Draft

Nitrogen loading in the Barnegat Bay – Little Egg Harbor estuary and watershed: Developing a conservative model for determining the contribution to the total nitrogen load from lawn fertilizers and a review of existing data.

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Abstract

Decreasing the total nitrogen input to Barnegat Bay is crucial to alleviating the impact of eutrophication, recognized to be one of the most severe problems affecting U.S. coastal waters (NRC 2000, EPA 2001). Several studies have attempted to quantify the amount of nitrogen entering the Barnegat Bay – Little Egg Harbor estuary and watershed (Mosner et al. 1998; Seitzinger et al. 1999; Hunchak-Kariouk and Nicholson 2001; Castro et al. 2003; Bowen et al 2007; Kennish et al. 2007). However it has been postulated that these estimates over-credit the contribution fertilizer has to the total nitrogen load of the system. This paper calculates the amount that fertilizer derived nitrogen contributes to the Barnegat Bay – Little Egg Harbor estuary by comparing different usage scenarios to existing market data and known nitrogen leaching rates for similar soils and cool season turf varietals as those found in Ocean County, New Jersey (Guillard and Kopp 2004). Figure 1 illustrates a comparison of the total nitrogen sold in the state to established leaching rates and a conservative estimate of the total number of homes in Ocean County. This data was then compared to the NLOAD model (Bowen et al 2007) so as to eliminate scenarios that exceed accepted modeling estimates. Using these comparisons we conclude that fertilizer currently provides between 8 and 15% of the total nitrogen load to the Barnegat Bay – Little Egg Harbor Estuary. This paper indicates that the most plausible managerial strategy for abating the problem of nitrogen pollution from fertilizer is to regulate the amount of slow-release nitrogen contained in these products. Included below is also a review of the present research available to scientists and policy makers working to determine the contribution ground-water based nitrogen has to the total nitrogen load of the Barnegat Bay – Little Egg Harbor watershed.

Introduction

Nutrient Loading: A National Problem

Scientific evidence is clear: Nutrient loading is the largest pollution problem affecting U.S. coastal waters (National Research Council (NRC) 2000). In 2000, the NRC concluded that 87% of U.S. coastal estuaries are threatened by eutrophication. The process of eutrophication is driven by the excessive addition of nitrogen to the system. Thanks predominantly to the combustion of fossil fuels and the extensive use of fertilizer, two times the natural amount of nitrogen are entering the Earth's soils (Seitzinger 2008). As a result of human activities, estuaries along the Atlantic and Gulf coasts receive an estimated 2 to 20 times more nitrogen than prior to the industrial revolution (Boynton et al. 1995; Howarth et al. 1996; Jaworski et al. 1997; Goolsby 2000; Castro et al. 2003).

In 2001, the United States Environmental Protection Agency (EPA) formally recognized the need to regulate nitrogen pollution entering coastal waters throughout the United States and developed the "Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters" as an initial step in the regulatory process (EPA 2001). The impetus for this report arose predominantly from the published findings of the NRC which concluded that in response to an increasingly large body of scientific evidence it has been definitively determined that nitrogen is the driving factor behind eutrophication in "many and probably most" estuaries in the temperate zone (NRC 2000). As elaborated below, the Barnegat Bay-Little Egg Harbor estuary is no exception.

Nutrient Loading: A Problem in Barnegat Bay-Little Egg Harbor Estuary

A growing body scientific evidence indicates that the Barnegat Bay-Little Egg Harbor estuary, part of a U.S. Environmental Protection Agency designated National Estuary Program site, is being adversely affected by excessive nutrient loading. According to the National Oceanic and Atmospheric Association (NOAA), the Barnegat Bay – Little Egg Harbor estuary exhibits characteristics associated with a highly eutrophic ecosystem, including high chlorophyll-a counts, high turbidity, elevated phytoplankton and macroalgal abundance, loss of submerged aquatic vegetation (SAV), loss of benthic macro-invertebrates such as hard clams, and an increase in the occurrence of harmful algal blooms (Seitzinger and Styles 1999; Bologna et al. 2000, 2001; Kennish, 2001*a,* 2007; Lathrop et al. 2001; Olsen and Mahoney 2001; New Jersey Department of Environmental Protection (NJDEP) 2002). As with many estuaries throughout the Mid-Atlantic States, eutrophication presents an imminent threat to the overall health and safety of this ecosystem.

The connection between eutrophication and nitrogen is well documented in studies dating back to the middle 1950s. (Ryther 1954; Lee and Olsen 1985; Nixon et al. 1986; Valiela 1992; Bricker et al. 1999). Over the last decade, the eutrophic conditions found throughout Barnegat Bay, as documented by Kennish et al. (2001*a*) have occurred in congruence with factors thought to increase nitrogen inputs to the system. Such factors include land use changes, increased energy consumption, human population increase, and increases in terrestrial and atmospheric deposition of nitrogen into the waterbody (Howarth et al.1996; Hunchak-Kariouk and Nicholson 2001, Kennish 2001*b*). Decreasing the total nitrogen input to Barnegat Bay is crucial to reducing the impact of eutrophication.

Several studies have attempted to quantify the amount of nitrogen entering the Barnegat Bay – Little Egg Harbor estuary and watershed (Mosner et al. 1998; Seitzinger et al. 1999; Hunchak-Kariouk and Nicholson 2001; Castro et al. 2003; Bowen et al 2007; Kennish et al. 2007). Though modeling methods for non-point source pollutants are prone to a certain level of inaccuracy due to the variations and gaps in data they are a scientifically accepted tool for gaining a perspective on potential regulatory and managerial strategies. It is valuable to consider these models as estimates as to the impact that limiting fertilizer usage can have on water quality.

Methods:

Using Market Data to Estimate Fertilizer Contribution to the Nitrogen Load in the Barnegat Bay Little – Egg Harbor Estuary: Building a Conservative Estimate.

When estimating the role that fertilizer derived nitrogen plays in the total nitrogen load entering the Barnegat Bay – Little Egg Harbor estuary, it is important to compare existing simulations against known quantities of nitrogen sold in Ocean County. Adopting this system of comparison allows both researchers and policy makers to gauge the accuracy and efficacy of different strategies for reducing the nitrogen load. Beyond providing a benchmark by which to compare differing simulations, estimating the nitrogen load using industry derived sales data represents the most conservative method available to researchers. Figure 1 illustrates a comparison of the total nitrogen sold in the state to established leaching rates and a conservative estimate of the total number of homes in Ocean County. Using these data points researchers are able to adjust independent variables, determine the effectiveness of differing managerial approaches to mitigating nitrogen leaching and estimate the total nitrogen input derived from home-use lawn fertilizers.

Existing modeling studies have been criticized for potentially presenting an over-estimate of the amount fertilizer contributes to the total nitrogen load. These criticisms are largely based on the necessary use of specific assumptions inherent in most computer model estimates for nonpoint source pollution. It has been postulated that these models assume excessive application rates, or account for usage that exceeds total fertilizer sales for Ocean County. In an effort to alleviate such claims, researchers investigated the contribution of fertilizer to leaching in comparison to the available market data. Fertilizer vendors are required to report the tonnage of fertilizer sold statewide. Additionally, these vendors also provided the percentage of fertilizer sold per county. Using fertilizer sales data from 1999, publically available from the USDA, researchers calculated application rates in lbs/1000sq.ft and compared them to the leaching rates determined by Guillard and Kopp. (2004).

Guillard and Kopp (2004) examined the leaching rates for three different fertilizer formulations, an all soluble ammonium nitrate 34-0-0 product; a polymer-coated sulfur-coated urea containing 15.1% slow release nitrogen; an organic fertilizer containing 70% slow release nitrogen; and an unfertilized control. Fertilizer was applied to a cool season turf grass blend grown in Paxton fine sandy loamy soil. These data points were selected because the grasses were grown under home turf management conditions and due to the fact that the soil composition a similar type to that found throughout Ocean County.

Usage Rates: Adopting Conservative Estimates

Researchers chose several plausible fertilizer usages and application scenarios. First, the total pounds of fertilizer is calculated as if applied by the average home applicator following the Partnership for Nonpoint Source Pollution Control in the Barnegat Bay Watershed[1] lowest recommended fertilization rate (hereinafter by referred to as the minimum rate). This rate is defined in Low Maintenance Landscaping (2005) as 2.5 lbs. N/1000 sq. ft annually. However, it has been speculated that these recommendations are not congruent with actual applicator behavior. Despite the fact that fertilizer industry recommends 3-4 fertilizer applications annually, industry data suggests that only 50% of home owners apply fertilizer at all, and the majority (86%) apply only once or twice times annually (Scotts MiracleGro, 2008). Industry research also suggests that, of the 50% of the population who apply fertilizer, 10% use a professional lawn service; these services generally apply using a multiple applications model (the Green Industry Council, personal communication; Scotts MiracleGro 2008). In efforts to account for these discrepancies, researchers posited comparative scenarios in which both

[1] This partnership includes: Rutgers University Cooperative Extension, Ocean County Soil Conservation District, The Barnegat Bay National Estuary Program, The USDA-Natural Resource Conservation Service, Ocean County Planning Board, The NJDEP, and the South Jersey Resource Conservation and Development Council.

that 100% and 50% of the total homes in Ocean County apply fertilizer (hereinafter referred to as 100% and 50% homeowner compliance). Using these discrete application rates addresses homeowner usage discrepancies and allows researchers to calculate the contribution from those individuals applying both once and twice a year.

Application Rates: Adopting Conservative Estimates

In order for this model to be congruent with market data and similar to the industry recommended rate per single application, researchers used both the minimum rate (2.5 lbs. N/1000sq. ft.) and a rate of 1 lb. N/1000sq. ft in determining total pounds applied. By utilizing an application rate of 1 lb. N/1000sq. ft., researchers were able to account for those members of the populations who apply at a lower rate, biannually as suggested by industry data.

Scientific data indicates that fertilizers containing a slow release nitrogen component leach significantly less than quick acting or water soluble nitrogen fertilizers (Gross et al. 1990; Liu et al. 1997; Owens et al. 1999 Guillard and Kopp 2004; Easton and Petrovic 2004, King and Torbert 2007). The present market leader controls approximately 50% market share of the do-it-yourself fertilizer market. Many of the products they provide for sale contain some percentage of slow release nitrogen. The remainder of the market is dominated by the nationally best selling fertilizers, the generic "triple ten" products, most of which contain no slow release component (S. Simon, personal communication). This report will consider that half of all applicators use a product with a slow release component, while the remainder uses a quick acting product, thus accounting for market share discrepancies. These considerations represent a conservative estimate of reasonable comsumer behavior. Again this number will be compared to both 100% and 50% homeowner compliance.

Home Definition: Limiting Discrete Variables

Homes are considered to be U.S. Census defined 1-unit-detached-homes[2], thus excluding partnership owned or condominium developments, schools, parks, community owned lands, or multiple-home dwellings.

Results

Market research suggests that the average national home lawn size is approximately 8000 square feet (C. Wible personal communication). Therefore, at the minimum rate each home lawn application would account for 20 lbs of nitrogen annually. According to the 2000 U.S. Census, there are 186,722 1-unit-detached-homes in Ocean County. Considering a 100% homeowner compliance using the minimum rate, a total of 37.34×10^5 lbs. of nitrogen would be applied countywide. Guillard and Kopp (2004) calculated the leaching rate for fertilizers containing no slow-release content applied to cool season turf grasses at 16.8%. At this rate a total of 6.27×10^5 lbs. of nitrogen would leach into the ground-water annually when these products are applied at the minimum

[2] 1-Unit, Detached--This is a 1-unit structure detached from any other house; that is, with open space on all four sides. Such structures are considered detached even if they have an adjoining shed or garage. A one-family house that contains a business is considered detached as long as the building has open space on all four sides. Mobile homes or trailers to which one or more permanent rooms have been added or built also are included. http://quickfacts.census.gov/qfd/meta/long_58576.htm

rate (fig. 1). At 50% homeowner compliance, 93,361 homes would apply 18.67×10^5 lbs of fertilizer annually. At the minimum rate, this would account for 3.14×10^5 lbs. nitrogen leachate annually (fig.1).

Conservatively assuming that 50% of the homes apply only 1 lb N/1000 sq. ft to the average home lawn once annually, using a quick-release product the total nitrogen contribution would drop to 1.25×10^5 lbs (fig.1). Though a significantly smaller amount, this estimate still accounts for a significant contribution to the overall nitrogen load to the bay as determined by Mosner et al. (1998).

This paper also calculated the potential leaching rate if 50% of the products applied to Ocean County lawns contained 15% slow release nitrogen, the minimum amount required to be called "slow release" legally, and the remainder used water-soluble products. Guillard and Kopp (2004) determined the leaching rate for these products, to be 1.7%. If all homes in Ocean County applied an equal ration of slow release products to non-slow release products at the minimum rate and at a rate of 1 lb N/1000sq. ft. the total leaching would equal 3.45×10^5 and 1.73×10^5 lbs. respectively (fig.1). Significant decreases did not occur until half the population applied the combined products at a rate of 1 lb N/1000 sq. ft.

Researchers then compared these calculations against sales percentage data for Ocean County provided by Scotts MiracleGro. This data suggests that Ocean County accounts for 4.3% of the total fertilizer sales in New Jersey (Scotts MiracleGro 2008). These numbers are likely low considering that the available data considers Middlesex County, one of the states most highly urbanized regions, as having the highest sales percentage in the state. The fact that many large distribution hubs are located within Middlesex County could possibly account for this discrepancy.

According to the USDA 134,483 short tons of non-farm use fertilizer were sold in New Jersey (USDA accessed 5 July 2008). It is important to note that only 54,323 tons of farm use fertilizers were sold, indicating a significant majority of the fertilizer market is dominated by the homeowner and non-farm applicator. The USDA also tabulated total nitrogen sales at 22,866 tons. At 50% home owner compliance and at the minimum rate, researchers found that a total of 4.1% of the total nitrogen sold in the state was applied within Ocean County. Additionally, at 100% home owner compliance and at the 1 lb N/1000 sq. ft only 3.3% of the nitrogen sold was applied. Both estimates fall below industry fertilizer usage data for Ocean County (4.3%). Using the most conservative estimates, these calculations indicate that both homeowner fertilization accounts for a significant percentage of the nitrogen load to the system and that homeowner application exceeds 1 lb N/1000 sq. ft annually.

Additional studies have also quantified the nitrogen load to the Barnegat Bay – Little Egg Harbor Estuary system. In applying the NLOAD model of Bowen et al. (2007), Kennish et al. (2007), calculated the total nitrogen input from terrestrial sources alone to be 15.18×10^5 kg N/yr, thus confirming the previous nitrogen load estimate determined by Moser et al. (1998). It is important to note that these estimates exclude internal loading or direct atmospheric deposition to the bay surface. This noted, NLOAD model determined that 29% of the total load resulted from fertilizer (Kennish et al. 2007).

NLOAD is designed specifically to estimate the contribution that particular sources of nitrogen have to the total load within a waterbody. It functions by tabulating the aggregate result of several different models when estimating varying sources affecting the overall nitrogen load and then applies an adjustment factor (Bowen et al. 2007). In this case, estimates of fertilizer input are derived via the on-site and fertilization model (Gains 1986) which assumes the input from fertilization at 4.8 kg/ N/year per household. This model is deliberately simple, in an effort to provide rough insight of nitrogen loads in ground water based systems and functions best in systems where agriculture is not a dominant feature in the landscape.

Bowen et al. (2007) determined the total nitrogen input from fertilizer to equal 4.4 x 10^5 lbs N/yr. Using this data point as the upper extreme of the total contribution of fertilizer to the nitrogen load in the Barnegat Bay Watershed, researchers were able to eliminate the 100% minimum rate compliance scenario as it exceeds the extreme. Researchers then averaged the results of the three remaining scenarios to determine the aggregate results of the three possible application scenarios resulting in a total application estimate of 13.69 x 10^5 lbs N/yr and total leachate of between 2.3 x 10^5 and 1.26 x 10^5 respectively. Using the total nitrogen load figure of 15.18 x 10^5 determined by Bowen et al (2007) we conclude that home fertilizer application accounts for 8 to 15% of the total load to the Barnegat Bay Little Egg Harbor.

Figure 1. Application Scenarios, leaching rates & total percentage of fertilizer sales in Ocean County and as compared to USDA fertilizer sales for the State of New Jersey in 1999.

Application Statistics	**Total N Applied per yr. (% of N sold in NJ)**	**Resultant leaching Rate (Guillard and Kopp 2004)**		
		16.8%	**1.7%**	**9.3%**[3]
100% Minimum Compliance	3,734,440 (8.2)	627,386	63,485	345,436
50% Minimum Compliance	1,867,220 (4.1)	313,693	31,742	172,718
100% 1 lb. N/1000 sq. ft.	1,493,776 (3.3)	250,954	25,394	138,174
50% 1 lb. N/1000 sq. ft.	746,888 (1.6)	125,477	12,697	69,087
Average (1/4 of the population chooses one method)	1,960,581 (4.3)	329,378	33,330	181,354
Average – if each chooses a fertilizing method except 100% Min. Comp.	1,369,295 (3.0)	230,042	23,278	126,660

Nitrogen contamination management: Actions Based on Conservative Load Estimations

It is important to note the combination slow release and non slow release statistics. In this case we do not see a significant drop in the total amount of nitrogen leachate until application is reduced to 50% of homeowners applying once annually at a rate of 1 lb per 1000sq. ft. This is due to the fact that the leaching rate for quick release products is significantly higher than the rate for the slow release products. At 50%

[3] This rate represents the combination product usage rate and was determined by the author of this paper.

homeowner compliance at the minimum rate of application, 1.73 x 10^5 lbs of nitrogen still leach into the system. However, when only slow release products are applied, the total leachate drops to below 1.0 x 10^5 lbs N, thus accounting for a substantial decrease in the total nitrogen load. In terms of limiting the impact that fertilization and nitrogen pollution has on groundwater quality in Ocean County, even when we compare the most conservative leaching numbers available, it becomes clear that fertilizer provides a significant portion of the nitrogen load to the system. Further Lathrop and Conway (2001) estimate that development within the Barnegat Bay Watershed could increase by between 25 and 43%. Should the increase in development lead to a linear increase in the application of fertilizer, the contribution to the load total nitrogen load to the system would increase comparatively.

The need to regulate the sale of slow release fertilizers within Ocean County is clear. Reducing the application rate to one pound of nitrogen per 1000 square feet will have little impact on the total leachate entering the waterbody, if the use of quick release products continues. The simplest and most effective way to reduce the amount of nitrogen that leaches into Ocean County ground-water is to increase the percentage of slow release nitrogen contained within home use fertilizer products. Further, these numbers are of particular importance from a resource management perspective. This is due to the fact that the Barnegat Bay – Little Egg Harbor Estuary, unlike many of the estuaries in the world, receives little to no nitrogen input from human-derived wastewater (Castro et al 2003; Bowen et al. 2007). As described by Bowen et al. (2007), the two significant sources of nitrogen entering Barnegat Bay are fertilizer and atmospheric deposition. In order to effectively reduce the amount of nitrogen entering Barnegat Bay, managers must focus on deposition from these two sources.

Regulating Anthropogenic Nitrogen Sources in Ocean County: Addressing the Coextension of political and Geologic boundaries.

Ocean County, located on the outer Atlantic Coastal Plain, is the largest of the five physiographic provinces of New Jersey (Barnegat Bay National Estuary Program, Science and Technical Advisory Committee, 2001). A large ridgeline along the western portion of the county separates the drainage from the Atlantic Ocean and the Delaware Bay. Within Ocean County, all naturally-occurring waterbodies except for the Crosswicks/Rancocas Creek, the Mount Misery Brook, and the Oswego Rivers flow directly into Barnegat Bay (Ocean County Planning Board, 1988). As a result, management of the water resources contained within Ocean County is paramount to reducing the impact nitrogen loading has on Barnegat Bay. This does not, however, exclude the applicability such strategies in Monmouth, Burlington or Atlantic Counties, which also contain water sources that contribute to the Barnegat Bay – Little Egg Harbor estuary.

Comparing Anthropogenic Nitrogen Sources within the Barnegat Bay Watershed to other Estuaries in the North East

Castro et al. (2003) considered the anthropogenic nitrogen inputs to 34 estuaries throughout the Atlantic and Gulf coasts of the United States. This comparison allows for consideration to be given to the variation in size, location, and nitrogen sources to different estuaries on a regional scale. For the purposes of this paper, consideration will be given only to estuaries within the Northeast region. Castro et al. (2003) examined ten estuaries throughout this region (fig. 2) and found a statistically significant correlation between urbanization and high levels of nitrogen loading. By comparing the different sources of anthropogenic nitrogen, managers can reasonable consider how to best manage the nutrient load to each system.

In the Barnegat Bay watershed, fertilization accounted for 4.7 kg N ha^{-1} yr^{-1}, or 13% of the total load, thus ranking it 5^{th} highest among the regional waterbodies studied (Castro et al. 2003). However, when compared with the other regional waterbodies, Barnegat Bay ranks 9^{th} in terms of watershed size (fig. 3). Size comparison is valuable when considering that fact that despite many of the waterbodies having larger drainage areas; fertilization contributes less to the nitrogen load of these systems. This is an important consideration in terms of managing the system as well. The Barnegat Bay watershed has undergone a demographic shift over the last 20 years, moving away from agriculture and towards a more urbanized landscape. In relation to land use, a higher percentage of the fertilizer contribution to the nitrogen load within the watershed is being derived from home lawn-use products as opposed to agricultural fertilizers. These products merit regulation in order to reduce their overall contribution to the nitrogen load in the estuary.

Fig 2. Net anthropogenic nitrogen inputs (kg N ha^{-1} yr^{-1}) to each watershed and the percentage (in parentheses) of the total anthropogenic nitrogen inputs to each watershed from different anthropogenic sources. (Castro et al. 2003)

Watershed Location	**Nitrogen Fixation**	**Fertilization**	**Atmospheric Deposition**	**Total**
Long Island Sound, CT	1.5 (5)	3.4 (13)	9.1 (33)	27.4
Casco Bay, ME	0.9 (7)	1.6 (12)	4.5 (33)	13.7
Great Bay, NH	0.8 (5)	1.1 (7)	5.6 (35)	15.9
Merrimack River, MA	0.9 (4)	1.5 (7)	7.6 (37)	20.8
Massachusetts Bay, MA	0.8 (1)	3.9 (6)	7.9 (12)	63.7
Buzzards Bay, MA	1.4 (4)	9.9 (24)	7.9 (19)	40.9
Narragansett Bay, RI	1.2 (3)	5.5 (14)	8.8 (22)	40.3
Hudson River-Raritan Bay, NY	4.4 (10)	4.7 (11)	10.0 (24)	41.8
Great Bay, NJ	3.4 (10)	9.2 (26)	10.3 (29)	35.1
Barnegat Bay, NJ	2.1 (6)	4.5 (13)	10.3 (30)	33.8
Regional Average	**1.7 (5.5)**	**4.5 (13)**	**8.2 (27)**	**33.3**

Fig. 3. The total drainage of Northeast watersheds in square miles

Watershed	Long Island	Massachusetts Bay, MA[5]	Hudson River –	Merrimack River,	Narragansett Bay, RI[8]	Casco Bay,	Great Bay,	Buzzards Bay,	Barnegat Bay,	Great Bay

	Sound, CT[4]		Raritan Bay, NY[6]	MA[7]		ME[9]	NH[10]	MA[11]	NJ[12]	NJ[13]
Drainage sq. miles	20477	8654	7409	5010	1600	985	930	881	786	561

Nitrogen contamination in Coastal New Jersey Ground-Waters: Reviewing the Existing Evidence

Natural sources of nitrogen, such as precipitation and plant residues have little impact on the overall contribution of nitrate to New Jersey ground-water (Stackelberg et al. 1997). However, anthropogenic sources of nitrate such as residential and agricultural fertilizers significantly increase the load to ground-water in urban and agricultural areas (Stackelberg et al. 1997).

Human activities associated with urban and agricultural land uses are the principle factors adversely affecting aquatic health throughout New Jersey (Ayers et al. 2000). Findings further indicate that when urban and suburban development replaces forest, and wetlands there is a shift towards more tolerant species and away from species richness in aquatic ecosystems. Additionally, this shift away from natural vegetation increases the load of nitrate to ground-water (Stackelberg et al. 1997). This biotic shift can be characteristic of the degraded conditions considered to have a significant impact on the overall sustainability of the ecosystem.

Sampling of surficial aquifers – aquifers replenished by groundwater that is generated via precipitation percolating through the soil profile – demonstrated elevated concentrations of nitrate and frequent detection of pesticides and volatile organic chemicals (VOCs) throughout the Long Island – New Jersey Coastal Plain (Ayers et al. 2000). Findings indicate that these water sources, which supply the majority of the ground-water entering the Barnegat Bay – Little Egg Harbor estuary as well as drinking water to approximately 40% of the domestic households and public drinking-water throughout the Long Island – New Jersey Coastal Plain, are vulnerable to chemicals commonly used in urban and suburban areas (Weiben 2007; Ayers et al. 2000).

A recent U.S. Geological Survey (USGS) study examined the quantity of nitrate entering the shallow, unconfined Kirkwood-Cohansey aquifer system. This system is the largest source of freshwater to the Barnegat Bay – Little Egg Harbor Estuary, supplying 71-93% of the surface water to the bay (Watt 2000). Due to the fact that this aquifer is unconfined – lacking a confining layer that would impede land derived contaminants (Watt 2000) – it is particularly susceptible to anthropogenic contamination (Wieben

[4] http://www.epa.gov/nep/programs/lis.htm
[5] http://www.epa.gov/nep/programs/mass.htm
[6] http://www.harborestuary.org/aboutestuary.htm
[7] http://www.nae.usace.army.mil/projects/ma/merrimack/merrimackwas.pdf
[8] http://www.napawash.org/pc_economy_environment/narragansett.pdf
[9] http://www.cascobay.usm.maine.edu/pdfs/watershed2.pdf
[10] www.nhep.unh.edu/explore/index/htm
[11] http://www.epa.gov/nep/programs/buzz.htm
[12]https://darchive.mblwhoilibrary.org/bitstream/1912/1804/3/Ecological%20Applications%20Table%201.pdf
[13] http://www.state.nj.us/dep//watershedmgt/DOCS/WMAFactsheets/WMA14.pdf

2007). According to the USGS, 31.6% (557 of 1764 sites tested) exceeded the EPA recommended nitrogen criterion level of 0.71 mg/L for rivers and streams in the Eastern Coastal Plain (EPA 2000; Wieben 2007). Though no precise nitrate criteria have been developed for coastal estuaries, in the Chesapeake Bay, dissolved inorganic nitrogen (DIN) (nitrate makes up a significant percentage of DON) concentrations greater than 0.15 mg/L are considered detrimental to the survivability of eelgrass beds (Kemp et al. 2000). Testing exceeded this threshold for 48.5% (855 of 1764) of the samples tested. The USGS concluded that "ecological thresholds are being exceeded in a high percentage of ground-water samples from the Barnegat Bay – Little Egg Harbor watershed (Wieben 2007)."

Modeling studies of the surficial aquifer system in Southern New Jersey indicate a direct relationship exists between the concentration of nitrate in streams and public wells and both the type of land use in the recharge area as well as the time required for recharge water to reach the end-source (Ayers et al. 2000). Ayers et al. (2000) incorporated several hypothetical changes to the nitrate uses throughout the systems in an effort to estimate the impact that differing management strategies might have in decreasing the degradation of streams and public supply wells (Ayers et al. 2000).

Three hypothetical changes to the nitrate-use pattern were tested: (1) Nitrogen usage was fixed at year 2000 levels; (2) decreased to 0 by the year 2050; (3) immediately reduced to zero (fig. 4).

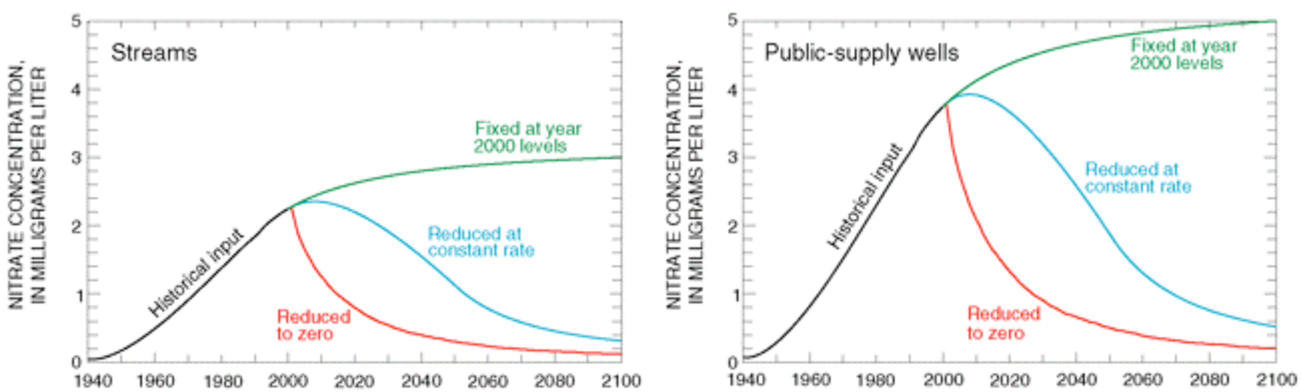

Figure 4. Simulated concentrations of nitrate in streams and public-supply wells for three hypothetical nitrogen-use patterns, Glassboro study area, New Jersey. A decrease in nitrate concentrations to half of the concentration in year 2000 will take 10 or more years because of the amount of time required for water introduced before 2000 to move through the aquifer system.[14]

These findings demonstrate the concentration of nitrogen in streams and public supply wells only decreases rapidly when nitrogen inputs are immediately reduced to zero. Due to the amount of time required for the ground-water to move through the system and recharge to the sub-laying aquifer, reducing nitrogen concentrations gradually will still take decades to decrease significantly (Ayers et al. 2000).

[14] Ayers, M.A., Kennen, J.G., and Stackelberg, P.E. 2000. Water quality in the Long Island – New Jersey Coastal Drainages New Jersey and New York, 1996-98. *U.S. Geological Survey Circular 1201. 40p.* http://pubs.usgs.gov/circ/circ1201/major_findings_2.htm#predicting. Accessed 2008 June 21.

Perhaps more crucial in terms of decreasing the impact nitrogen has on ground water quality is the fact that Ayers et al. (2000) conclude that:

> "if nitrate concentrations in recharge remain at current (year 2000) levels, the concentration of nitrate in streams and public-supply wells will actually continue to increase for several decades before leveling off at a concentration corresponding to the amounts of nitrate applied to urban, agricultural, and undeveloped lands in recharge areas… Even if nitrate concentrations in recharge [waters] are reduced at a constant rate to zero in the year 2050, nitrate concentrations in streams and public-supply wells will continue to increase for 5 to 10 years (fig. 16)…Finally, if the concentration of nitrate in recharge [water] that had been steadily increasing since 1950 could be immediately reduced to zero in the year 2000 (fig. 16), the concentration of nitrate in streams and public-supply wells would begin to decrease almost immediately as the result of the influx of young, uncontaminated ground water. The decrease in nitrate concentrations in streams and supply wells to one-half of the concentration in the year 2000, however, would still take 10 or more years because of the amount of time required for water introduced before 2000 to move through the aquifer system and discharge to a stream or well."

It is vital to consider these factors in relation to the findings of Modica et al. (1998) which demonstrate significant increases in nitrogen-based fertilizer usage over the past fifty years. Should fertilizer use increase for the next 50 years at rates consistent with those determined by Modica et al. (1998), it is very likely that nitrate contamination in groundwater will exceed EPA water quality standards in areas where nitrogen-based fertilizers are most heavily used (Ayers et al. 2000). These areas include locations where land use has transitioned from natural vegetative area to urban and suburban development.

According to the U.S. Census Bureau, between 2000 and 2006, the population of Ocean County, New Jersey increased from 510,916 to 562,335 representing an overall increase of 10.1% (US. Census Bureau, 2006). When compared to the over all population increase for New Jersey during the same period, only 3.7%, it is reasonable to conclude that land in Ocean County is being converted from natural vegetation to urban and suburban development an accelerated rate in to accommodate the rapid population increase with in the county. This shift represents the land use changes that Ayers et al (2000) consider to be a principle factor in increasing the nitrate load to the system.

These studies demonstrate conclusively that as the land use changes identified by Ayers et al. (2000) continue to increase the load of nitrate entering the ground-water with in Ocean County, the ability of these streams to remove this pollutant will decrease substantially. In consideration of the high total nitrogen load in both New Jersey ground-water and the Barnegat Bay – Little Egg Harbor estuary, it is clear that policy makers must concentrate on reducing nitrate pollution both to prevent further detriment to the aquatic ecosystem and alleviate the potential human health risk posed herein (Seitzinger et al. 1999, 2008; Mosner et al. 1998; Hunchak-Kariouk and Nicholson 2001; Kennish et al. 2007; Bowen et al 2007; Mulholland et al. 2008)

Increased Nitrogen Contamination Decreases the Denitrification Capabilities of Aquatic Ecosystems.

An array of physical and chemical characteristics inhibits researchers' ability to accurately measure the fate of anthropogenic nitrate added to the system. Despite these limitations, Mulholland et al. (2008) performed perhaps the most comprehensive study of nitrate removal in aquatic systems completed to date. They compared the fate of small amounts of nitrate labeled with the rarely occurring nitrogen isotope 15N into 72 streams, varying in quality from pristine to urban, through out the U.S. and Puerto Rico. Due to the fact that 15N occurs at less than 0.4% of the abundance of the common 14N isotope, it is very easy to detect discreet increases in the amount of this isotope converted to different forms during the denitrification process (Seitzinger 2008). In naturally functioning streams denitrification by microbes and aquatic plants drastically decreases the amount of nitrate present in the system. However, this study demonstrated that as the nitrate load to the system increases, the ability of the aquatic systems to remove increasingly larger portions of the total nitrate input, termed nitrate efficiency, decreased by six orders of magnitude (Mulholland et al. 2008).

The Barnegat Bay Little Egg Harbor Estuary is a lagoonal – shallow – estuary and is particularly susceptible to nitrogen pollution (Howarth 2006). As the nitrogen load increases in these systems, fixation rates gradually decrease causing a "boom and bust" non-linear loading pattern (Nixon et al. 2001). The fact that the Barnegat Bay – Little Egg Harbor estuary is less able to remove excess nitrogen added to the system and that it receives proportionally the same contribution from fertilizer as waterbodies of substantially larger size, it becomes clear that managers must address the input from fertilizer in order to alleviate the effects of eutrophication.

Nitrate: A Potential Human Health Risk

The addition of nitrate to ground-water not only poses risks to the stability and overall health of the aquatic ecosystem, it has been identified as posing a significant risk to human health when high dosagages are present in drinking water. Infants are particularly subject to the disease methemoglobinemia commonly called "blue-baby syndrome". Methemoglobinemia occurs when levels of methemoglobin (metHB) in the blood increase in response to elevated nitrate levels. Elevated metHB levels decrease the infant's ability to transport oxygen, resulting in the characteristic blue pallor and can subsequently result in anoxia and death if untreated (Center for Disease Control and Prevention (CDC), 1993). In response to this health threat, the EPA has established a maximum contaminant level (MCL) of 10 mg/L of nitrate in water considered safe for human consumption (Stackelberg et al. 1997). Since in Ocean County surficial aquifers supply drinking waters both to wells and to the Brick Township MUA reservoir, and since the amount of nitrate in surficial aquifers is known to be steadily increasing, placing appropriate limits on fertilizer use may avert a future public health problem.

Conclusion

It is clear that fertilizer derived nitrogen provides a significant proportion of the nitrogen entering the Barnegat Bay – Little Egg Harbor Estuary. Further, we conclude that the simplest and most effective method for reducing nitrogen contamination within the watershed is to regulate the slow release content of home use fertilizers. The existing research proves that the groundwater in Ocean County is being contaminated by excess nitrogen, to both the detriment of the Barnegat Bay – Little Egg Harbor and a source of drinking water to many county residents. Regulating possible sources of nitrogen contamination to this waterbody is a much needed managerial strategy that should be implemented throughout New Jersey.

The Neuse River Basin in North Carolina successfully reduced baseline nitrogen loads thanks part to aggressive fertilizer management strategies. Although much of the nitrogen contaminating this 6000 square mile waterbody resulted from agricultural sources and several point sources (mostly hog farms), resource managers and members of the agricultural community were able to reduce the total nitrogen load to the system by 42% (EPA accessed 1 August 2008). Administers actively targeted fertilizer contamination in the Neuse River by adopting fertilizer management practices including reducing total application and regulating application timing. Although this particular case involves predominantly agricultural contamination, resource managers in Ocean County can confidently look to managing nitrogen fertilizer usage as a proven solution to abating the problems associated with eutrophication.

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