# Nitrogen Fertilizer Management of Turfgrass in Suffolk County

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## Executive Summary

Pollution of our streams, rivers, lakes, estuaries and oceans is often a subject of the media and usually focuses on glaring point source pollution problems associated with landfills, sewage discharge, and industrial sources. However, the increase in land use and the urbanization of our land has created a much broader problem with non-point pollution of groundwater with potentially dangerous implications for watersheds, aquifers and coastal marine ecosystems. The Long Island region has been an area of growing concern and considerable study to understand the nature or hydrology of the water supply and how escalating changes in land use affect the supply. The Long Island Sound, the Peconic Estuary and South Shore Estuary Reserve are already endangered. Over the last several years, changes have been seen in the increased frequency of brown tides and algal blooms along with reductions in the population and diversity of marine life. A leading cause of the eutrophication of these marine ecosystems is increased nutrient loads from runoff and groundwater recharge. Long Island also depends on its aquifers as the only source of drinking water. Trend lines indicate that the nitrate levels in the groundwater are rising closer to the EPA's maximum contaminant level for drinking water.

In a concerted effort to arrest any further damage, Suffolk County has marshaled the resources of many groups to identify and implement corrective action. One of the countywide programs is to establish guidelines for the use of nitrogenous fertilizers for turfgrass. These guidelines are intended for private, public and commercial lawns.

Understanding the geology of the island and the specific area of management in proximity to the geologic features of the island will help define specific management practices. There are four soil types that determine four soil associations that make up 77% of the area in Suffolk County. These soils tend to be excessively drained increasing their susceptibility to leaching and groundwater contamination. The shape of the terrain and the proximity to groundwater or sensitive marine areas will be critical features.

It will be equally important to factor climatic conditions typical to the island, basing nutrient management decisions on historical data, local weather stations and forecasts. Precipitation and irrigation practices will be one of the largest factors in managing nitrogen use and the impact on groundwater quality. Evapotranspiration will be an essential factor for timing. Soil temperatures will be another factor.

This review will look at nitrogen as the most abundant element in our atmosphere and the natural processes of the Nitrogen Cycle in our atmosphere, soils, and oceans. Trends in land use, population growth and the use of fertilizers have steadily increased.

Conditions should be carefully evaluated to select the right products, to be applied at the right time, and in a manner that can sustain plant requirements while minimizing the risks of contaminating groundwater. This review will look at the forms of nitrogen fertilizers available on the market and the release characteristics of these products. The plant physiology for nitrogen uptake varies not only between species but also between cultivars within a species. Choosing the right turfgrass is an essential element of sustainable fertilizer management.

Studies have examined the mass balance of nitrogen to assess the fate of nitrogen applications. These studies have looked at the timing and rate of applications under various conditions to understand how much nitrogen is taken up by the plant and how much is stored in the soil profile. These studies also identify the potential losses due to runoff, leaching, volatilization and denitrification. This mass balance depends in part on the species, the cultivar, the soil type, the amount of organic matter and a number of management practices. These factors also vary depending on the age of the turf stand with increased water quality risks in newly established stands. Depending on prior land use, as a turf stand ages, the soil profile has increasing capacity to store and release organic nitrogen. Clippings management is a very important factor returning nitrogen to the soil. Returning clippings can reduce the overall fertilizer requirement but can also increase the risk of leaching in older turfgrass systems.

While attention may be primarily focused on leaching, the other losses reported are problematic. Certainly, conditions that promote runoff can lead directly to groundwater pollution. The topography of a site, the soil profile, slopes, and the inherent infiltration rates are major determinants of runoff. Elevation changes and contours might channel or collect water. Drainage from these areas and other man-made areas including roadways, sidewalks, cart paths, parking lots and buildings should be considered. If the drainage or collection area receives water in excess of the infiltration rate, runoff will occur. Turfgrass increases infiltration rates and water retention, reducing the risk of runoff losses.

Atmospheric losses could result in poor response by the plants. The turf manager may react by applying even more nitrogen potentially increasing the risk of groundwater pollution. Similarly, plant physiological differences, soil conditions and cultural practices may limit nitrogen uptake or leave excess nitrogen freely in the soil profile to be washed out. In fact, some cultural practices may directly increase nitrogen runoff and leaching. Topographical or site features of the landscape may contribute as well. The fate of nitrogen is a very dynamic process.

Research and field studies confirm that nitrogen, if managed properly, can be used for turfgrass without deleterious effects to our groundwater and marine ecosystems. The objective is to establish best management practices (BMP) for non-professional lawn care, primarily residential lawns, and for professional lawn care including landscapes, sports fields and golf courses, with the collective interest of maximizing plant response and reducing nitrogen losses to the environment. To reiterate the point, best management practices could be summarized as applying fertilizers at the right rate, at the right time and the right place. When turfgrass is fertilized and managed properly, leaching losses are typically less than 10% and leachate is typically less than 1 mg $L^{-1}$. Improperly managed, areas with poor groundcover will not only increase the risks of leaching but will also pose greater risk in sediment erosion and run-off. The run-off will contain both organic and inorganic nutrients. Improperly managed, leaching and run-off from turfgrass can each be significant hazards to groundwater quality and estuary health.

## Level of Maintenance

Turf management practices could be grouped in terms of the intensity of management. A low maintenance program might then be a consideration for reducing the chemical inputs including fertilizers and pesticides thereby lowering the risks to the environment. Low maintenance may

simply imply that it is mowed infrequently or receives no irrigation. Conversely, high amenity fields of turf may require a multiple chemical inputs and a variety of preparatory operations to maintain them. Certainly, golf courses have a need to provide uniform and consistent playing surfaces that are free of weeds and the effects of disease. Sports fields might require superior density and the ability to recover quickly. More aesthetic reasons might determine that certain areas of parks and public areas be immaculately kept. Homeowners will likely have a range of expectations but will certainly be critical of weedy lawns made bare in areas by wear or poor management.

On Long Island, a low maintenance turf program will depend on the species and cultivar. Overseeding with low input rated turfgrass would help reduce inputs while still providing a proven turf quality. Depending on the cultivars selected, a low maintenance level of 1.0 lb N $M^{-1}$ $yr^{-1}$ might be sufficient. With an historical average annual rainfall on Long Island of 46.8 inches, pretty evenly distributed throughout the months of the years, low maintenance turf, especially those cultivars that are proven to be drought resistant, should perform well.

## Leaching in Turfgrass Systems:

Leaching occurs when chemicals or compounds are washed through the soil profile. Highly soluble compounds, like nitrate, pose the greatest risk of leaching. Research has demonstrated that there are several major risk factors that lead to or increase leaching.

Soil Type

Well-drained soils with coarse textures and high percolation rates have lower water holding capacity, greater infiltration and higher risks of leaching. Newly seeded areas or areas with poor turf density pose higher risks than well-established stands of turfgrass.

Organic Matter

Soils with low amounts of organic matter have lower biological capacity to assimilate nitrogen and are more susceptible to leaching. Clippings returned to turf can add 3-4 lbs $M^{-1}yr^{-1}$ to the soil organic nitrogen reservoir and reduce fertilizer requirements by 1.5-2.0 lbs $M^{-1}yr^{-1}$.

Growth Phase

Newly seeded stands of turfgrass present very high risks.

Turfgrass in early stages of growth (1-20 yrs) has increasingly greater capacity to store and release nitrogen, reducing fertilizer requirements.

Mature turf (>20-30yrs) with clippings returned poses an exponentially higher risk of leaching.

Increased root mass or density increases nitrogen uptake while reducing the risk of leaching losses.

Product

Water soluble or readily available fertilizers, used at improper rates and timing, pose increased risks. Whereas, water insoluble or slow release products including organics or NBPT inhibited products, used properly, have a lower risk.

Fertilizer Rate

Excessive applications of any fertilizer product can create high soil nitrate levels susceptible to leaching.

Research has shown that the accumulation of nitrogen in the soil organic nitrogen reservoir increases with the age of a turf stand. Annual fertilizer rates of 1.5 to 3.0 lbs N $M^{-1}yr^{-1}$ are adequate for the cool season turfgrass species including creeping bentgrass, Kentucky bluegrass, perennial ryegrass and tall fescue. Annual rates below 1.5 lbs N $M^{-1}$ with clippings removed could lead to reduced root biomass, unacceptable turf quality and increased risk of leaching.

Single applications should be limited to a maximum of 1 lb N $M^{-1}$. More frequent applications of 0.5 lbs N $M^{-1}$ or less are preferred. The application should not exceed 0.5 lbs N $M^{-1}$ of any water soluble or immediately available nitrogen.

Timing

Applications made too early in the spring or too late in the fall will result in higher soil nitrate levels posing a greater risk to groundwater quality. Spring applications are only recommended to improve density and reduce weed encroachment. Only apply fertilizers when soil temperatures are above 50º F. Reduce application rates during peak summer stress and avoid late fall applications. Applications in September or splits in Early September and Early October are better timed.

P-ET/Irrigation

The greatest risk of leaching occurs during episodic weather events when precipitation frequency, intensity and/or duration contribute to soil moisture and then exceed soil water holding capacity. Similarly, excessive or uncalibrated irrigation applications can create similar leaching conditions. Risks of leaching are higher when evapotranspiration (ET) rates are lowest. The risks are also high when plant nitrogen uptake rates (NUR) are lower. For this reason, irrigation should be reduced or controlled during peak summer depending on species and during mid to late fall as plants begin dormancy. Use local data centers to record the difference of the amount of Precipitation – Evapotranspiration (P-ET) and reapply water at 60-100% of any negative P-ET value. Insure that the irrigation system provides measured rates and uniform coverage to all areas. Adjust application rates to take into account shaded areas or areas with lower air flow. These areas will have lower ET rates.

Application Site

Applications made onto impervious surfaces, near storm drains and near open bodies of water may be washed into storm drains and surface water. Good practice requires proper placement of fertilizers. Maintain a “no spray/no application” buffer zone of at least one pass of the sprayer or a minimum of 20 feet. Buffer areas are very effective at reducing runoff and leaching.

Because of the intensity of flow around storm water drains, the area around the drains should not receive any direct application of any water-soluble products including slow release urea formulations.

Identify the drainage characteristics and the proximity to the water table. Shallow water tables may require practices using much reduced rates at more frequent intervals.

Not only should equipment be inspected and calibrated before every use, the job itself needs to be assessed. Determine the actual area of coverage. Calculate material required. Familiarity with the site will identify any peculiarities.

Any application onto an impervious surface should be swept or blown off onto the turf to insure that this material is not washed away into surface waters, storm drains or ground water recharge basins.

Wash Stations:
There are currently no state or county regulations for the design and operation of wash stations. Discharge of wastewater from wash stations with low concentrations of pesticides and fertilizer onto an intended (labeled) target area does not require any special permits. However, USEPA regulations do apply to any wastewater that is discharged to a storm water runoff system, storm drains or ground water recharge basins. It is advisable to check your local laws for specific rules.

Pesticide application equipment should be washed in separate areas. For this equipment, it is advisable to either recycle the wastewater using specialized equipment or to discharge the water across a grassy area away from sensitive areas.

Clippings collected from turf and wash stations, if not composted, should be dispersed over a wide area. Clippings should not be dispersed near any water feature or wetland.

## Abbreviations

$NO_3$ ($NO_3$-N): Nitrate; $NH_4$: Ammonium; BMP: Best Management Practice; lbs per 1000 $ft^2$ per year. (lbs $M^{-1}$ $yr^{-1}$)

# A Global Nitrogen Perspective

Any discussion on the use of nitrogen should be first framed in an understanding of its origin and manifestation on a global and regional scale. The nitrogen cycle is a natural phenomenon and only recently, in the perspective of human history, the influence of man has created increasingly larger changes or fluxes in the cycle.

Up until the industrial revolution, natural processes converted nitrogen ($N_2$) in the atmosphere to reactive nitrogen ($N_r$). The $N_r$ would be emitted into the atmosphere either escaping into the upper atmosphere as nitrous oxide ($N_20$) or reacting from nitrogen oxide ($NO_x$) to form nitric acid ($HNO_3$) and precipitating to the earth's surface. Biological nitrogen fixation would convert atmospheric nitrogen ($N_2$) for use by soil microbes and ultimately plant life.

With the industrial revolution and the Hauber-Bausch process of nitrogen fixation, the man-made contribution of nitrogen to the global cycle increased 127 Tg N $yr^{-1}$ from 1860 to the early 1990's (Galloway et al. 2004). $N_r$ is expected to increase by another 103 Tg N $yr^{-1}$ by the year 2050. (One Tg is equivalent to 1.1 million tons.)

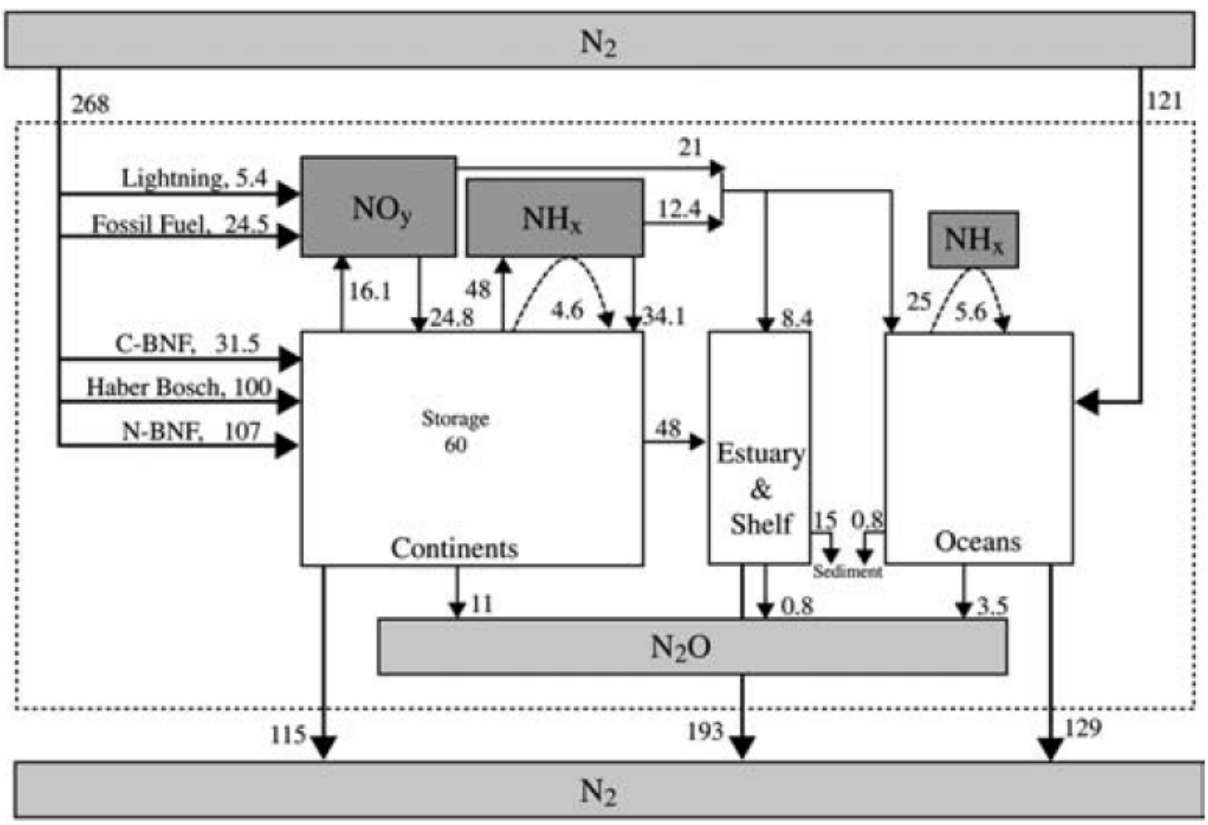



**Figure 1: Global Nitrogen Cycle from Nitrogen cycles: past, present and future. Galloway, J.N. et al, Biogeochemistry, 2004, 70, 153–226. The figure depicts the Nitrogen Cycle for the early 1990's.**

Figure 1 depicts the global flux of $N_r$ in its various forms for the early 1990's. The model represents the interaction between various reservoirs and our atmosphere. The continental reservoir absorbs 268 Tg N $yr^{-1}$ of which 100 Tg is through fertilizer inputs (Hauber- Bausch). It is important to distinguish the contribution made by Natural Biological Nitrogen Fixation (N-BNF)(107 Tg N $yr^{-1}$) from Cultivated Biological Nitrogen Fixation (C-BNF)(31.5 Tg N $yr^{-1}$). A significant amount of nitrogen is naturally deposited into our soils and waters. Atmospheric deposits to marine estuaries and shelves are 14.9% (8.4 Tg N $yr^{-1}$) of the nitrogen inputs to these ecosystems. The sum of all processes represents a "nitrogen cascade" that was once balanced but population growth and increasing demand of nitrogen create larger terrestrial reservoirs of reactive nitrogen (Galloway et al. 2003). The increases due to fossil fuel combustion, fertilizer use and increases in land use have doubled the rate of nitrogen input into our environment leading to increased nitrogen transfer to coastal regions, long term declines in fisheries and a loss in marine biodiversity (Vitousek et al. 1997) (Gray 1997).

## Suffolk County Geology and Aquifers

The geologic history describes the formation of Long Island across four glacial periods. The last, the Wisconsin glacier, nearly 11,000 years ago, formed Long Island Sound and most of the topographical features of Suffolk County today. The soils of Suffolk County are the result of glacial deposits of sorted sand and gravel, glacial till and to a much smaller extent, some alluvial silt and clay deposits. The advance of the glacier pushed large quantities of mixed material ahead of it forming a terminal moraine, called the Ronkonkoma moraine. This feature runs from the Nassau County line to Montauk. The glacier retreated and then advanced again pushing more material ahead to form the Harbor Hill moraine along the north shore. After each advance, as ice melted, water washed through materials, mixing and reworking material, leaving large stratified areas. This material is generally the sorted sand and gravel left in a broad plain ahead of the terminal moraines that defines much of the sub soil of Suffolk County. After the retreat of the last glacier, accumulations of water or wind deposited silt, clay and fine sand in varying depths.

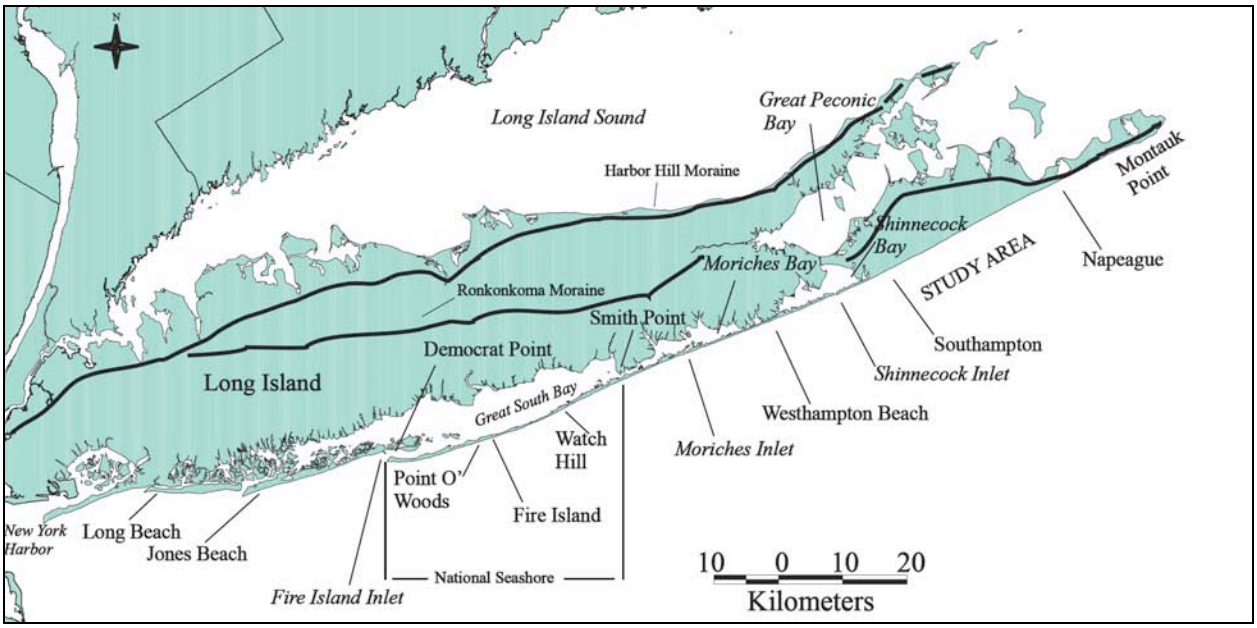
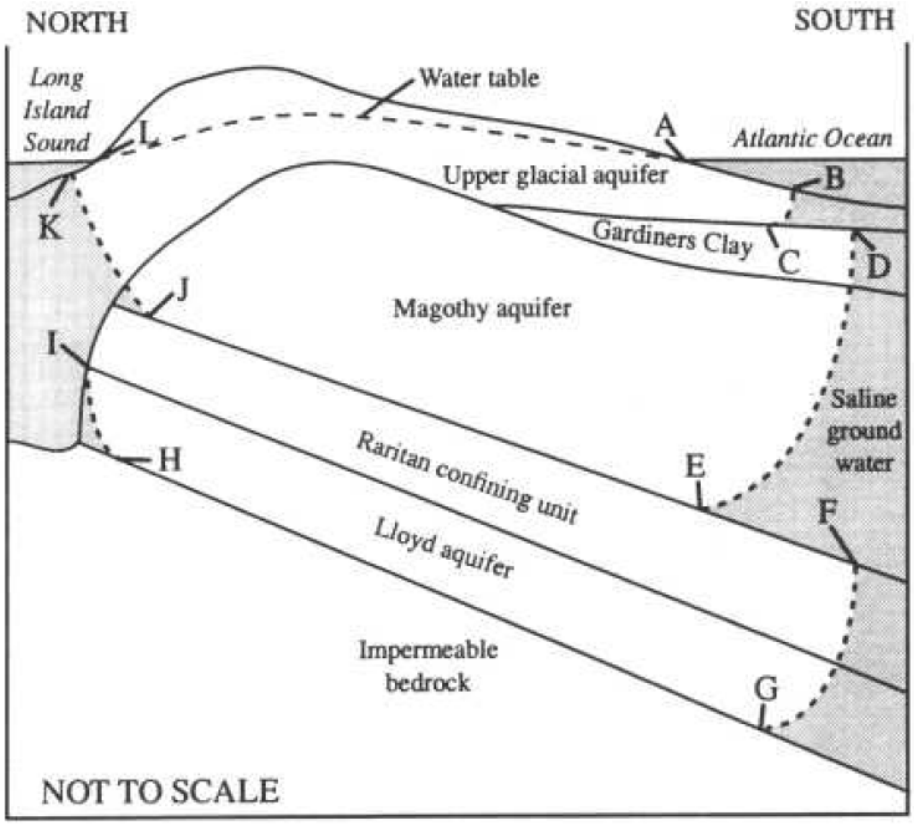



**Figure 2: Long Island Moraines, by Schwab, W.C., Thieler, E.R., Denny, J.F., Danforth, W.W., and Hill, J.C., U.S. Geological Survey, Coastal and Marine Geology, Woods Hole Field Center, Woods Hole, MA derived from Open File Report 00-243, http://pubs.usgs.gov/of/2000/of00-243/images/fig1.jpg**

The geologic process defined a land formation that contains three aquifers (Buxton and Smolensky, 1999). The Lloyd, the Magothy and Upper Glacial aquifers are bounded on two sides by the Long Island Sound and the Atlantic Ocean (See **Figure 3**). However, the Upper Glacial and Magothy are both recognized as being "unconfined" since there are no restrictions in flow between the two. There is a formation called Gardiners Clay along the south shore of the island that does restrict flow and defines a portion of the Magothy aquifer that is sometimes referred to as the Jameco Aquifer (Clawges et al. 1999). A confining unit referred to as the Raritan formation, in contrast, defines the Lloyd. The upper boundary limit of the Upper glacial

aquifer defines the upper boundary of the water table. Groundwater contamination in the Upper Glacial aquifer may mix with water in the Magothy in most areas on the island except along the south shore. It may also be discharged to the adjoining saltwater bodies via land features that describe boundary edges of the Upper Glacial aquifer. Groundwater flow or the rate of movement may be as slow as a fraction of an inch per day in clay to several feet per day in sand. Horizontal hydraulic conductivity is stated to be the highest (270 ft/day) in the southern part of the island; the rate is lower (130 ft/day) in the north central part of the island (McClymonds and Franke 1972). Three areas around Peconic Bay (Meetinghouse Creek, Sag Harbor Cove and West neck Bay) were studied to determine the groundwater recharge to the bay (Schubert 1999). In the case of Meetinghouse Creek, the recharge was split 50% as base flow to the stream and 50% as shoreline underflow. The Upper Glacial aquifer carried 85% of the recharge, the Magothy carried 15%; the average travel time was 7 and 120 years for each aquifer, respectively.




| Boundary Segment | Hydro-geologic Feature | Flow Characteristics |
|---|---|---|
| LA | Water table and streams | Recharge and head-dependent |
| HG | Consolidated bedrock | No flow |
| AB, KL | Shore discharge | Constant head |
| BC, DE, FG, HI, JK | Saltwater-freshwater Interface | No flow |
| CD, DE, IJ | Subsea discharge | Head pressure |

**Figure 3: Generalized hydro-geologic section showing major boundaries of Long Island aquifers. USGS Water-Resources Investigations Report 98-4069.**

Concentration of nitrates generally decreases at increasing depths of the soil/groundwater profile (Clawges et al. 1999). Deeper water is older water and less affected by human activities; deeper profiles provide more time for physical and chemical reactions to migrating contaminants; and, a greater volume of ground water flow dilutes contaminants. Groundwater withdrawals can also affect groundwater contamination levels. Withdrawals from water wells for household use or irrigation systems can draw shallow water with higher contamination levels downward and outward.

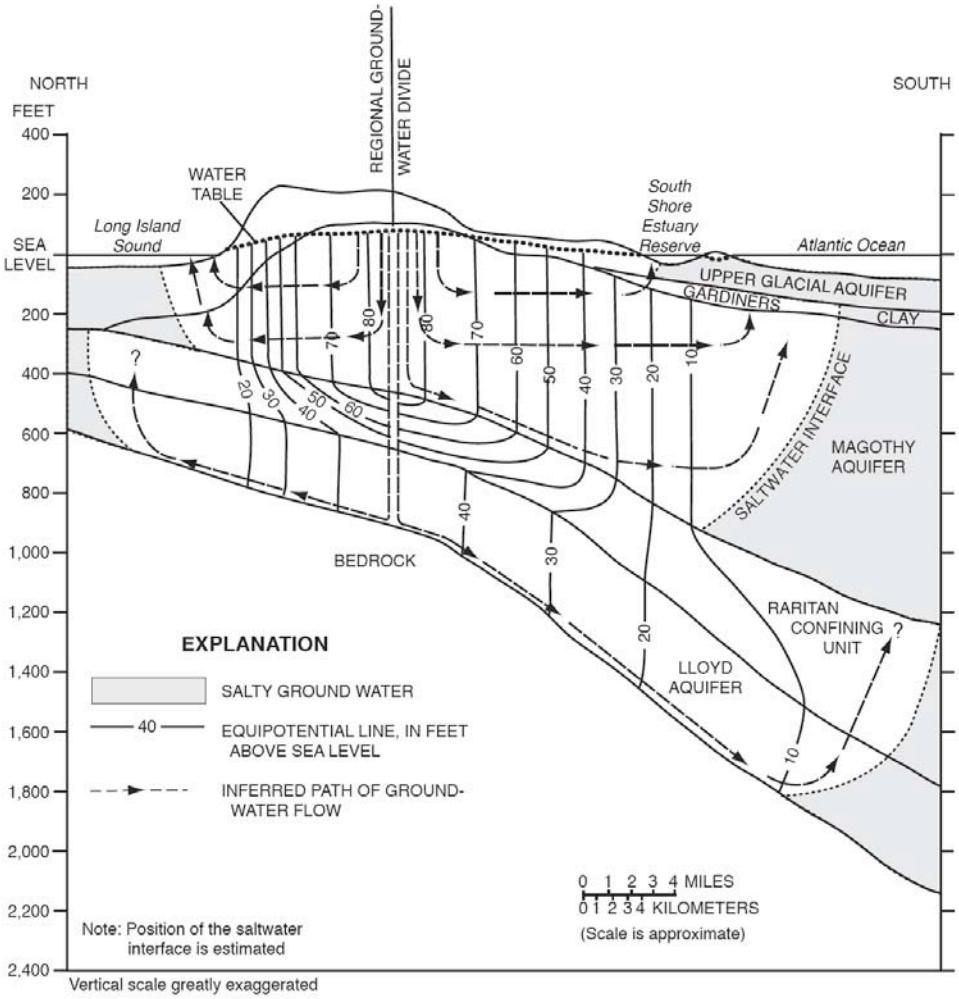



**Figure 4: Generalized section showing hydrogeologic units and generalized directions of groundwater flow on the north and south shores of Long Island, NY. (Monti and Scorca 2003)**

The hydrology of the Island is a set of complex relationships that define the flux in groundwater levels. The cycle is dependent on the amount of Precipitation, Evaporation and Transpiration (EvapoTranspiration or ET), Runoff and Recharge. Recharge to groundwater may be defined as the amount of precipitation that percolates through the soil, the amount of precipitation that collects as storm-water runoff in groundwater recharge basins, and discharge from septic systems (Leamond et al. 1992). Depending on the differences in soil properties, a soil can absorb varying amounts of water. At the point the ground is completely saturated, gravitational flow carries

precipitation (or irrigation) downward washing nutrients, pesticides and volatile organic compounds deeper into the soil and eventually into ground water. Evapotranspiration (ET) from the soil and plants is one of the important losses of water that escapes back into the atmosphere. Precipitation that is not lost to ET or held by the soil adds back into the Upper Glacial Aquifer as recharge. While the recharge rate is generally stated as 50%, the recharge rate in fact varies during the course of the season (Steenhuis et al. 1985). A three-year study on the island measured and tested models of recharge rates. A 50% recharge may aptly describe a long-term average. However, results determined that recharge rates tend to 0% in the mid-summer months during peak ET and then climb as high as 75-90% between October and May as ET rates subside. Consequently there is a higher risk of groundwater contamination in late fall, winter and early spring months. Buxton and Smolensky (1999) established similar guidelines listing evapotranspiration at 47%, runoff at 1% and recharge at 52%.

In its native undeveloped state, recharge on Long Island added about 1.1 billion gallons per day to groundwater (Buxton and Smolensky 1999). Urbanization has placed increasing demands on the aquifers. The demand for water from wells has created localized effects such as changes in shallow water flow patterns; reductions in ground water levels; drying up of streams; reduction in wetlands and saltwater intrusion. Urbanization and agricultural use have also introduced anthropogenic sources of nitrogen primarily through sewage discharge and the use of fertilizers. Land use has also created localized discharge or concentrated recharge areas that can exacerbate the nitrogen loading into groundwater.

## Land Use

Suffolk County occupies an area of approximately 590,080 acres. In 1975, the land use was classified as being 13% farm, 34% woodland, and the balance defined as idle or built-up (United States Soil Conservation Service. et al. 1975). Porter (1980) suggested that Suffolk County had more than 200,000 acres in turfgrass based on 1975 Regional Planning Board survey. There has been a steady decline in agricultural land. The 13% agricultural land use noted in 1975 equates to 75,710 acres of farmland. The current agricultural census identified a total of 34,404 agricultural acres in Suffolk County (NASS, National Agricultural Statistics Service 2010). By 1981, residential land use accounted for 37% of the area in Nassau and Suffolk County; vacant space, open or recreational areas, 39%; agricultural, 7%, transportation and utilities, 5%; institutional, 5%; commercial, 3%; industrial 2%; and open water, 2% (Eckhardt and Stackelberg 1995).

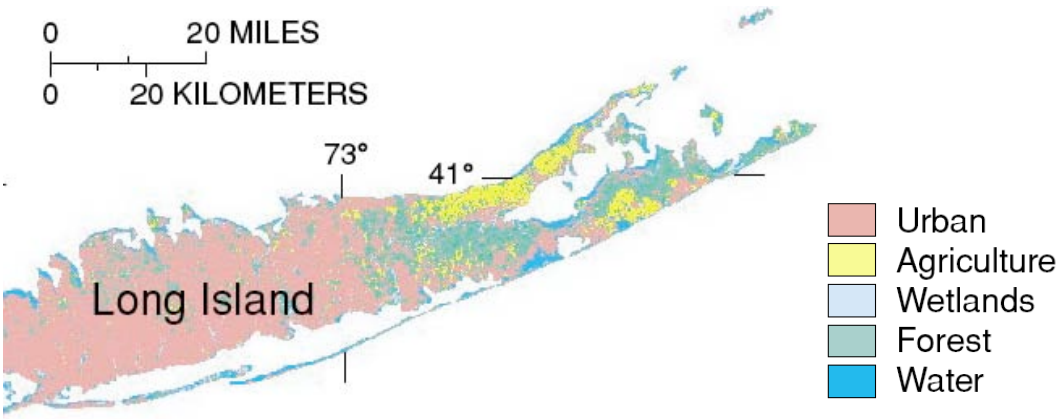



**Figure 5: Land Use 1992-1995**
**Water Quality in the Long Island-New Jersey Coastal Drainages**
**USGS Circular 1201, (Ayers, M.A., Kennen, J.G., and Stackelberg, P.E. 2000)**

Leamond et al. (1992) measured identified population densities in areas of varied land use intensity. The highest population density was 10-14 people per acre in a sewered district in Nassau County. Densities declined as they moved eastward into Suffolk County. An unsewered area in western Suffolk County had a population density of 6 people per acre. The agricultural and undeveloped areas had a density of 1 person per acre.

The population in Suffolk County surpassed Nassau County in the 1990 Census. Suffolk County had grown 10% since 1980 compared to a 1% increase in Nassau County (Long Island Index 2004). By 2000, residential land use in Suffolk County alone had increased to 40.7%; vacant space, open or recreational areas, 37.6%; agricultural, 6%; institutional, 6.9%; commercial, 3.6%; and industrial 4.3%. The Long Island Regional Planning Board projected that Suffolk County population would continue to grow from its 2000 level of 1,419,000 to 1,557,000 in 2010 and another 12% over the next 20 years.

The Peconic Estuary Program (2007) reported a total of 51,898 acres within the Peconic Bay watershed including 46,112 acres of residential zoned land noting a significant trend of land being converted to residential use over the period of 1976-1995. Land use has been inventoried and preservation measures adopted with the intent of limiting development and the associated increases in nitrogen inputs.

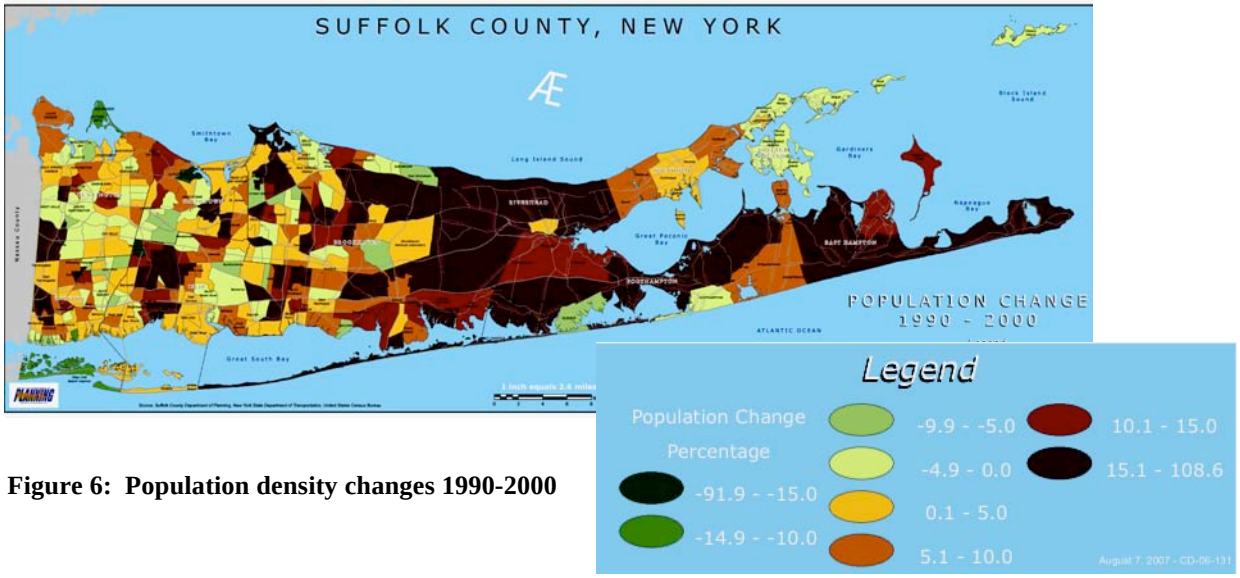



**Figure 6: Population density changes 1990-2000**

**http://www.co.suffolk.ny.us/Home/departments/planning/Cartography%20and%20GIS/Cartography/Online%20Maps.aspx**

Howarth (1996) assembled a nitrogen budget to account for the fluxes in nitrogen inputs into our North Atlantic waters. Where population densities are high, sewage is often the largest factor. However, sewage inputs only accounted for 11% of the total nitrogen input for all North Atlantic watersheds. However, the Northeast was much higher than average with 26% of the total nitrogen originating from sewage. Another assessment looked at the Northeast to account for net anthropogenic nitrogen inputs (Howarth 2008). The Northeast is a net importer for food and feed accounting for 28.1 % of the nitrogen. Biological nitrogen fixation adds 21.1 %; atmospheric deposition adds another 33.9%; and, fertilizer inputs were 16.9%.

| **Inputs to Northeastern United States**: | **Lbs N per square mile per year** |
|---|---|
| Food and Feed | 5,698 |
| Biological N Fixation | 4,274 |
| Fertilizer | 3,419 |
| Atmospheric Deposition ($No_x$) | 6,838 |
| **Outputs To River Basins / Watersheds** | |
| Non-Point Source | 4,501 |
| Sewage Treatment Plant Discharge | 1,595 |

**Table 1: Nitrogen flux in Northeastern United States (Howarth 2008)**

The assessment states that approximately 30% of the nitrogen inputs are leaked out to the northeastern watersheds through non-point source and sewage treatment plant discharge. The balance is held as organic nitrogen in plants and soil.

The role of turfgrass has been criticized for contributing contaminants to groundwater. Some sources identify 50% of the fertilizer applied to turf to be leached into groundwater (Flipse et al. 1984). Their assumption was based on early research showing that plant uptake was measured to be 50% of the nitrogen applied as fertilizer (Snow 1976). The nitrogen not absorbed by the plant was assumed to be lost to groundwater. The erroneous extrapolation has been propagated into other work and carried on in nitrogen load calculations (Peconic Estuary Program 2007). Research has defined the role of turfgrass as a source of contaminants to our environment (Easton and Petrovic 2005). Turfgrass has been shown to have leaching losses measuring less than five percent of the fertilizer applied (Barton and Colmer 2006). The "Nutrient Management for Turfgrass " section (pg 53) reviews the research for the mass balance of nitrogen applied to turfgrass.

Given the natural cycling of nitrogen in our environment, it is important to establish a basis for comparing nitrate levels in groundwater. Nolan and Hitt (2003) established background levels 1.1 mg N $L^{-1}$ for shallow wells (< 98 feet deep) within undeveloped land areas using data from national surveys. Median nitrate levels beneath rangeland were 1.2 mg N $L^{-1}$ compared to 0.06 mg N $L^{-1}$ beneath forested land. Where coarse textured or gravely deposits were measured under rangeland, median nitrate levels were as high as 1.4-2.7 mg N $L^{-1}$. The authors suggest these levels may be typical to areas like Suffolk County due to nominal nitrogen loads associated with natural organic and inorganic sources in hydro-geologically susceptible areas.

## Water Quality Issues

Nitrates may potentially leach into groundwater posing a potential health risk with drinking water. Stormwater may similarly wash nutrients away in runoff to depressions that act or were designed as groundwater recharge basins.

The groundwater recharge to the estuaries and any surface water runoff can increase nutrient loading to the estuaries resulting in increased organic matter production, or eutrophication, and a number of secondary problems. Those secondary problems include reduced oxygen, lower light penetration, and harmful algal blooms. Eutrophication can alter the habitat for submerged aquatic vegetation and marine life reducing the size and diversity of the ecosystem and fisheries. Some algal blooms, sometimes referred to as red or brown tides, in addition to accelerating the eutrophication process, can also be toxic to crustaceans, fish and humans.

The EPA's ECOTOX database (http://cfpub.epa.gov/ecotox/quick_query.htm) records only 18 tests on aquatic organisms for nitrate as a toxin (CAS Number: 14797558). In marine ecosystems and Long Island's estuaries, nitrate alone has not been shown to be toxic. However, the indirect effect of increased nutrient loading in rivers, lakes and marine ecosystems has been shown to be harmful.

Given the unique characteristics of Long Island's aquifers, Suffolk County has accounted for the hydrological conditions of the aquifers, groundwater flow and recharge areas to establish that the entire county can be described as a "critical water area". The population of Suffolk County must recognize that their land use can alter the groundwater quality, endangering the drinking water supply and altering the marine ecosystems of the principle estuaries of the island.

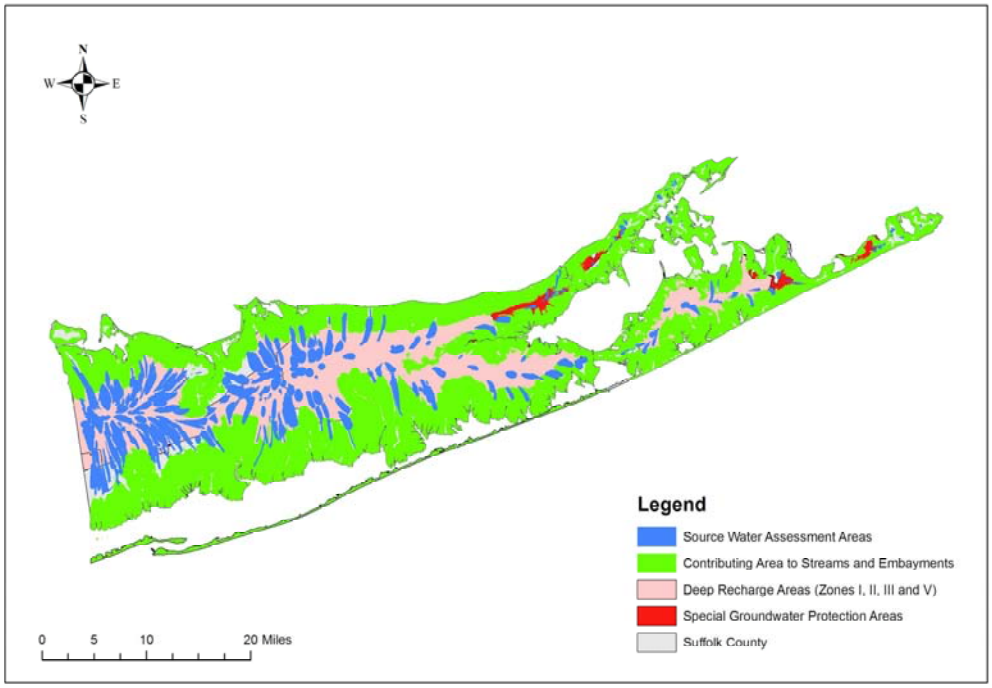



**Figure 7: Critical water areas of Suffolk County (Trent 2010).**

## Drinking Water Contamination

The Environmental Protection Agency (EPA) is empowered by the Safe Drinking Water Act (1974) to protect public health by regulating public drinking water and it's sources. The original act, subsequent amendments, and adoption of New York States Sanitary Code (10NYCRR) and modifications by the New York State Department of Health, now require monitoring 91 different contaminants in Suffolk County's drinking water (CDM 2010a). The County Public and Environmental Health Laboratory currently monitors 341 water quality attributes including inorganic elements and compounds, volatile organic compounds, and pesticides. Nitrates and nitrites are inorganic compounds tested and regulated by the EPA and New York State because of their association with a disease in infants, methemoglobinemia, sometimes referred to as "blue baby syndrome" (Fan and Steinberg 1996). A Maximum Contamination Limit (MCL) of 10 and 1 mg N $L^{-1}$ has been set by the EPA for nitrates and nitrites, respectively (EPA 2009a).

There was an international conference in 2004 to review the health related issues of nitrates in drinking water (Ward et al. 2005). There are challenges to the validity of tests and limits for Methemoglobinemia (Avery 1999). Other studies have suggested that nitrates are transformed into N-nitrosa compounds that are linked to a number of health related problems. For example, there are concerns that drinking water with nitrates in excess of 4 mg $L^{-1}$ may be related to non-Hodgkin's lymphoma (Ward MH et al. 2000)(Ward MH et al. 1996). Nitrate levels of 2-8 mg N $L^{-1}$ may increase the level of insulin dependent Type II diabetes (Kostraba et al. 1992). These claims have not influenced the EPA or New York State to modify the nitrate standards.

The U.S. Geological Survey (USGS) implemented a National Water Quality Assessment (NAWQA) program in 1991. In their most recent scientific investigations report for the period of 1991-2004, the USGS evaluated the measurements from 2100 wells sampled in 48 states across 30 regional aquifers used for water supply (DeSimone 2009). The study found 219 different properties or contaminants including nutrients, pesticides, volatile organic compounds, and fecal indicator bacteria:

- 23% of wells sampled had one or more contaminants at concentrations greater than human health limits.
- 4.4 % of wells sampled had nitrate levels greater than the maximum contaminant level (MCL) of 10 mg N $L^{-1}$.
- Low-level occurrence of pesticides and man-made compounds were found in 60% of wells sampled.
- Microbial contamination was found in as many as one third of the wells sampled

This national study found nitrate concentrations were higher in areas of agricultural land use with 7.1 % of the wells sampled exceeding the MCL compared to 3.1 % in areas of urban land use. But even undeveloped areas had wells that exceeded the MCL. Concentrations were positively correlated with fertilizer use in areas around tested wells and were higher in areas with well-drained soils. A separate analysis of 436 shallow wells in relatively intensive agricultural areas showed that concentrations of nitrate exceeded the MCL on 25% of the wells tested. Land use is a significant factor in nitrate contamination of groundwater but other factors create nutrient loads even in undeveloped areas.

Long Island and New Jersey are included as one unit of study for the National Water-Quality Assessment (NAWQA) Program. The 6,000 sq mi area is one of the most heavily urbanized and populated units under study. One study found that 35% of the urban-residential and 21% of the urban-nonresidential wells sampled had nitrate concentrations above 3 mg $L^{-1}$ compared to 70% in agricultural areas (Clawges et al. 1999). In undeveloped areas, 10% of the wells exceeded 3 mg $L^{-1}$. Less than 3% of the wells sampled in urban residential, urban non-residential, and undeveloped areas exceeded the 10 mg $L^{-1}$ MCL, whereas 22 percent of the wells in agricultural areas exceeded the MCL. The median levels for urban residential, urban nonresidential, undeveloped and agricultural areas were 1.4, 0.9, 0.1 and 5.5 mg $L^{-1}$, respectively. Another study reported much higher median levels of 5.1, 5.8, 6.6 and 8.9 mg $L^{-1}$ for long term sewered, short term sewered, unsewered and agricultural areas, respectively (Leamond et al. 1992). The undeveloped wells sampled had a median nitrate level of 0.2 mg $L^{-1}$. In the Leamond study (1992) there was a greater percentage of wells exceeding the USEPA drinking water MCL with 25% of the short term sewered and unsewered wells and 40% of the agricultural area wells exceeding the 10 mg $L^{-1}$ MCL.

Suffolk County Department of Health Services (SCDHS) and the USGS, together, test 495 monitoring wells throughout the County to verify water quality in the aquifers (CDM 2010a). Nitrate levels in 10% of the private wells tested in the last ten years exceed the 10 mg $L^{-1}$ MCL. During the same period, 29% of the private wells tested had nitrate levels over 4 mg $L^{-1}$ but less than the MCL. This data is inline with the earlier studies describing problems with shallow wells.

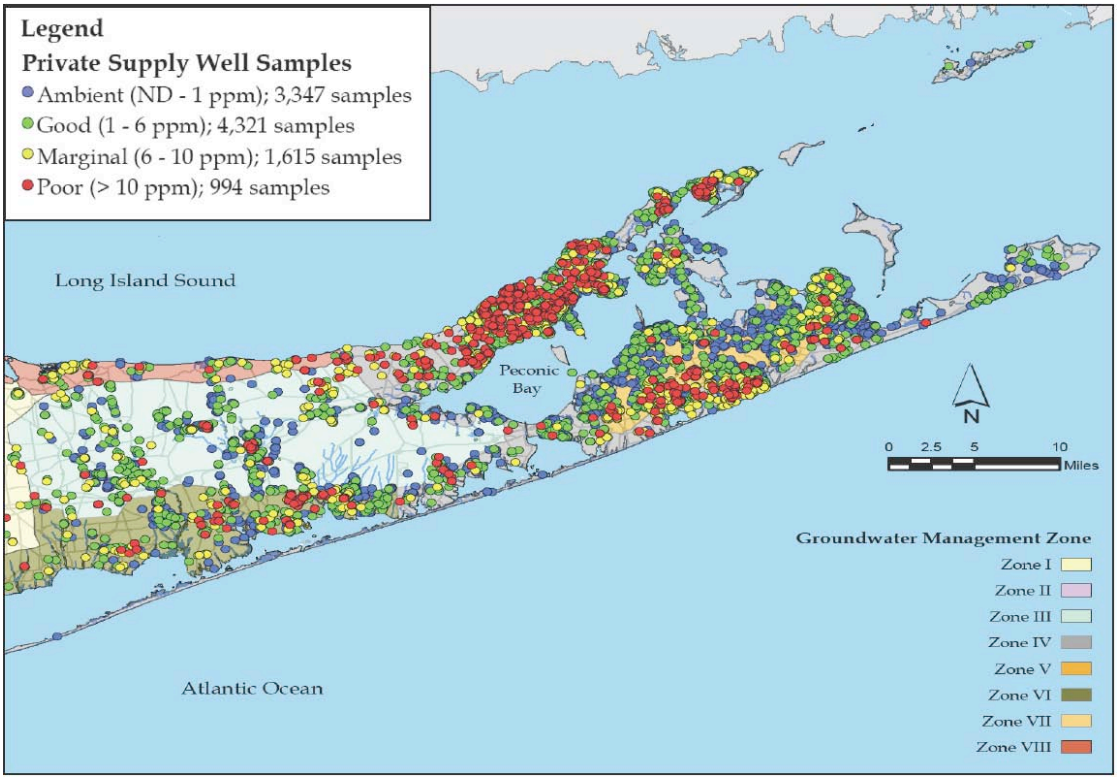



**Figure 8: Private Well Testing 1997-2006 (CDM 2010b) Suffolk County Comprehensive Water Resources Management Plan, Task 4.1 - Groundwater Quality**

Testing has also probed the aquifers to assess contamination. The average concentration of nitrates in the Upper Glacial and the Magothy aquifers has increased from 3.12 to 4.34 and 1.14 to 3.43 mg $L^{-1}$, respectively, from 1987 to 2005.

Results have also confirmed the presence of volatile organic compounds and pesticides in public supply and private wells at levels and frequencies that are consistent with national studies.

Clearly, there needs to be an increased sensitivity to groundwater quality and an understanding of the physical nature of the aquifers, groundwater flow, and the influence that land use has on the quality of drinking water supplies.

## Eutrophication

Eutrophication has many definitions and is still under some debate (Andersen et al. 2006). For consistency with some of the leading biogeochemistry experts of coastal waters, eutrophication is defined as the increased accumulation of organic matter, usually as a result of increased nitrogen and phosphorus inputs, but possibly resulting from an excess of organic carbon (Nixon 1995). The inclusion of carbon has been noted as causing secondary effects of eutrophication including harmful algal blooms (HAB) and low dissolved oxygen levels (Rabalais 2002). With increased nutrient loading, primary production increases with a variety of plants including phytoplankton, microalgae and macroalgae including sea grasses. Increases in phytoplankton production are usually associated with increases in turbidity and a decrease in light penetration. A series of changes begin with reduced growth to plants at lower depths, which in turn reduces habitat. The response of phytoplankton and macroalgal growth has been shown to vary depending on the depth of water and the degree of nutrient loading.

Phytoplankton blooms are a significant part of the eutrophication process. The increase in phytoplankton growth have been linked with increased nutrient loading (Rabalais et al. 2009). The increased organic matter productivity associated with eutrophication, especially algal blooms, leads to increases in dead organic matter falling to the estuaries bottom. Aerobic bacteria consume the detritus, depleting the water of oxygen resulting in reduced levels of oxygen. At reduced levels of oxygen, plants cannot sustain themselves and sea life flees the area of impairment. The benthic (bottom) microfauna become stressed and die. The accumulation of biomass, nutrient load and lack of oxygen changes the reduction and oxidation dynamics (McMahon and Chapelle 2008). The effects start at the deepest depths but conditions promulgate the processes of oxygen depletion higher in the water column. Sulfate respiration takes the place of oxygen respiration, creating toxic hydrogen sulfide. The bottom sediment begins to break up, increasing the waters turbidity, adding to the reduced light conditions and the secondary effects of eutrophication.

Hypoxia is a state of reduced oxygen levels. Rabalais (2009) defines hypoxia at levels of dissolved oxygen $< 5$ mg $L^{-1}$ in contrast to anoxia, an extreme condition, where the water is void of any oxygen (dissolved oxygen = 0 mg $L^{-1}$). The definition for hypoxia varies. The EPA defines it as a "non-specific level of dissolved oxygen that has a negative effect on plants and marine life" (EPA 2001). Parker and O'Reilly (1991) noted pronounced summer declines in the Long Island Sound when dissolved oxygen was $< 3$ mg $L^{-1}$. Suffolk County has based their management plans on two tiers of hypoxia taken from data collected from the Peconic Bay: chronic hypoxia is where the average daily dissolved oxygen level is $< 4.8$ mg $L^{-1}$ and acute hypoxia is defined as any reading $< 3$ mg $L^{-1}$ (Peconic Estuary Program 2007).

The levels of dissolved nitrogen and phosphorus in marine systems have been characterized to approximate the remineralization of phytoplankton where the ratio of carbon to nitrogen to phosphorus (C:N:P) was defined as the Redfield ratio at 106:16:1 (Redfield 1958). The fundamental ratio of these chemicals in water can limit phytoplankton growth. As phytoplankton are the base of the food web, if their growth is limited, then primary production is limited. Given the Redfield Ratio, if there were an increase in nitrogen without a commensurate increase in

phytoplankton growth, the growth would be phosphorus limited. Similarly, if no primary production increases with the addition of phosphorus, then the system is nitrogen limited.

Howarth (1988a) suggests that nutrient limitations be defined as a "limit in net primary production" noting that three factors will identify whether nitrogen or phosphorus is limiting: (1) the ratio of nitrogen and phosphorus in the inputs to the estuary; (2) the losses of each of these nutrients in the photic zone; and (3) the extent that nitrogen fixation replaces the nitrogen lost in this zone. Estuaries tend to differ from lakes in that cyanobacteria do not make up a significant portion of the phytoplankton. Consequently there is less nitrogen fixation. Bioassays of estuaries have shown increases in net primary production with increases in nitrogen, but bioassays with only phosphorus additions did not always increase production (Smayda 1990). Interestingly, bioassays with increases of both nitrogen and phosphorus tended to have more of an effect than nitrogen alone. References are made to water samples taken from the Peconic Bay and Long Island sound with dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphorus (DIP) of 1.5:1 and 3.9:1, respectively, suggesting that both samples indicated nitrogen as a limiting nutrient (Howarth 1988a). While DIN:DIP may vary seasonally and spatially, any ratio below the Redfield ratio will be nitrogen limited. Conversely, any ratio greater than 16:1 will be phosphorus limited. Howarth (1988) suggests that estuaries are typically nitrogen limited because of the high phosphorus content of the sewage inputs to estuaries.

Many scientists have criticized the limitations of bioassays to measure nutrient limitations. Large scale tests have now conclusively established that nitrogen is the *most* limiting nutrient *most* of the time (Howarth and Marino 2006). Generally, these tests observed increases in organic matter and chlorophyll when phosphorus and nitrogen were added together and when nitrogen was added alone. There were no increases when phosphorus only was added. Only in the last decade has science come to terms with the differences between lakes and estuaries identifying plausible differences: 1) Salinity >10-12 will restrict the nitrogen fixation process. The degree of groundwater recharge and mixing would influence salinities in shallow or brackish bays. 2) Estuaries have relatively higher levels of phosphorus due to desorption as salinities increase and lower sediment storage. However, differences have been observed where phosphorus adsorption and storage was higher in some estuaries. 3) Ocean water tends to have very low DIN:DIP ratios compared to riverine/terrestrial water. The mixing of ocean water into estuaries will tend to drive the ratios in one direction. However, shallow estuaries with significant sea grasses and algal mats tend to have very high primary production even when nitrogen inputs are low. These waters tend to have nitrogen fixation with benthic and epiphytic cyanobacteria. The dynamics vary. Estuaries have still been observed to have phosphorus limitations even when there are extremely high nitrogen inputs. The outcomes vary. Sometimes, estuaries have been observed to have more anoxic conditions associated with nitrogen limitations. Primary production tends to decline in phosphorus limited waters suggesting that oxygen depletion may be better controlled by limiting phosphorus inputs.

High phosphorus has also been related to increases in undesirable macro-algae (Howarth and Marino 2006). The relative amounts of nitrogen to phosphorus (N:P) and phosphorus to silicon (P:Si) and the reduced availability of silicon have been related to the loss of diatoms, a reduction in the quality of the food web, and increased harmful algal blooms (Smayda 1990). Rabalais (2002) cites multiple limitations among nitrogen, phosphorus, and silicon that vary by the

salinity of the water and the season. There are positive correlations with the non-linear production of phytoplankton and fisheries yields. The entire system seems to prosper. However, there is some threshold of nutrient increases where water quality will degrade and the system collapses. As the Si:N ratio approaches 1:1, aquatic food webs may be compromised, shifts in phytoplankton species may occur, and harmful or noxious algal blooms may increase in size and frequency. Increasing amounts of nitrogen in amounts that approximated another variation of the Redfield ratio, a Si:N:P ratio of 16:16:1, would result in increasing phytoplankton production. A relationship was also found with decreasing Si:P ratios and increased phytoplankton blooms, both toxic and non-toxic (Paerl 1997; Smayda 1990).

Mills and Arrigo (2010) have demonstrated that rapidly growing phytoplankton with low nitrogen to phosphorus uptake ratios reduce the phosphorus available for nitrogen fixation; and, systems with slow growing phytoplankton with high nitrogen to phosphorus uptake ratios create nitrogen deficits and enhance nitrogen fixation. They argued that the "balanced" system in a static N:P Redfield ratio is better understood with a N:P plasticity where ratios would be lower during algal blooms and higher during oligotropic periods dominated by cyanobacteria. They proposed that the remineralization of phytoplankton of varying, non-redfield N:P ratios is a natural feedback system that helps rebalance marine inventories of N and P. Howarth (1988b) suggests the presence of cyanobacteria and nitrogen fixation is low in estuaries when N:P ratios are low. The inhibition is thought to be the result of limitations of iron, an essential element for nitrogen fixation (Paerl 1997). However, if reducing conditions are right and there is a high level of dissolved organic carbon, iron may be more available accounting for phytoplankton blooms.

Reduction and oxidation processes (Redox) is another manner in which contaminants can be mobilized or immobilized in groundwater and marine ecosystems (McMahon and Chapelle 2008). While oxygen has the highest redox potential, nitrate has the second highest potential. In water with depleted oxygen content, nitrate can react with dissolved organic carbon to produce nitrogen ($N_2$) and bicarbonates; it may also react with sulfides. The authors suggest that water samples be tested for oxygen to provide some measure of the redox capacity and the relationship to contaminant levels. They found a very strong correlation between oxygen levels and the degree of nitrates and volatile organic compounds in the principle aquifers tested. This may, in part, describe the surface water tests of the Peconic Bay where nitrate levels have been lower in recent years in the waters noted to have lower dissolved oxygen.

The suggestion is made that estuaries are very complex with spatially and seasonal variations (Howarth and Marino 2006). Noting observations that some estuaries have been observed to be phosphorus limited in the spring and nitrogen limited in the summer, simplistic N limiting models may be incomplete and more research is required to understand the dynamic limitations of each element. The relative ratios of nitrogen and phosphorus and their ratios with other elements such as silicon have also been shown to be fundamental to increases in primary growth (Smayda 2008). As Howarth (2006) states, perhaps the best course of action is to limit the influx of both nitrogen and phosphorus in our coastal waters.

## Harmful Algal Blooms

The increased nutrient inputs into estuarine waters can stimulate organic matter production of phytoplankton, microalgae and macroalgae. The overall increase in productivity may be beneficial to the entire ecosystem up to the point that the biomass increases become disproportionate to the capacity of the system (GEOHAB 2006). When the system is unbalanced, large blooms of phytoplankton can become harmful. As the blooms die off, their decay consumes oxygen and can result in hypoxic waters that alter the habitat for other forms of marine life.

The conditions of Long Island's estuaries have been found to have medium to high levels of phosphorus and nitrogen, high chlorophyll measurements associated with high concentrations of algae, and low levels of dissolved oxygen (NOAA 1997). High levels of chlorophyll have been observed in the Peconic River outlet and the western side of Flanders Bay (Szekielda et al. 2006).

Phytoplankton populations typically bloom in the stratified water that occurs as a function of several dynamics including, but not limited to, daily and seasonal temperature profiles and mixing from tides, currents, and wind (Gentien et al. 2005). The blooms typically occur in the mixed layer from the surface to the thermocline. This mixed layer is superficially heated by increasing summer temperatures, and oddly, often depleted in nutrients. The hypothesis is that motile phytoplankton strip the surface layer of nutrients, descending at night to feed on nutrients in lower layers, and ascending again in the day time for photosynthesis (Anderson 1994). The blooms typically peak during summer months. The cycle of these blooms can be seen with associated reductions in dissolved oxygen (Peconic Estuary Program 2007).

When blooms of phytoplankton occur in such abundance, the small-pigmented plants can change the color of the sea often termed "Red tides" but they may in fact be red, brown or green. In 1987, blooms of harmful algae occurred along the US Atlantic coast from Canada to North Carolina that caused three human deaths and 105 cases of acute poisoning (Anderson 1994). Symptoms included disorientation, dizziness, vomiting, and diarrhea. Other symptoms included respiratory distress and eye irritation. In the same period, five humpback whales where found beached having also suffered from phytoplankton toxins.

There are many species of phytoplankton. They occur in ecological niches that define their distribution and behavior (Anderson 1994). The patterns are still not fully defined or understood. A common species, *Dinophysis,* has strains that occur along the European Atlantic coast and are toxic causing Diarrheic Shellfish Poisoning (DSP) among humans. Yet the same species occur along the U.S. Atlantic coast but are not toxic. There are blooms of phytoplankton that discolor the water but are not toxic. And there are blooms that are colorless and non-toxic, but can kill marine life in other ways. For instance, the dynoflagellate *Gymnodinium breve* causes large fish kills by asphyxiation. A diatom, *Chaetoceros convolutes*, is non-toxic but has long spines that lodge in the gills of fish causing a mucus response, degeneration of the gill function, and death.

One report identified over 200 different species of toxic phytoplankton with seventeen different groups of toxins (Landsberg 2002). The effects of the toxins can be acute or chronic. The toxin can be transferred directly or indirectly through the food chain. In some species, the toxins are still not fully documented or understood; their chemistry is variable. Many of the toxins are produced as alkaloids, polyethers and substituted amines (Plumley 1997). These toxins are popularly considered to be secondary metabolites; or substances produced when normal or balanced growth ceases. This becomes a strong argument in the debate that high nutrient zones and depleted nutrient zones can both trigger the production of toxins.

There are thousands of species of phytoplankton that form the base of the food web. Toxic species consist mostly of dinoflagellates, prymnesiophytes or chloromonads. Shellfish ingest the phytoplankton (and toxins), generally without effect. The toxins accumulate or biomagnify to a point that they can cause harm or death to humans in a variety of illnesses recognized as Amnesic, Paralytic, Diarrhetic and Neurotoxic Shellfish Poisoning (ASP, PSP, DSP and NSP) (Anderson 1994; Plumley 1997). Another problem, ciguatera fish poisoning, CFP, is caused when dynoflagellates that are attached to seaweed are eaten by fish. The toxins accumulate in the fish causing sickness to humans that eat the fish.

Asexual reproduction is very fast and can create large blooms rapidly. Sexual reproduction produces "Cysts" that can persist for years in the sediment. When conditions are right, the cysts will germinate and repopulate the waters. These cysts can also be propagated in ocean currents and carried into new waters. The incidence of red tides has been increasing and the number of observed toxic blooms has also increased. One criticism is that science is far more sensitive to the problem with larger numbers of observers and better methods of detection. The consensus associates the incidence of blooms with increased coastal pollution. Some scientists suggest that the pollution has created an increase in phytoplankton blooms both toxic and non-toxic, indiscriminately (Anderson 1994). Others suggest that the pollution is selectively stimulating harmful or toxic algal blooms (Smayda 1990; Smayda 2008). The theory is based on the changes in the nitrogen (N) to phosphorus (P) to silicon (Si) ratios. Since sewage has little or no silicon, the N:P:Si ratios are imbalanced with higher N and P. Diatoms are less favored and other species of phytoplankton are favored. The selectivity concept is also consistent with the findings that toxins are produced as secondary metabolites stimulated by imbalanced growth conditions (Plumley 1997). One noted field study observed a 7.5 fold increase in phosphate ($PO_4$) and a 3-fold increase in nitrate over two decades with an increase in the number of unusual blooms (Smayda 1990). The field data notes substantial increases in nutrient loading but a declining ratio of N:P. In contrast to the nutrient loading argument, Smayda (2008) points out that large blooms have also been evident in nutrient poor, oligotrophic waters. Smayda (1997b) has also shown that there are significant differences between species of phytoplankton and their affinity for nutrients.

Studies in Florida have shown that cyanobacteria, diatoms and dynoflagellates respond differently to different sources of nitrogen and phosphorus (Glibert et al. 2004). Cyanobacteria showed a preference for dissolved organic nitrogen and phosphorus. Dynoflagellates and diatoms preferred inorganic nutrients, but each had regionally different responses to the additions of dissolved organic nitrogen and phosphorus. The complexity may be seen where diatoms flourish in the spring, feeding off of inorganic nutrients. The diatoms die off, decompose, and enrich the

waters with organic forms of nutrients that stimulate dynoflagellate blooms. But Smayda (1997a) cautions that basing the seasonal cycle of blooms on the first spring diatom bloom is too simplistic. This sentiment is better reflected in the complex array of factors and conditions assigned to harmful algal bloom dynamics (Glibert et al. 2005a). Increased nutrient loading, in all its forms, and altered ratios of nutrient elements are central to all discussions. Dissolved Organic Matter (DOM) has also been identified as another nutrient form of carbon, nitrogen and phosphorus and ties have been made to the agricultural sources such as manure (Glibert et al. 2005b). The forms of nutrients are not only being linked to an overall increase in harmful algal blooms, the forms are also being tied to increases in the level and composition of toxins (GEOHAB 2006). These nutrient ratios are also being linked with the phytoplanktons ability to produce allelochemicals. In conditions of limited nutrient sources the phytoplankton emit allelochemicals to fend off and kill competition allowing the phytoplankton to flourish.

The long term trend suggests more frequent blooms across wider and wider areas of the world either as a consequence of increased pollution or a suite of changes in nutrient loads and natural environmental parameters (Okaichi et al. 1989; Smayda 2008). Climate change could be one example where surface water temperatures change or precipitation changes altering groundwater recharge. The debate continues as to whether there is a global increase in eutrophication and a general increase in harmful algal blooms; or, is there a global phenomenon of disrupted plankton habitat where alterations are inducing increased numbers of harmful algal blooms (Smayda 2008). Those alterations may be changes in currents, tides, and storms as variables in mixing; or temperature increases associated with global change; or alterations in nutrient ratios that favor one species over another. The scientific community recognizes the enormity of the tasks that lie ahead to better understand the biogeochemistry of harmful algal blooms (GEOHAB 2006). Many agree that reducing the nutrient loads to our coastal waters is an important first step to restoring balance and preserving marine ecosystems (Carpenter et al. 1998; Howarth and Marino 2006; Smith et al. 2006).

## Long Island Estuaries

The EPA is entrusted by the Clean Water Act to regulate discharges of pollutants and setting water quality standards for surface waters. Under the act, when areas of water are impaired, the EPA requires Total Maximum Daily Limits (TMDL's) be established to control discharges.

In 1987, the Clean Water Act was amended to adopt a National Estuary Program and this program specifically listed the Long Island Sound. The Estuaries and Clean Waters Act of 2000 added the Peconic Bay to the national program. The purview of the National Estuary Program is expanded to maintain water quality, to protect shellfish, fish, and wildlife, and requires the control of point and nonpoint sources of pollution.

The EPA has reported that coastal waters in the Northeast are generally in poor condition (EPA 2008; EPA 2009b). These recent EPA reports rated 37% of the 28 registered national estuaries in poor condition. Another assessment listed 52% of the US estuaries as having reduced (hypoxic) oxygen levels across 8-19 % of their area from May through October (Rabalais et al. 2009). The National Oceanic and Atmospheric Administration listed 67% of the 82 national estuaries surveyed to be moderately to severely impaired by eutrophication (Bricker et al. 1999). There is a scientific consensus that nitrogen is the largest pollution problem that threatens coastal waters and their ecosystems (Howarth and Marino 2006; Nixon 1995). The most recent EPA congressional report identified metals (primarily mercury), nutrients, and organic enrichment/low dissolved oxygen as the leading causes of impairment in bays and estuaries (EPA 2009b). The leading source for impairment was unknown or unspecified. This implies that the problems were from non-point sources of contamination. Other significant sources of impairment were listed as Industrial, Sewage Treatment Plants, Mining, Urban runoff/stormwater and atmospheric deposition. Closer examination of the three Long Island estuaries shows that the Long Island Sound, the Peconic Bay and the South Shore Estuary Reserve (Great Bay) are under stress.

## South Shore Estuary Reserve

The South Shore Estuary Reserve extends 75 miles east from the Queens/Nassau County line to the village of Southampton in Suffolk County. There is approximately 326 square miles of watershed with a population of 1.5 million people. The National Oceanic and Atmospheric Administration (NOAA) has listed the Great South Bay as having high symptoms of eutrophication with periods of anoxia and hypoxia, moderate to high chlorophyll-a levels, losses in submerged aquatic vegetation and a frequency of harmful algal blooms (Bricker et al. 1999).

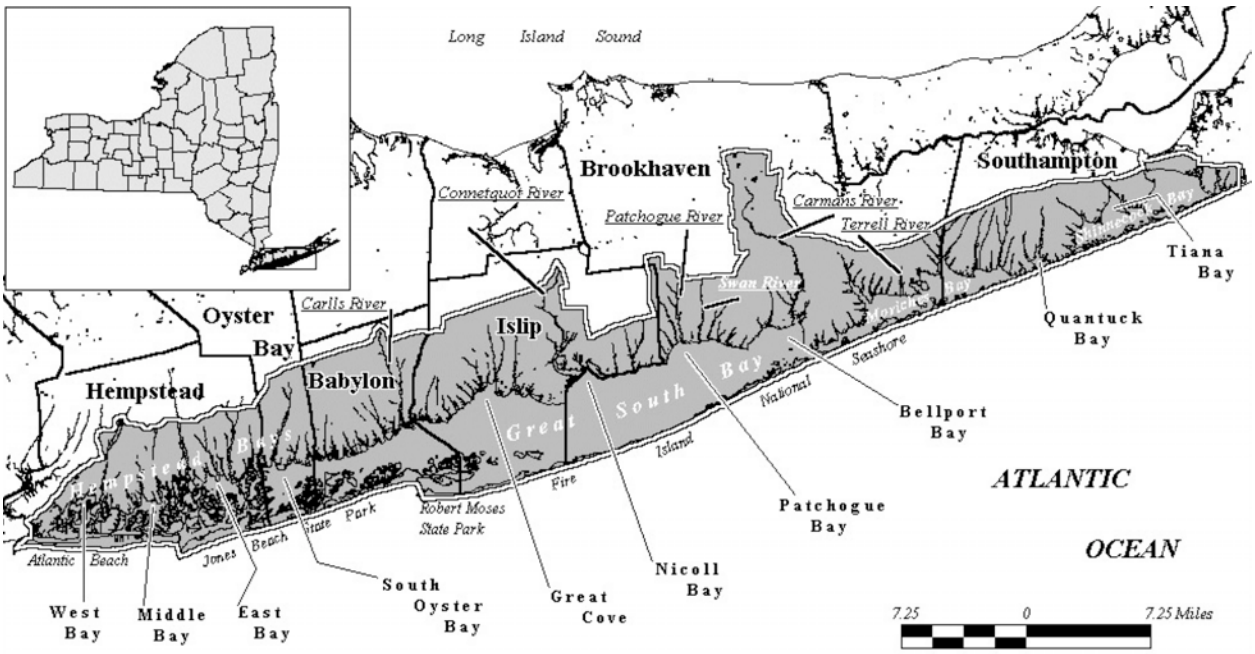



**Figure 9: South Shore Estuary Reserve and Watershed (http://www.estuary.cog.ny.us)**

Measuring water quality in streams and wells along the south shore, Monti (2003) found the highest seasonal variation in the Carlls river with 3.4 and 4.2 mg N $L^{-1}$ between summer and winter. The median nitrate level of wells tested between 1952-97 was 1.74 mg $L^{-1}$ and <0.1 mg $L^{-1}$ for shallow and deep wells respectively. Shallow wells tested had ranges from 0.01 to 21.6 mg $L^{-1}$. Deep wells had a test range of 0.01 to 4.93 mg $L^{-1}$. Groundwater under densely populated areas tended to have higher nitrate levels. Carmans River has the lowest median total nitrogen level of 1.25 mg $L^{-1}$. Patchogue River has the highest median total nitrogen of 2.8 mg $L^{-1}$. Connetquot and Swan Rivers averaged 2 mg $L^{-1}$ total nitrogen. Clear trends were shown in reduced total nitrogen in Pines Brook, East Meadow Brook, Bellmore Creek, Massapequa Creek, Santapoue Creek, Carlls River Sampawams Creek and Penataquit Creek after the completion of sewer districts. Based on the nitrogen levels measured and the hydrology of the study areas, Monti was able to calculate the nitrogen loads discharged in the South Shore Estuary. The total load had a peak in 1979 at 1260 tons N per year and a downward trend in successive years to a reported low of 755 tons N per year in 1997.

## Long Island Sound

The Long Island Sound covers 1320 square miles. There are 600 miles of coastline contributing groundwater recharge and another 16,820 square miles of watershed, primarily from the Connecticut River basin, that drains into the sound. Long Island Sound monitoring stations along the Nassau County shore have measured a steady downward trend of summer average and bottom dissolved oxygen levels to severely hypoxic levels (< 3 mg L-1) in the western and central basins (Parker and O'Reilly 1991). A snapshot of the anoxic and hypoxic areas of the Sound clearly shows the extreme conditions present (Figure 10). The western narrows was anoxic (dissolved oxygen = 0 mg L-1) in 1987 and by 1989 more than 63% of the Sound's bottom water was in varying degrees of hypoxia (dissolved oxygen < 3 mg L-1) (Wolfe et al. 1991).

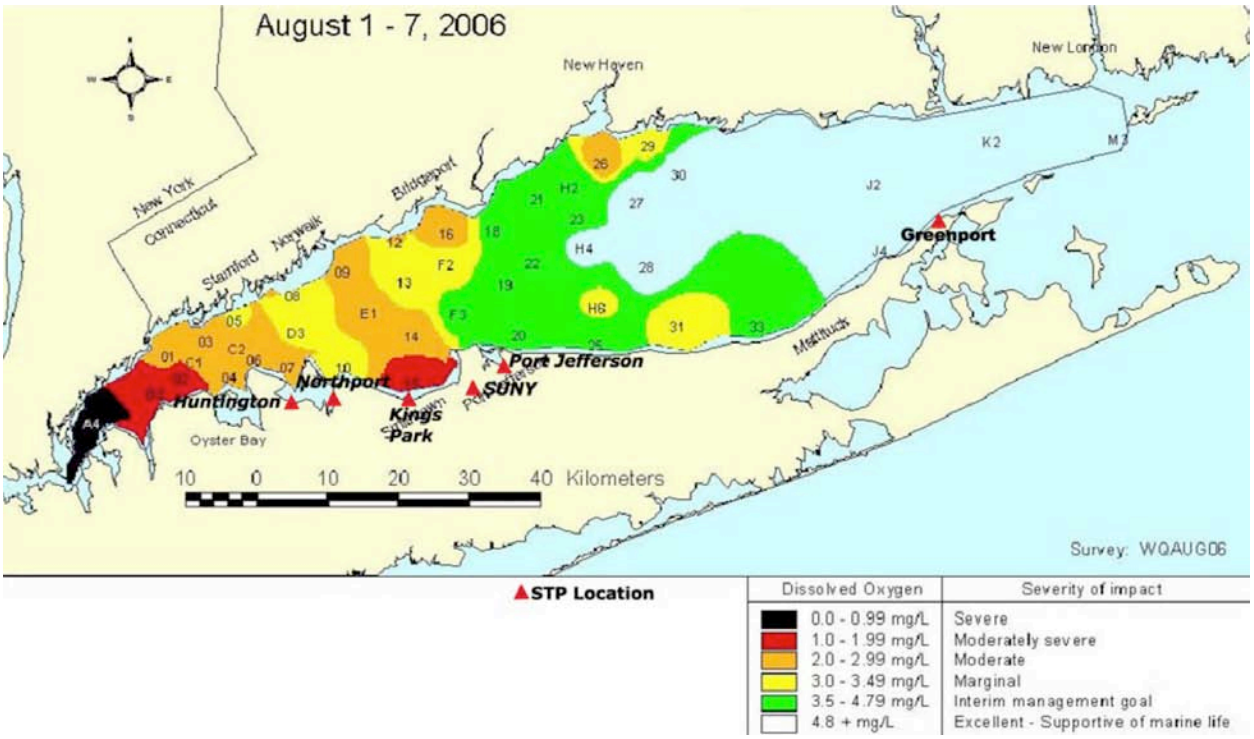
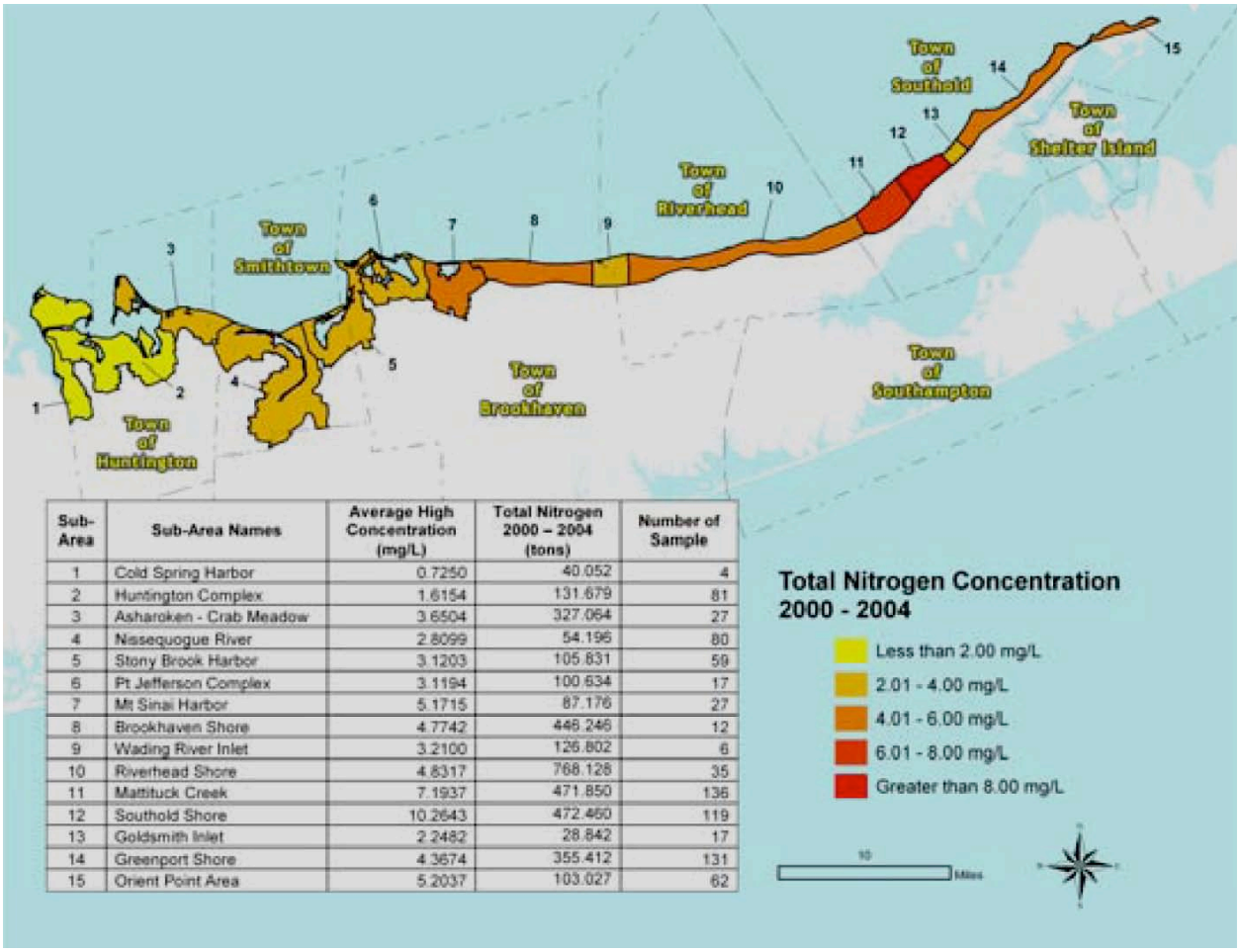



**Figure 10: Dissolved Oxygen in Long Island Sound bottom waters and locations of Suffolk county Sewage Treatment Plants (STPs) (LISS 2007)**

While Suffolk County's north shore only accounts for 1.3% of the watershed area, 72-82% of the nitrogen load to the Sound in 1990 originated from non-point sources along the north shore (LISS 2007). The nitrogen loading in 1990-1993 was broken down by the following sources:

| Source of Nitrogen from North Shore | Tons N/Yr |
|---|---|
| Sewage Treatment Plants | 204.4 |
| Conventional Sanitary Systems | 371.2 |
| Fertilizer in groundwater | 119.3 |
| Fertilizer in stormwater | 166.5 |
| Atmospheric Deposition | 234.9 |

There has been nearly a 50% reduction in the nitrogen load from sewage treatment plants using measurements from 2000-2004. However, monitoring well data and groundwater flow calculations still show very high nitrogen levels (Figure 11).




| Sub-Area | Sub-Area Names | Average High Concentration (mg/L) | Total Nitrogen 2000 – 2004 (tons) | Number of Sample |
|---|---|---|---|---|
| 1 | Cold Spring Harbor | 0.7250 | 40.052 | 4 |
| 2 | Huntington Complex | 1.6154 | 131.679 | 81 |
| 3 | Asharoken - Crab Meadow | 3.6504 | 327.064 | 27 |
| 4 | Nissequogue River | 2.8099 | 54.196 | 80 |
| 5 | Stony Brook Harbor | 3.1203 | 105.831 | 59 |
| 6 | Pt Jefferson Complex | 3.1194 | 100.634 | 17 |
| 7 | Mt Sinai Harbor | 5.1715 | 87.176 | 27 |
| 8 | Brookhaven Shore | 4.7742 | 448.246 | 12 |
| 9 | Wading River Inlet | 3.2100 | 126.802 | 6 |
| 10 | Riverhead Shore | 4.8317 | 768.128 | 35 |
| 11 | Mattituck Creek | 7.1937 | 471.850 | 136 |
| 12 | Southold Shore | 10.2643 | 472.460 | 119 |
| 13 | Goldsmith Inlet | 2.2482 | 28.842 | 17 |
| 14 | Greenport Shore | 4.3674 | 355.412 | 131 |
| 15 | Orient Point Area | 5.2037 | 103.027 | 62 |

**Figure 11: Average groundwater nitrogen concentrations along the north shore (2000-2004) (LISS 2007)**

## Peconic Bay

The Peconic Estuary covers 246 square miles of surface water and is situated between the north and south forks of eastern Long Island. The watershed has an area of 196 square miles extending nearly 100 miles from west to east and 20 miles from north to south (Peconic Estuary Program 2007). Suffolk County has joined together with representatives from the EPA, the New York State Department of Environmental Conservation, and other private groups and citizens to form the Peconic Estuary Program (PEP) to study, monitor and establish a Comprehensive Conservation Management Program (CCMP) for the estuary in accordance with National Estuary Program management requirements.

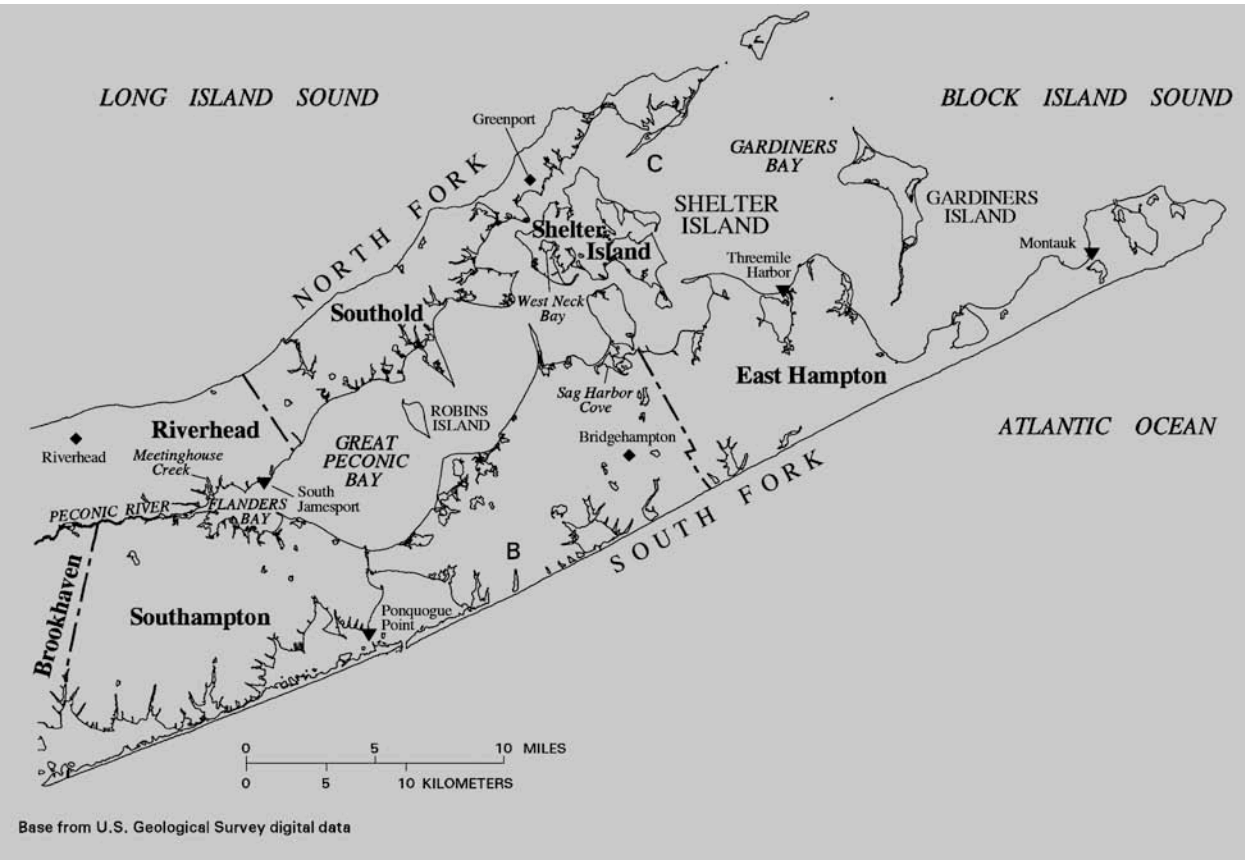



**Figure 12: Peconic Bay Watershed (Schubert 1999)**

In the estimated baseline year, 5,357,364 pounds of nitrogen enters the Peconic Estuary, consisting of: 3,015,041 pounds (56%) from atmospheric deposition; 2,175,031 pounds (41%) from groundwater, 66,242 pounds (1%) from the Peconic River and seven western tidal creeks, 53,689 pounds (1%) from three sewage treatment plants, and 47,361 pounds (1%) from

stormwater. The County has summarized average nitrogen concentrations in the Peconic Estuary and watershed to range from a low of 0.65 mg $L^{-1}$ in the clean freshwater portion of the Peconic River to a high of 9 mg $L^{-1}$ along areas of the North Fork (Peconic Estuary Program 2007). Average nitrogen levels in groundwater were 13 mg $L^{-1}$ in agricultural areas, 6 mg $L^{-1}$ in non-agricultural areas, 3.58 mg $L^{-1}$ on golf courses, 3.75 mg $L^{-1}$ in special vegetation preservation areas, and 1 mg $L^{-1}$ in vacant open areas.

Based on monitoring and modeling, the PEP used Dissolved Oxygen (DO) to rate the condition of areas tested in the estuary and calculate the necessary reductions in nitrogen loads. Effectively, the PEP set the Total Maximum Daily Limits (TMDLs) necessary to achieve the water quality standards for DO and reduce the other eutrophication related impairments such as algal blooms, poor water clarity, inhibited submerged aquatic plant growth, and stress to marine organisms. Based on their standards for acute levels of hypoxia (DO less than 3.0 mg/L at any time) and chronic levels of hypoxia (DO not less than a daily average of 4.8 mg/L at any time), data from 1990 to 2000 show that the Lower Peconic River (range of 2.0 - 4.9 mg/L), the Western Flanders Bay area (range of 4.2 – 4.9 mg/L), and Meetinghouse Creek, Terry's Creek and Tributaries (range of 0.2 - 4.9 mg/L) are impaired areas and subject to management controls by the EPA as stipulated by the Estuaries and Clean Water Acts.

The PEP has indentified significant point sources including the Riverhead Sewage Treatment Plant (STP) and storm water from the Towns of Riverhead, Southampton and Brookhaven. Non-point sources identified include fertilizer losses from agriculture and turf grass maintenance, wastewater from septic systems, atmospheric deposition and organic sediment.

## Suffolk County Nitrogen Management

Suffolk County has established a nitrogen management plan as part of their Comprehensive Conservation and Management Plan (CCMP) (SCDHS 2009). The EPA and the governor of New York approved the plan in 2001. The Clean Water Act requires the EPA to set controls for water bodies that fail to meet standards. One of the controls set is a Total Maximum Daily Limit (TMDL) for nitrogen loads to the estuaries based on calculations of nitrogen inputs in groundwater recharge (Peconic Estuary Program 2007). The TMDL focuses only on nitrogen and not on phosphorus or the deleterious effects of any other contaminants introduced by surface water runoff or groundwater recharge.

This CCMP establishes and projects achievable nitrogen loading rates from agricultural operations, golf courses, and existing and new developments. The plan calls for stepped reductions in nitrogen loads in each of these areas (Peconic Estuary Program 2007). The allocation of reductions is consistent, calling for a 25% total nitrogen reduction in groundwater recharge from agricultural areas, existing developments and golf courses. In areas that border impaired portions of the estuary, 50% reductions are noted. The reductions are not stated as reductions in fertilizer use. They should be viewed as reductions in groundwater nitrate levels.

The plan also defines the need to slow development by preserving farmland and open spaces. Limits are established on sewage treatment plants for total nitrogen content and flow restrictions. Finally, an agricultural environmental stewardship program is detailed to significantly reduce nitrogen leaching and run-off from farm operations (CDM 2010b).

With respect to turfgrass, the plan sets out to establish a number of program points:

1. Recommendations for homeowners to eliminate or minimize fertilizer use.
2. Education and outreach program on proper residential fertilizer use.
3. Certification of commercial landscapers
4. Targeted programs for commercial and industrial properties; for governmental and quasi governmental properties (schools, libraries, etc.) and for all other properties (places of worship, not-for-profits, etc.).
5. Recommendations for golf courses to reduce nutrient losses using nitrogen reduction goals, best management practices and on-site evaluations. The County has implemented a nitrogen challenge asking golf courses to reduce their fertilizer use to less than 2.8 lbs. N per 1000 sq ft and to keep groundwater nitrate levels below 2 mg $NO_3$-N $L^{-1}$.
6. Local Law 41-2007 controls the use of fertilizer in Suffolk County, banning the application of fertilizer to any turf in the county between November 1 and April 1. Training of applicators and public education are also important elements of this law.

Using the Environmental Fluid Dynamics Code (EFDC) model with the load reductions projected in all areas, the model shows that hypoxia in the western end of the Peconic Bay can be significantly improved (Peconic Estuary Program 2007). The efforts extended across the entire County should have an equally significant impact on water quality in each of the Long Island estuaries. However, the report warns that estuaries are complicated ecosystems, that nitrogen loading may not be the only indicator for eutrophication stress. The EFDC model is based on the

kinetic modeling of phytoplankton used in the CE-QUAL-ICM, a eutrophication model of the Chesapeake Bay (Peconic Estuary Program 2007)(Cerco 2000). The CE-QUAL-ICM model utilizes 24 variables including nitrate, dissolved organic nitrogen, total phosphate, labile particulate organic phosphorus, and dissolved organic phosphorus. The importance of dissolved organic nitrogen and phosphorus, in general, has already been established for their potential effect on phytoplankton blooms. The TMDL calculations are linking dissolved oxygen levels in the estuary strictly on nitrate levels in groundwater recharge. The sensitivity of these other variables and the effects of eutrophication are not quantified. The CE-QUAL-ICM model using all 24 variables has been fairly consistent with observed values in the Chesapeake Bay (Cerco and Noel 2005).

The lag time between management intervention and a measureable response in environmental quality ranges from one year to greater than fifty years (Meals et al. 2009). Nutrient management programs took at least four years before changes were observed in nitrate levels in the studies reviewed. The lag times vary depending on a number of factors including the hydrology, soil properties, vegetative growth and ecosystem linkages. Groundwater flow was one of the most noted factors in nitrate management. The average travel time was already portrayed in the Upper Glacial and Magothy aquifers as 7 and 120 years, respectively, in the study of the watershed on the western end of Peconic Bay (Schubert 1999). Selecting the right indicators for improvement, implementing monitoring systems to measure changes and focusing on small watersheds close to sources are effective ways to measure improvements.

The Bridge and Sebonack golf courses are two properties that perhaps best describe two turfgrass management systems designed to monitor and protect groundwater quality. These courses have a series of groundwater monitoring wells and a sampling program to measure their groundwater quality (Barnes and Cohen 2010)(Petrovic 2010). Both clubs use less than two pounds of nitrogen per 1000 square feet of managed turf. The Bridge averages less than 2.0 mg $NO_3$-N $L^{-1}$ and monitoring wells are typically less than the background nitrate levels showing an overall assimilation of nitrogen in the turfgrass system. Conversely, Sebonack has nitrate levels that are above the target 2.0 mg $NO_3$-N $L^{-1}$ but below the EPA 10 mg $NO_3$-N $L^{-1}$ MCL. These two areas provide contrasting examples of the challenges in watershed management.

## Fertilizers

The USDA 2007 Farm Census listed 40.8% of the land area in the United States or 922,095,840 acres as farmland (Economic Research Service 2009). New York State is reported to have a total land area of 30,162,489 acres of which 7,174,743 acres is farmland. Milesi (2005) estimated that turfgrass covers 49,341,755 acres in the United States or 5.4% of the land area. A survey of New York State lists a total of 3,428,322 turf acres (NASS 2004). The largest areas of turf use are listed below in descending order:

| **Sector** | **Turf Area** | **%** |
|---|---|---|
| Private Residences | 2,825,900 | 82.4 |
| Lawn Care Service Companies | 278,850 | 8.1 |
| Golf courses | 101,480 | 3.0 |
| Parks | 65,100 | 1.9 |
| Schools | 54,675 | 1.6 |
| Other | | 3.0 |

**Table 2: New York State Turfgrass Area by Use**

The International Fertilizer Association (IFA) reported 12.8 million tons of nitrogen fertilizers used in the United States in 2007 (Heffer 2009). A category of crops including root and tubers, nuts, tobacco, ornamentals, turf, pastures and forestry accounted for 18% of the total fertilizer. The IFA and the USDA do not list statistics specifically for turf.

Data collected by New York State Department of Agriculture and Markets listed total fertilizer usage of 36,621.37 tons for Suffolk County for the period of 2009 (Kelly 2009). Total nitrogen applied in 2009 was reported at 3,846.84 tons or 7,693,680 lbs. If 19.7% of the fertilizer use is for agriculture (Kelly 2009) and 18,306 acres (total of 34,404 agricultural acres) in Suffolk County were fertilized (NASS 2010), the average nitrogen rate of application is 82.8 lbs of nitrogen per acre or 1.9 lbs N per 1000 sq ft. Dividing the non-farm fertilizer nitrogen by Porter's (1980) estimate of 200,000 acres of turfgrass in the County, the average nitrogen rate for turfgrass is 30.9 lbs per acre or 0.71 lbs per 1000 sq ft.

| Suffolk County Fertilizer Sales | | |
|---|---|---|
| Year | Total Fertilizer Sales (tons) | Total Nitrogen Content (tons) |
| 2005 | 34,963.97 | 4,817.79 |
| 2006 | 40,525.54 | 5,581.78 |
| 2007 | 38,042.53 | 4,910.68 |
| 2008 | 26,005.69 | 2,932.19 |
| 2009 | 36,621.37 | 3,846.84 |

**Table 3: Suffolk County Fertilizer Sales 2005-2007 as reported by NYS Department of Agriculture and Markets**

The bulk fertilizer tonnage was reported by the Department of Agriculture and Markets with varying nitrogen content and includes tonnage for fertilizers without any nitrogen content. Some specific fertilizer classes such as urea (46-0-0) and IBDU (31-0-0) appear to be understated. Given the growing sensitivity to groundwater quality and nutrient use, the state system needs to be refined to accurately track totals but also to accurately track the type of fertilizers sold. The report can potentially track the use of organic and slow release fertilizers.

Another study presented county-level fertilizer usage deriving specific usage numbers for nitrogen and phosphorus fertilizers showing a total of 4,724,091 kg (10,393,000 lbs) of nitrogen being applied to land surfaces in Suffolk County in 2001 (Ruddy et al. 2006). Farm use was stated as 60% of the total (2,841,331 kg or 6,250,928 lbs). Non-farm use was given as 40% of the total (1,882,760 kg or 4,142,072 lbs). The farm use split is much higher than the more recent figures supplied by the NYS Department of Agriculture and Markets. Over the period of 1987 to 2001, farm use declined 10% and non-farm use increased 361%. This report also estimates atmospheric nitrogen additions to land surfaces as 18.7% of the total inputs for 2001, approximately 0.1 lbs per 1000 sq ft per year. The data is presented graphically in Figure 13.

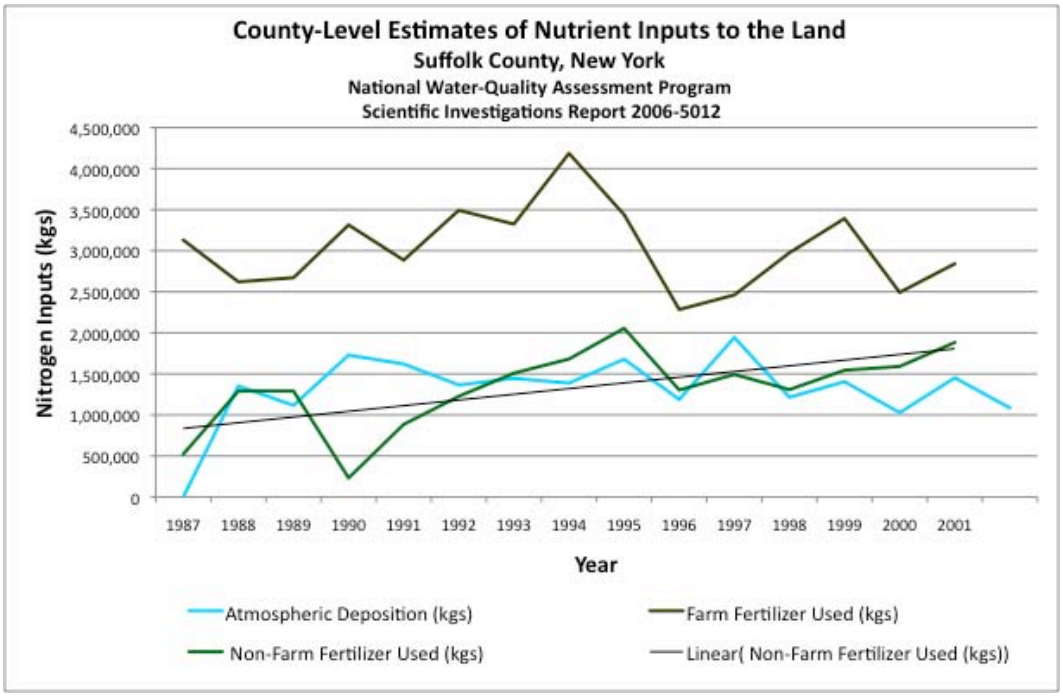



**Figure 13: Nitrogen inputs to land surfaces in Suffolk County, 1987-2001**

Tracking total fertilizer sales in the county is an important baseline control of water quality. The IFA data shows turf within a class of fertilizers users. The Ruddy (2006) report reasserts the

emphasis of land use by presenting the magnitude of difference in fertilizers used by agriculture compared to non-farm use. The trends are significant particularly given the projections in population growth. Unfortunately, the data in these reports does not present any definition for the amount of fertilizer or trends of use for turfgrass.

A survey published in 2004 lists fertilizer expenditures by lawn care sector in New York (NASS 2004):

| Sector | Fertilizer Expense ($) |
|---|---|
| Private Residences | 88,080,000 |
| Lawn Care Service Companies | 17,981,730 |
| Golf courses | 11,337,242 |
| Parks | 1,187,140 |
| Schools | 1,577,414 |

**Table 4: Fertilizer Expenditures in NYS (2003) by Sector (NASS 2004)**

The NYS survey found 25% of the private residences surveyed used private lawn care service companies to maintain their lawns. The average resident spent $900 per year on their service. The lawn care business in 2003 was estimated at $825 million.

Consistent with the NYS survey, a national survey also identified that 75% of homeowners apply fertilizers themselves and the balance use lawn service companies (Augustin 2007). The survey found that 93% of the home applications were made once or twice a year using 0.8 to 1.8 lbs of N per application. A survey of homeowners in Nebraska found that 91% of the homes applied fertilizers to their lawns with 66% of the homeowners doing the application themselves (Sewell et al. 2010). Approximately 50% of the homeowners made 1-2 applications per year; another 32% made 3-4 applications. The study also determined that only 52% of the homeowners followed the instructions on the label. Another survey in North Carolina looked at fertilizer practices across 5 economically different communities. The fertilizer applications ranged from 1.5 to 3 applications per year ranging from 0.5 to 3.0 lbs per 1000 square feet (Osmond and Hardy 2004). There was a significant difference in the amount of fertilizer used and the size of the household income. Commercial applicators averaged 4.0 lbs per 1000 square feet. The higher rates of application were made even though fescue was the predominant turf species.

In contrast to these homeowner surveys, a national survey of golf courses showed an average annual fertilizer application rate of 3.1 lbs of nitrogen per 1000 square feet per year where 33% of the fertilizers used were quick release and 67% were slow release (Throssell et al. 2009b). Of the total fertilizer used, 30% was from organic sources. The rates varied by region depending on turfgrass species and the length of the growing season. The Northeast averaged 2.2 lbs per 1000 square feet per year.

The County should undertake a survey to map the actual turfgrass area in the County to specifically denote “managed” turfgrass, that which is irrigated and/or fertilized, and native or natural turf areas. Surveys of homeowners and landscapers would help establish profiles of use.

## Fertilizers for the Turf Industry

Nitrogen is the most essential element of the macronutrients. Insufficient N will limit the formation of carbohydrates and stunt root growth. With a weaker root system and lower reserves, the plant will not be as fit for periods of stress. Too much N, on the other hand, can lead to excessive shoot growth and weaker plant structure (Marschner 1995). The relationship of macronutrient levels is dynamic. Growth as measured by clipping yields and evapotranspiration rates have been shown to vary at different levels of N, P and K (Ebdon et al. 1999). There is typically enough potassium and phosphorus in the soil to support plant growth (Petrovic et al. 2005a). Phosphorus additions are generally only needed as start-up doses for grow-in. Recent research has shown that turfgrass performs across a wide variety of soil potassium levels and that additions did not improve turf performance (Woods 2006).

Micronutrients are also generally available in the soil. One of the most significant factors in soil and nutrient management is the pH of the soil. As shown in the chart below, pH can limit the nutrient availability binding cations or anions to the soil exchange sites depending on whether the soil is acidic or alkaline.

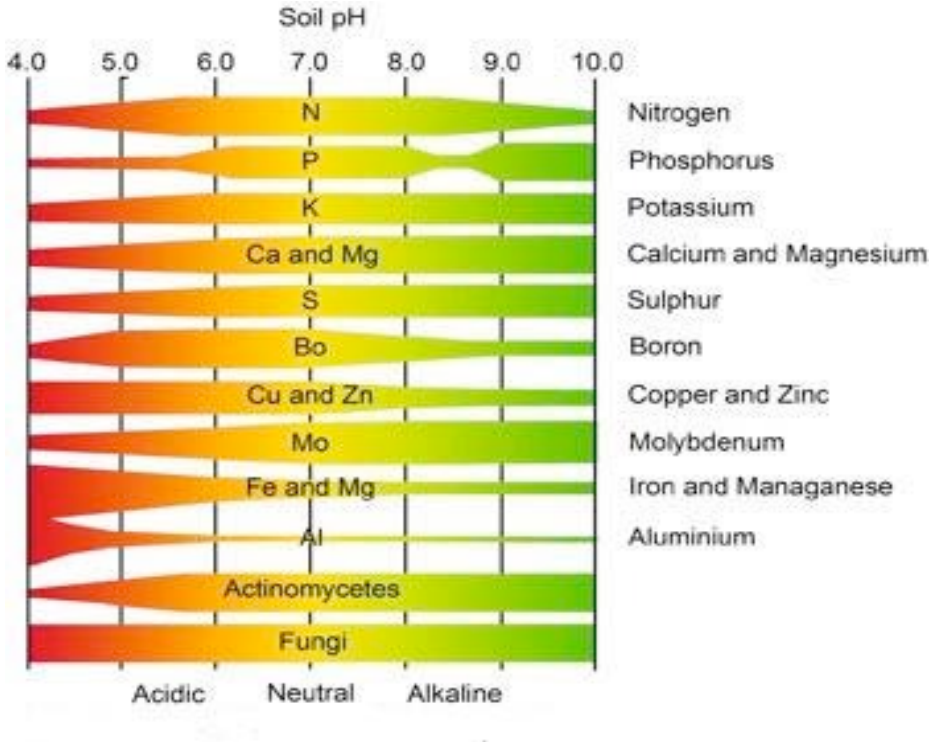



**Figure 11: Nutrient availability across the pH range**
**http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_soil_reaction_ph.html**

Typically, iron is the key micronutrient that is deficient at high pH. Magnesium is typically deficient at low pH. At the other extreme, care must be taken to not oversupply nutrient elements. Plants have toxicity levels for each of the nutrients. The key is to balance nutrient supply. Tracking the pH of the soil and water supply is essential.

After the design and implementation of a fertility management plan, the plan can be checked by taking samples of leaf tissue for a tissue analysis. The lab report will identify all the key nutrients in the tissue test, verifying plant uptake and identifying any deficiencies. Small adjustments can then be made to balance the fertility plan. This careful planning and verification insures that operating costs are not wasted and that a micronutrient deficiency or toxicity is not mistaken as a nitrogen deficiency. It insures that the plant receives enough, but not too much, of the essential nutrients.

Some useful points of interest are provided for guidance (Jones et al. 1991):

1. The availability of nitrogen changes at different pH values. $NH_4$ is best absorbed at a pH around 7.0 and less absorbed at more acidic pH. $NO_3$-N is best absorbed at an acidic pH.
2. $NH_4$ sources will reduce the pH of the soil affecting nutrient availability. Conversely $NO_3$-N sources will tend to increase pH. Soils can be buffered to minimize these pH changes.
3. Forms of nitrogen may cause some regulation in the Ca and Mg composition of roots, but the plant regulates the transport of Ca and Mg concentrations to shoots. Increasing $NO_3$-N relative to $NH_4$ increased the concentrations of K, Mg, Cu, Mn and Zn in leaf lettuce but decreased total N and P while increasing K, Ca, Mg and Mn in watermelon shoots and roots. The increase in Mn was serious enough to create toxicity problems.
4. Iron (Fe) content is also affected by the form of nitrogen. Plants receiving only $NH_4$ have higher concentrations of Fe than plants receiving $NO_3$-N
5. Volatilization losses are highest at pH's above 7.5 while denitrification losses can occur across a broad range of pH (4.0-10) but are the highest in the range of 7.0-7.5.

## Types of Nitrogen Fertilizers

Nitrate ($NO_3$-N) and ammonium ($NH_4$-N) are the principle sources of inorganic nitrogen for plants. While ammonium must be assimilated into organic compounds in the roots, $NO_3$-N can be absorbed and freely travel the plant vascular system (Marschner 1995). As such, $NO_3$-N can provide an important function in cation-anion balance within the plant but must be reduced to $NH_4$-N before it can be transformed into organic structures. The reduction to $NH_4$-N is controlled by the presence of nitrate and nitrite reductaces. The stimulation and balance of the reactions are dependent on root and leaf morphology, the photosynthetic processes, and environmental conditions, which determines the nitrogen uptake rate (NUR) (Hull and Liu 2005). The internal nitrogen use efficiency (NUE) is strictly defined as the dry matter yield produced per unit of nitrogen (Jiang and Hull 1998).

There are many types of nitrogen fertilizers and their use will vary by form (Christians 2007; Turner and Hummel 1992) (Clark and Kenna 2000). The water-soluble type (WSN), including inorganic N and organic urea, are released quickly into the soil running the risk of burning the turf and leaching. Inorganic sources include ammonium nitrate, ammonium sulfate and calcium nitrate. There are organic sources and synthetic organics. Both of these, unlike the inorganic sources, contain carbon (C). Carbon is an essential element in supporting soil microbial activity.

The natural organics tend to be low in the nitrogen content (% N), are slow release and rely on soil microbes to break down the fertilizer. Therefore applications must be made when soil temperatures are greater than 50° F (Christians 2007; Zak et al. 1999). Animal composts usually contain a portion of nitrogen that is immediately available. Natural organics, as by-products of other industries, may be commercially available at lower pricing compared to synthetics.

Urea contains 46% N. It is an organic compound and is 100% soluble in water. It has the highest percentage content of nitrogen. Typically, the total cost per pound of N delivered will be lower for urea than other, lower percentage N, products. Urea can burn turf but it has a lower burn potential than other inorganics. Losses due to volatilization may also be high. Urea is also available coated in sulfur and/or a polymer for slow release and as a deterrent to volatilization.

Other forms of urea include methyleneureas (MU), ureaformaldehyde (UF), triazone, and isobutylidene diurea (IBDU). The MU and UF fertilizers are available in short or long chain chain C-H or methyl links. Shorter chains will increase the burn potential. The long chain formulations releases over a longer period of time with lower burn potentials. The products are grouped according to their "fraction". These distinctive fractions have characteristic water solubility and release (see Table 5).

The Association of American Plant Food Control Officials requires that ureaformaldehyde products be defined to contain at least 35% N-nitrogen, largely as insoluble but slowly available products with a Water Insoluble Nitrogen (WIN) content of at least 60% (Turner and Hummel 1992). In their example, a ureaform produced with a 1.3:1 ratio of urea to formaldehyde contains 38% N of which 65-71% is WIN. A methylene urea product with a 1.9:1 ratio contains 39% N of which 36% is WIN. Flowable urea formaldehyde (FLUF) has a 1.8:1 ratio, contains 18% N

and is 20-25% WIN. Products are often produced with a mixture of other water-soluble nitrogen sources and a percentage of WIN ureaformaldehyde. It is very important to understand the product being used, the percentage of water solubility and the exact form of urea formaldehyde.

| **Urea, Methyleneureas and Urea Formaldehyde Products** | **Ureaform Fraction** | **% Water Soluble** |
|---|---|---|
| Urea | Cold Water Soluble | 100 % |
| Methylol urea | Cold Water Soluble | 100 % |
| Methylene diurea | Cold Water Soluble | 34 % |
| Dimethylene triurea | Cold Water Soluble | 25 % |
| Trimethylene tetraurea | Cold Water Insoluble<br>Hot Water Soluble | 16 % |
| Tetramehylene pentaurea | Cold Water Insoluble<br>Hot Water Soluble | 10 % |
| Pentamethylene hexaurea | Cold Water Insoluble<br>Hot Water Insoluble | 4 % |

**Table 5: Forms of urea and their water solubility**
**(Turner and Hummel 1992)**

The UF and MU fertilizers require microbial activity to release their N. A urease enzyme hydrolizes the urea to $NH_4$ and bacteria nitrify the $NH_4$ to $NO_3$. Like the organic fertilizers, little N will be released unless the soil temperature is over 50° F. As the soil warms, and activity increases, more N will be released.

Urea-triazone is typically 28% N but not less than 25% N. Triazone is also broken down by microbes but may be foliarly absorbed and converted by plant metabolism (Bowman and Paul 1991).

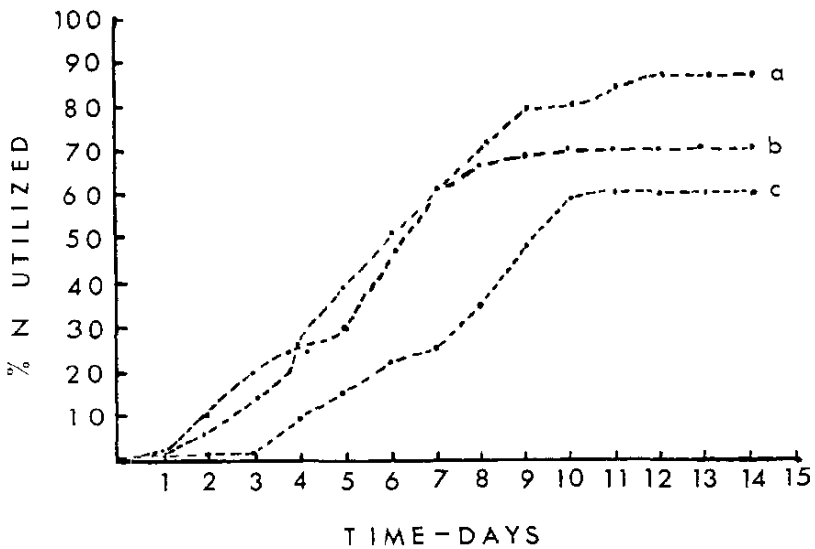
IBDU, typically 31% N, does not require microbes. It is slowly hydrolized by water. IBDU is available in two grades: A coarse grade that is 90% WIN and a fine grade that is 85% WIN.

Be careful to consult with the manufactures to determine the composition of the products considered for use.

## Release rates

Research has often evaluated different forms of fertilizers, rating each product according to turf quality, color and clippings as a measure of growth (Bigelow et al. 2007; Cisar et al. 2001; Miltner et al. 2004; Soldat et al. 2008). While these comparisons are important, determining what portion of the fertilizer's nitrogen content is immediately available, and the release rate, will help in selecting products and balancing rates with plant requirements and reduce the risk of excess nitrates being leached from the soil.

Water solubility increases the risk of leaching. While ammonium cations ($NH_4^+$) can be held within the soils cation exchange sites, Long Island's typical sandy soils will have low cation exchange capacity to hold ammonium. Nitrates are freely solubilized and mobile in the soil solution. The hydrolization and nitrification of methyleneurea and ureaform "slow release" products introduces a source of "bioavailable" nitrogen in a nitrate form (Katy and Fassbender 1966). This is added to any other quick release products often mixed in a fertilizer. Figure 14 summarizes the percent of nitrogen released from methylene ureas over time.

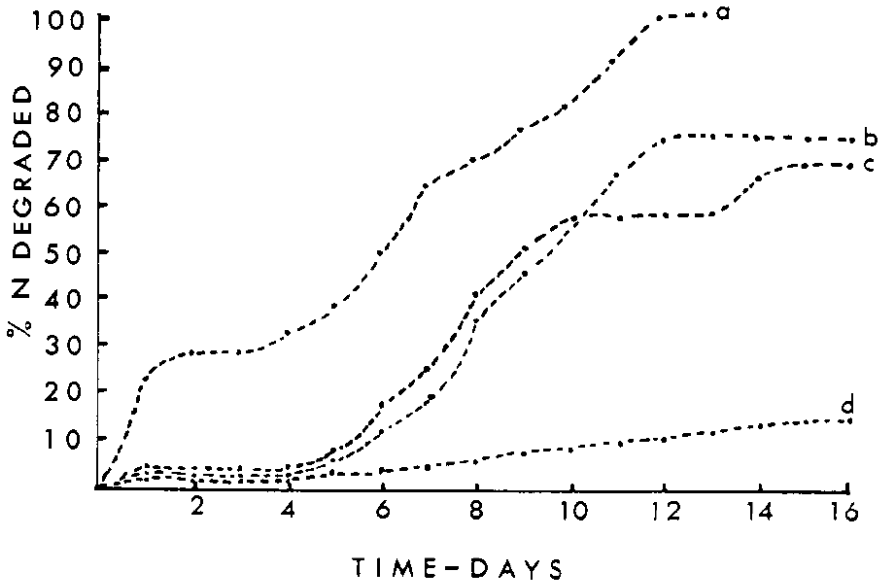



**a – methylene diurea**
**b – dimethylene triurea**
**c – trimethylene tetraurea**

**Figure 14: Bioavailability of nitrogen from methyleneureas (Katy and Fassbender 1966)**

Figure 15 lists the release rates for each of the ureaform fractions based on their water solubility. In a matter of days, the cumulative release of nitrogen as nitrate quickly adds up. If too much nitrogen is available for the plant to take up over a period of time, an irrigation or precipitation event may wash the nitrate beyond the root zone, deeper into the soil profile or into ground water. Water solubility of the product is only one of the key factors. The release rate of the

product selected is another important consideration. An active soil may react quickly to work on the water insoluble portion of the fertilizer adding more nitrogen.




**a – Water-soluble nitrogen**
**b – Cold water-insoluble, hot water soluble nitrogen**
**c – Total water soluble nitrogen**
**d – Hot water-insoluble nitrogen**

**Figure 15: Bioavailablity of ureaform fractions**
**(Katy and Fassbender 1966)**

Another study evaluated nineteen different fertilizers for their long-term release rates and found that the release rates could be characterized by fertilizer type (Claassen and Carey 2007). The inorganic synthetic and slow release fertilizers released 100 % of the nitrogen applied; the organic blends released an intermediate amount of nitrogen with a signature of a quick pulse followed by a slower long term release; and the final group of compost materials that also had an initial pulse followed by a lower long term release rate (See Figure 16). This final group released less than 10% of the nitrogen over the 200 days of incubation.

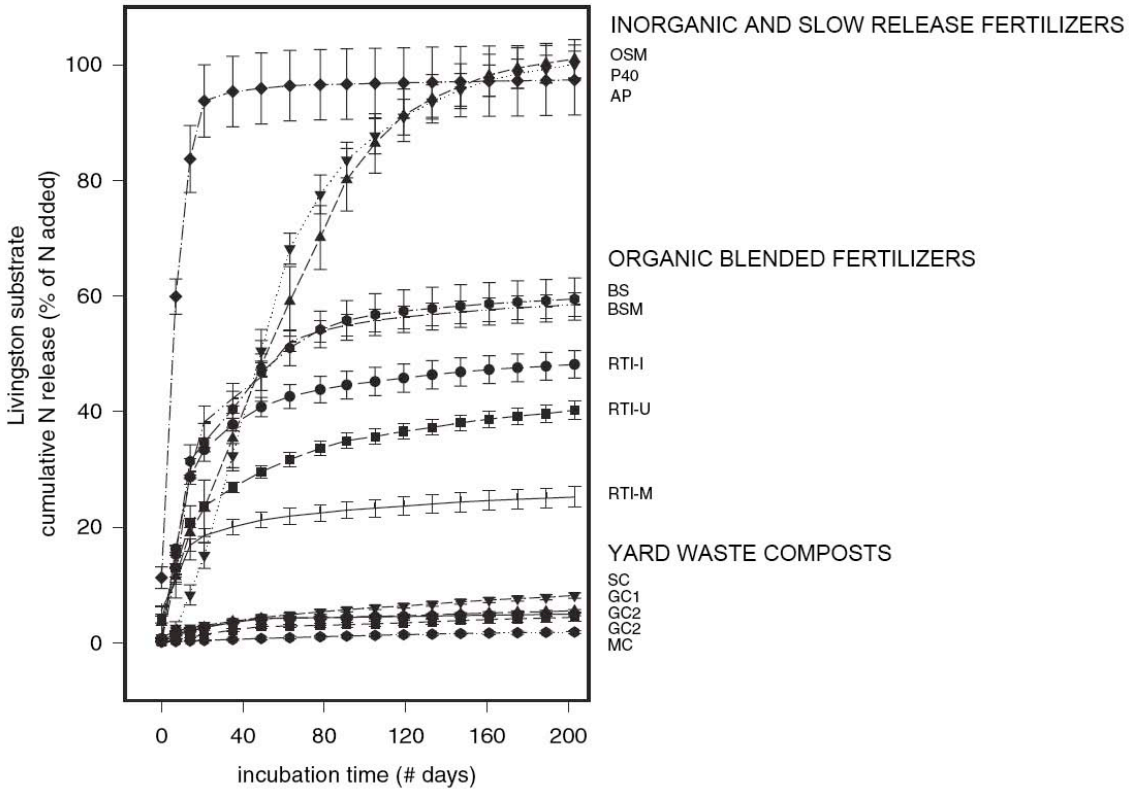



**Figure 16: Release of nitrogen from various forms of synthetic, slow release, organic and composted fertilizers (Claassen and Carey 2007)**

A series of studies confirmed that, under active growing conditions, perennial ryegrass, Kentucky bluegrass, tall fescue and creeping bentgrass could assimilate nitrogen, either as nitrate or ammonium, within 48 hours of applications (Bowman et al. 1989a). There were significant differences in the overall amount of nitrogen absorbed. Kentucky bluegrass only absorbed 60% of the nitrogen that was absorbed by perennial ryegrass. Such differences are further discussed in the cultivar section of this report (pg. 79). The results suggest that using prudent rates of application, the plant can quickly absorb the immediately available nitrogen that is applied.

Leaching studies conclude that applying fertilizers during clear weather can avoid episodic losses of nitrates to groundwater (Guillard and Kopp 2004). The use of quick release, water soluble, immediately available nitrogen sources is an acceptable practice when properly applied. Conversely, over-application or applications that are stacked due to short interval application schedules using some slow release products can increase the risk of leaching. The nitrogen will be released over a time period such as those shown in Figure 14 and Figure 15. Precipitation events and excessive irrigation can drive the nitrates deeper into the soil profile.

One study identified types of fertilizers and the losses associated with runoff and leaching for phosphorus, nitrate and ammonium (Easton and Petrovic 2004). The study determined that once turf was established, natural organics lost 3-6% of the nitrogen applied as $NO_3$-N leachate

compared to 8.6-11.1% lost for synthetic organics. There was very little difference between sulfur-coated urea and the immediately available urea or ammonium phosphate fertilizer. Natural organics, notably dairy and swine composts, did however increase the percentage losses of phosphorus.

There is a wide variety of "engineered products" or formulations available to the professional turf manager. Each has some claim for plant health or reduced risk for nitrogen losses. Contact was established with seven major suppliers of commercial and professional turf fertilizers including Agrium, Agrotain, Andersons, Lesco, Lebanon, Scotts and Sustane. The objective was to identify specific release rates for their products. The conclusion was there is insufficient scientific research to classify products with release rates. Turf managers are apt to develop their own sense of timing based on growth rates and color. There is enough uncertainty to safely state that users are at risk of making mistakes that might compromise groundwater quality.

The problem of establishing a standard for determining release rates is confounded by the wide variety of products, soils, and growing conditions. There is an effort to establish an accelerated and economical lab procedure to properly classify any "enhanced efficiency" class of materials that use inhibitors or slow release materials (Sartain et al. 2003). In a recent update, the new method is in the final stages of rigor testing for acceptance by the Association of Official Agricultural Chemists (AOAC), a group set up by the USDA to establish uniform methods of analysis for fertilizers (Sartain 2010).

## Suffolk County Climate

Suffolk County is situated in a plant hardiness climate zone denoted as 6b and 7a (www.usna.usda) where the average minimum annual temperatures do not fall below -20 ºC. The area is also designated as a humid transitional zone for turfgrass (Beard 1998). For turfgrass, the zone is typified by winters that can result in killing temperatures and summers that generally require irrigation in June, July and August to sustain growth and prevent dormancy. The cool-season or C3 turfgrass species thrive in this environment. The C3 species typically utilized on private and commercial lawns include *Poa annua* spp (Annual bluegrass or *Poa*). *Poa pratensis* (Kentucky Bluegrass), *Lolium Perenne* (Perennial Ryegrass), *Agrostis* spp (typically, Creeping Bentgrass), and *Festuca* spp (Turf Type Fescue).

A profile of the climate from 1971 thru 2000 is shown in Table 6 listing temperatures, Growing Degree Days (GDD) and precipitation for Riverhead Station (Kowalsick 2009; National Climatic Data Center).

| Suffolk County Climate Data 1971-2000 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Riverhead Station** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Annual** |
| **Temperature** | | | | | | | | | | | | | |
| Daily Max | 39.4 | 40.7 | 48.8 | 59.3 | 70.6 | 79.3 | 84.2 | 82.5 | 75.4 | 64.7 | 54.0 | 44.3 | |
| Daily Min | 24.4 | 25.7 | 32.3 | 40.0 | 49.8 | 59.1 | 64.8 | 64.0 | 57.6 | 47.0 | 38.7 | 29.7 | |
| Mean Temp | 31.9 | 33.2 | 40.6 | 49.7 | 60.2 | 69.2 | 74.5 | 73.3 | 66.5 | 55.9 | 46.4 | 37.0 | |
| **Growing Degree Days ($GDD_{50}$)** | | | | | | | | | | | | | |
| $Monthly_1$ | 0 | 0 | 14 | 77 | 329 | 586 | 770 | 727 | 504 | 213 | 54 | 4 | |
| Accumulative | 0 | 0 | 14 | 91 | 420 | 1006 | 1776 | 2503 | 3007 | 3220 | 3274 | 3278 | |
| **Precipitation** | | | | | | | | | | | | | |
| Highest Monthly | 12.40 | 6.34 | 7.92 | 11.43 | 8.27 | 11.63 | 7.63 | 9.36 | 7.61 | 9.12 | 9.42 | 7.79 | |
| Lowest Monthly | 0.80 | 0.83 | 0.98 | 1.83 | 0.65 | 0.19 | 0.60 | 0.41 | 1.07 | 0.46 | 0.48 | 0.91 | |
| Median | 4.11 | 3.21 | 4.19 | 4.09 | 3.57 | 2.92 | 2.85 | 3.81 | 3.62 | 3.73 | 3.85 | 4.01 | 45.4 |
| Highest Daily | 3.60 | 2.40 | 3.06 | 2.48 | 2.78 | 5.27 | 4.89 | 6.34 | 6.46 | 3.96 | 3.40 | 3.02 | |
| Days > than or = 0.50 | 2.9 | 2.4 | 3.0 | 2.8 | 2.8 | 2.3 | 2.3 | 2.3 | 2.5 | 2.7 | 3.2 | 2.6 | 31.8 |
| US Department of Commerce, National Oceanic & Atmospheric Administration, Riverhead Research Farm | | | | | | | | | | | | | |
| http://cdo.ncdc.noaa.gov/climatenormals/clim20/ny/307134.pdf, DOA: October 16, 2009 | | | | | | | | | | | | | |

**Table 6: Climate Summary for Suffolk County, 1971 - 2000**

While Riverhead may be considered centrally located in the county, there are still significant differences in the Precipitation and Evapotranspiration (P-ET) values around the county (Kowalsick 2009). Notably the southshore is slightly warmer (hardiness zone 7a) compared to the northshore or western portion of the county (hardiness zone 6b). Significant variations in temperatures and precipitation exist between the eastern and western areas of the county.

Profiles are shown for soil temperatures in Jamesport during 2008 and P-ET for Westhampton. Note that the soil temperature warms as a function of accumulated growing degree-days. As 2008 GDD is very similar to historical data from 1971-2000, soil temperatures for 2008 can be viewed to be representative for the Riverhead area.

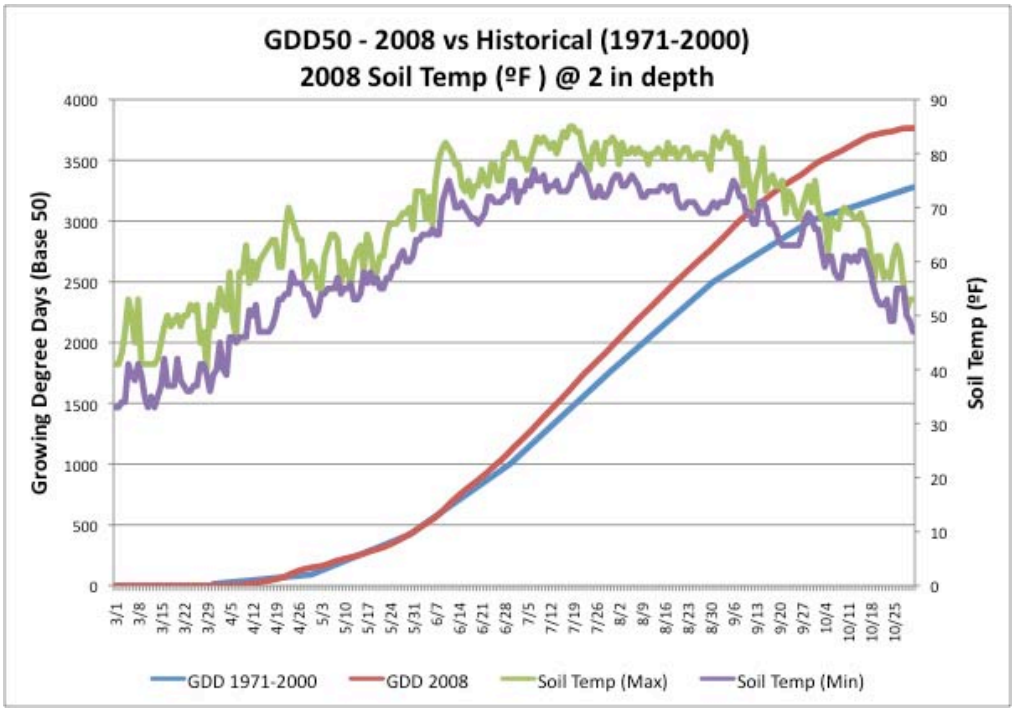



**Figure 17: Soil temperature for 2008 in Jamesport, NY as a function of $GDD_{50}$.**

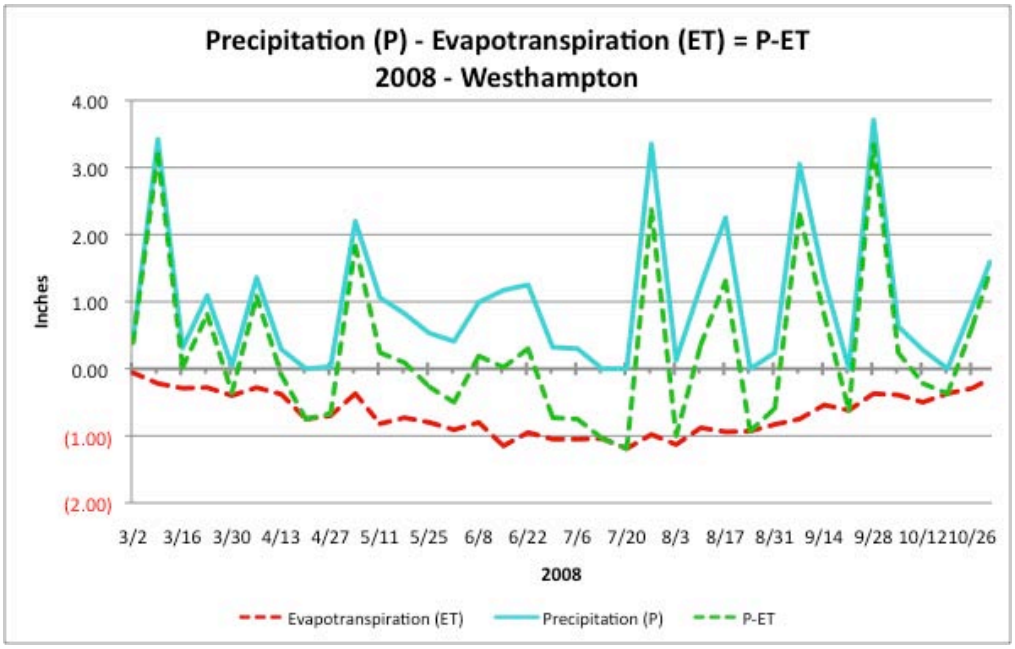



**Figure 18: Precipitation - Evapotranspiration (P-ET) for Westhampton, 2008**

Climate data for Suffolk County is available from two very reliable sources. Cornell Cooperative Extension of Suffolk County collects and publishes data from weather stations located throughout the county. Reports are available at http://ccesuffolk.org/growing-degree-days-soil-temperature-precipitation-and-evapotranspiration-rates-reports-294/. Similarly, regional data can be obtained from the Northeast Regional Climate Center at http://www.nrcc.cornell.edu/.

## Soils of Suffolk County

There are ten soil types that describe all of Suffolk County (United States. Soil Conservation Service. et al. 1975). The soils are identified by taxonomic names and list specific properties for particle size, texture, chemical and hydraulic properties. A listing below describes the major soil series identified in Suffolk County.

| Soil Series Description | % of Area |
|---|---|
| Bridgehamptom silt loam | 2.1 % |
| Carver and Plymouth sands | 17.6 % |
| Haven Loam | 13.5 % |
| Montauk fine sandy loam | 1.2 % |
| Montauk silt loam | 1.4 % |
| Montauk loamy sand | 1.3 % |
| Plymouth loamy sand | 14.7 % |
| Riverhead sandy loam | 19.1 % |
| Riverhead and Haven soils | 11.1 % |
| Other soil types or uses | 12.4% |
| Tidal Marsh | 2.7 % |
| Beaches | 1.2 % |
| Dunes | 1.7 % |
| Total Area | 100.0 % |

**Table 7: Soil Series of Suffolk County**

The combination of glacial substrate, the moraines, the outwash plains ahead of these moraines and subsequent deposits of silt, clay and sand create unique soil characteristics. For instance, Haven and Bridgehampton soils are examples of silty deposits over stratified sand and gravel. In contrast, Carver and Plymouth are deep sandy soils with little or no silt. Montauk soil is a silty soil over a mixed till. Furthermore, the geologic formations and time have created topographic associations of soils. There are ten associations. Four of them account for 77% of the county. They are composed of mixtures of the Carver-Plymouth sands, Plymouth loamy sand, Riverhead sandy loam and Haven loam. They are typified as being well to excessively drained. Yet some soils have a well defined fragipan at 20-30 inch depths that restricts drainage. Prior agricultural use in other areas has produced a similarly restrictive plowpan.

Given the geologic associations and the extremity of conditions, a first step in developing a nutrient plan is to identify the Area Under Management (AUM). The Natural Resources Conservation Service (NRCS) offers a tool to locate and identify the AUM. The NRCS Web Soil

Survey (WSS) is an online tool to obtain specific soil descriptions for your property (http://websoilsurvey.nrcs.usda.gov/app/).

WSS reports can be custom generated to list a number of soil properties and land use characteristics. Each soil area can be detailed. Some of the important parameters available using WSS for turf management are listed below:

- Depth to the upper and lower boundaries of each layer is indicated.
- Cation-exchange capacity is the total amount of extractable bases that can be held by the soil. Soils having a low cation-exchange capacity hold fewer cations and may require more frequent applications of fertilizer than soils having a high cation-exchange capacity. The ability to retain cations reduces the hazard of groundwater pollution.
- Particle size is the diameter of a soil particle. The broad classes are sand, silt, and clay, ranging from the larger to the smaller. The content of sand, silt, and clay affects the physical behavior of a soil.
- Bulk density is the weight of soil (oven dry) per unit volume. Bulk density data are used to compute available water capacity, total pore space, and other soil properties. The moist bulk density of a soil indicates the pore space available for water and roots.
- Saturated hydraulic conductivity (Ksat) refers to the ease with which pores in a saturated soil transmit water.
- Available water capacity refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in inches of water per inch of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure. Available water capacity is an important factor in the design and management of irrigation systems.
- Organic matter is the plant and animal residue in the soil at various stages of decomposition. Organic matter has a positive effect on available water capacity, water infiltration, soil organism activity, and tilth (the overall health of a soil). It is a source of nitrogen and other nutrients for turf and soil organisms.

Conducting a physical survey of the AUM will provide specific location perspectives. Bear in mind that site construction may have disturbed the soil. Core samples can be studied to see the uniformity of the soil, the texture, and layers (including thatch) that create impervious water boundaries.

Soil samples should be collected and analyzed for nutrient analysis. The reports are created with respect to managing turf. Soil nutrient levels, Cation Exchange Capacity (CEC) and pH are provided along with recommendations for all the macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium and sulfur) and the essential micronutrients (molybdenum, manganese, copper, zinc, boron, iron and chlorine).

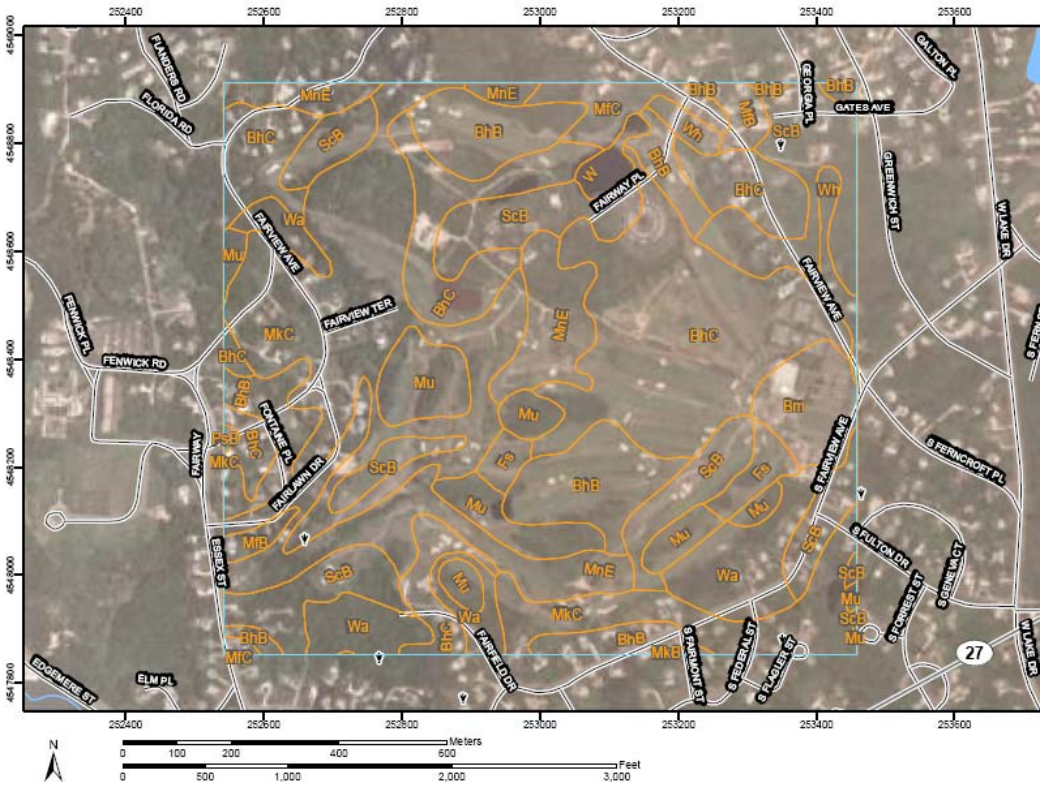



**Figure 19: NRCS Soil Survey Map, Montauk Downs GC**

**Summary Points:**

The soil survey could be summarized to state that the county soil profile is largely a sandy soil. The predominant soil associations tend to be excessively drained, heightening concerns over leaching.

Additionally, the major soil associations are strongly acidic with pH values of 4.5-5.5. These conditions can exacerbate the interpretations of the plants mineral nutrition requirements as an acidic soil can lead to several micronutrient deficiencies. Coupled with plant demand and fertilizer use, liming may be necessary to adjust the pH of the soil.

As a final point, the survey indicates that the soil organic content is typically 1-2.5% which can generate a release of nitrogen ranging from 0.9 – 2.3 lbs per 1000 $ft^2$ per year. (lbs $M^{-1}$ $yr^{-1}$).

## Nutrient Management for Turfgrass

The Nitrogen Cycle embodies the living processes and interactions of the plant, soil and atmosphere (Brady 2008). This cycle provides a complete perspective on the fate of nitrogen. Biologically fixed nitrogen (BNF) and atmospheric depositions are natural inputs. The soil matrix includes life forms that consume nitrogen as well as the plant root system. As these life forms expire, their residue decays and becomes a part of the soil. This biomass of the soil describes a reservoir of Soil Organic Nitrogen (SON) incorporating living and dead tissue.

The fate of any nitrogen addition to the soil may be summarized in six categories: the fraction that is taken up by the plant (1); that portion that is held in the SON reservoir (2); the amount that is volatized (3) and denitrified (4), both lost back to the atmosphere; and the portion that is lost due to runoff (5) or leaching (6). (Hull and Liu 2005) (Tisdale 1993).

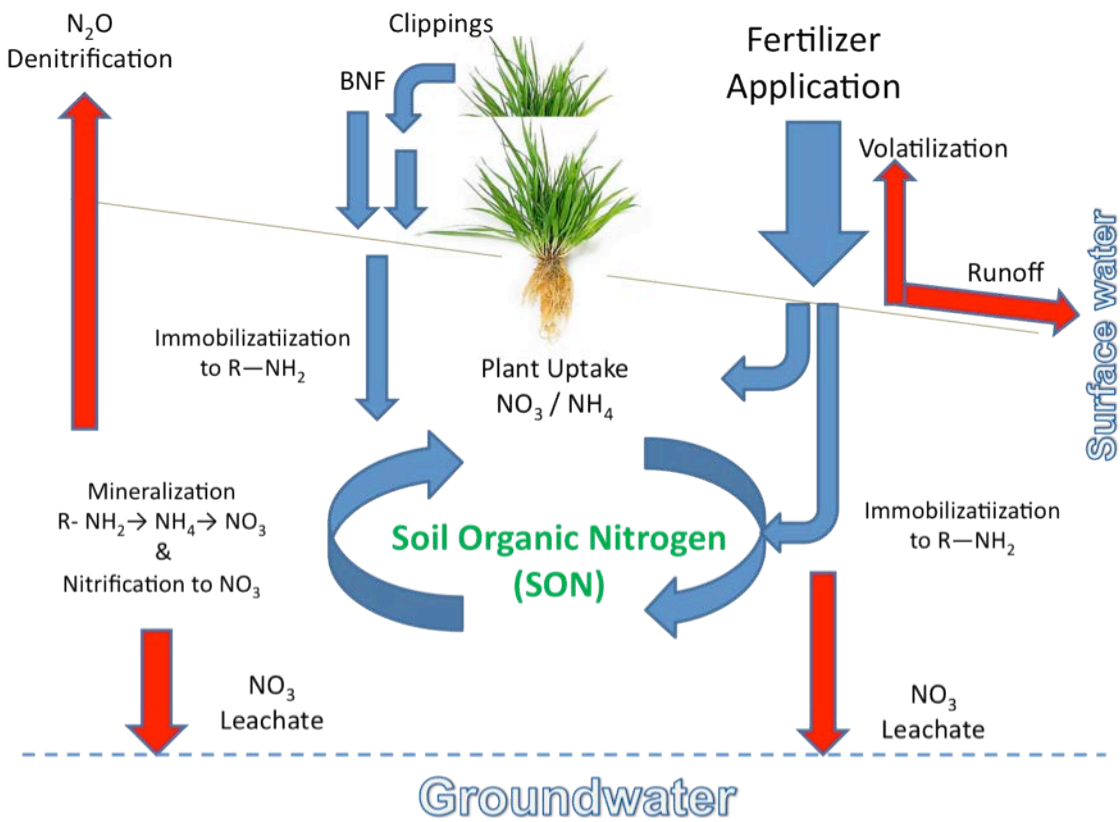



**Figure 20: Fate of Nitrogen in a Turfgrass System.**
**Fertilizer additions are utilized by the plant, held within the soil matrix as soil organic nitrogen, lost as runoff or leachate, or evolved to the atmosphere through volatilization or denitrification.**

Scientific testing has looked at different species of turfgrass and cultivars within species to determine those that perform the best in their environments. Studies have examined the use of nitrogen fertilizers under different conditions to measure the fate of nitrogen, specifically, to

quantify the losses to runoff, leaching, volatilization and denitrification. One of these studies is frequently cited and underscores the dynamic processes involved (Starr and DeRoo 1981).

Starr and DeRoo evaluated plots of a Kentucky bluegrass/fescue mix on a sandy loam without irrigation, measured only trace amounts of nitrates ($NO_3$) at a depth of 70-95 inches and monitored upstream and downstream wells measuring $NO_3$ at 0.9-2.7 ppm (0.9-2.7 mg $L^{-1}$) (Starr and DeRoo 1981). The plots had been fertilized for two years using 50% water soluble nitrogen (WSN) and 50% Urea formaldehyde (UF). Fertilizer was applied at 3.9 lbs $M^{-1}$ in the first two years and at 3.7 lbs $M^{-1}$ in the third year. Applications were split between May and September. In the third year, a label fixed nitrogen (LFN) ammonium sulfate, $(^{15}NH_4)_2SO_4$, was used to track nitrogen use and sinks. The plots were tested with clippings removed (CR) or clippings returned (CRT). The study provides a wide array of information. Overall, the fate of nitrogen was accounted as LFN measured in plant uptake, soil N, thatch N, and leaching. The total LFN recovered was 64% of LFN applied for CR and 76% for CRT. The balance was presumed as lost to volatilization and denitrification. The fertilizer applied was taken up or immobilized into the thatch and soil fractions within 30 days. The study identified that only 35% and 20% of two fertilizer applications were taken up by the plant directly. Plant growth afterwards was derived from SON mineralized into plant useable N. Returning clippings has a cumulative effect as the clippings decay with a portion of the inherent nitrogen being released and the balance immobilized into the SON fraction. Thatch, including roots, absorbed approximately one third of the total N. The study identified that 9.1% of the nitrogen uptake was derived from current year clippings and 20% of the uptake was from the previous two years. Clippings potentially added a fertilizer equivalent of 0.8 lbs $M^{-1}$. CRT increased yield by 30% and turf grew 60% faster.

**Summary Points:**

The study demonstrated the dynamic interaction of a turfgrass system, the cycling of nutrients within the soil organic layer, and the value of clippings management. The total nitrogen recovered was 64% when clippings were removed and 76% when clippings were returned.

Returning clippings added a potential nitrogen source of 0.8 lbs $M^{-1}$ $yr^{-1}$.

The study also established a benchmark for leaching studies. In selecting a reasonable rate using a fertilizer source that was both immediately available and slow release, leaching rates were within the background levels for nitrates as measured in natural forests and grasslands.

## Soil Reaction and Nitrogen Release

It is often stated that nitrogen efficiency increases at higher, more alkaline pH levels in the soil. And, the statement is not qualified as to whether it applies to nitrogen uptake rates (NUR) or to Nitrogen Use Efficiency (NUE). NUR is a strict measure of how much nitrogen is taken up by the plant either as ammonium ($NH_4$) or nitrate ($NO_3$) for a given fertilizer application. NUE is a measure of the biomass increase per unit of nitrogen applied. NUR varies by plant species, the type of fertilizer applied and by a number of environmental conditions (Jones et al. 1991; Tisdale 1993). Economically, a fertilizer use efficiency (FUE) should be based on how little nitrogen is wasted or lost. Environmentally, the concern should be solely focused on FUE and factors that limit or restrict losses.

The fate of nitrogen is dependent on the form of the addition as either an organic form (amine groups, R-$NH_2$) or mineral forms $NH_4$ or $NO_3$ (Tisdale 1993). Organic N mineralization increases with temperature and requires adequate but not excessive soil moisture and good aeration. To be effective, the organic fertilizer should have a C:N ratio below 20:1. C:N ratios above 20:1 will result in mineral depletion of nitrogen in the soil at the expense of the turf. Soil enzyme activity associated with the decomposition of organic matter was found to be higher in alkaline soils than in acidic soils (Yao et al. 2009). The microbial respiration was twice as high at 77ºF than at 50ºF and three times as high as 41ºF (Zak et al. 1999). Mineralized N at 41º F was 384 mg N $kg^{-1}$ increasing to 524 mg N $kg^{-1}$ at 77º C.

Nitrification, the conversion of $NH_4^+$ to $NO_3$, is also dependent on soil temperature and moisture, the soil population of nitrifying organisms, good aeration ($O_2$) and soil pH (Tisdale 1993). Nitrification occurs best at a volumetric moisture level of 80-90%[1], a temperature range of 25-35ºC and a pH of 8.5. Nitrification is reported to slow at a pH below 5.0 (Sartain 1985)(Weier and Gilliam 1986). Weier measured a 30-50% reduction in nitrification when pH of the soil was reduced from 6-7 to 4-5. Acidification was found to reduce soil $N0_3$ approximately 50% as pH dropped from 5 to 4 (Kemmitt et al. 2005). Inorganic forms of nitrate, such as potassium nitrate ($KNO_3$) and calcium nitrate ($Ca(NO_3)_2$) being water soluble, are more freely mobile in the soil profile. While ammonium forms ($NH_4$) can be bound to the soil. The combined form of ammonium nitrate ($NH_4NO_3$) requires balancing soil conditions that promote nitrification without risking losses of $NO_3$.

**Summary Points:**

Fertilizer use efficiency is a more comprehensive term to account for the mass balance of nitrogen applications. Effective utilization minimizes losses to the environment.

Mineralization increased 36% in warmer, moist, but not saturated, soils. Biological activity and mineralization substantially increase when soil temperatures are above 50º F.

Nitrification can be reduced 30-50% in low pH (4-5) soils reducing overall soil nitrate levels.

[1] Classically, a cubic volume of soil is 50% solid particles and 50% pore space. The volumetric water level is stated as a percent of the pore space that is occupied by water.

## Clippings

Starr and DeRoo (1981) found the N content of clippings was equally derived from the fertilizer applied, the soil, and the clippings returned. Overall, the nitrogen assimilated in the clippings represented 53, 78 and 87% of the fertilizer applied in each of the three years of the study. Growth, measured as dry matter yield (DMY), increased 15, 55 and 33%, respectively. Kopp and Guillard (2009) also confirmed that returning clippings increased total N uptake by 61% in greenhouse samples and 150% in field samples The study was conducted using equal parts of perennial ryegrass, Kentucky bluegrass and tall fescue in fine sandy loam.

Clippings N content can vary by species. However, it has also been shown that plants deficient in N had lower shoot N content then those plants with a steady N supply (Bowman et al. 1989a). Well fed perennial ryegrass plants produced shoots with 5.8% N whereas N deficient plants had 4.3, 3.7 and 2.3% N when deprived of nitrogen for 1, 2 or 4 weeks respectively. Well fed Kentucky bluegrass plants produced shoots with 4.9% N and 4.3, 3.5 and 2.6% for the deprivation treatments. At the DMYs reported, clippings provide potential N sources of 0.02-0.24 and 0.01–0.24 lbs organic N $M^{-1}$ $day^{-1}$ for perennial ryegrass and Kentucky bluegrass respectively.

| **Study** | **Clippings % N** | | | | |
|---|---|---|---|---|---|
| | **Tall Fescue** | **Perennial Ryegrass** | **Kentucky Bluegrass** | **Creeping Bentgrass** | ***Poa*** |
| (Walker et al. 2007) | 3.2 | 3.5 | 3.4 | --- | --- |
| (Bowman et al. 1989a) | --- | 5.8 | 4.9 | --- | --- |
| (Bushoven and Hull 2001a) | --- | 2.7 | --- | 2.3 | --- |
| (Liu and Hull 2006) | 3.7 | 4.2 | 4.3 | --- | --- |
| (Pare et al. 2006) | --- | --- | --- | 5.2 | 4.3 |
| (Soldat et al. 2009) | --- | --- | --- | 3.5 | --- |

**Table 8: Summary of Clippings N Content**

Variations in growth in total biomass and the portioning of that growth to roots and shoots at wide ranges of fertilization rates (0.35 to 17.7 lbs $M^{-1}$) have been demonstrated for perennial ryegrass (Bushoven and Hull 2001b). Using a rate of approximately 3 lbs $M^{-1}$, clippings were evaluated for tall fescue, Kentucky bluegrass and perennial ryegrass (Liu et al. 1997). This fertilization rate is perhaps more typical of expected high maintenance rates for Suffolk County. The study found significant variations between species and cultivars within species as well as seasonal interactions. Selecting the right turfgrass species and cultivars within that species is an important factor. Extrapolating the daily nitrogen recoveries in clippings to a typical growing season of 184 days, the clippings N contribution to SON is 4 lbs $M^{-1}$ for tall fescue and Kentucky bluegrass and 3 lbs $M^{-1}$ for perennial ryegrass. The mineralization of this N source in mature stands of turf can be expected to reduce N fertilization requirements from 30% (Starr and DeRoo 1981) to 50% (Guillard and Kopp 2004). Studies have often found the total N accounted to be in

excess of the N applied, demonstrating the active mineralization of organic N to $NH_4$ and $NO_3$ (Miltner et al. 1996; Pare et al. 2006). The variances may also be due to rounding errors, over-estimation of component values and sampling techniques.

**Summary Points**:

Clippings returned to turf can add 3-4 lbs $M^{-1}yr^{-1}$ to the soil organic nitrogen reservoir and reduce fertilizer requirements by 1.5-2.0 lbs $M^{-1}yr^{-1}$.

**Research Requirements:**

An extensive body of work exists for the physiological characteristics of Kentucky bluegrass and perennial ryegrass and to a lesser extent for tall fescue. Additional work is needed on creeping bentgrass, *Poa* and cultivars within each species.

## Soil Storage

Sampling golf courses around the country, N reservoirs were found to be larger in older stands of turfgrass (Shi et al. 2006). Mineralization of nitrogen was three to four times greater in older turfgrasses compared to younger turfgrass. The 0-2 inch layer had greater activity and transformation of carbon (C) and nitrogen (N) than the 2-6 inch layer. A twenty one year old green held three times the amount of soil organic nitrogen (SON) (15.8 lbs N $M^{-1}$) compared to a four year old green (5.1 lbs N $M^{-1}$) (Kerek et al. 2003).

After testing Kentucky bluegrass, fertilized at high (3 lbs N $M^{-1}$) and low (1.5 lbs N $M^{-1}$) rates on a loamy soil, a model of the C and N interactions was constructed (Qian et al. 2003). The model confirmed that the SON reservoir increases with age and clearly projects the effect of these increases with or without clippings removed on fertilizer requirements and potential leaching. Clippings returned (CRT) reduces N requirements 25% in the first ten years of a stand of turf. The contribution increases to 35% in years 11-25, 50% in yrs 26-50 and 60% thereafter. Not only do clippings return organic N to the soil but also add assimilated C. At 3 lbs N $M^{-1}$ rate with clippings returned, the average rate of SON assimilated was approximately 1.3, 0.55, and 0.28 lbs N $M^{-1}yr^{-1}$ during 1 to 30, 31 to 60, and 61 to 100 yr periods after turfgrass establishment, respectively. Soil organic carbon (SOC) accumulated at an average rate of 12.7 lbs $M^{-1}yr^{-1}$ over the first 50 years after establishment or an equivalent of 0.03% for the top 6 inch layer of a USGA sand based green. Both SON and SOC accumulation rates taper as the capacity of the soil is attained. This aging function was also found in a study of Long Island lawns (Porter et al. 1980). The rate of increase in the % N in the 0-4 inch layer increased rapidly from the age of 0-10 years and then declined to a rate of 0.13 lbs N $M^{-1}$ $yr^{-1}$ after 30 years. The % N accumulated in the Long Island study may be lower because the soils of the Long Island study have lower clay content. In addition to quantifying the N contribution of clippings with respect to the age of the

turf, Qian's modeling projected leaching to be at a minimum or trace level with clippings removed (CR) at high or low fertilizer rates. However, at the higher fertilization rate with clippings returned, leaching will increase exponentially after 20-30 years.

The tests help to bracket some management practices. Recommendations were made for fertilizer rates that provide optimum biomass and turf quality for Kentucky bluegrass. These practices could be differentiated by the management practice of either removing or returning clippings.

| **Age of Site** | **Clippings Returned** | **Age of Site** | **Clippings Removed** |
|---|---|---|---|
| 1 -10 yrs | 3.0 lbs $M^{-1}$ | 1 – 15 yrs | 4.0 lbs $M^{-1}$ |
| 11 - 25 | 2.0 | 16 - 50 | 3.0 |
| 26 - 50 | 1.5 | 51-100 | 2.8 |
| 51-100 | 1.2 | | |

**Table 9: Recommended Fertilizer Rates Based on Age and Clippings Management**

Results from the test also showed that the low rate (1.5 lbs N $M^{-1}$) with clippings removed led to reduced root biomass and unacceptable turf quality. The findings are significant when carried over to golf course greens management where clippings are necessarily removed. While there are physiological differences in species, there is some level of fertilization, perhaps similar to the 1.5 lbs N $M^{-1}$ in this study, where any applications less than that pivotal point will lead to biomass decline jeopardizing the overall health of the turf.

**Summary Points:**

The Soil Organic Nitrogen (SON) reservoir and release of nitrogen varies with the age of the turf stand and clippings management. As the age of the stand increases, the risk of leaching also increases. Fertilizer recommendations should be adjusted for age and clippings management. Older sites may only require one third to one half of the amount normally applied to younger stands.

**Research Requirements:**

Studies should be conducted to determine the age/clippings management relationship with other species. Particularly important, creeping bentgrass and *Poa* should be studied since they are typical of greens where clippings are removed. This work should document root mass to determine the pivot point where root mass declines.

The accumulation rates of organic soil carbon and nitrogen and any associated risks of leaching should be verified on other soils in different climate zones.

## Thatch and Soil Organic Matter (SOM)

The layer of living and dead stems, leaves and roots found between the green vegetation of the turfgrass and the underlying soil surface has been defined as thatch (Beard 1998). Bunch type grasses, such as perennial ryegrass, tend to produce a matted layer of dead leafs and stems. The thatch or mat is more porous leading to higher percolation rates and greater risks of leaching. In addition to the embodied nitrogen with the living and dead plant tissue, the thatch or mat layer is also a biologically active zone with soil microbes.

Leaching losses from thatch cores were 81% of the applied urea nitrogen compared to 32% lost on bare soil (Nelson et al. 1980). Leaching losses were reduced to 5% in thatch and 23% in soil using Isobutylidene diurea (IBDU). The thatch was observed to dry out faster than the soil and may have had reduced rates of IBDU hydrolysis. The application rate of 5.2 lbs N $M^{-1}$ coupled with irrigation rates of 0.9 inches every day are excessive. However the study demonstrates the importance of the source of fertilizer and the potential leaching losses in bare soil compared to thatch. The higher water solubility of urea led to higher leaching losses in the more porous thatch. More importantly the study demonstrates that slow release fertilizers can make a substantial reduction in losses when excess water (or rainfall) is applied.

Bowman et al.(1989b) measured the rate of N absorption in Kentucky bluegrass thatch to be twice as high for ammonium ($NH_4$) as was measured for nitrate ($NO_3$). In a 22.5 hr period, 0.6 inches of thatch absorbed the equivalent of 1.2 lbs $M^{-1}$ $NH_4$ compared to 0.63 lbs $M^{-1}$ $NO_3$.

In another evaluation, thatch producing Kentucky bluegrass was compared with mat producing perennial ryegrass. Labeled Fertilizer Nitrogen (LFN), applied at 1.0 lbs $M^{-1}$ followed by five more monthly treatments of straight ammonium sulfate, $(NH_4)_2SO_4$, was measured from shoot tissue, thatch (mat), and across the sandy loam soil profile (Engelsjord et al. 2004). While thatch absorbs more N than mat, mat still takes on a significant portion of N applied. Within the soil profile, 94% and 87% of the LFN was recovered in the 0-2 inch layer for Kentucky bluegrass and perennial ryegrass, respectively. The LFN was recovered as follows:

| | **Kentucky Bluegrass: % Label Fixed Nitrogen Recovered** | | | **Perennial Ryegrass: % Label Fixed Nitrogen Recovered** | | |
|---|---|---|---|---|---|---|
| | **Shoots[1]** | **Thatch** | **Soil** | **Shoots[1]** | **Mat** | **Soil** |
| **2 Days after Treatment** | 34 | 38 | 20 | 25 | 28 | 27 |
| **365 Days after Treatment** | 47 | 20 | 9 | 43 | 10 | 14 |
| [1]Clippings removed | | | | | | |

**Table 10: Recovery of Label Fixed Nitrogen comparing Kentucky bluegrass thatch to perennial ryegrass mat.**

**Summary Points:**

The organic layer of a soil including the thatch (mat) layer is a biologically active zone for immobilization of nitrogen added in any form including fertilizers, clippings or other organic amendments.

This organic layer can absorb 20-40% of the fertilizer applied within a couple of days of application. Over time, the fertilizer absorbed is mineralized from the Soil Organic Nitrogen reservoir and released into the soil profile.

The plant, thatch (or mat) and soil can absorb 87-94% of the fertilizer applied.

**Research Requirements:**

A convention for reporting the organic matter content as a % organic matter, g C $kg^{-1}$ should be reported in all leaching and mass balance studies. The thatch or mat layer should be distinguished separately, perhaps noted by its depth or thickness and bulk density. The organic layer would perhaps best be described as the thatch/mat layer and the upper soil profile much like the O horizon in soils analysis. This layer should be described in detail with notations to the organic and inorganic N content.

## Nitrogen Uptake: Physiological Characteristics by Species and Cultivar

Several turfgrass species were surveyed to determine the typical ranges of mineral nutrients sufficient for growth (Jones et al. 1991). The nitrogen content varies by species within a range of 2.6 to 6.0%. The research on the nitrogen content of clippings, presented in Table 8 on page 56, specified data generally found within these ranges. Values will be dependent on growing conditions and the cultivars tested.

| Element | Sufficiency Average | | | |
|---|---|---|---|---|
| | Creeping Bentgrass | Kentucky Bluegrass | Perennial Ryegrass | Tall Fescue |
| | % | % | % | % |
| N | 4.50-6.00 | 2.60-3.50 | 4.50-5.00 | 3.40-3.80 |
| P | 0.30-0.60 | 0.28-0.40 | 0.35-0.40 | 0.34-0.45 |
| K | 2.20-2.60 | 2.00-3.00 | 2.00-2.50 | 3.00-4.00 |
| Ca | 0.50-0.75 | --- | 0.25-0.30 | --- |
| Mg | 0.25-0.30 | --- | 0.16-0.20 | --- |
| S | --- | --- | 0.27-0.32 | --- |

| Element | Sufficiency Average | | | |
|---|---|---|---|---|
| | Creeping Bentgrass | Kentucky Bluegrass | Perennial Ryegrass | Tall Fescue |
| | ppm | ppm | ppm | ppm |
| **B** | 8-20 | --- | 9-17 | --- |
| **Cu** | 8-30 | --- | 6-7 | --- |
| **Fe** | 100-300 | --- | --- | --- |
| **Mn** | 50-100 | --- | 40-60 | --- |
| **Mo** | --- | --- | 2-10 | --- |
| **Zn** | 25-75 | --- | 14-20 | --- |

**Table 11: Mineral Plant Sufficiency Levels for Turfgrass**
**Plant Analysis Handbook, 1991, Jones**

These sufficiency ratings have been recognized as general guidelines for turfgrass management. However the attention to the effect of nutrients on water quality has led to a series of more in-depth investigative studies to better understand nutrient use by turfgrass plants.

The National Turfgrass Evaluation Program (NTEP) studies the growth and quality characteristics of cultivars of all major turfgrass species (Morris 2008; NTEP 2009). Turf is rated for color, density, coverage and texture. Six cultivars of Kentucky bluegrass were evaluated selecting two of the highest rated NTEP trials, two of the lowest and two that were rated in the middle (Sullivan et al. 2000). The Nitrogen Uptake Rate (NUR) of these cultivars was significantly different and positively correlated with the length, surface area and volume of fibrous roots and the weight (fresh, FW, or dry, DW) of adventitious roots. NUR was negatively correlated to increased number of rhizomes. While the highest NTEP rated cultivar happened to have the best NUR, the second highest rated cultivar had one of the lowest NUR's.

Differences were also found studying soil water nitrate levels at a depth of 23.6 inches while studying ten cultivars within each species of Kentucky bluegrass, perennial ryegrass, and tall fescue (Liu et al. 1997). Any nitrogen not absorbed by the plants root system or held within the organic reservoir, might be left in the soil profile at risk of being washed through the soil as leachate. This study sought to determine the physiological differences between species and cultivars within a species for their absorption or uptake. Kentucky bluegrass had consistently higher soil water nitrate levels. The soil water nitrate levels of some Kentucky bluegrass cultivars were considerably higher for several months of the year while four cultivars were notably lower. Similar variations were seen with perennial ryegrass. Generally lower than Kentucky bluegrass, some perennial ryegrass cultivars had months when soil water was as high as the highest Kentucky bluegrass cultivars. Tall fescue samples were the lowest.

Similarly, perennial ryegrass and creeping bentgrass were studied for Nitrogen Uptake Efficiency (NUE) by measuring nitrate reductase activity (NRA) and the biomass partitioning between roots and shoots (Bushoven and Hull 2001a). In general, creeping bentgrass had nearly

twice the root:shoot ratio of perennial ryegrass. The lowest root biomass of all the creeping bentgrass cultivars was equal to the highest root biomass of the perennial ryegrass. Yet perennial ryegrass absorbed $NO_3$ at 2.56 times the mean rate of all creeping bentgrass cultivars on a root weight basis. There were only a few significant differences amongst cultivars within the species but, overall, creeping bentgrass had a slightly higher NUE (45.2 g DW mg $N^{-1}$) compared to perennial ryegrass (38.2 g DW mg $N^{-1}$). The authors suggest that creeping bentgrass has a better NUE because less N is translocated to the shoots or that $NO_3$ uptake by roots is better balanced with root NRA. They also affirm that $NO_3$ assimilation in the roots is related to greater biomass accumulation in the roots; that increased root biomass, in turn, leads to increased nutrient absorption. Easton and Petrovic (2004) observed reductions in runoff and leaching with increased shoot densities. Cultural practices that promote rooting characteristics and increased turf density can be an effective deterrent to nitrate leaching.

Bushoven and Hull (2001b) further studied perennial ryegrass to observe that increasing levels of nitrate concentrations in their nutrient solutions led to increased transport to the leaves, increased shoot biomass and reduced root biomass. At a point around 0.09 mMol of $NaNO_3$, roughly equivalent to 3.1 lbs N $M^{-1}$, the root system becomes saturated. In effect, fertilizer applications near or beyond this point will actually reduce root mass and produce unwanted top growth. They suggest that fertilization rates above 3.1 lbs N $M^{-1}$ are a waste of fertilizer and pose an increased risk of leaching. Comparing the results using $NH_4$, they found similar limitations in root mass partitioning with restrictions presumably caused by carbon allocations between assimilation and root growth (Bushoven and Hull 2009). High nitrogen fertilization of Kentucky bluegrass was also shown to have saturated the N metabolic processes (Jiang and Hull 1998). The result could be seen in much higher shoot to root and lower C:N ratios. Partitioning N to shoots increases shoot growth and limits carbon transfer to roots. This leads to a reduction in root growth thereby limiting the overall plant capacity to absorb soil nitrogen. Until genetic variations are available in new cultivars, increasing the photosynthetic capacity of the plant by raising mowing heights and increasing light conditions are two cultural adjustments to increase carbon assimilation and improve nitrate uptake.

Clearly, selecting cultivars should not be based solely on "turf quality" ratings but should consider rooting characteristics and "ratings" with respect to nitrogen uptake.

**Summary Points:**

There are variations in nitrogen uptake from one species to another and amongst cultivars within a species.

Kentucky bluegrass has a pronounced decline in uptake rates during the peak summer months and again declines more rapidly in the fall compared to perennial ryegrass and tall fescue.

Root mass is proportionately related to nitrogen uptake rates. Cultural practices that promote root growth will improve nitrogen uptake and reduce the risk of nitrate leaching.

Soil nitrate levels should not be compared to groundwater nitrate levels.

**Research Requirements:**

The relationship of soil nitrate levels to flow weighted leachate nitrate concentrations has to be further defined to account for spatial variability, capillary flow back up to the plant during high evapotranspiration (ET) conditions and downward flow at varying levels of irrigation or rainfall.

## Volatilization

Volatilization is a loss uniquely associated with fertilizers composed of ammonium ($NH_4^+$) salts or urea ($(NH_2)_2CO$). The gaseous loss of ammonia ($NH_3$) is primarly associated with wet humid soil surfaces at warmer temperatures in alkaline soils (Tisdale 1993). Losses are highest in calcareous soil with urea products

Volatilization losses after applying urea to bare soil were 5% compared to 39% in thatch cores but was reduced to 2% and 4% using IBDU (Nelson et al. 1980). Torello et al.(1983) measured volatilization losses of 10.3% of applied N on Kentucky bluegrass lawns on silt loam soils using urea at a equally high application rate. The losses were also reduced to 2.3% using sulfur-coated urea (SCU) or poly-coated urea (PCU). Granular applications were better than sprays. Conversely, Knight et al.(2007) measured losses of 35-40% on bentgrass greens on loamy sand and an 80:20 sand:peat mix. The higher losses were not due to higher pH soils but were attributed to the fact that the treatment was not watered in. Products with a nitrification inhibitor, dicyandiamide (DCD), were not as effective in reducing volatilization as products with urease inhibitors, n-butylthiophosphoric triamide (NBPT) (Clay et al. 1990). Volatilization losses were highest at peak daytime temperatures.

The economics of using urea are compelling compared to the costs of engineered products. If urea is used, then the application must be made with respect to temperature, moisture and placement. Losses were found to increase from 50-68º F and changed very little between 72-90º F (Titko et al. 1987). At the higher temperatures, relative humidity and soil moisture increased volatilization. Overrein and Moe (1967) found that losses were reduced at deeper soil placement and wetter soils. Where Torello found reduced losses with granular applications compared to sprays, Titko had higher losses using granular products unless they were washed in with 0.1 inches of water.

**Summary Points:**

Volatilization increases in higher pH soils and at higher temperatures. Losses can be as high as 40-60% of N applied.

Warm, moist soil conditions (and high relative humidity) increased losses fivefold. However, watering a fertilizer into the soil profile with at 0.1-0.2 inches of water nearly eliminates volatilization losses.

Under controlled conditions, losses are initially higher with straight urea (≈ 10%) compared to slow release fertilizers (≈2-4%). Urease inhibitors were most effective at reducing losses.

**Research Requirements**:

Volatilization tests have typically been short duration tests of 10-21 days. Longer term evaluation tests are needed to properly compare the volatilization losses of slow release fertilizers to urea, sulfur coated urea and poly coated urea.

Given the popularity of urea based products, the volatilization losses can be a significant factor in the fertilizer use efficiency. A better understanding of these losses as they apply to Long Island would be desirable factoring in sandy soils, organic content, temperature and moisture conditions typical to the area.

## Denitrification

Starr and DeRoo (1981) measured the fate of nitrogen assessing how nitrogen was utilized by the plant and what portion was held in thatch or soil or lost in leachate or other losses. They could only account for 64-76% depending on whether clippings were removed or returned. Numerous studies embarked on confirming or enhancing the understanding of factors involved. Most encountered similar summations where a significant portion of the N applied was lost and those losses were attributed to be atmospheric losses. The concentrated efforts of Nelson, Torello, Titko, Knight, Overein and Clay have firmly mapped volatilization losses. Little was known about denitrification losses in turfgrass systems.

As soils become saturated and water-logged, oxygen is absent and anaerobic micro-organisms decompose mineral substances to obtain their oxygen, in some cases releasing $N_2$ and $N_2O$. The process is called denitrification and is thought to be of some significance as the only manner in which reactive nitrogen, Nr, acquired naturally in our soils through biological nitrogen fixation or anthropogenic addition such as fertilizers, can be returned back to the atmosphere as $N_2$ (Tisdale 1993). Soil water content, high rates of organic matter, temperature, soil pH and the supply of $NO_3$ are key factors in denitrification. Dentirification is lower in acidic soils. The risks of losses increase with temperature increases from 41º F to 77º F and higher.

A recent study compared Kentucky bluegrass in a silt loam soil to bare soil identifying $N_2$ losses ranging from 3.3% of N applied in springtime to 21.3% in the summer (Horgan et al. 2002). Diurnal variations were observed with peaks at the end of the day when temperatures were the highest. Gas emissions were twice as high at the end of the day compared to the morning. During one four day period in the summer, only four days after fertilization, the site received 3.5 inches of rain. There were more emissions in the next 7 day period than collected over the six weeks of spring. Separately comparing turf to bare soil, turfgrass evolved 19% of the N applied compared to 7 % for soil. The higher turf value was accredited to frequent wetting of the soil from irrigation. Using a label fixed nitrogen (LFN), Horgan measured atmospheric and leaching losses, soil N and plant N and was only able to account for 84.2% of the nitrogen applied to bare soil and 70.6% applied to turf. Methodology was checked and verified. The confounding

results, while consistent with recovery values in other studies, suggest that gas emissions tests may still have significant errors or there is some other unidentified loss.

**Summary Points:**

Denitrification occurs in saturated anaerobic soils and limits fertilizer use efficiency.

Losses increase at higher pH and higher soil temperatures. These losses may range from 3.3% of the N applied in the spring to 21.3 % of the N applied during warmer summer months.

To minimize volatilization, a fertilizer application needs to be watered into the soil but not so wet as to create saturated conditions and the risk of denitrification.

Sandy, well drained soils of Suffolk County should have minimal denitrification losses. However, specific site conditions, application schedules, and irrigation practices can create conditions that promote losses. Best mananagement practices would include: (1) Improve drainage by eliminating site problems such as compaction or soil layering, (2) Apply fertilizers in the morning, (3) Water fertilizer into the soil profile, but do not overwater.

**Research Requirements:**
Unfortunately, the mass balance summation is still incomplete due to spatial variability in samples, test measurement variances, or some other losses. More work is required to assess applications and losses in a turfgrass system. This work should attempt to differentiate well drained soils, USGA specified greens mixes, and other layered soils.

## Runoff Losses in Turf Systems

Runoff losses were found to be five times greater on the lower slope than the upper slope in a study conducted on a 6-8% slope on sandy loam soil (Easton et al. 2005). The greater losses were associated with higher clay accumulation, lower infiltration rates and reduced lateral flow. The losses in the lower slopes are indirectly noted by higher saturation levels. It was generally noted that runoff is due to saturation excess not due to infiltration excess. Slope profiles in the topography of a site can lead to accumulated saturation zones that are prone to runoff. Such areas may also have shallow profiles with a clay or bedrock layer that creates and or restricts lateral flow. The restrictions will increase runoff losses in that area. The creation of shallow lateral flow channels will tend to carry losses to other areas including groundwater recharge.

For newly seeded sites, infiltration rates in turfgrass systems increase with age (Easton and Petrovic 2004). Increased infiltration rates were also noted with increased shoot density through establishment. As the infiltration rate increased, runoff decreased. Soil properties related to infiltration were similarly reported to be more important than vegetative factors (Soldat and Petrovic 2008). The frequency, duration and intensity of irrigation or precipitation events can be over-riding factors in ground saturation and runoff.

In a field study conducted in Minnesota using simulated precipitation (approximately 3.2 inches of total precipitation in a 2.3 hour event), less than 10% of the nutrients applied were collected in runoff (Rice and Horgan 2009). The study extrapolated the effects of runoff from a 24.7 acre area into a 2.47 acre x 6.6 ft water body. The nitrate levels were projected to be below the 1 mg $L^{-1}$ level that was associated with algal growth and 500 times below the drinking water standard of 10 mg $L^{-1}$. While runoff was not a significant factor for groundwater pollution with consideration of nitrates, this study did report values of phosphorus that exceeded MCL's for aquatic life.

A watershed study looked at a 71.6 acre area containing 10 greens, 7 fairways and tees draining into a creek that bisected the area (King et al. 2007). The area under study encompassed 23 acres of managed turf and 16 acres of reduced management rough. The area receives considerable input from an adjacent airport area. The soils were highly disturbed and redistributed clayey soils. The irrigation water contained nutrient levels 0.3 mg $NO_3$-N $L^{-1}$ and was applied to match evapotranspiration. Average annual fertilizer applications were 0.75 lbs $M^{-1}$ for the 71.6 acre area. There were 115 rain events with annual rainfall during the 5 year study ranging from 20-38 inches. Runoff ranged from 13% to 28% of precipitation during the study. Nitrate ($NO_3$) concentrations in the runoff were 0.12 mg $L^{-1}$. The mean concentration of nitrates in the water exiting the course was 0.44 mg $L^{-1}$. These levels accounted for 3.3% of the nitrogen applied. The losses did not occur at times of fertilization but peaked in the fall months when plants had reduced nitrogen uptake or were dormant.

**Summary Points:**

The topography of a site, the soil profile, slopes, and the inherent infiltration rates are major determinants of runoff. Irrigation and precipitation events can increase soil saturation to a point that runoff losses are at high risk.

**Research Requirements:**

More research is needed on the relationship of nitrogen source, soil classificiation and runoff.

Very little is known about sustainable management programs and their impact on runoff.

## Leaching in Turfgrass Systems:

Ammonium ($NH_4$) is understood to be tightly held in the clay or organic profile of a soil typically within the upper 0-2 inch layer. Studies typically report only trace amounts of $NH_4$ in leachate even under high fertilization and irrigation schedules (Bowman et al. 1998; Frank et al. 2005). Excluding the effects of runoff, nitrate ($NO_3$-N) is the object of study with respect to the impact of leaching on groundwater quality.

Prior reviews pointed out the range of data in leaching studies and indicated that leaching losses were influenced by management practices, soil texture and irrigation with losses reported as high as 56.1% but generally less than 10% (Petrovic 1990). A number of studies have expanded on prior work to better understand variations in conditions and the physiological differences between species. Barton and Colmer (2006) summarize more recent work reporting leaching losses as high as 30% noting that losses can generally be less than 5% on established turfgrass, fertilized at a rates as high as 4-6 lbs N $M^{-1}$ and irrigated properly. A summary of the studies since 2000 is presented in Table 12.

In many cases, researchers strive to induce leaching events and gain some measure of the volume and concentration under a set of conditions. Simply stated, they tend to force leaching events and see how well the web of soil and plants hold nitrogen. Therefore, the data is sometimes remarkable to see that losses might be so low under harsh testing conditions. The data also provides insight to the testing levels, particularly fertilizer rates and irrigation schedules that produce trace levels of $NO_3$-N concentration.

| Grass | Nitrogen | | | | Soil Texture | Irrigation | % of Applied N Leached | Conc. NO3-N mg $L^{-1}$ | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | Source | Sgl N Rate lbs $M^{-1}$ | Yearly N Rate lbs $M^{-1}$ | Timing of Sgl Application | | | | | |
| Mixed: Kentucky Bluegrass/Tall Fescue Institutional Lawns | Lo Maint. Manure<br>High Maint Not Specified | | Not Specified<br>2 & 4 | Occasional<br>Spring | Fine Loamy<br>Sandy Skeletal | Precip. Only | 0 – 40% | 3.1 -7.8 | (Groffman et al. 2009) |
| Kentucky Bluegrass Lawn | Labeled Urea (LFN)<br>Urea | 5 X 49<br>4 X 24.5 | 5.0<br>2.0 | MJJSO<br>MJJO | Fine Sandy Loam | 80% of ET | 11%<br>1.2% | 21<br>4 | (Frank et al. 2005) |
| Tall Fescue | $NH_4NO_3$ | 0.5<br>1.0<br>1.5 | | monthly | Sand | Saline Solutions<br>0 meq $L^{-1}$<br>15 meq $L^{-1}$<br>30 meq $L^{-1}$ | 2%<br>1%<br>0.7% | < 1 typ<br>3 Max | (Bowman et al. 2000) |
| Mixed: Kentucky Bluegrass, Perennial Ryegrass, Tall Fescue | $NH_4NO_3$<br>PCSCU<br>Organic | 1.0<br>1.0 | 3.0<br>3.0 | MJN<br>JJN | Fine Sandy Loam | Precip. Only | 16.8%<br>1.7%<br>0.6% | 4.6<br>0.57<br>0.31 | (Guillard and Kopp 2004) |

| Grass | Nitrogen | | | | Soil Texture | Irrigation | % of Applied N Leached | Conc. NO3-N mg $L^{-1}$ | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | Source | Sgl N Rate lbs $M^{-1}$ | Yearly N Rate lbs $M^{-1}$ | Timing of Sgl Application | | | | | |
| Creeping Bentgrass | Peat Moss BioSolid Manure Manure+ Moss | 0.5 (0.25 in summer) | | Every 2 wks | Sand Mix | 27.4 in 0.3 to 2.7 in in durations of 1 hr to 3d | NA | < 20 <50 to 130 <50 to 160 <50 to 300 | (Boniak and Chong 2005) |
| Creeping Bentgrass | 78% $NH_4NO_3$ 22% Urea | | Yr 1: 6.3 Yr 2: 3.0 Yr 3: 2.6 | | Amended Sand Mixes | 100% ET + Rainfall 45% > 30 yr norm | 34 – 61 % | Avg 4.2 - 7.5 | (Soldat et al. 2009) |
| Bare Soil Creeping Bentgrass Poa | $NH_4NO_3$ | 0.5 | | Bi-monthly | 80:20 Sand:Peat | 2.5 in $wk^{-1}$ | 83.1 % 1.8% 7 - 29% | NA | (Pare et al. 2008) |
| Kentucky Bluegrass | Urea SCU MU,UF IBDU PCU $KNO_3$ Biosolid | 1.0 2.0 | 2.0 4.0 | St.Charles Late Fall (Nov) Riverhead Yr Rnd (MJJS) | LI: 46-67% Sand 16-18% Clay 2-4% OM | Precip Only Yr 1 < Avg Yr 2&3 > Avg | Precip< Avg: 0.5-7.4% Precip> Avg 2.2-29% | $KNO_3$ > Urea > Slow Release Late Fall 4X Season | (Petrovic 2004) |
| Kentucky Bluegrass Perennial Ryegrass | Organic Biosolid Urea SCU | 1.0 2.0 | 4.0 | JASO or MJAO JS or MA | Sandy Loam | Precip Only 33 storm events studied for Runoff and Leaching | Yr 1 35-59% Yr 2 5-8% | 2 lb rate was 1.5 - 4X more than 1 lb rate | (Easton and Petrovic 2004) |
| Timing referenced by months of application, i.e. MJN = May, June November | | | | | | | | | |

**Table 12: Leaching Studies of Turfgrass Systems, 2000 to present**

Guillard (2004) found that leaching flow and concentration levels were highest in winter and spring. "Episodic" leaching events were observed with ammonium nitrate ($NH_4NO_3$) in the summer months when precipitation events build up soil conditions to create flow. Whereas losses with the slow release fertilizers were substantially less. Based on their findings, slow release fertilizers were recommended at a rate of 2-3 lbs N $M^{-1}$ and applications should not be made in November. Late fall applications create situations where plant uptake cannot absorb excess build up of $NO_3$ in the soil resulting in leaching (Guillard and Kopp 2004). Soil nitrate levels were observed to be highest in the fall to support Guillard's conclusion that a rain event could potentially wash nitrates through the soil profile (Liu et al. 1997). In general, lower soil water nitrate levels were experienced in late spring or early summer. Higher nitrate levels were found during periods of slow growth. Soil nitrate levels were highest in the fall for Kentucky bluegrass and highest in early spring for perennial ryegrass and tall fescue. Kentucky bluegrass levels were reported as means of 5.7 and 2.7 and 12.2 and 3.6 mg N $L^{-1}$ for the October-December and January-March periods in the '90/'91 and '91/'92 seasons, respectively.

*Poa* was found to have higher leaching losses than creeping bentgrass (Pare et al. 2006). Losses varied by ecotype. Overall, 10-11 % of the nitrogen supplied as ammonium nitrate ($NH_4NO_3$) was lost in leachate. There was also a very high correlation between biomass and leaching losses with the greater biomass (roots, shoots and clippings) associated with lower losses.

It is reasonable to assume that the intensity and duration of any precipitation or irrigation event can increase the "washing out" of fertilizers. Easton and Petrovic (2004) already identified factors such as hill slope position and infiltration rates on saturation levels, runoff and leaching. Climate data records for Riverhead Station listed average annual precipitation of 46.8 inches (National Climatic Data Center). This is equivalent to 1,270,732 gals $acre^{-1}$ of which an average of 50% is groundwater recharge (Steenhuis et al. 1985). So, on average, a fertilizer applied at 4 lbs N $M^{-1}$, that leaches 10%, will generate an average leaching concentration of 3.3 mg N $L^{-1}$ in the recharge water. However, an "Episodic" leaching event that generated 0.5 inches of rainfall on already saturated ground or high infiltration soils, such as those well-to-excessively drained sands of Suffolk County, could generate concentrations levels of 77 mg N $L^{-1}$ at the same leaching rate after fertilizing at a rate of 1 lb N $M^{-1}$. The climate history for Riverhead shows there are 31.8 days per year with rainfall in excess of 0.5 inches. (National Climatic Data Center) The magnitude of 27,164 gals $acre^{-1}$ at 77 mg N $L^{-1}$ is great cause to examine our practices carefully.

Newly established turf poses a very high risk for leaching and runoff losses. Numerous reports have noted this condition: Nutrient concentrations and losses were the highest in the 20 week period following establishment (Easton and Petrovic 2004). Nitrogen losses varied by fertilizer source during this period and were reported as high as 77.8% N in leachate and 70.6% N in runoff. Soldat et al.(2009) also observed leaching losses of 7-18.2% of the N applied during establishment. Even in tests of buffered and unbuffered fairway plots, Stier and Kussow (2009) had leaching concentrations of 15-35 mg N $L^{-1}$ in the first year.

Studying Kentucky bluegrass mowed at a height of 2 inches under normal irrigation practices and clipping removed, Bowman measured N absorption in the plant, N held in soil solution and N absorbed by 0.6 inch layer of thatch (Bowman et al. 1989b). The calcium nitrate ($CaNO_3$) and ammonium sulfate ($(NH_4)_2SO_4$) plots showed that approximately 70% of applied N (1 lb N $M^{-1}$) was absorbed in the first 8 hrs. All $NO_3$ and $NH_4$ were depleted after 48 hrs. Less than 2% of the N was held as $NO_3$ in soil solution in a depth up to 4 inches. The rate of depletion was similarly confirmed for perennial ryegrass, tall fescue and bentgrass species. Perennial ryegrass absorbed $NO_3$ applied at rates of 0.35, 1.0 and 1.7 lbs N $M^{-1}$ within 3 hours (Bowman 2003). Tall fescue absorbed fertilizer applied at a rate of 1 lb N $M^{-1}$ within 24 hours of application (Bowman et al. 2006). After a 3hr period of inducement, creeping bentgrass had developed rapid uptake rates (Bowman et al. 1998). Bowman suggests that this rate of depletion is a characteristic of all turf species. They also suggest the link to this rapid response and the short duration of the "greening" of turf using inorganic fertilizers. The extension of thinking implies that such rapid absorption/immobilization rates along with moderate rates of water soluble fertilizers can minimize the risk of leaching. Conversely, any episodic precipitation events or over-application of irrigation water that occur immediately after fertilizer applications will potentially wash out more N that has not been assimilated in soil matrix or taken up by plant.

A study in the Northwest examined the nitrate levels at the entry and exit points of a creek that was bordered for 80% of its length on both sides by three golf course holes (Hindahl et al. 2009). The topography and drainage system directed water towards the creek. The holes were constructed with sand based greens and the rest of the terrain was typically a gravelly loam with 0-8% slope. A total of 7,049 lbs of fertilizer was applied in year one of the study with another

7,003 lbs applied in year two (avg of 2.6 lbs N $M^{-1}$). Applications were 60% and 45% slow release for each year with four major applications each year accounting for 87% of the total applied. These applications occurred between the months of April and November. The area is typified as having wet mild winters. Precipitation was 37.6 inches in the first year and 33.9 inches in the second with the wettest months in December (6.3 in. avg). The study found nitrate levels tracked precipitation levels. Exit levels were lower than entry levels for 15 of 17 measurements. Only two exit samples exceeded entry levels and were higher by 0.1 mg $L^{-1}$. All samples were in a range of 1-4 mg $NO_3$-N $L^{-1}$.

**Summary Points:**

While the research to date is extensive, it is still not a complete body of work. However, work has demonstrated that there are several major risk factors that contribute to or increase leaching.

Soil Type

Well drained soils with coarse textures and high percolation rates have lower water holding capacity, greater infiltration and higher risks of leaching. Newly seeded areas or areas with poor turf density pose higher risks than well-established stands of turfgrass.

Organic Matter

Soils with low amounts of organic matter have lower biological capacity to assimilate nitrogen and are more susceptible to leaching.

Growth Phase

Newly seeded stands of turfgrass present very high risks.

Turfgrass in early stages of growth (1-20 yrs) has increasingly greater capacity to store and release nitrogen reducing fertilizer requirements.

Mature turf (>20-30yrs) with clippings returned poses an exponentially higher risk of leaching.

Turfgrass with higher density increases infiltration rates reducing the risk of runoff losses.

Increased density of root mass increases nitrogen uptake while reducing the risk of leaching losses.

Product

Water soluble or readily available fertilizers, used at improper rates and timing, pose increased risks if wet conditions are present Whereas, water insoluble or slow release products, including organics or NBPT inhibited products, used properly, have a lower risk.

Fertilizer Rate

Excessive applications of any fertilizer product can create high soil nitrate levels susceptible to leaching.

Timing

Applications made too early in the spring or too late in the fall will result in higher soil nitrate levels, posing a greater risk to groundwater quality. Similarly, applications should be curbed during summer decline when plant uptake is reduced.

P-ET/Irrigation

The greatest risk of leaching occurs during episodic weather events when precipitation frequency, intensity and/or duration contribute to soil moisture and then exceed soil water holding capacity. Similarly, excessive or uncalibrated irrigation applications can create similar leaching conditions.

Application Site

Applications made onto impervious surfaces, near storm drains and near open bodies of water may be washed into storm drains and surface water.

**Research Requirements:**

The rate of uptake should be confirmed for each turf species under different conditions to better understand the time for the plant-soil matrix to absorb fertilizer applications. This time interval is a high risk period when episodic events can wash nitrogen through the soil and into groundwater.

Research studies report leached volumes of water and $NO_3$ concentrations as two separate values. The concentration data typically is graphed and a statement is made to the mean or median. What is more significant: a small volume event with a high concentration or a high volume event with a lower concentration? Kopp and Guillard (2005) reported concentrations using a flow weighted concentration (FWC) and Groffman et al. (2009) used a volume weighted concentration (VWC).

Furthermore, most studies routinely compare concentrations with the EPA drinking water MCL. In only a few cases, have any studies represented the data with respect to nutrient loading of water systems and the potential impact on eutrophication or the toxicity to riverine and marine ecosystems.

As was noted by Easton and Petrovic (2005), there is a need to conduct work on a watershed scale extending plot research to measure the effects of nutrient management practices to consider the plant, soil, climate and landscape interaction.

There is clearly a direct relationship between volume and intensity of precipitation and irrigation events, the "washing" out of soil, and the leaching volumes. If field studies could isolate the data from these events and report the results, there would be a better understanding on the impact of the intensity and duration of these events on volumes and concentrations in the well drained sandy soils of Long Island. These studies should look at increments of fertilizer additions in a range of 1.0 to 3.0 lbs N M-1 identifying turf quality characteristics and leaching for low maintenance versus high maintenance programs or as sustainable versus traditional management.

## Best Management Practices

The objective in nutrient management in Suffolk County must consider maintaining adequate turfgrass quality while optimizing the recovery of nitrogen applied and minimizing losses, particularly to groundwater. Optimizing this efficiency has been summarized as applying fertilizers at the right rate, at the right time and the right place (Roberts 2008).

## Level of Maintenance

Turf management practices could be grouped in terms of the intensity of management. A low maintenance program might then be a consideration for reducing the chemical inputs including fertilizers and pesticides thereby lowering the risks to the environment. Low maintenance may simply imply that it is mowed infrequently or receives no irrigation. Conversely, high amenity fields of turf may require multiple chemical inputs and a variety of preparatory operations to maintain them. Certainly, golf courses have a need to provide uniform and consistent playing surfaces that are free of weeds and the effects of disease. Sports fields might require superior density and the ability to recover quickly. More aesthetic reasons might determine that certain areas of parks and public areas be immaculately kept (Cockfield and Potter 1985). Homeowners will likely have a range of expectations but will certainly be critical of weedy lawns made bare in areas by wear or poor management.

Low Input Sustainable Turfgrass (LIST) has been under study to determine the species and cultivars best suited to low maintenance. However, the definitions vary. Some have suggested that a low input lawn will be a uniform stand of turfgrass that will persist under prevailing environmental conditions implying no inputs at all (Diesburg et al. 1997; McKernan et al. 2001). Another interpretation allowed low input turf to receive 1 lb N $M^{-1}yr^{-1}$ but was not irrigated. Alternatively, high maintenance turf received 4 lbs N $M^{-1}yr^{-1}$ and was irrigated as needed (Burt and Christians 1990). Cockfield and Potter (1985) described high maintenance lawns being mowed to a height of 2-3 inches with scheduled care in fertilizer and pesticide treatments. Low maintenance lawns were mowed only. Yet another perspective graded institutional lawns at a secondary school and university campus into low, medium and high intensity (Groffman et al. 2009). The low intensity lawn received no fertilizers but some occasional manure applications. They were mowed only 2-4 times per year. The medium intensity lawns received 2 lbs N $M^{-1}$ each spring in two split applications and were mowed to a height of 4 inches every 2-3 weeks. The high intensity lawn received 4 lbs N $M^{-1}$ in two spring applications and was mowed every 1-2 wks to a height of 2 inches.

In a trial of 84 cultivars of Kentucky bluegrass, some cultivars performed well in low maintenance plots that allowed 1 lb N $M^{-1}yr^{-1}$ while others did not (Burt and Christians 1990). Those that fared poorly in low maintenance tended to perform well under high maintenance. In contrast, the cultivars that did perform well on low maintenance did not perform well under high maintenance management. The study found that the low maintenance plants had different morphological characteristics denoted as lower shoot to root ratios with 56% more root weight, narrow leaf blades, more leaf folding, longer sheaths and lower shoot moisture content.

The grasses that performed the best, individually or in mixtures, to low maintenance criteria were a hard fescue (*Festuca ovina* var duriuscula cv. Aurora and *F.ovina* var duriuscula cv Spartan), sheep fescue (*F. ovina* L. cv Nakiska) and creeping red fescue (*F. rubra* cv. Dawson) (Burt and Christians 1990; Diesburg et al. 1997; McKernan et al. 2001). These tests were conducted without any additional inputs as a measure of Diesburg's interpretration of low maintenance. These studies found that mowing at 3.0 inches had the best results and that no mowing had intermediate results for all species tested.

Similar results were found testing three fescues under different mowing regimes where no fertilizer or irrigation was added after seedling emergence (Dernoeden et al. 1994). The Bighorn blue fescue and Aurora hard fescue performed better than the tall fescues in all treatments. They study found the best quality in plots mowed frequently to a height of 2.2 inches. Those plots that were mowed monthly to a height of 3.2 inches did nearly as well. Those mowed only once a year did poorly. This coincides with the concept put forward by Qian, that turfgrasses receiving less than 1.5 lbs N $M^{-1}yr^{-1}$ would experience declines in growth and that clippings returned provided a significant source of nitrogen input (Qian et al. 2003).

On Long Island, a low maintenance turf program will depend on the species and cultivar. Overseeding with an LIST rated turfgrass would help reduce inputs while still providing a proven turf quality. Depending on the cultivars selected, a low maintenance level of 1.0 lb N $M^{-1}$ $yr^{-1}$ might be sufficient if mowing is conducted in the 2-3 inch range at least monthly depending on growth characteristics. With an historical average annual rainfall on Long Island of 46.8 inches, pretty evenly distributed throughout the months of the years (National Climatic Data Center), low maintenance turf, especially those cultivars that are proven to be drought resistant, should perform well. The density and growth habits of the turf should keep weed encroachment to a minimum as found in the studies noted above.

**Summary Points:**

Use endophytic (disease resistant) and drought resistant tall fescue blends or "low input" validated perennial ryegrass and Kentucky bluegrass cultivars.

Mow to 2-3 inch height at least monthly.

Irrigate only when evapotranspiration exceeds precipitation.

**Research Requirements:**

The research cited for the evaluation of low input turfgrass was conducted in Maryland, Pennsylvania, Illinois, Iowa, Kentucky and Alberta. The soils ranged from silt loams to clayey in both fine and coarse textures. Some tests were conducted outdoors in natural environments while others were controlled greenhouse tests. More research is required to identify and select species and specific cultivars that would perform well in the microclimate and sandy soils of Suffolk County.

## Rates

Tall fescue, perennial ryegrass and Kentucky bluegrass were evaluated for color and turf quality at several points in a growing season in West Lafayette, Indiana (Walker et al. 2007). The test varied fertilizer rates and time of application. Kentucky bluegrass was the greenest followed by tall fescue then perennial ryegrass at any rate. Looking at means of the entire study, tall fescue had higher quality ratings and Kentucky bluegrass was higher than perennial ryegrass. While higher fertilization rates led to increased color and quality, the species had acceptable ratings for high maintenance standards at the following fertilizer rates:

| | |
|---|---|
| Tall fescue | 1.0 – 2.5 lbs N $M^{-1}yr^{-1}$ |
| Kentucky bluegrass | 1.5 – 2.5 |
| Perennial ryegrass | 2.5 – 4.0 |

Guillard and Kopp (2004) evaluated the same three species in Connecticut and recommended slow release fertilizers at a rate of 2-3 lbs N $M^{-1}$. However, single dose rates of urea at 1.0 lb N $M^{-1}$ were found to generate much higher leaching concentrations than rates of 0.5 lbs N $M^{-1}$ on Kentucky bluegrass lawns in Michigan (Frank et al. 2005).

Perennial ryegrass had unacceptable turf quality at a fertilizer rate of 2 lbs N $M^{-1}$ in a lawn study conducted in Seattle, WA. (Miltner et al. 2005). Turf quality increased at higher rates of 4 and 6 lbs N $M^{-1}$. The turf had reduced disease severity and lower incidence of weeds at these higher N rates. But Bushoven and Hull (2001b) suggested that perennial ryegrass root systems would not be able to take up any more than 3.0 lbs N $M^{-1}$.

Three bentgrass varieties for lawns were also evaluated in Seattle. Colonial mowed at 0.75 inches was found to have acceptable quality and thatch levels compared to velvet and highland varieties when fertilized at the lower annual rate of 1.0 lb N $M^{-1}$. Turf quality was generally improved at the higher annual fertilization rate of 3.0 lbs N $M^{-1}$ applied in three split applications (Rhinehart et al. 2005). The fertilizer was 67% slow release sulfur coated urea. Velvet bentgrass mowed at 0.75 inches and all other cultivars mowed at 1.5 inches produced unacceptable thatch levels.

While the results are translated from a study in Fort Collins, Colorado, Qian et al. (2003) provided the best summary of recommended rates taking into account clippings management and the mineralization rates of the soil organic nitrogen (SON) in maturing turf stands. Recommendations were made for fertilizer rates based on Clippings Removal or Clippings Returned practices that provide optimum biomass and turf quality for Kentucky bluegrass. The recommended rates are consistent with the turfgrass results and recommendations from Walker (2007), Guillard and Kopp (2004), Frank (2005), Miltner (2005) and Rhinehart (2005) for each species evaluated.

| Recommended Fertilizer Rates from Table 9: | | | |
|---|---|---|---|
| **Age of Site (yrs)** | **Fertilizer Rates with Clippings Returned** (lbs $M^{-1}$) | **Age of Site (yrs)** | **Fertilizer Rates with Clippings Removed** (lbs $M^{-1}$) |
| 1 -10 | 3.0 | 1 – 15 | 4.0 |
| 11 - 25 | 2.0 | 16 - 50 | 3.0 |
| 26 - 50 | 1.5 | 51-100 | 2.8 |
| 51-100 | 1.2 | | |

Notations were also made stating that rates below 1.5 lbs N $M^{-1}$ with clippings removed could lead to reduced root biomass, unacceptable turf quality and increased risk of leaching.

**Summary Points:**

Rates of 1.5 to 3.0 lbs N $M^{-1}yr^{-1}$, depending on the age of the turf and clippings management, are adequate for the cool season turfgrass species including creeping bentgrass, Kentucky bluegrass, perennial ryegrass and tall fescue.

Limit single applications to a maximum of 1 lb N $M^{-1}$. More frequent applications of 0.5 lbs N $M^{-1}$ or less are preferred.

No more than 0.5 lbs N $M^{-1}$ water soluble or immediately available nitrogen per application.

**Research Requirments:**

Sustainable lawn management should be studied in greater detail to identify cultivars within species that perform the best in Long Island and the rates necessary to sustain turf quality.

## Timing

The growth response or nitrogen uptake efficiency (NUE) of the plant varies by plant species with the cool season (C3) grasses being less efficient than the warm season (C4) grasses (Moore and Black 1979). Cool season grasses have the greatest NUE in spring and fall (Hull and Liu 2005). Hull and Liu suggest that as mid- season temperatures rise, roots become heat stressed and nitrate absorption is slowed. Once temperatures recede, plant functions are fully restored

and nitrate absorption resumes. Measuring soil $NO_3$-N levels through several seasons, Liu et al. (1997) found much higher levels under Kentucky bluegrass in the summer months compared to perennial ryegrass and tall fescue. All three species have reduced shoot growth during peak summer conditions (Liu and Hull 2006). This data suggests that C3 turfgrasses do not require as high a fertilization rate during summer. Maintaining high split rates during this period increases the risk of higher $NO_3$-N levels in the soil. While evapotranspiration (ET) may be at its highest and groundwater recharge at its lowest during this period, any excess irrigation or episodic precipitation event increases the risk of leaching from mid-summer fertilizer applications.

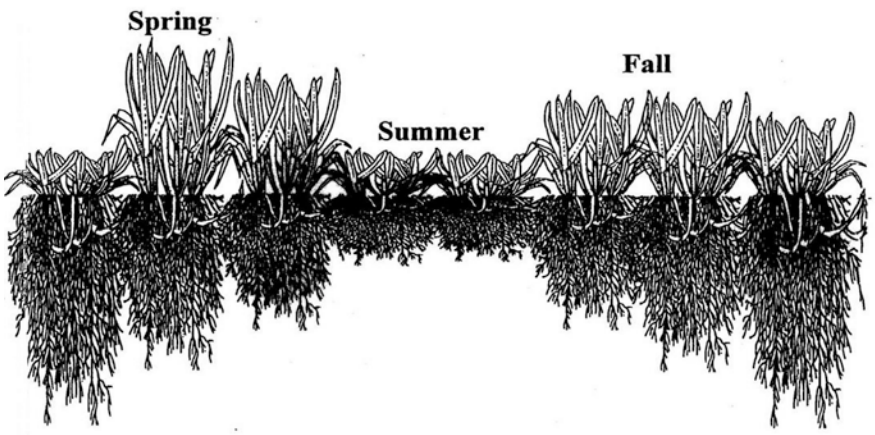



**Figure 21: The Seasonal Growth Characteristics of a Cool-season Turfgrass**

The application of nitrogen might begin at spring green up to increase shoot density. Light applications should be considered to avoid over stimulating growth. Consideration must also be given to the type of fertilizer being used and soil temperatures for those products that are released by microbial activity. Fertilizing in periodic intervals using readily available fertilizers produces surges in growth and N content in clippings when compared to steadier supply from slow release fertilizers, fertigation systems, or light and frequent applications of 0.1 lbs N $M^{-1}$ (Bowman 2003). Summer application rates should be trimmed to maintain color but recognizing that the plants are in summer decline. As temperatures subside from peak summer highs, shoot and root growth are resumed. Fall applications can help turf recover from wear and injury. Fall applications can also build up root reserves improving spring green up (Moore et al. 1996). Late season applications can also create significant losses to groundwater; the later the application, the greater the losses (Guillard and Kopp 2004).

Varying the amount and timing of nitrogen application from a low of 1.0 or 1.5 lbs N $M^{-1}$ $yr^{-1}$ in a single fall application, 2.5 lbs N $M^{-1}$ $yr^{-1}$ in a spring only or fall only split application and 4.0 lbs N $M^{-1}$ $yr^{-1}$ fall and spring application, three cultivars were evaluated for clippings yield and turf quality (Walker et al. 2007). Medium rate fall applications (1.5 lbs N $M^{-1}$) were found to produce acceptable quality factors year round compared to spring only or higher rate spring and fall schedule. A program that started lightly in the spring (0.5 lbs N $M^{-1}$) and included two fall applications of 1.0 lbs N $M^{-1}$, had greater root mass in the spring.

The late fall application is best applied at a time when the nitrogen is processed into root reserves to support growth for the following season and not used in unwanted top growth[2]. A late application of 0.5-1.0 lbs N $M^{-1}$ should be made when air temperatures cool to 35-40° F and soil temperatures remain at 58-65° F (Christians 1988).

Late fall applications also create situations where plant uptake cannot absorb excess build up of $NO_3$ (Guillard and Kopp 2004) and a period where soil nitrate levels are highest (Liu et al. 1997). As fall temperatures decline, evapotranspiration (ET) is reduced. As soil water moisture levels increase, fall precipitation results in larger increases in soil washing and groundwater recharge (Steenhuis et al. 1985).

Late fall applications of nitrogen and large fall applications do not improve the cold hardiness of turf plants. The cold hardiness of turfgrass evolves during a period of cold acclimation just prior to winter dormancy (Gusta and Fowler 1977). The acclimation period begins as daytime temperatures drop below 50º F and shoot growth ceases (Christians 2007). Super-cooling a plant will result in higher killing temperatures (Gusta and Fowler 1977). Temperature cycles will also result in incremental reductions in freeze tolerance. As the duration of freezing exposure increases, the lethal temperature rises. However, fertilization can also be a factor. Too much nitrogen can increase tissue N content and crown hydration, raising the temperature at which plant tissue can be killed. The cold hardiness of perennial ryegrass was best with total annual N applications of 1.0-3.0 lbs N $M^{-1}yr^{-1}$ (Webster and Ebdon 2005). Higher fertilization rates increased freeze stress and the incidence of gray snow mold. Fall applications at the lower rates did not increase freeze stress or killing temperatures. Killing temperatures for creeping bentgrass (-20 ºC) were found to be lower than annual bluegrass (-13ºC) accounting for the propensity of winter kill on *Poa annua* (Tompkins et al. 2000). Dehardening of the plants and the commensurate increase in crown hydration was closely associated with soil temperatures (Tompkins et al. 2004). Where bentgrass survived at low temperatures through 90 days of treatment, the *Poa* tested was dead after 75 days.

**Summary Points:**

Spring applications are only necessary to improve density and reduce weed encroachment.

Reduce rates during peak summer stress.

Avoid late fall applications. Recommended applications in September or splits in Early September and Early October.

Only apply fertilizers when soil temperatures are above 50º F.

[2] Suffolk County prohibits any fertilizer applications on turf being made between November 1st and a April 1st.

## Application

Good practice requires proper placement of fertilizers. It starts with calibration. Not only should equipment be inspected and calibrated before every use, the job itself needs to be assessed. Determine the actual area of coverage. Familiarity with the site will remind or identify any peculiarities.

Special consideration should be given to storm drains, streams, ponds and wetlands. Maintain a "no spray/no application" buffer zone of at least one pass of the sprayer or a minimum of 20 feet. Buffer areas are very effective at reducing runoff (Baird et al. 2000) and leaching (Stier and Kussow 2009).

Any application onto an impervious surface should be swept or blown off onto the turf to insure that this material is not washed away into surface waters, storm drains or groundwater recharge basins.

**Summary Points:**

Inspect and calibrate equipment before applications.

Review area of application for square footage and special features.

Calculate material required.

Do not apply fertilizers within 20 ft of storm drains or waterbodies.

Sweep up any material applied to impervious surfaces.

## Other Cultural Management Practices

## Recommended Cultivars

The rating system and testing of turfgrass coordinated by the National Turfgrass Evaluation Program (NTEP) has already been noted. Cultivars are generally rated for "turfgrass quality" based on characteristics such as density and color. Kentucky bluegrass has been classified into genetic groups by trait characteristics (Park et al. 2005; Curley and Jung 2004). Similarly, other programs have classifications for disease resistance (Bonos et al. 2006) or drought resistance (Karcher et al. 2008; Richardson et al. 2008). The classifications are useful tools for selection. Park et al. (2005) list Kentucky bluegrass cultivars in the following groups: Compact, Compact-Midnight, Compact-America, Mid-Atlantic, Julia, CELA, Aggressive, Shamrock, BVMG, Common, and Other. The Compact-Midnight and Julia types were the best Mid-Atlantic types that demonstrated use in high-traffic areas. The research study fertilized cultivars tested at 4.5 lbs N $M^{-1}yr^{-1}$ in split spring/fall applications. These tests did not evaluate performance at different fertilizer rates.

Tall fescue, perennial ryegrass and Kentucky bluegrass were evaluated to see how each species and cultivars within each species performed in taking up nitrogen from the soil water (Liu et al. 1997). $NO_3$-N mean levels for each species were 0.7, 1.8 and 4.6 mg $L^{-1}$, respectively. These tests were conducted in Kingston, Rhode Island, on Enfield silt loam soils that are described as well drained coarse silt over sand. Cultivars are listed below with their respective performance:

| | |
|---|---|
| Tall Fescue: | All cultivars tested had soil $NO_3$ levels less than 1.2 mg N $L^{-1}$.<br>Including Apache, Arid, Falcon, Rebel and Jaguar. |
| Kentucky Bluegrass: | Best: Able I and Eclipse.<br>Mid: Parade, Joy, Midnite, Bristol, Kenblue.<br>Worst: Liberty, Blackburg, Trenton. |
| Perennial Ryegrass: | Worst performing perennial ryegrass cultivar better than best performing Kentucky bluegrass cultivar.<br>Best: Repel, Ranger.<br>Worst: Manhattan, Linn, Tara, Yorktown, Derby. |

Many of these cultivars were subsequently tested to see which had the highest (or in some cases the worst) daily nitrogen recovery (DNR) inferring that higher nitrogen uptake rates (NUR) would relate to lower soil $NO_3$ water levels (Liu and Hull 2006).

| | |
|---|---|
| Tall Fescue: | Jaguar and Falcon best overall. |
| Kentucky Bluegrass: | Midnight and Blackburg had lowest (worst) DNRs.<br>Kennblue, Able I, Bristol had the highest.<br>Joy, Trenton, and Eclipse had mid performing DNR's but good in the summer.<br>Bristol was the best performing in the fall. |
| Perennial Ryegrass: | Experimental cultivars and Linn. |

One study specifically looked at low and high maintenance cultivars of Kentucky bluegrass (Sullivan et al. 2000). These tests were conducted in Beltsville, Maryland. Low maintenance was identified as those cultivars that performed well with less nitrogen fertilizer and minimum irrigation but did poorly under high maintenance routines. Conversely, cultivars judged to be high maintenance did poorly under low maintenance management.

| **Low Maintenance** | **Mid Maintenance** | **High Maintenance** |
|---|---|---|
| Kennblue | Adelphia | Midnite |
| Park | American | Majestic |
| So. Dakota Common | Ram I | Glade |
| | Vantage | Cheri |
| | Welcome | |

**Table 13: Low, Mid and High Maintenance Kentucky bluegrass Cultivars**

Looking at perennial ryegrass and creeping bentgrass, cultivars are shown below that had turf quality ratings greater than 6.0[3] and demonstrated the best root:shoot ratios (Bushoven and Hull 2001a):

| Creeping Bentgrass | Perennial Ryegrass |
|---|---|
| L-93 | Palmer III |
| Penn G-2 | |

Unfortunately, there is very little information on the physiology of *Poa* related to nitrogen uptake or morphological characteristics. One study conducted in Ontario, Canada, did identify several ecotypes of *Poa* finding that nitrogen losses in leachate were much higher relative to creeping bentgrass but with some significant differences within ecotype (Pare et al. 2006). The losses were reported as follows:

| **Species** | **Cultivar** | **% N losses** |
|---|---|---|
| *Poa* | US Ecotypes | 34-40 % |
| | Ontario Ecotypes | 36-57 % |
| | Quebec Ecotypes | 61-71 % |
| Creeping Bentgrass | Vesper | 6 % |
| | Highland, Penn A4, Penncross | 10-11 % |

**Table 14: creeping bentgrass Cultivars and *Poa* Evaluations**

[3] The turfgrass rating system is a standard NTEP system where 9 is the best and 0 is worst. A 6.0 is considered the minimum acceptable turfgrass rating.

In general, Pare noted that when *Poa* had greater above ground biomass, it also had greater root mass and lower leaching losses.

Rutgers University maintains a turfgrass breeding and evaluation program to test cultivars of cool season turfgrass species for overall quality and disease resistance. Their test plots are located in Adephia and North Brunswich, NJ. These test areas have climate conditions very similar to Long Island. A series of studies rate cultivars of each major species over a period from 2004-2008 (Koch et al. 2008). Test cultivars that were rated the best are listed in Table 15.

| Turfgrass Species | Creeping Bentgrass | Perennial Ryegrass | Kentucky Bluegrass | Fine Fescue | Tall Fescue |
|---|---|---|---|---|---|
| Mowing Hgt | Greens: 0.125 in<br>Other: 0.375 in | 1.5 in | 1.5 in | 1.5 – 2.5 in | 1.5 in |
| Clippings Mgmt | Removed | Returned | Returned | Returned | Returned |
| Lbs N $M^{-1}yr^{-1}$<br>(excludes year of establishment) | Greens: 3.71 – 4.81<br>Other: 1.95 – 4.78 | 1.5 – 3.3 | 0.8 – 3.8 | 0 – 2.0 | 2.8 – 3.5 |
| Best Cultivars: | Greens:<br>Tyee<br>Shark<br>Runner<br>Authority<br>Kingpin<br>Declaration<br>007<br>Other:<br>Declaration<br>Tyee<br>Shark<br>007 | All*Star 3<br>Derby Xtreme<br>Uno | Compact Type:<br>Prosperity<br>Emblem<br>Blueberry<br>Moon Beam<br>Compact-Midnight Type:<br>Everest<br>Award<br>Impact<br>Compact-America Type:<br>None over 6.0<br>Mid-Atlantic Type:<br>Zinfandel<br>(No other types or commercial cultivars > 6.0) | Chewings Fescue:<br>LongfellowII<br>Treasure II<br>Hard fescue:<br>Predator<br>Viking<br>Strong Creeping :<br>Audubon<br>Cindy Lou | 3rd Millennium<br>Falcon V<br>Shenandoah III<br>Cochise IV<br>Faith |

**Table 15: Cultivars with Best Turf Quality Ratings from Turf Trials Conducted in New Jersey**

One of the North Brunswick trials and two of the Adelphia trials were conducted with declining rates of nitrogen applied to Kentucky bluegrass (Shortell et al. 2008a). During establishment in

2005 rates ranged between 4.1 to 5.0 lbs N $M^{-1}yr^{-1}$ then declined to 2.3-3.7 in 2006, 2.3-2.7 in 2007 and 0.8-1.4 in 2008. Only four of the cultivars tested had quality ratings that were greater than 6.0. The ratings suggest that the cultivars tested performed as well in 2007 at rates below 3 lbs N $M^{-1}yr^{-1}$ as earlier years at higher rates. This could be attributed to the clippings being returned building up the soil organic nitrogen reservoir and better developed, maturing root systems. At the lbs 0.8-1.4 lbs N $M^{-1}yr^{-1}$, the rating tend to decline slightly. Three of the four cultivars, Moonshadow, Langara, and Cabernet, demonstrated acceptable quality levels at these reduced rates.

In a separate low maintenance test at the Adelphia site, fine fescues were compared with selected cultivars of Kentucky bluegrass at declining rates of 2.0, 1.0 and 0.0 lbs N $M^{-1}yr^{-1}$ in 2006, 2007 and 2008, respectively (Shortell et al. 2008b). The fescues are generally considered to only require 1-2 lbs N $M^{-1}yr^{-1}$ (Turgeon 2005). Amongst the fine fescues evaluated at the declining rates, the hard fescue cultivars of Lucy, Nordic, Oxford and Stonehedge had exceptional quality ratings at any fertilization rate. A number of experimental cultivars in the strong creeping and chewings fescue groups performed well. All other commercial cultivars received ratings below 6.0. There is a group of cultivars that generally held turf quality ratings between 5.5 and 6.8 at the 1 and 2 lb rates. This group included the Kentucky bluegrass cultivar, Aura. Most cultivars showed very little change at the zero rate. However some of the fescue cultivars and Aura fell below 5.1 in 2008 when no fertilizer was applied. These tests suggest that most fescues cannot meet our expectations of a "quality" level at published 1-2 lb rates. However, if we are willing to downgrade our expectations, there are a number of cultivars that will perform satisfactorily. The declining quality ratings at declining rates of fertilization may also indicate reductions in physiological health. The tests did not measure any morphological characteristics for shoot or root growth.

**Summary Points:**

Tall fescue is a preferred low nitrogen input turfgrass species for lawns with excellent season long nutrient uptake. Perennial ryegrass would be a good second choice. Kentucky bluegrass generally has poor performance during peak summer periods and the fall.

Little information is available for selection of more popular creeping bentgrass cultivars. However, creeping bentgrass performance is generally good and much better than *Poa.*

Management practices should be employed that promote creeping bentgrass growth over *Poa*. These practices would include maintaining a lower pH soil, eliminating phosphorus components of your fertilizer mix, and seedhead management.

**Research Requirements:**

Turfgrass ratings tests should routinely measure quality at various fertilization rates and also account for morphological and physiological characteristics as they relate to leaching.

## Establishment

Newly established turf poses a very high risk for leaching and runoff losses (Easton and Petrovic 2004; Soldat et al. 2009; Stier and Kussow 2009). Preplant preparation of the top 3-4 inches of soil may require 1-2 lbs of nitrogen, phosphorus and potassium (Beard 1973). If possible, applications should not be made until germination has been completed. New turf should be fertilized at very light nominal rates of 0.5 lbs N $M^{-1}$ per month. Slow release fertilizers should be considered over water soluble, readily available sources if higher rates are needed.

**Summary Points:**

Spiking turf with high nitrogen prior to germination is not required.

After germination, spoon feed at 0.1-0.25 lbs N $M^{-1}$ biweekly.

Use slow release products over water soluble products.

## Irrigation:

Using fast release nitrogen sources and ideal growing conditions, Bowman et al. (1989a) demonstrated that the rate of nitrogen depletion is rapid and typically fully used within 48 hrs of application. The results were found to be the same for tall fescue, creeping bentgrass, Kentucky bluegrass and perennial ryegrass considering nitrate ($NO_3$) and ammonium ($NH_4$ ) applications at 1.0 lb N $M^{-1}$. Separately, Bowman found that irrigating at 0.4, 0.8 and 1.2 inches per day resulted in leachate with $NO_3$-N as high as 26.5 mg $L^{-1}$ for shallow rooted plants irrigated the day after fertilization (Bowman et al. 1998). That rate dropped to 13.5 mg/L for deep rooted plants irrigated 1 day after fertilization. Withholding irrigation for 3 to 5 days after treatment reduced N losses to trace amounts for deep rooted plants. Shallow rooted plants irrigated 3 to 5 days after fertilization had $NO_3$-N levels of 4 and 2 mg $L^{-1}$, respectively. Bowman suggests that increasing the time for the plant and soil to immobilize the inorganic fertilizer reduces the amount of fertilizer dissolved in soil water and the risk of leaching. Bowman suggested that immobilization is still possible when the fertilizer remains in the upper soil profile containing plant roots and organic material.

The adage of "light and frequent irrigation does not promote good rooting compared to deep and long irrigation cycles" is problematic. The best practice is somewhere between the two. Deep and long practices will percolate $NO_3$-N deeper into the soil profile increasing risks of groundwater contamination. Light and frequent would be good enough if it sufficiently wetted the soil profile. Many managers attempt to judge the watering requirements of their turf by looking at the turf for indications of wilting stress. Others test core samples for soil moisture by feel. Whether you are irrigating by hand or using an installed system, the amount of water applied is a critical factor in managing risks.

There are seasonal considerations. Risks of leaching are higher when evapotranspiration (ET) rates are lowest. The risks are also high when plant nitrogen uptake rates (NUR) are lower. For this reason, irrigation should be reduced or controlled during peak summer depending on species

and during mid to late fall as plants begin dormancy. The leaching studies reviewed in Table 12 on page 68l. Whether you are irrigating by hand or using an installed system, the amount of water applied is a critical factor in managing risks.

There are seasonal considerations. Risks of leaching are higher when evapotranspiration (ET) rates are lowest. The risks are also high when plant nitrogen uptake rates (NUR) are lower. For this reason, irrigation should be reduced or controlled during peak summer depending on species and during mid to late fall as plants begin dormancy. The leaching studies reviewed in Table 12 on page 68 summarize results with concentrations often less than 1 mg N $L^{-1}$ using irrigation rules that replaced 80% of ET or applied around 0.2 inches or less. Use local data centers to record the difference of the amount of Precipitation – Evapotranspiration (P-ET) and reapply water at 60-100% of any negative P-ET value[4]. Insure that the irrigation system provides measured rates and uniform coverage to all areas. Adjust application rates to take into account shaded areas or areas with lower air flow. These areas will have lower ET rates.

Golf courses in the Northeast were reported to irrigate an average of 54 acres of turf using a total of 13.8 million gallons of water compared to a US average usage of 51.5 million gallons (Throssell et al. 2009). The 13.8 million gallons is equivalent to 9.4 inches of water per acre. There were sixteen weeks in the 2008 growing season when P-ET was negative (Kowalsick 2009). These weeks had a total negative P-ET of 10.04 inches.

**Summary Points:**

Irrigation requirements must be balanced to wet a soil enough to eliminate volatilization losses with any urea, but not to saturate the soil so much as to cause denitrification.

Water based on need, not on a schedule.

Use local data centers to record the difference of the amount of Precipitation – Evapotranspiration (P-ET) and reapply water at 60-100% of any negative P-ET value.

Wet the root zone of the turf, typically the top 4-6 inch layer.

Adjust water rates to take into account shaded areas or areas with lower air flow. These areas will have lower ET rates.

Keep mowing heights as high as possible in the summer months.

## Mowing

Uptake on $N0_3$ was three times greater on well fed perennial ryegrass plants mowed four days before treatment compared to those mowed 30 minutes prior to treatment (Bowman et al. 1989a). N-deficient plants, however, responded quite differently with equal absorption suggesting that the reduced leaf area has little to do with the assimilation or as a sink of $NO_3$. Evaluating

[4] Local media, including newspapers, television, and radio, along with other literature and web resources should relate cumulative P-ET values to provide recommended timing for garden and lawn maintenance. For additional information, consult with the Northeast Regional Climate Center at http://www.nrcc.cornell.edu/

perennial ryegrass lawns at heights of 1.5, 2.0 and 2.5 inches, Miltner et al (2005) measured higher turf quality at lower cuts but fewer weeds at higher cuts.

If clippings are collected from mowing, they should either be composted or spread over a wide area. Excessive clippings aggregation can lead to elevated soil nitrogen levels and increase the risk of nitrates washed through the soil profile (Bigelow et al. 2005). Soil nitrate levels increased from less than 2.5 mg N $kg^{-1}$ to a range of 15-30 mg N $kg^{-1}$ across the 3-12 inch profile in areas that received four times the amount of normal clippings return.

**Summary Points:**

Mow lawns to a height of 2-3 inches.

Do not mow just prior to fertilizer applications. Mow at least two days, preferably four days, prior to fertilization.

## Salinity

Tall fescue treated at three relatively low salinity levels (0, 15 and 30 meq $L^{-1}$) and three fertilization rates (0.5, 1.0 and 1.5 lbs N $M^{-1}$ $mo^{-1}$) demonstrated that there was no salinity effect on nitrogen uptake or leaching (Bowman et al. 2000). Expanding on these results, tall fescue was tested again at higher salinities (40, 80 and 120 meq $L^{-1}$)(Bowman et al. 2006). Nitrogen deprived tall fescue had $NO_3$ uptake rates that were similar at all salinity levels, but less than the control. Uptake of well-fed plants was reduced as much as 60% by higher salinity levels.

**Summary Points:**

At low salinity levels, perhaps best associated with ocean spray, there is no affect on nitrogen uptake.

At higher salinity levels, perhaps associated with areas of turfgrass on tidal marshes, nitrogen uptake is reduced by as much as 60%. In these tidal surge areas, turfgrass should be fertilized more frequently at reduced rates, much like spoon feeding. A fertigation system is recommended.

## Pesticide Applications:

Spray applications are commonly mixed with fertilizers. Unfortunately, good management practices will often mandate separate tank applications. The fertilizer application needs to be washed into the soil profile. Other products such as contact pesticides, Primo® and iron need to be foliarly applied.

**Summary Points:**

Do not mix fertilizers with foliar spray pesticides.

Fertilizers must be washed into the soil profile with a approximately 0.1-0.2 inches of water.

## Thatch Management

The importance of the organic layer including thatch has already been described. Clearly this layer has a prominent role in the storage and release of nitrogen. Other considerations for thatch remain. The thatch layer can add to the spongy softness of turf and be a consideration for play. More problematically, it can absorb too much water. It can lead to the desiccation of crowns. If a thatch layer is buried under topdressing, it can isolate any roots below and create a perched water table. Hollow tine aerification and verticutting are particularly important cultural processes.

**Summary Points:**

Thatch should be controlled to approximately ½ inch or less.

Subsurface layering of organic material can create poor drainage, increases losses through runoff and denitrification, and results in reduced efficiency of fertilizer.

## Plant Health

Promoting good plant health is a sure way of maximizing nitrogen uptake rates. Building good plant health is also one of the best stress management tools for summer decline or high pest pressure.

**Summary Points:**

Keep cuts as high as possible.

Maximize carbon assimilation by increasing light exposure.

Improve air circulation to minimize excess moisture and enhance transpiration.

## Soil Management

Certain conditions, such as compaction, will induce runoff. The increased bulk density of a compacted soil will have a reduced infiltration rate. Thinner turf density, associated with

compacted areas, also contributes to reduced infiltration and reduced resistance to erosion. Compacted soils should be aerified and renovated to restore turf coverage.

Soil health, particularly in the rooting zone, should be promoted to the best extent possible. Management practices should carefully insure that the soil is never so saturated as to promote anaerobic conditions. Efforts such as drill and fill can frequently improve drainage problems. More extensive drainage problems may require installing drain tiles to redirect excess water. Frequent top dressing will also build a good soil profile that will promote good structure from the crown down into the root zone while also promoting good biological activity. Depending on the soils specific organic matter content, some soil amendments may promote and enhance activity.

**Summary Points:**

Compacted soils should be aerified and renovated to restore turf coverage.

Extensive drainage problems may require installing drain tiles to redirect excess water.

Frequent top dressing will also build a good soil profile.

Consider organic fertilizers and amendments for newer stands of turf to increase the nitrogen absorption.

## Weeds

Fertility and height of cut were found to be the most effective management tools for weed management (Calhoun et al. 2005). Comparing plots fertilized at a rate of 3 lbs N $M^{-1}yr^{-1}$ in a split spring fall application schedule (JJSN) with unfertilized plots at mowing heights of 2 and 4 inches, the six year study found fertilization at the higher mowing height with only two post emergent herbicide applications in Oct of year one and year three provided 95% control of weeds. Miltner et al (2005) determined that 2 lbs N $M^{-1}yr^{-1}$ was too low a fertilization rate on perennial ryegrass lawns and resulted in heavy weed infestation. While synthetic fertilizers generally produced better turf quality than organic fertilizers, organic fertilizers at higher cutting heights had markedly good quality.

**Summary Points:**

Use light spring applications to improve turf development to crowd out weeds.

Maintain high cuts of turf.

Organic fertilizers may provide better weed prevention particularly at higher cutting heights.

## Plant Growth Regulators (PGRs)

Evaluating the effect of trinexapac-ethyl (Primo®) and nitrogen in reduced light conditions, creeping bentgrass on a sand-based green exhibited increased tillering on lower fertilization rates

(3.1-3.5 lbs $M^{-1}$) compared to higher rates (4.5 lbs $M^{-1}$) (Goss et al. 2002). Primo treatments also increased tillering. There was no increase in root mass under any Primo® treatment. Primo® with low N treatments improved the turf coverage in reduced light environments and also reduced the amount of algae. Overall, 80% shade cover had severe effects on turf. However, under 60% shade, turf quality could be maintained with applications of 0.1-0.23 oz $M^{-1}$ on 2-4 week intervals. Furthermore, low N treatments provided increased turf coverage and increased root mass. Selecting cultivars with improved fibrous and adventitious roots was shown to improve nitrogen uptake rates. Selecting proper management practices can also be a positive influence. Fagerness and Yelverton (2001) also studied the use of Primo® and Paclobutrazol on creeping bentgrass greens concluding that PGRs did not have any effect on root biomass. They did quantify a 76% decline in root mass between May and September that was associated to root die-back due to heat, followed by resurgence from September to January. Turf mowed at 1.3 inches had lower biomass than turf mowed at 1.6 or 1.9 inches and a slower autumn resurgence. The summer decline and the consequent reduction in the nitrogen uptake rate (NUR) is good reason why fertilization rates need to be trimmed during peak temperatures.

Steinke and Stier (2003) found bimonthly applications of Primo® (0.16 fl oz $M^{-1}$) improved turf quality, density, and chlorophyll content of supine bluegrass, Kentucky bluegrass, and creeping bentgrass. The plots were on a Troxel silt loam and maintained at 0.5 inches with clippings removed. Nitrogen applications were made at 14 day intervals comparing a liquid or granular urea (46-0-0) at 0.2 lbs $M^{-1}$.

**Summary Points:**

PGR's can be effective in reducing *Poa* which has poorer nitrogen uptake rates that other cool season turfgrasses.

Primo is effective at limiting top growth while improving tillering and overall density. This density will promote better infiltration rates.

Rates vary for lawns, fairways, and greens. Consult the product label for recommended rates.

## Surfactants

A fertilizer product blended with a surfactant produced a healthier, lower stress plant compared to fertilizer alone (Malazian et al. 2009). Tall fescue turf treated with a surfactant blend had higher quality characteristics during induced drought pressure.

**Summary Points:**

The implication is that turf under drought stress need not necessarily be treated with more nutrients to maintain a quality level; that fertilizer efficiency may be improved through the use of surfactants.

## Biostimulants:

There were no significant relationships using biostimulants to microbial populations or microbial activity that might increase nutrient use in the Soil Organic Nitrogen (SON) fraction, nor were there any positive relationships to nutrient use in the creeping bentgrass samples studied (Mueller and Kussow 2005). However, there was a significant improvement in turfgrass quality ratings and a correspondingly strong reduction in localized dry spot.

**Summary Points:**

Biostimulants may augment turf quality allowing some reduction in the overall amount of nitrogen applied.

## Site Considerations:

### Topography:

The topography of an area describes natural and man-made physical features. Elevation changes and contours that might channel or collect water are of particular interest. Drainage from these areas and other man-made areas including roadways, sidewalks, cart paths, parking lots and buildings should be considered as the overall topography. The topography must also describe the proximity of these features to surface water. If the drainage or collection area receives water in excess of the infiltration rate, runoff will occur (Easton et al. 2005). Because of the intensity of flow around storm water drains, the area around the drains should not receive any direct application of any water soluble products including slow release urea formulations.

Buffer areas should be developed around impervious areas and surface water features. These buffers are effective at absorbing runoff and nutrients (Steinke et al. 2009). Buffer areas should be at least one half the size of the impervious area. In hill slope areas, a buffer of at least 20 feet is recommended.

The NRCS Web Soil Survey is an online tool to obtain specific soil descriptions for your property (http://websoilsurvey.nrcs.usda.gov/app/). Identify the drainage characteristics and the proximity to the water table. Shallow water tables may require more careful applications using slow release water insoluble products.

**Summary Points:**

Map topography and isolate problem areas.

Identify collection areas and drainage outlets.

Do not apply water soluble or slow release soluble formulations within 20 ft of surface water, storm drains or groundwater recharge areas.

Maintain buffer areas around impervious surfaces and surface water features.

Identify soil characteristics, drainage properties, and proximity to the water table.

## Wash Stations:

There are currently no state or county regulations for the design and operation of wash stations. Discharge of wastewater from wash stations with low concentrations of pesticides and fertilizer onto the ground does not require any special permits. However, USEPA regulations do apply to any wastewater that is discharged to a storm water runoff system. It is advisable to check your local laws for specific rules.

In a survey of 20 Long Island golf courses, 75% of the courses utilize concrete or asphalt wash pads (Petrovic 2005). The survey showed very low levels of ammonium (2-13 mg $L^{-1}$). Nitrate levels were below detection limits (< 1 mg $L^{-1}$). However, phosphorus was measured at 6-8 mg $L^{-1}$. The USEPA sets a limit of 0.1 mg L-1 for phosphorus in stormwater. Wash water should not be discharged into runoff areas or groundwater recharge basins.

Low levels of pesticides were found in washwater and holding/recycling tanks were found to accumulate pesticide residues even months after their application. Pesticide application equipment should be washed in a separate wash area with the discharge applied to a grassy swale away from sensitive areas or a special wastewater system should be used that is specifically designed for pesticides.

Clippings collected from wash stations should either be composted or spread over a wide area. Excessive clippings aggregation can lead to elevated soil nitrogen levels and increase the risk of nitrates being washed through the soil profile (Bigelow et al. 2005). Soil nitrate levels increased from less than 2.5 mg N $kg^{-1}$ to a range of 15-30 mg N $kg^{-1}$ across the 3-12 inch profile in areas that received four times the amount of normal clippings return.

**Summary Points:**

No State or County regulations apply to wash stations and wastewater discharge. Consult local town ordinances for their specific rules.

New construction may require special permits.

Wastewater should not be discharged into stormwater runoff areas, storm drains or groundwater recharge basins.

Pesticide application equipment should be washed in separate areas. For this equipment, it is advisable to either recycle the wastewater using specialized equipment or to discharge the water across a grassy area away from sensitive areas.

Clippings collected from turf and wash stations, if not composted, should be dispersed over a wide area. Clippings should not be dispersed near any water feature or wetland.

## Storage:

Many fertilizers should be stored separate from solvents and pesticides, preferably in a well constructed concrete structure. If there is any risk of flooding, fertilizers should be stored on shelving above the floor level. Storage buildings should be built on a pad with a protective curbing to contain any spills. Drains should not be tied into storm drains.

**Summary Points:**

Store fertilizers separately from pesticides and solvents in well constructed buildings.

Protective curbing should be used to contain spills.

Insure that building drains are not connected to storm drains.

## Groundwater Leaching Models

Groundwater modeling has largely focused on pesticides where the risk of leaching is dependent on the interaction of chemical and soil properties. Among 82 models reviewed, 54 were found to be pesticide/soil models (Siimes and Kamari 2003). The other 28 were solute transport models, more pertinent to nitrate leaching. Models range from complex research based models to simpler extension/farm user models (Loague and Green 1991). There are single-process, multiple process, comprehensive and field scale models. The field scale models are typically comprehensive models taking account of many differences such as variations in soil types, land use and hydrology. Some models may account for temporal changes such as rain events over time.

A simple nitrate-leaching model was developed by Williams and Kissell (1991) using annual precipitation rates, timing of precipitation and characteristics of the soil to create a static rating for the risk of leaching. Soils are grouped into hydrological classifications by their water storage capacity and saturated conductivity as denoted by their soil classification in the Suffolk County Soil Survey (United States. Soil Conservation Service. et al. 1975). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation for a long period of time. The Soil Survey defines the four hydrologic soil groups as:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

In reviewing the soil characteristics of Suffolk County, 77% of the land area was defined as excessively or well drained. These soils fall into Group A and B posing a relatively high risk of leaching.

Using values assigned to each of these hydrologic soil groups a Leaching Index (LI) was formulated from a Percolation Index (PI) and Seasonal Index (SI) (Williams and Kissel 1991). The LI is currently the basis for agricultural nutrient management in New York State (Czymmek

et al. 2003). An LI value below 2 indicates a very low leaching potential. An LI over 10 is a high-risk index and requires the implementation of best management practices. LI's between 2-10 are intermediate values and best management practices are suggested on a case-by-case basis.

There are circumstances where the values assigned to soils and precipitation in an area causes the Percolation Index (PI) to be negative. A variation of the LI index corrects for the negative PI and adjusts for irrigation to create a Percolation Factor (PF) (Williams and Goss 1992). Any PF greater than eleven is considered a high risk for leaching. There are 5.4 million acres of non-federal land in New York State, nearly 20.4% of the state, that have PFs greater than 11.

The field scale models for nitrate leaching must take into account the sources of contamination, the reaction rates, transit times, mixing and ground water flow characteristics in varying hydrogeologic settings (McMahon et al. 2008b). The sources of nitrogen vary by land use, including agricultural and urban settings, representing nitrate additions from fertilizers and septic systems. The reaction rates should account for plant uptake, incorporation in the soil nitrogen reservoir, denitrification and reduction/oxidation rates. The groundwater residence times, mixing and flow have been well documented for Suffolk County (Buxton and Smolensky, 1999; CDM 2010b). The success of the Counties nitrogen management plan, its ability to reduce groundwater nitrate levels and restore estuary health, depends on the accuracy of the models used, the parameters and the inputs (Loague and Green 1991)

Ideally, a model would dynamically account for the land use variations across the county. Geographic information systems would map or aggregate agricultural areas, turf areas, forestland, and open/vacant land. Source calculations would be made for nutrient loads from fertilizer inputs but also distinguish loads from sewered and unsewered districts. Modeling should account for nutrients, primarily nitrate, leached through the root and vadose zone into groundwater. Furthermore, the model should account for nutrient loads, organic and inorganic, associated with runoff and storm water.

Two models for nitrogen leaching, NLEAP and RZWQM, are noted for being field scale models that account for soil water and nitrogen, track the soil organic nitrogen mapping decay and mineralization, include values for plant nitrogen uptake, and compute losses for volatilization and denitrification (Shaffer 1995). The Nitrogen Leaching and Economic Analysis Package (NLEAP) is an agricultural based model that can evaluate management practices, soils and climate to establish a risk of leaching (Shaffer et al. 1991). It can also be run using event–by-event analysis to track precipitation, irrigation and fertilization to estimate nitrate leaching into groundwater. The Root Zone Water Quality Model (RZWQM) was presented by the USDA Agricultural Research Service (ARS) in 1992 and recently reviewed (Wauchope et al. 2004; Ma et al. 2007). RZWQM was designed as a pesticide/soil-leaching model. It is regarded more as a tool to present a scenario or outcome when all the inputs are known. It does allow inputs to vary the amount of fertilizer applied and the method of application. Both NLEAP and RZWQM have limited ability to compute nutrient losses in runoff.

The pesticide/soil models appear to be more comprehensive models with elaborate field scale calculations for chemical and soil dynamics. There are often parameters in these models for the amount of chemical that is taken up by the plant or lost to evapotranspiration. There is more

emphasis on sediment losses in erosion and runoff. In addition to the chemical solubility, the pesticide models have complete chemical databases for each chemical's degradation factor ($T_{½}$) and soil adsorption ($K_{oc}$) (Wauchope et al. 2002; Gustafson 1989). These factors are used to calculate how likely a chemical will be held in the soil profile and to estimate leaching below the root zone. In addition to the hydrologic grouping, soils are classified by surface layer thicknesses, texture and organic content. Consideration is often given to the depth to the water table. One of the earliest models utilized and still employed independently and as a subset of more recent models, the Groundwater Loading Effects of Agriculture Management Systems (GLEAMS), presents losses in leaching and sediment erosion (Leonard 1987). The underlying parameters of GLEAMS have been used in the Soil Pesticide Interaction Screening Proceedure (SPISP) to provide spatial ratings for relative loss potentials (Goss and Maizel 1992). The National Pesticide User Risk (assessment) for Ground (and surface water), NPURG, was built using the underlying factors in GLEAMS and the previously described Leaching Index (LI). The DOS based program has not been updated and now has been surpassed by a number of other models.

A multitude of pesticide/soil models exists with variations to confound. Reviews have found many to be either too simplistic or too complicated (Siimes and Kamari 2003) or found inherent problems with the parameterization of interactive soil and plant process (Köhne et al. 2009). From the reviews, GLEAMS, MACRO, PEARL, PELMO, PRZM and RZWQM were well regarded and tested well in the field validations. The Soil Water Assessment Tool (SWAT) has also been evaluated in the field and compared to PRZM (Parker 2007). The SWAT model was developed to model water quality in a larger spatial context of a watershed that takes into account hydrology, weather, sedimentation, soil temperature, plant growth, nutrients, pesticides and land management (Arnold 1998). SWAT-WB is a modified version of SWAT used by the Soil Water Lab at Cornell University with improvements in predicting the runoff component, nutrient load or contamination concentration, and water quality condition (White 2009).

Conceptually, fertilizer inputs could be added into pesticide databases to recognize their relative solubility. References have not yet been found for the assignment of K factors, $K_d$, or $K_{oc}$ for organic nitrogen (R-NH) or ammonium ($NH_4$). References have already been made to the role that organic forms of nutrients might play in eutrophication. Nutrient loads should account for the potential loading of organic nutrients from sediment displacement in erosion and stormwater associated with heavy and persistent precipitation events. For these reasons alone, modeling of nutrient loading is perhaps best achieved with modified pesticide/soil models. More compelling, the pesticide/soil models have evolved to represent the soil profile in much more detail and represent the key management considerations like type of fertilizer applied, application method and rate. They also have climate generators that simulate precipitation events and preferential water flow through the soil profile. The EPA and USDA are significant leaders in the authorship and field evaluations of these models. Through their agencies, Suffolk County may be able to obtain a much better representation of the nutrient loads inherent with the specific and aggregate land use in the County.

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