the watershed surface (adapted from Valiela et al. 1997).

NITROGEN LOSSES IN VADOSE ZONE AND AQUIFER		
Contributing Inputs	Watershed component	% of N loss in component
Nitrogen input 1+2+3	Vadose Zone	61% lost
Total nitrogen inputs (1+2+3+4)	Aquifer	35% lost
Total nitrogen load	Estuary	

Table 2: Summation of the nitrogen inputs and the percent of nitrogen lost in the NLM as groundwater nitrogen flows from the vadose zone to the aquifer to the estuary.

INPUT BREAK-DOWN TABLE (SUB-WATERSHED)		
	Value (kg N y⁻¹)	Percent (%)
Natural Vegetation (Atm Dep)	50	2.57%
Turf (Atm Dep)	4	0.21%
Agricultural Land (Atm Dep)	202	10.33%
Impervious Surface (Atm Dep)	16	0.84%
Poultry Litter (Fertilizer)	0	0.00%
Turf (Fertilizer)	20	1.02%
Agricultural Land (Fertilizer)	1,312	67.16%
Non-Symbiotic Nitrogen Fixation	221	11.31%
Wastewater	129	6.58%
Total N-Load to Estuary (kg N y ⁻¹)	1,954	100.00%

Table 3: Estimated current nitrogen yields from the Gargathy sub-watershed estimated at Stanhope's (2003) Gargathy Creek site and the relative importance of each source.

Input Break-Down Table (Gargathy watershed)		
	Value (kg N y⁻¹)	Percent (%)
Natural Vegetation (Atm Dep)	1,127	3.71%
Turf (Atm Dep)	36	0.12%
Agricultural Land (Atm Dep)	1,479	4.86%
Impervious Surface (Atm Dep)	168	0.55%
Poultry Litter (Fertilizer)	0	0.00%
Turf (Fertilizer)	175	0.58%
Agricultural Land (Fertilizer)	24,516	80.60%
Non-Symbiotic Nitrogen Fixation	1,957	6.43%
Wastewater	960	3.16%
Total N-Load to Estuary (kg N y ⁻¹)	30,418	100.00%

Table 4: Estimated current nitrogen yields from the entire Gargathy watershed entering Gargathy Bay and the relative importance of each source.

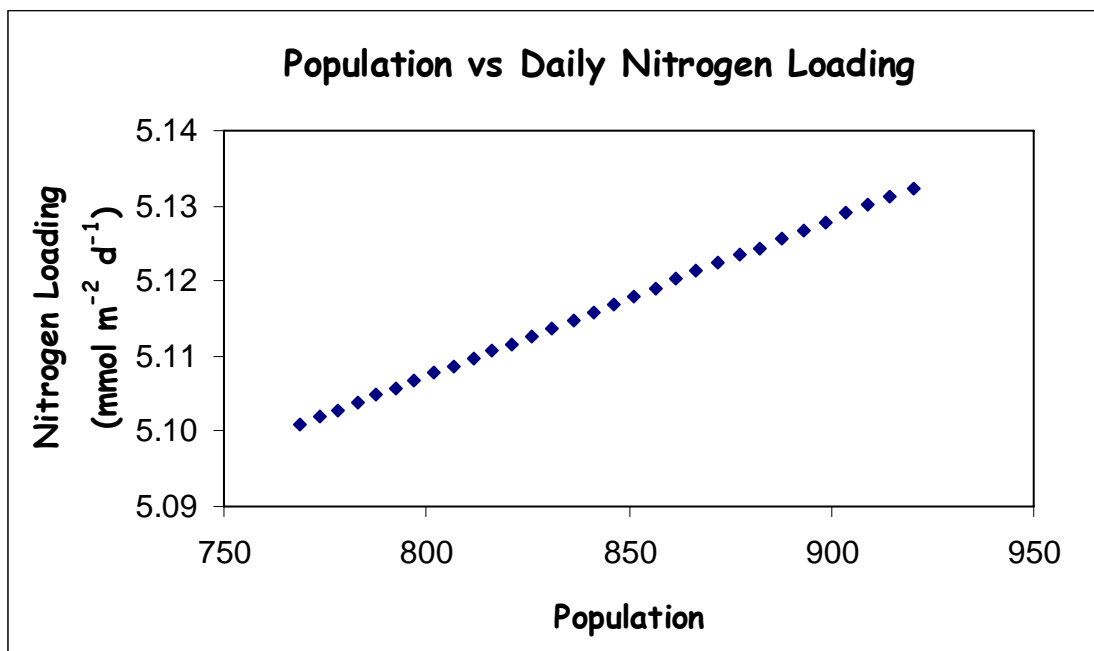


Figure 3: The predicted increase in daily nitrogen loading ($\text{mmol m}^{-2} \text{d}^{-1}$) as population in the Gargathy watershed increases.

Year	Population	Housing Units	Loads (kg N y^{-1})	Daily N Loading ($\text{mmol m}^{-2} \text{d}^{-1}$)	% N contribution (of wastewater)
2000	769	304	30,418	5.10	3.16%
2005	792	336	30,447	5.11	3.25%
2010	816	371	30,477	5.11	3.34%
2015	841	409	30,508	5.12	3.44%
2020	867	452	30,540	5.12	3.54%
2025	893	499	30,573	5.13	3.65%
2030	920	551	30,606	5.13	3.75%

Table 5: Estimated population (0.6% annual) and housing unit increases (2% annual) and the associated potential increases in total nitrogen load, daily nitrogen load, and the contribution of wastewater to total nitrogen load.

HALF-AND-HALF CONVERSION INTO RESIDENTIAL LAND				
Lot size	Number of houses	Number of people	Load (kg N y ⁻¹)	Turf Area (ac) *Imp. Surf. (ac)
¼ acre	12,140	30,350	62,264	152 1226
½ acre	6070	15,175	44,216	304 1074
¾ acre	4047	10,118	38,790	455 923
1 acre	3035	7588	36,493	607 741
5 acres	607	1518	30,725	910 468
10 acres	304	759	30,668	1062 316

Table 6: Different lot sizes and their associated housing density, population and predicted annual nitrogen loads under a conversion of half agricultural land and half natural vegetation to residential land.

*Impervious surface area includes current impervious surface area plus the predicted increase of impervious surface from development.

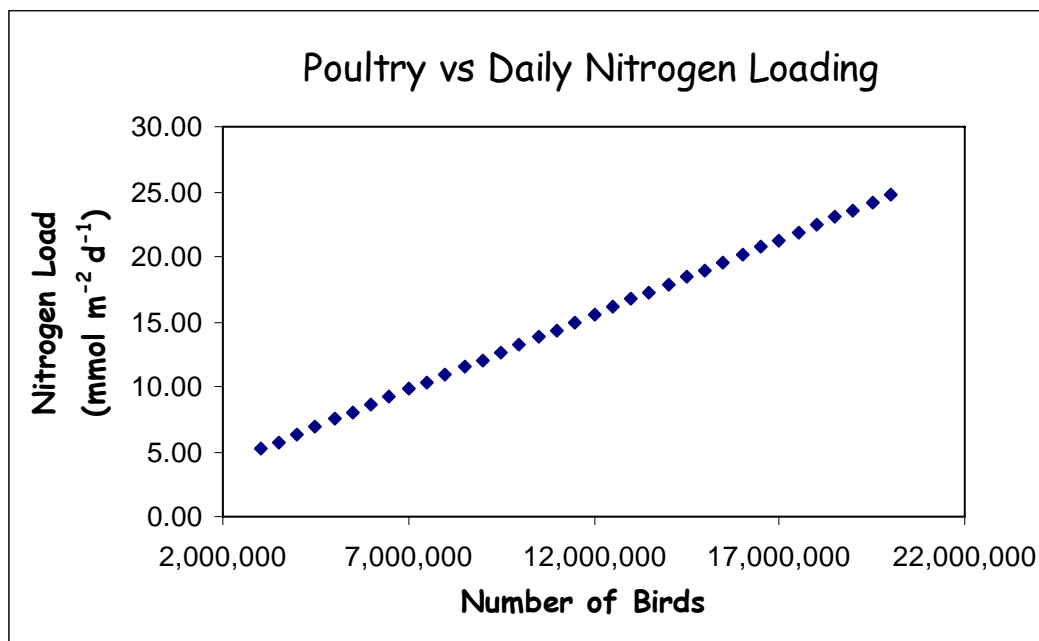


Figure 4: The predicted increases in daily nitrogen loading (mmol m⁻² d⁻¹) as the number of poultry in Gargathy watershed increases.

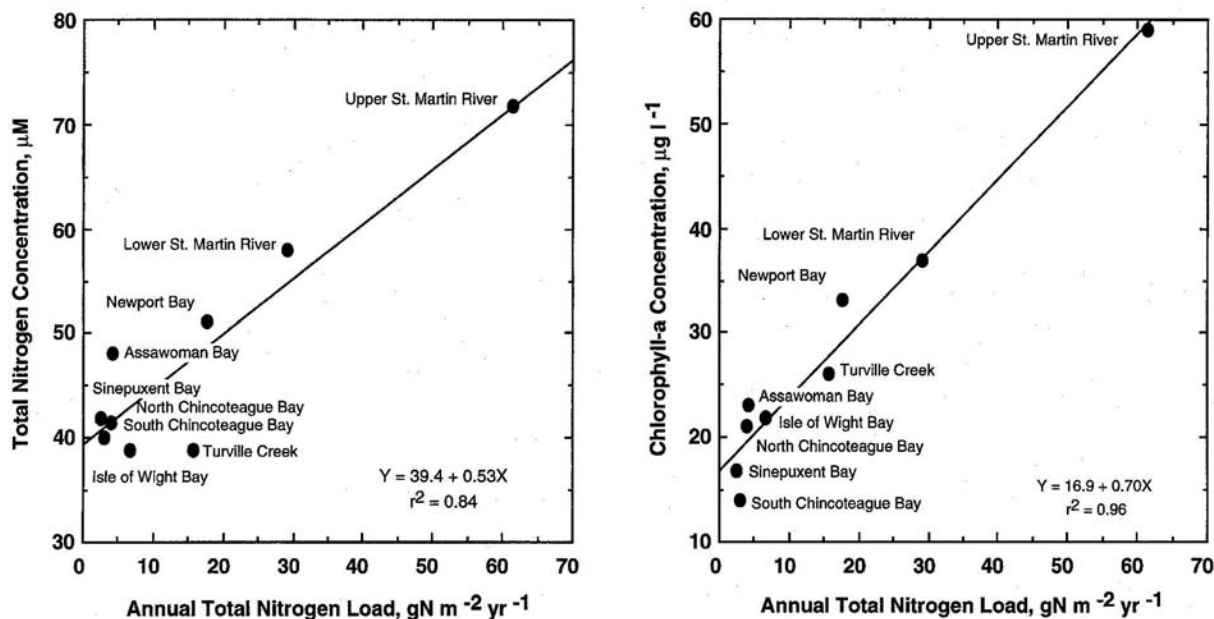


Figure 5: On the left, the relationship between the annual total nitrogen load ($\text{g N m}^{-2} \text{yr}^{-1}$) and annual average total nitrogen concentration in the water column (μM) for the Maryland Coastal Bays; on the right, the relationship between the annual total nitrogen load ($\text{g N m}^{-2} \text{yr}^{-1}$) and the annual average chlorophyll-a concentration ($\mu\text{g l}^{-1}$) in the water column of the same systems (figure taken from Boynton et al. 1996).

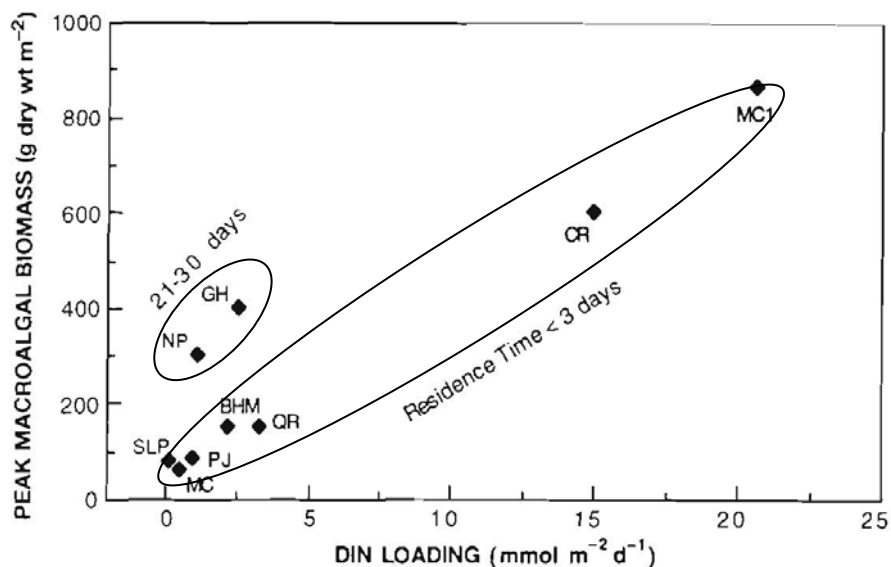


Figure 6: The relationship between peak macroalgal biomass (g dry wt m^{-2}) and nitrogen loading ($\text{mmol m}^{-2} \text{d}^{-1}$) for shallow New England estuaries. BHM: Bass Harbor Marsh; CR: Childs River, MA; QR: Quashnet River, MA; SLP: Sage Lot Pond, MA; GH: Green Hill Pond, RI; NP: Ninigret Pond, RI; PJ: Pt. Judith Pond, RI; MC: Mumford Cove, CT (after the diversion of a sewage treatment plant); MC1: Mumford Cove, CT (before the diversion of a sewage treatment plant) (figure taken from Kinney and Roman 1998).

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