

THE CONTRIBUTION OF LAWN FERTILIZER TO THE NITROGEN LOADING OF
CAPE COD EMBAYMENTS

BY

LISABETH M. WHITE

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Abstract

Eutrophication of estuaries and bays due to nutrient loading has led to the declining environmental quality of many coastal regions throughout the world. Cultural eutrophication is the enrichment of embayment waters by excessive nutrient flow in ground or surface waters caused by human activities. Nutrient overload in the form of nitrogen is largely the result of anthropogenic activities in watersheds, originating from a variety of sources, both point and nonpoint. Unlike point sources, nonpoint sources of nitrogen are diverse and difficult to measure. As one such source, residential fertilizer is an important contributor to the mass flux of nitrogen into an estuary. Southeastern Massachusetts, and particularly Cape Cod, has been experiencing a rise in the population, particularly of year-round residents. Concurrently, there has also been a rise in the number of embayments impacted by cultural eutrophication, resulting in a pressing demand for effective estuarine research, policy, and management strategies. In order to determine appropriate management measures, it is essential to accurately assess watershed nitrogen loading rates from all sources. A nitrogen loading model is one tool used to quantify the contribution of nitrogen to groundwater. Currently these models, when used for household fertilizer, are based on a number of assumptions: 1) the number of fertilizer applications per household per year; 2) the amount of fertilizer applied per application; 3) average lawn size; 4) leach rate; 5) attenuation. Consequently, residential fertilizer use has been estimated to contribute on average three pounds of nitrogen to groundwater per year. To facilitate the accurate determination of the contribution of nitrogen from fertilizers, a fertilizer use study was conducted in three Cape Cod

watersheds: Falmouth, Mashpee, and Barnstable. This study involved a questionnaire presented to residents regarding fertilizer use, as well as visual assessments of house lots to ascertain physical parameters. Data from the fertilizer use study revealed that the number of applications per household per year was significantly less than what was previously assumed, resulting in a corresponding reduction in the nitrogen load to groundwater per year for fertilizers. Further, residency data revealed that fertilizer application rates appeared to be significantly higher for year-round residents when compared to rates of seasonal residents. These results must be considered when determining appropriate management measures regarding fertilizer use. While results of this study indicate that the contribution to the watershed and therefore the impacts of fertilizer use is significantly less than what was historically projected, they also present a database from which future potential household fertilizer use can be extrapolated. For example, if the trend towards year-round residency continues on Cape Cod, it can be projected that fertilizer use will increase accordingly, therefore increasing the amount of nitrogen to watersheds from this source. As a result of this data, research and management of nitrogen can be properly focused on existing major sources while at the same time enabling the deliberation of future nitrogen loading and the impacts of these loads on the estuarine ecosystem.

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TABLE OF CONTENTS

	Page
Approval	i
Abstract	ii
Acknowledgements	iv
Table of Contents	v
List of Tables	vii
List of Figures	viii
Chapter I: Introduction	1
Research Problem	1
Problem Statement	2
Objective	5
Hypotheses	5
Statistics	6
Chapter II: Topic Overview	9
Nutrient Enrichment by Nitrogen	9
Nitrogen Sources	13
The Role of Nitrogen in Coastal Waters	15
Fertilizers	21
Nitrogen as a Component in Fertilizers	25
Regulations	27
Chapter III: Literature Review	34
Residential Impact of Fertilizer Use	34
Nitrogen Loading Methodology	35
Chapter IV: Methodology	44
Site Description	44
Research Methods	47
On-Site Resident Interviews	48
Visual Assessments	52
Chapter V: Results	57
Objective Data	57
Overall Percentage of Fertilizer Use	59
Average Number of Applications Per Year	60
Percentage of Use by Town and Location	60
Application Rate	64
Average Lawn Size	65
Secondary Parameters	68
Percentage of Residents Using a Lawn Care Company	69
House Age	70

TABLE OF CONTENTS cont.

	Seasonality	70
	Housing Density	72
Chapter VI:	Discussion	73
	Overall Percentage of Use	73
	Nitrogen Load to Groundwater	74
	Secondary Discussion	79
Chapter VII:	Conclusions and Recommendations	82
Chapter VIII:	Final Conclusion	89
Appendix A:	Acronyms	95
Appendix B:	Fertilizer Studies	97
Appendix C:	Nitrogen Loading Data	102
Appendix D:	Statistical Results	105
	Bibliography	107

LIST OF TABLES

Table	Page
1. A Breakdown of Fertilizer Use by Town and Watershed Zone	61
2. A Breakdown of Fertilizer Use by Watershed Zone	63
3. Summary of Estimated Nitrogen Load From Residential Lawn Fertilizer	74
4. Nitrogen Loads Within Each Town and Within Each Watershed Zone	76

LIST OF FIGURES

Figure	Page
1. Study Sites, Cape Cod, Massachusetts	43
2. 1:1 Variability Graph for Visual Observations	58
3. Percentage of Fertilizer Use In Survey	59
4. Percentage of Surveyed Residents Applying Fertilizer Within Each Town	62
5. Percentage of Surveyed Residents Applying Fertilizer Within Each Watershed Zone	63
6. Percentage of Fertilizer Use Within Each Watershed Zone Within Each Town	64
7. Percentage of Residents Using a Professional Lawn Care Company	69
8. Percentage of Seasonal and Year-round Fertilizer Use	71
9. Percentage of Seasonal Residents Applying Lawn Fertilizer	72

CHAPTER I

INTRODUCTION

Research Problem

One of the most significant long-term threats to coastal ecological health, both locally and globally, is the over-fertilization, or eutrophication of coastal embayments (Howes and Hampson, 2000). These environments are unique in that they integrate the exchanges between land and sea. Their bordering regions influence the environmental conditions in which these coastal areas exist. Coastal embayments are among the world's most productive ecosystems and possess diverse biota accustomed to organic rich multisaline waters.

The growth of human population in the 20th century has been primarily in coastal regions, such that at present more than 40% of the global population is within 60 miles of the sea. The result has been increased development with its associated environmental stresses upon these sensitive ecosystems. In their report to the Town of Barnstable, Massachusetts, Howes and Hampson (2002) stated that “the progressive and steady decline in nutrient related water quality represents one of the biggest problems facing coastal communities today.” Locally, the Buzzards Bay Project (BBP), a watershed management division of the Massachusetts Office of Coastal Zone Management, has identified the excessive addition of nitrogen to coastal waters from anthropogenic sources as one of the most serious long-term problems threatening Buzzards Bay (1992). As many embayments approach or reach their assimilative capacity, i.e., their ability to absorb excess amounts of nutrients with no detrimental effects, they begin to show signs

of declining ecological health, such as loss of eelgrass beds, fishery habitat, and benthic communities. As a consequence, such decline results not only in environmental impacts, but economic and social impacts as well, affecting the culture and economy of coastal communities. This has prompted environmental managers and town officials to initiate the development of watershed/embayment management strategies in order to address and mitigate nutrient over-enrichment.

Problem Statement

Eutrophication is the promotion of algal growth due to an excess addition of nutrients to an aquatic ecosystem, resulting in a decline in habitat health. Typically, nutrients in waters exist largely as nitrogen and phosphorous and originate from a variety of sources in the watersheds. In saltwater systems, nitrogen is commonly the nutrient that regulates plant growth, and excessive amounts are most often the major cause of eutrophication. As components of watershed management, the quantification and assessment of nitrogen load rates for watersheds from all sources are essential in order to determine appropriate management measures. As one such nitrogen source, fertilizer is an important contributor to the mass flux, or movement of nitrogen into an estuary. Residential fertilizer use is regarded by many as an obvious, easily traced, and easily and affordably managed source of nitrogen. However, assessment reports on fertilizer application are often based on assumptions and/or limited databases and sample sets, and lack substantive validation. Historically, the estimate of nitrogen loading to the aquifer, hence to coastal waters, from household fertilizer use is the integrated result of five factors (Howes, *et al.*, 2001):

1. Number of fertilizer applications per household per year
2. Nitrogen added per unit area per application
3. Average area of lawn per residence
4. Leaching rate, or the percent of applied nitrogen reaching the water table
5. Attenuation (loss), of nitrogen during transport through the aquifer to the receiving waters

At present, most nitrogen loading models generate a nitrogen-loading rate for household fertilizer use of 3-4.5 lb/N/lawn/year. This is based on the assumptions: (1) all homes apply fertilizer four times per year (2) the rate of application at 0.75 lbN/1000ft²/application (3) an average lawn size of 5000ft²/lot (4) a leaching rate of applied nitrogen of 20%-30% and (5) no attenuation of nitrogen during aquifer transport.

Of these factors, the largest range of values has been in the leaching rate. In the Long Island Report of 1978, Koppleman presented a leaching rate of 60%, while Brown *et al.* (1982) reported a leaching rate of 22%. Even controlled leaching experiments resulted in wide variations of leach rates, ranging from 0 to 56.1% (Petrovic, 1990). For this study, a leach rate of 20% was used, which takes into account the characteristics of Cape Cod soils and movement of nutrients to groundwater. It has also been a consistent figure in current nitrogen load studies.

To date, much of the research has focused upon the aquifer transport factor, or attenuation. There exists substantial research data showing undetectable attenuation in sandy outwash aquifers (Behnke, 1975; Johannes, 1980; Capone and Bautista, 1985; Cambareri, *et al.*, 1993). However, recent site-specific research has revealed higher attenuation rates than previously believed. For example, research conducted in the

Waquoit Bay watershed on Cape Cod established an attenuation rate of 35% (Valiela, et al., 2000). No site-specific studies concerning attenuation were performed for this study. The attenuation value of near zero has been well tested in Cape Cod aquifers and therefore this value was used in the study.

The remaining factors 1) number of applications per year; 2) nitrogen added per application; and 3) average lawn size have all been generally accepted by the scientific community (Holzmacher, *et al.*, 1970; Koppleman, 1978; CCPEDC, 1979; Giblin and Gaines, 1990; Horseley and Witten, 1991; Weiskel and Howes, 1991; CCC, 1992, 1998; Valiela et al., 2000). However, as critical components of nitrogen load determinations, these factors require specific attention in order to establish the most accurate load rate possible. Therefore, these three factors are the focus of research for this study.

Based upon the afore mentioned assumptions, environmental managers have developed nitrogen loading rates, which may not accurately represent contribution of residential fertilizer-nitrogen to the total load. Such methods of calculations may result in an over or underestimation of fertilizer contribution which in turn may skew final load numbers and inaccurately emphasize the management of a less significant nitrogen source. Because watershed management requires a large investment of economic and scientific resources, it is imperative that the most significant sources of nitrogen be recognized accurately and prudently, while avoiding unnecessary focus of time and money on lesser nitrogen sources. A precise determination of the percentage of fertilizer contribution to the nitrogen-loading rate of a watershed will facilitate the development of accurate and effective nitrogen management strategies by identifying and illuminating the magnitude of household fertilizer application.

Objective

The intent of this study is to accurately quantify the average nitrogen loading to a sandy outwash aquifer stemming from the application of nitrogen fertilizers to residential lawns. The purpose is to allow determination of the proportion of the nitrogen load of a watershed to adjacent waters that arises from residential lawn fertilization. The research approach is to quantify and qualify fertilizer application per household in predetermined watersheds on Cape Cod on a yearly basis in order to examine factors one through three above.

In order to achieve the overall objective, three specific research parameters were addressed:

1. The actual number of applications per household per year.
2. The actual rate of nitrogen per application in lbN/1000ft² for household use.
3. The accurate determination of average lawn size.

The results of this study are of use to resource managers developing watershed nitrogen management plans aimed at preventing eutrophication and/or the restoration of coastal waters.

Hypotheses

Currently, most land-use models that incorporate nitrogen-loading models are based on assumptions that have not been adequately tested through research and fieldwork. The primary purpose of this study is to accurately determine the contribution of household

fertilizer to the nitrogen load to Cape Cod embayments. Two research hypotheses were tested in this study:

- 1.) The percentage of households that apply fertilizer is significantly different than the assumed figure of 100% that is currently used in nitrogen loading models.
- 2.) There is a significant difference between the projected nitrogen load figures currently used in nitrogen loading models and the observed nitrogen load figures for those towns located in the study area.

Statistics

A Chi Square statistical analysis was conducted on non-parametric, categorical data contained in this study in order to determine if there was a statistically significant difference between the expected proportion of the number of residents applying lawn fertilizer and the observed number of residents applying lawn fertilizer. A goodness-of-fit test was conducted using the following formula:

Chi Square Test Formula (Kranzler, 2003):

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Where:

χ^2 is the Chi Square value

\sum is the summation sign

O is the observed frequency

E is the expected frequency

A Chi Square statistical analysis was conducted on non-parametric, categorical data contained in this study in order to determine if there were statistically significant differences in residential lawn fertilizer use between towns and between locations. This analysis involved a test of contingency in order to determine whether an association regarding fertilizer use existed between towns and between locations.

Student t tests were conducted in order to establish if there were differences in lawn size of those residents who applied lawn fertilizer at least one time per year. Statistical comparisons were conducted between each of the three towns and between each of the three locations. The tests were run for independent samples of unequal sizes, and consisted of two-tailed tests. A 0.05 level of significance was employed.

T test formula (Kranzler, 2003):

$$t = \frac{X_1 - X_2}{\sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}} \left(\frac{1}{n_1} + \frac{1}{n_2} \right)}$$

Where:

X_1 is the mean for Group 1

X_2 is the mean for Group 2

n_1 is the number of participants in Group 1

n_2 is the number of participants in Group 2

S_1^2 is the variance for Group 1

S_2^2 is the variance for Group 2

A small-sample one-tailed t test was conducted in order to determine if there was a significant difference between the observed number of fertilizer applications per household per year and the forecasted average number of fertilizer applications per household per year utilized in current nitrogen load studies. A 0.05 level of significance was employed.

Small-sample t test formula (Devore, 1987):

$$T = \frac{\bar{x} - \mu_0}{S/\sqrt{N}}$$

A linear regression statistical analysis was conducted in order to determine the relationship between individual residential lawn sizes measured visually and individual residential lawn sizes measured physically.

Regression Model Formula: (Kranzler, 2003):

$$Y = bX + a$$

Where:

Y is the predicted value based on a known value of X

B is the slope, or the direction of the line

a is the point at which the line crosses the y-axis

X is the value being used as the predictor

$$a = \frac{\sum y - b \sum x}{N}$$

$$b = \frac{\sum xy - (\sum x \sum y / N)}{\sum x^2 - [(\sum x)^2 / N]}$$

CHAPTER II

TOPIC OVERVIEW

Nutrient Enrichment by Nitrogen

Coastal systems are some of the most productive ecosystems on Earth. Because of their capacity to act as nutrient sinks, they are able to support extensive and diverse plant and animal communities, providing protection, food and nursery grounds for a myriad of species. Consequently, these areas are of significance to commercial and recreational fisheries and the tourist industry for their economic value, as well as to residents for their esthetic value (Howes, *et al.*, 2001). Nearly \$2 billion in annual earnings is generated from the Massachusetts marine environment with \$600 million from recreation and tourism and \$660 million from fishing and seafood sales (Howes and Hampson, 2002).

Pollutants from human activities on land threaten coastal waters throughout the world, with the United States being no exception. Pathogens, toxics, metals, viruses, and nutrients top the list of such pollutants, and among them, nutrient inputs have proven to be the most pervasive and unrestrained. Nitrogen is a nutrient that has increased dramatically in magnitude of input over the recent past, and therefore has become a primary concern of coastal environmental managers worldwide.

Eutrophication of estuaries and bays due to anthropogenic (resulting from human activities) nutrient overloading has contributed to the declining environmental quality of many coastal regions throughout the world. Southeastern Massachusetts, and particularly Cape Cod, is no exception to this pattern. Estuarine and shallow marine environments, such as those that dominate the Cape area, are considered to be sensitive to large inputs

of nitrogen (USGS, NWQAP, 2000). Nutrient overload can upset the balance of these fragile ecosystems by promoting excess algae growth, anoxic events, and changes in marine communities, and is a persistent threat. It has been estimated that non-point source discharge is responsible for fifty percent of water pollution in the United States (NOAA/EPA, 1988).

It is believed by scientists that nutrient inputs from anthropogenic sources will continue to increase and are so widespread that they will result in effecting major changes on the structure and function of shallow coastal ecosystems for many years (Valiela, *et al.*, 1990; Anderson, *et al.*, 2002; Deegan, 2002; Howarth, *et al.*, 2002; Paerl, *et al.*, 2002). The ensuing outcome will be a shift away from the more profitable commercial and recreational fish and shellfish species (Howes and Hampson, 2000), resulting in a downward swing in these economies. The aesthetic and recreational values that these coastal systems possess may also be adversely affected by resulting undesirable conditions and in turn may create further economic impacts. As more and more studies focus on the impacts of nutrients on marine habitats, trends are being recognized that include signature shifts in communities within shallow, nutrient-enriched estuaries of the urban and urbanizing areas of the United States, especially in the Northeast (Roman, *et al.*, 2000).

It is generally acknowledged that nitrogen is at the forefront of pollution problems along the coast, which in turn has spurred scientists and policy makers to initiate investigative studies in order to facilitate nitrogen management. Cultural eutrophication, the enrichment of embayment waters by excessive nutrient flow in ground or surface waters caused by human activity, has led to the declining environmental quality of most

coastal regions with very few exceptions. Although nitrogen may be introduced into the marine environment through natural pathways such as atmospheric deposition, human activities are the primary causes of the increased nutrient load to coastal waters (Nixon, 1995). It is a rare coastal embayment that does not show some signs of the effects nutrient enrichment. Many communities are beginning to address concerns about the health of their coastal environments.

Due to its geological history, the East Coast of the United States is characterized by a multitude of bays, inlets, salt ponds, and lagoons. Many of them meet the definition of a poorly flushed system, in which the movement of water in and out is impeded to some degree, making them susceptible to degradation by pollution. Needless to say, eutrophication as a result of nitrogen overload from human activities is common in these estuaries, embayments, bays, lagoons, and ponds up and down the coast, and is caused in large part by the increase in population. According to NOAA statistics, 110 million people, or almost one-half of the total United States population, now lives in coastal areas (NOAA, 1988). A recent survey showed that the population of coastal counties in the United States was growing at a rate three times that of the total United States population (Culliton, *et al.*, 1989; Culliton, *et al.*, 1992; Ernst, 1996). Globally, almost 40% of the world's population lives within 60 miles of the coast (Howes and Hampson, 2000). Over the next 30 years, global population is projected to grow by nearly two-thirds, to 8.5 billion (World Resources Institute, 1994; Ernst, 1996), and by the year 2010, the United States coastal population will have grown from 80 million to more than 127 million, a nationwide increase of almost 60% (Culliton, *et al.*, 1992; Ernst, 1996). Throughout the world, the coast has become the most desirable place to live because it offers so many

things to so many people, from accessibility to subsistence fisheries, to transportation and shipping activities, to aesthetic and recreational fulfillment. In the U.S., the northeast coastal fringe ranging from Maine to Virginia has been heavily affected by this population trend, with sixteen percent of the entire U.S. population residing there (Roman, 2000). As a result, the northeast is the most densely populated coastal region in the United States, and it is expected that its population will continue to rise, increasing by 30% by the year 2010 (Culliton, *et al.*, 1990, Ernst, 1996; Roman, 2000). In 1990, over 60% of this region's population lived within coastal counties, a land area that accounted for just 25% of the region (Roman, 2000). The population in Massachusetts has been following this growth trend for a number of years, increasing in coastal communities at more than two times the rate of inland communities state-wide (Howes and Hampson, 2000). Clearly, coastlines throughout the world are in danger of exceeding their capacity to incorporate and sustain such rapid growth along their shores, which in turn threatens to upset the stability and health of these fragile ecosystems. As populations have grown and moved toward the sea, the effects of this progression have been felt first and most "acutely" in estuaries and embayments (Bolcourt, 1993). Pollutants originating from individual households has left 56 percent of lakes, 37 percent of rivers, and 32 percent of estuaries in a state of degradation nationwide (Cochran, 1998), and studies of some coastal areas have shown that medium and high density residential developments have the highest loading factors for nitrogen of all land uses (South Jersey RC&D Council, Inc., 2000).

Nitrogen Sources

It is becoming clear that the increases in residential development and the desire for year-round versus seasonal residency are creating significant impacts on many estuarine environments as human activities begin to overwhelm these coastal systems. Population growth has been fairly rapid and in turn has been adversely affecting water quality as the assimilative capacities of these aquatic resources are pushed to their limits. Natural terrain, which acts as an absorption and filtration system for numerous pollutants, is replaced by buildings and impervious surfaces such as parking lots and roads, which expedite runoff and increase the volume of nutrients reaching coastal waters. In many coastal areas, a rise in the construction of new septic systems or ISDS's (Individual Sewage Disposal Systems), or the shift from seasonal to year-round use, often corresponds to a rise in new and/or permanent residences. In both instances, a majority of the nitrogen, which enters each septic system, is not taken up and absorbed but rather leaches to groundwater as an available nutrient for terrestrial and eventually for estuarine plant growth. An increase in the leaching of lawn care products to groundwater, the deposition of oil, gas, and paint residues directly into coastal waters from recreational boating activities, and the noxious runoff from cars and emissions from boats enters bay waters and are all associated with a rise in population and housing units in coastal areas.

Nutrient-related impacts such as eutrophication and toxic blooms are a result of ascending nitrogen discharge quantities from multiple sources, both point and non-point. Point sources tend to be large, distinct and easily quantifiable, and since the 1980's have been regulated and quantified (Giblin, *et al.*, 1990; Howes and Goehringer, 1999; Howes and Hampson, 2000). The most common examples of point sources are wastewater

treatment plants, which discharge both nitrogen and phosphorous-loaded effluent directly into bays, harbors, and open waters. Long recognized as a major and discrete contributor of nitrogen to the load entering marine environments, these facilities have recently been subjected to a tightening of requirements, restrictions, and regulations in order to minimize impacts and maximize water quality at the point of discharge. On the other hand, non-point sources are far more numerous and widespread, making them difficult to identify and measure. Non-point sources represent a relatively recent area of research and have a larger error associated with them (Howes and Hampson, 2000). While point source loads may commonly be measured directly and accurately, non-point source pollution is much more complex in regard to the identification of both sources and the receiving waters. The ecological problems associated with non-point source pollution (NPSP) require the management of all the individual pollution sources. However, the difficulty with managing nitrogen loading can be characterized by a.) its widespread distribution originating from b.) a diversity of sources and c.) multiple pathways of input (Howes and Goehring, 1999).

In addition, there is often a time lag between input and output of non-point source pollution ranging from weeks to years as the pollutant travels through the watershed to the receiving waters, resulting in a delay between cause and effect. Non-point sources include septic systems, lawn and garden fertilizers, agricultural fertilizers, golf course fertilizers, domestic pets, runoff from park areas, animal farming, and car emissions, all of which may contribute the majority of nitrogen to an embayment (Nixon, 1995; Jaworski, *et al.*, 1997; Valiela, *et al.*, 1997; Roman, 2000).

At both the federal and state government levels, non-point source pollution has been addressed by a number of legislative initiatives. Federally, these initiatives include amendments to the Clean Water Act (CWA 1972: PL 92-500. 86 stat. 816; 33 U.S.C. 1251 et seq.), which established the Section 319 Non-point Source Program, and the Coastal Zone Act Reauthorization Amendments (CZARA 16 U.S.C. s/s 1455b), which established Section 6217 Coastal Non-point Source Pollution Control Program. On the state level, Massachusetts addresses non-point source pollution through the Department of Environmental Protection's (DEP) Clean Water Act Non-point Source Program (part of Section 319) and through a cooperative effort by DEP and the Office of Coastal Zone Management (CZM) in their Non-point Source Management Plan (part of Section 6217).

The Role of Nitrogen in Coastal Waters

The Nitrogen Cycle

Nitrogen in its gaseous form (N_{2g}) comprises almost 80% of the air that we breathe. Nitrogen as a nutrient is essential to organisms in the synthesis of proteins and the structure of DNA. However, nitrogen must be converted to inorganic form before it can be taken up by phytoplankton and most aquatic plants. Aquatic animals then obtain nitrogen by either consuming aquatic plants and converting plant proteins to specific animal proteins, or by eating other aquatic fauna which feed on plants, and are commonly referred to as grazers and consumers, respectively.

One method of conversion of organic nitrogen forms to inorganic forms is the reductive process of nitrogen fixation, where atmospheric nitrogen (N_{2g}) is transformed into available inorganic forms of nitrogen such as ammonium (NH_4^+) and nitrate (NO_3^-),

and is accomplished by bacteria in soils or by cyanobacteria in aquatic systems. This fixed nitrogen can then be taken up by plants and animals successively and used to synthesize nitrogenous organic compounds such as amino acids and the nitrogenous bases of DNA. However, nitrogen fixation accounts for only a small percentage of available nitrogen. Dissolved inorganic nitrogen (DIN) in the form of ammonia, nitrite (NO_2^-), and nitrate (NO_3^-), is typically added to coastal surface from sources such as fertilizers, septic systems, and acid rain. In a healthy marine system, this available “free” nitrogen is taken up by algae and other aquatic plants, which in turn either die or are consumed by organisms in the next trophic level. As these organisms die, their particulate matter settles out on the bottom as detritus, where bacteria break down the large protein molecules into ammonia in the process of ammonification or mineralization, using the carbon in the detritus for energy. This ammonia may be either utilized as a nutrient by the benthic microorganisms or will diffuse back into the sediments or the water where it is available for further conversion to usable forms. Nitrification for example, is the process whereby NH_4^+ is oxidized to form nitrite (NO_2^-) and further to form nitrate (NO_3^-). Nitrate is easily and efficiently assimilated by phytoplankton and aquatic plants and provides another source for growth and reproduction. The excretions of aquatic organisms are also very rich in ammonia, releasing more available nitrogen into the water column, which may also then be taken up by aquatic flora as recycled nutrients.

The accumulation and sedimentation of detritus on the bottom may result in the adsorption of NH_4^+ to the sediments, whereby NH_4^+ is weakly bound to soil particles by electrostatic attraction, a process referred to as flocculation (Nixon and Pilson, 1983). Nitrogen may also accumulate as bottom sediment in the form of organic matter that has

not yet been decomposed. In fact, most of the fixed nitrogen in estuarine systems is found in the sediments (Nixon and Pilson, 1983), where it may be “stored”, along with inorganic nitrogen, as future sources of input to the nitrogen cycle.

Not all of the nitrogen stays stored for long, however. Much of the organic matter reaching the bottom is remineralized rapidly in the upper few millimeters of the sediment (Nixon and Pilson, 1983), and nitrification may also occur in the sediments as NH_4^+ is transformed to nitrate. Both forms are then available as they leave the sediments for assimilation by organisms. This release of inorganic nitrogen in the form of NH_4^+ and NO_3^- from the sediments is termed “benthic flux,” and is a major contributor to the nitrogen regeneration, or recycling, that occurs between the water column and sediments.

Some nitrogen may be lost from the system as it undergoes denitrification or volatilization, the conversion of NO_3^- and NH_4^+ to atmospheric gasses (N_2 , N_2O , or NH_3), respectively. However, the majority of nitrogen in most ecosystems is recycled locally by decomposition and assimilation (Nixon and Pilson, 1983).

Eutrophication

In all ecosystems, the compilation, assimilation, and cycling of nutrients is vital to the growth and reproduction of the flora and fauna which they encompass. In aquatic systems, phytoplankton, macroalgae, and benthic microalgae assimilate inorganic nutrients from the surrounding water and sediments in order to obtain energy for photosynthesis and in turn provide organic matter and oxygen for organisms higher in the food chain. Most of these nutrients required by the algae for this process are in abundant supply. However some, like nitrogen and phosphorous, occur in limited quantities and

tend to be taken up rapidly. Because of this limiting capability, it is the availability of these nutrients that controls the rate of organic production in fresh and saltwater systems. In freshwater systems, phosphorous is generally the limiting nutrient, while in most temperate coastal systems, nitrogen is limiting to algae and plant productivity (Ryther and Dunstan, 1971). At low nitrogen levels in coastal waters, an incremental increase in the nitrogen load can be beneficial to organisms, stimulating production and replenishing the nitrogen cycle through growth and decay. In healthy systems, there exists a balance between this cycle of nutrient input and uptake by aquatic plants and algae, facilitating the success and diversity of both pelagic and benthic communities. Phytoplankton are sensitive to changes in the availability of these nutrients however, and at significantly higher levels, increased nitrogen loadings are likely to lead to a rise in oxygen demand as the concurrent increase in plant production and decay take up more free oxygen in the water column and sediments. When oxygen demand exceeds the rate of oxygen supply from photosynthesis and atmospheric mixing, there often exists a periodic depletion of oxygen within the water column, referred to as hypoxic (low oxygen) or anoxic (lack of oxygen) conditions. If these conditions prevail for a significant length of time and/or occur with greater frequency, the resultant stress caused to individual organisms may in turn lead to adverse impacts on both plant and animal communities as a whole (Howes and Goehringer, 1999). As a consequence, changes in community structure corresponding to rising nitrogen levels will occur, as species intolerable to the resultant stresses move or die off and opportunistic and hardier species replace them.

The ability of affected coastal systems to receive more nutrients without deleterious effects is termed “assimilative capacity”, and when this capacity is exceeded, it results in

ecological degradation and a reduction in biological production and diversity, and in some cases, fish kills and massive plankton blooms. In 1990, EPA and NOAA sponsored workshops focusing on nutrient enrichment, where a group of experts put together a list of the characteristics of coastal environments that have been over-enriched. These characteristics act as ecological indicators of water quality conditions in nitrogen-impacted systems, and include such things as:

- Reduced species diversity;
- A shift from large to small phytoplankton species;
- A shift in the species composition of the phytoplankton from diatoms to flagellates;
- Increased incidence of toxic phytoplankton blooms;
- Increased incidence of undesirable phytoplankton blooms;
- Increased seaweed biomass;
- Loss of sea grass;
- A shift from filter-feeding to deposit-feeding benthos;
- A shift from larger, long-lived benthos to smaller, rapidly growing but short-lived species;
- Increased disease in fish, crabs and/or lobsters and;
- Increased production of some greenhouse gasses.

When considered as a one-time mass load, the calculation of the contribution of nitrogen from a distinct source may appear insidious, or at the very least, is often underestimated. However, a single input of nitrogen into an embayment may be recycled by production and decay between sediments and the water column many times over, with

its impacts to the system being magnified each time cycling occurs (Howes and Goehringer, 1999), as more nitrogen is added and more oxygen is consumed. How many times the nitrogen is recycled before being flushed out of the lagoons, ponds, and embayments or buried permanently in the sediments is directly related to the embayment's potential for eutrophication, with nutrient loading highest in enclosed or semi-enclosed, poorly flushed systems and lowest in open, rapidly flushed systems (Howes and Goehringer, 1999). The tolerance of small and shallow embayments to nitrogen inputs is lower compared to larger, more open near-shore areas of bays, primarily due to their relatively slow flushing rates in regards to tidal movement (Valiela and Costa, 1988). A strong tidal influence and hydrodynamic exchange, typical of deeper coastal basins, reduces the accumulations of nutrients and phytoplankton by hindering the formation of a persistent surface mixed layer where phytoplankton have access to light and nutrient inputs (Anderson, *et al.*, 2002). In shallow embayments, excessive nutrient loading may overwhelm the assimilative capacity of the system when nitrogen input from the adjacent watershed is large compared to the volume of the receiving waters, and if tidal exchange is restricted, the resultant flushing may be inadequate for the removal of nitrogen from embayment waters. As a result, nutrient inputs may stimulate phytoplankton growth and production to the point where biomass decay causes oxygen depletion and ecological stress (Costa, *et al.*, 1996). Increased oxygen demand in the water column and sediments from increased plant production and decay can exceed the rate of oxygen supply produced from photosynthesis and mixing with the atmosphere and result in the periodic depletion of oxygen within the bottom waters of coastal basins (Howes and Goehringer, 1996). With continued over-enrichment, eutrophication

progresses as the addition of nutrients stimulates the production of phytoplankton, epiphytic algae, and macroalgae that compete with sea grass for light and space (Deegan, 2002). The concurring increase in respiration for production, the decrease in the amount of sunlight reaching the bottom, and the increase in decomposition and detritus all contribute to the suppression of oxygen levels, which may lead to hypoxia (low oxygen level) or anoxia (no available oxygen) in both the pelagic and benthic regions of the basin. Excessive nutrient loading may cause a shift in community structure as stressful conditions force existing organisms out while being replaced by opportunistic but less-desirable species. Hypoxic conditions may lead to a change in behavior and abundance of small prey organisms such as zooplankton and benthic invertebrates, while anoxic conditions may lead to fish kills or out-movement of the population (Rainer and Fitzhardinge, 1981; Diaz and Rosenberg, 1995; Breitberg, *et al.*, 1997; Deegan, 2002). The ecological, aesthetic, and economic impacts of eutrophication may be felt for years to come, as accumulated organic nitrogen deposited from the overlying water column to the bottom sediments is stored and continue to provide a source of nitrogen for biological production years after the original inputs have diminished or ceased (Nixon and Pilson, 1983).

Fertilizers

When most people think of fertilizer usage, the images that come to mind are often the large fields of corn or other crops, or the green, lush grass of a manicured lawn. Because of the benefits that fertilizer has to offer as a growth enhancer for terrestrial flora, it is often incongruous to people that fertilizers could be so detrimental to the

marine environment. The fact is, nitrogen is not limiting to plants on land, and a portion of the excess nitrogen in applied fertilizer is generally leached from the soil to groundwater, or transported away by runoff, or taken up by the multitude of microbes in the soils. A percentage of fertilizer ultimately reaches the receiving waters of coastal shorelines, and because of nitrogen's limiting ability in ocean waters, the assimilative capacity of these waters is far less than land systems, while the complexity and sensitivity of estuarine systems enhances their vulnerability to overfertilization.

Fertilizers provide plants with readily available nutrients and act to enhance the vegetative growth of grasses while producing sturdier, hardier stalks. It is manufactured in many combinations due to the numerous growing and application conditions in which it is utilized. There are three fundamental nutrients that comprise the largest percentage of fertilizer composition: nitrogen (N), phosphorous (P), and potassium, or potash (K). Nitrogen is essential for the vegetative growth of plants, is mobile, moves easily through the soil in soil water, and is easily leached. Nitrogen is also a component of DNA and a building block for proteins. Phosphorous promotes root growth, flowering, seed formation, and aids in maturation. It is non-mobile in aerobic soils and has limited leaching. Potash allows plants to withstand stress, strengthens them, and makes them more disease resistant and hardy (The Fertilizer Institute, 2001). It also has a tendency to be non-mobile.

Lawn care fertilizers are identified by three numbers, which are the percentages by weight of nitrogen (N), phosphorous (P), and potash (K). For example, a 50lb bag of fertilizer might read: 24-4-8, indicating a nutrient composition of 24% N, 4% P, and 8% K. A fertilizer is "complete" when it contains all three elements. There are also micro-

nutrients contained in fertilizers, such as iron, zinc, copper, calcium, manganese, and, magnesium, all of which are essential in the life cycle of plants but are required in very small quantities (Williams, 2001).

Fertilizers are available to homeowners in two forms, granular and liquid. Granular fertilizers, which are applied in dry form, are the most commonly used due to their ease in transportation, application, and their long span of effectiveness. Liquid fertilizers are sold in concentrated form and must be mixed with water through a hose before being sprayed on the lawn or other vegetation. This form of fertilizer is beneficial in that the method applies fertilizer evenly and nutrients are readily available for fast response. The downside is that 1) it requires more applications due to quick uptake; 2) the necessary equipment must be available; and 3) costs tend to run higher than for dry fertilizers (www.allaboutlawns.com. 2000).

Granular fertilizers are offered as two types: fast-release and slow-release. Fast-release fertilizers are water-soluble and show results quickly, are easy to use, relatively inexpensive, and work well in cold weather. However, because of their speed of effectiveness, more applications are needed to maintain a consistent rate of growth. They also have a tendency to leach, require frequent watering, and may burn the lawn if too much is applied per unit area. Slow-release fertilizers gradually release the nutrients through a permeable coating around the fertilizer granules. This type of fertilizer only has to be applied every few months, is easy to use, and tends to reduce leaching and the chance of burning. However, its costs may be higher compared to fast-release fertilizers and results may be delayed due to conditions such as low temperatures or the absence of precipitation or irrigation. It also requires warmer conditions for best results

(www.allaboutlawns.com., 2000). Both forms of fertilizer may be blended in one bag in order to provide a fairly immediate response followed by a slower, maintenance response.

Homeowners today have the option of choosing a synthetic fertilizer or an organic fertilizer. Synthetic fertilizers originate from natural sources but are manufactured chemically by combining natural gas with nitrogen from the atmosphere. They contain nitrogen in its simplest inorganic forms, where it dissolves easily and is readily taken up by grasses (Ashumet Plume Citizens Committee, 2001). Nitrogen is the dominant component of these fertilizers, sometimes doubling the percentage of the other two nutrients. Results from application are rapid due to the almost immediate release of nitrogen, yet are often temporary due to the fact that grasses cannot take up all the available nitrogen at once, and most of it leaches out into the groundwater. Professional lawn care companies base their business on results and therefore lean heavily on the synthetic nitrogen-rich fertilizers.

Organic fertilizers ideally are natural in origin and are derived from once-living organisms. Mixed organic fertilizers may contain ingredients that are artificial, such as super-phosphate, or harmful natural ingredients like nitrate of soda or sewage sludge (NOFA, 2002). Because this type of fertilizer is sold in organic form, it must be converted to inorganic form by microorganisms in the soil before it can be taken up by plants. It is slow to break down, delaying the release of nitrogen, and as a consequence provides a lusher, hardier, even lawn that stays green and healthy longer than one on which synthetic fertilizer is applied. Grasses are able to absorb more of the nitrogen and very little is leached to the groundwater, and the plants may be more resistant to insects and fungus. Organic fertilizers are considered slow-release, as they are able to spread

their effectiveness over a long period of time. Some of the negative impacts of organic fertilizers are that they may be hard to apply evenly and results may be unpredictable. They also require warmer temperatures and adequate moisture for best results, and are currently far more costly than synthetic fertilizers.

Historically, synthetic fertilizers were much more popular and outsold organic fertilizers by a large margin. Recently however, quantities of organics sold each year has been slowly rising as more and more people become aware of its benefits as an effective lawn care product and because of its “environmentally friendly” attributes. Although high costs and slower results continue to restrict sales, the trend towards organic fertilizers is noticeable in most stores on the Cape that sell lawn and garden products (Store Correspondence, 2001).

Nitrogen As A Component In Fertilizers

Because nitrogen is a limiting nutrient in most saltwater systems, and thus the facilitator of eutrophic conditions, there is a growing concern about nitrogen as a component in fertilizer application. Unlike aquatic systems, where the supply of inorganic nitrogen from fertilizers is generally in dissolved form, in soil systems a majority of the nitrogen is available through direct application. Nitrogen is also made available to plants through fixation, which is the reduction of atmospheric nitrogen to ammonia by bacteria in plant roots and soil. Since nitrogen is beneficial to plants only in its inorganic forms ammonia, nitrite, and nitrate, organic fertilizers require conversion to organic form by microorganisms found in the soil before it can be taken up. As the

organic matter in organic fertilizers is decomposed, ammonium is released in a process called mineralization or ammonification, whereby organic compounds, such as proteins and amino acids, are broken down to smaller organic molecules, available both as particulate and dissolved forms, and ultimately as ammonium, which may then be taken up by plants (Jones and Jacobson, 2001). This process also occurs as plants die and the resulting detritus accumulates on and in the soil, providing a continuous recycling of organic and inorganic nitrogen. Synthetic, or inorganic fertilizers, on the other hand, provide nutrients that are readily available to plants.

As the ammonium (NH_4^+) in these fertilizers is attracted to the negative charge in soil particles through cation exchange, or sorption. Because of this attraction, ammonium is prevented from moving rapidly through the soil, and tends not to be lost easily to ground or surface waters. Conversely, nitrite (NO_2^-) and nitrate (NO_3^-) are negatively charged and are therefore repelled by soil particles, resulting in relatively high diffusion values (Jones and Jacobson, 2001). Consequently, it is mostly nitrite and nitrate that ultimately reach the groundwater in watersheds. These two forms of inorganic nitrogen are made available to plants by a nitrifying bacteria through the process of nitrification, in which bacteria converts ammonium to nitrite and then to nitrate in the presence of oxygen. This process occurs fairly rapidly in well-aerated soils, and though this may increase nutrient availability to plants, nitrate must be converted to ammonium after it is taken up in order to be made into proteins. This conversion requires extra energy by the plant (Jones and Jacobson, 2001). Excess inorganic nitrogen from fertilizers that is not taken up may be lost to groundwater, surface runoff, or denitrification. This process involves the conversion of nitrate to atmospheric nitrogen gas ($\text{N}_{2(g)}$), as denitrifying

bacteria breakdown nitrates to obtain oxygen, and most commonly occurs in poorly-drained or saturated soils.

With fertilizers, nitrogen availability and uptake by plants may be dependent on many factors, such as soil conditions (wet/dry), alkalinity, oxygen levels, and soil type, as well as temperature, precipitation, organic material, and plant type. Application rates and fertilizer types are also essential in the cycling of nitrogen between soils and plants, and all must be considered prior to the development of a general statement concerning fertilizer use

Regulations

In 1956, Congress passed the Federal Water Pollution Control Act as the first official act to address national water quality concerns. Although subsequent amendments were designed to clarify and strengthen the original law, the regulation of water quality by federal authorities did not become a serious initiative until Congress enacted the Federal Water Pollution Control Act Amendments in 1972 (CWA 1972: PL 92-500. 86 Stat. 816; 33 U.S.C. 1251 et seq.), after public awareness regarding water pollution was brought to the forefront of the political scene. In 1977, amendments were again enacted which created the Clean Water Act (CWA, 1977: PL 95-217. 86 Stat. 816; 33 U.S.C. 1251 et seq.). The primary goal of this act was to achieve water quality levels that are fishable and swimmable and “to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters (CWA 1977: PL 95-217. 86 Stat. 816; 33 U.S.C. 1251 et seq.). It was designed to mitigate point sources of pollution, and identified three major sources: municipal, industrial, and wastewater treatment plants

(CWA 1977: PL 95-217. 86 Stat. 816; 33 U.S.C. 1251 et seq.). With its focus primarily on point source pollution, the original Clean Water Act has been successful in controlling the input of pollution from these specific sources. However, it was not until 1987, in amendments to the Clean Water Act (CWA 1987: PL 100-4. 86 Stat. 816; 33 U.S.C. 1251 et seq.) and the Coastal Zone Management Act, as amended, that non-point source pollution was addressed.

The Clean Water Act and Amendments

Under the provisions of the CWA and its amendments, each state is obligated to identify impacted waters within their borders that do not meet applicable water quality standards (CWA 1987: PL 100-4. sec 303(d). 86 Stat. 816; 33 U.S.C. 1251 et seq.), and establish priority rankings for such waters (CWA 1987: PL 100-4. sec 404(d). 86 Stat. 816; 33 U.S.C. 1251 et seq.). In addition, each state must identify sources of pollution to these impacted waters and to keep current a list of pollutants from these sources (CWA 1987: PL 100-4. sec 304(a). 86 Stat. 816; 33 U.S.C. 1251 et seq.). Further, states must describe state and local programs established to address and control pollution added from these sources (CWA 1987: PL 100-4. sec 303. 86 Stat. 816; 33 U.S.C. 1251 et seq.). While these sections of the CWA successfully worked to restrict pollution from large point sources, it was section 319 of the CWA Amendments of 1987 (CWA 1987: PL 100-4. 86 Stat 816; 88 U.S.C. 1251 et seq.) that focused on non-point source pollution, with Congress recognizing the need for greater federal leadership to help focus state and local non-point efforts (USEPA, 2002).

Section 319 Non-point Source Program

Section 319 Non-point Source Program (CWA 1987: PL 100-4. section 319. 86 Stat. 816; 33 U.S.C. s/s 1251-1387) is the first federal legislative initiative that acknowledges non-point sources of pollution affecting the nation's waters. This program obligates each state to commence four phases of control and remediation in order to address non-point source pollution in waters within their borders (CWA 1987: PL 100-4. sec 319(a). 86 Stat. 816; 33 U.S.C. 1251 et seq.):

1. Identify those navigable waters that are impacted by non-point source pollution and which do not meet applicable water quality standards set forth in the CWA.
2. Identify non-point sources of pollution to these impacted waters.
3. Identify Best Management Practices to reduce the level of pollution, with emphasis on intergovernmental coordination and public participation.
4. Identify and describe state and local programs established to address and control pollution added from non-point sources.

In addition, this amendment authorizes federal funding for non-point source pollution control by providing grant money for such things as technical and financial assistance, education, training, and technology (USEPA, 1993). Section 319 affords the opportunity for individual states to address non-point source pollution by providing guidance and funding from a federal agency, the Environmental Protection Agency (EPA). It also encourages intergovernmental coordination and public participation, underscoring the need for such cooperation in order to achieve success in the control and remediation process.

The Coastal Zone Act Reauthorization Amendments (CZARA)

The Clean Water Act is not the only federal program that addresses non-point source pollution. In 1972, Congress passed the Coastal Zone Management Act (16 U.S.C. s/s 1651 et seq.) and established the Coastal Zone Management Program (CZMP) to manage the nation's coastal resources. The CZMP is administered at the federal level by the Coastal Programs Division (CPD), a department of the National Oceanic and Atmospheric Administration's (NOAA) Office of Ocean and Coastal Resource Management (OCRM) (OCRM, 2002). This program promotes a federal-state partnership for coastal management "while balancing competing national economic, cultural, and environmental interests" (OCRM, 2002). OCRM works with States to develop federally approved coastal management programs by providing funding and technical assistance.

In 1990, Congress approved the reauthorization of the Coastal Zone Management Act and passed amendments that are known as the Coastal Zone Act Reauthorization Amendments (CZARA) (16 U.S.C. s/s 1455b). As part of this reauthorization, Section 6217 The Coastal Non-point Source Pollution Control Program (section 306. 16 U.S.C. s/s 1455b) was established. This section places responsibility on the states to control non-point source pollution by requiring those states with approved Coastal Zone management Programs to develop coastal non-point pollution control management plans, and is administered jointly by NOAA and EPA (USEPA, 2002A). These management measures must conform with those described in the document

provided by NOAA and EPA, “Guidance to Specifying Management Measures for Sources of Non-point Pollution in Coastal Waters” (EPA-840-B-93-001c. January 1993).

State and Local Programs

The establishment of these federal non-point source pollution control programs has led to a greater cooperation and coordination between state and federal agencies, and has impelled the creation of a number of programs at the state and local levels. In Massachusetts, the Department of Environmental Protection (DEP), an agency under the Executive Office of Environmental Affairs (EOEA), took the lead and developed a Clean Water Act Non-point Source Program that focuses on the state’s surface waters. The role of this program is to identify the sources of non-point source pollution and assist local governments in the development of management and remediation plans (MA. Office of Coastal Zone Management, 1994). As part of this program, DEP has established the Watershed/Basin Initiative which aids cities and towns in the development of permitting strategies for point source and non-point source pollution (MA. Office of Coastal Zone Management, 1994). In addition, DEP has put together the “Non-point Source management Manual: A Guidance Document for Municipal Officials”, which outlines management practices and offers model bylaws for the implementation of these management practices (MA. Office of Coastal Zone Management, 1994).

The Massachusetts Office of Coastal Zone Management (CZM) is another agency at the state level that focuses on non-point source pollution. This agency is also part of the EOEA and is funded jointly by NOAA and EPA. In conjunction with DEP, CZM is responsible for developing and implementing the Coastal Non-point Source

Pollution Control Program that was set out under Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (Department of Commerce, 1993). Program development brings together environmental experts, polluters, industry, NGOs, homeowners, regulatory experts, and the public. Major categories of non-point source pollution have been identified under this program, and management measures for these sources have been put forth in the guidance manual developed by NOAA and EPA.

Currently, there are no initiatives at the federal and state levels that address residential fertilizer as a non-point source of pollution. Locally, however, there has been progress towards addressing water quality in relation to nitrogen loading to embayments. The Buzzards Bay National Estuary Program was established in 1985 as part of the U.S. EPA's National Estuary Program (CWA 1987: PL 100-4. section 320. 86 Stat. 816; 33 U.S.C. 1251 et seq.) and is administered by the Massachusetts Office of Coastal Zone Management (Buzzards Bay Project, 1987). In 1991, the project completed a Comprehensive Conservation and Management Plan for Buzzards Bay, which is, as cited in the plan, "an example of an emerging nationwide effort to develop management strategies that take into account the uniqueness of certain coastal areas." A major component of the plan is a tiered nitrogen loading limit system which sets Total Maximum Annual Limits (TMAL) based on flushing times and areal measurements of the system (Eichner, *et al.*, 1998; Costa, *et al.*, 1999). Estimates of mass loading rates from watersheds are developed based on a variety of environmental measurements, including a quantification of nitrogen from point and non-point sources based on land parcel evaluations (Costa, *et al.*, 1999). By establishing this tiered system, TMALs developed by the Buzzards Bay Project can be integrated with existing, state and federal

water quality classification systems (Costa, *et al*, 1999). A program such as that developed by the Buzzards Bay Project is becoming a blueprint for integrated management strategies for coastal embayments impacted by nitrogen. It utilizes proactive measures such as strategic planning and zoning by-law initiatives, analyzes future watershed growth potential, and encourages stakeholder involvement. With this type of program available, environmental managers will be better equipped and much more informed when the time comes to make critical decisions concerning the management of nitrogen sources.

CHAPTER III

LITERATURE REVIEW

Nitrogen loading studies conducted on Cape Cod and in Southeastern Massachusetts frequently utilize data from previous surveys, and are oftentimes based on assumptions about fertilizer loading rates. These rates may lack site specificity and accuracy due to the fact that they have been drawn from other studies and are generalized figures. Most surveys undertaken to determine residential use of fertilizer on the Cape have been limited in scope and population survey numbers. The intent of this study is to accurately quantify the amount of fertilizer that a household contributes to the nitrogen load per year on Cape Cod by conducting an expanded survey of individual households. Such a study may not only provide more precise measurements of use and contribution, but also develop into a database from which extrapolations can be made for further nitrogen management.

Residential Impact of Fertilizer Use

Although nitrogen-loading determinations have historically lacked a consistent methodology, there has been an almost universal agreement among scientists that the increases in nutrient loads to embayments correspond to the increase in development along coastlines (Gold, *et al.*, 1990; Thorne-Miller, 1993; Peckol and Rivers, 1996; Costa, *et al.*, 1999; Howes and Hampson, 2000). In a Chesapeake Bay watershed study, it was found that medium and high-density residential development has the highest loading factors for nitrogen and phosphorous in the Bay area (Chesapeake Bay Program,

1995). A similar study conducted in Rhode Island concluded that medium-density residential development has the highest loading factor of pesticides and fertilizers of all land uses in the state (RIDEM, 1988; Ernst, 1996). Results from a number of investigations of Cape Cod embayments have tied together the degradation of coastal waters and housing developments, and have concluded that nitrogen levels in receiving waterbodies tend to increase gradually with the incremental development of coastal watersheds (Peckol and Rivers, 1996; Howes and Hampson, 2000; Puckett, 2000; Ramsey, *et al.*, 2000). Koppleman, in his 1978 study of nitrogen loading on Long Island, demonstrated that housing density may effect fertilizer use, since density and the extent of impervious areas are directly related, and are inversely related to the size of the vegetated area. Such conclusions are logical and therefore generally undisputed, since it follows that by increasing housing density, the number of households that contribute nitrogen as a non-point source is similarly expanded, therefore magnifying the cumulative nitrogen load from these areas.

Nitrogen Loading Methodology

Although all nitrogen loading methodologies involve a certain number of assumptions, there has not yet been a scientific consensus regarding which values and methods are appropriate when calculating nitrogen loads (Eichner and Cambereri, 1992). A critical assumption that is made in most nitrogen modeling studies is that all houses apply fertilizer. In the few actual surveys of households conducted in various studies it was found that the number of respondents using fertilizer ranged from 34% to 83% (Koppleman, 1978; IEP, Inc., 1988; Schueler, 1994; Cochran, 1988; Valiela, *et al.*, 1992;

South Jersey Report, 2000). However, conclusions drawn from these studies are limited by the small population sizes the surveys encompassed and the absence of data specific to Cape Cod.

Nitrogen loading models seek to incorporate present load rates for the various sources of nitrogen in a watershed in an attempt to portray existing conditions and forecast future impacts. In these models, the terminal product is a figure that depicts the annual nitrogen load from a specific source to a waterbody. This figure is derived from the compilation and calculation of values from a number of parameters. For fertilizers, it is necessary to establish a per unit loading factor of pounds of nitrogen per 1000 square feet of lawn per year (lbs N/1000ft²/year), which is relevant to residential household use as well as for parks, cemeteries, golf courses, and playing fields.

As a consequence of increased research and published literature, the methodology used when performing nitrogen-loading calculations often varies among studies and hence there exists a certain level of confusion concerning proper values and methods (Eichner and Cambereri, 1992). Studies regarding fertilizer use and load rates often cite data developed in previous reports, and/or may present and incorporate original data. Percentage of household fertilizer use, average lawn size, annual application rate, leaching rate, and attenuation rate are all parameters that are critical components of nitrogen loading models, and require intensive and often site-specific research. Values for these parameters are constantly subject to change as data is refined over time. Because this research may require a large investment in scientific and financial resources, it is not unusual for nitrogen load studies to “share” information.

Annual Nitrogen Application Rate

The 1978 Long Island Study, undertaken to determine nitrogen loading as part of waste treatment management plan, was among the first of its kind seeking to quantify nitrogen loading with any degree of accuracy, and therefore much of the data submitted in the report is original. In order to determine load rates from fertilizer use as a source of nitrogen, it was necessary to calculate annual application rates per household by obtaining data specific to this need. In this study, over 400 households were contacted in a door-to-door survey in an effort to ascertain household fertilizer use on Long Island. A questionnaire was distributed inquiring about such things as amount of fertilizer used, lawn size, lot size, the extent of watering, type of turf, population density, and household income. The final data revealed an annual application rate in the range of 1.70-3.75 lbs N/1000ft²/year (Koppleman, 1978). A smaller study undertaken in the New York area prior to the Long Island Study resulted in a application rate figure of 2.2lb-3lbs N/1000ft²/year (SCDEC, 1974). In this report by the Suffolk County Department of Environmental Control for the Twelve Pines area in Medford, N.Y., 161 households were surveyed in order to determine localized fertilizer use. However, this study surveyed a much smaller population and was not as intensive when questioning residents, posing fewer and more general questions concerning fertilizer use.

On Cape Cod, two nitrogen loading studies were conducted for specific embayments and watersheds over the years, some which have involved household fertilizer use surveys and some which have incorporated estimates of use and other parameters from previous studies. For the Town of Yarmouth for example, consultants chose not to rely on assumptions when they developed their Water Resources Protection

Study for fear that they might not be applicable to the Cape Cod region which their study encompassed. A tally of the 131 households that returned questionnaires gave an average annual application rate of 2.8lb N/1000ft²/year. In 1990, Giblin and Gaines surveyed Orleans stores and determined that the average application rate for that area was 3lb N/1000ft²/year.

The assumed annual application rate used in a number of other studies has generally agreed with the load figure established in the Long Island Report. In their 1979 report on Water Supply Protection, the Cape Cod Planning and Economic Development Commission (CCPEDC) utilized 3lbs N/1000ft²/year, as did Valiela and Costa in 1988 and Horsley and Witten in 1991 in their reports on Buttermilk Bay. The Water Resources Office of the Cape Cod Commission (CCC, which replaced the CCPEDC) has historically based their nitrogen loading reports on the 3lbN application rate figure and has incorporated it into their 1992 Nitrogen Load Report Technical Bulletin, as well as into their 1998 Cape Cod Coastal Embayment Project and Pleasant Bay nitrogen loading reports.

Nitrogen Leaching Rate

There seems to be less consensus among scientists regarding nitrogen leaching rates. Surface and groundwater flows are pathways for the transfer of land-sourced nutrients, including nitrogen, to coastal waters when nitrogen is converted to nitrate that is readily transported through oxygenated groundwater systems (DeSimone and Howes, 1998; Ramsey *et al.*, 2000). Studies have found that in shallow bays and lagoons common along Northeast shorelines groundwater is the principal freshwater source of

nitrogen and phosphorous to these ecosystems (Strahler, 1966; Ryther and Dustan, 1971; Johannes, 1980; Capone and Bautista, 1985; Culliton and Warren, 1989; Giblin and Gaines, 1990; Gold, *et al.* 1990; Valiela, *et al.*, 1990; Bolcourt, 1993; Anderson, *et al.* 2002).

Leaching is the removal of materials by dissolving them away as water passes through the soil. In the case of fertilizers, water-soluble nutrients such as nitrogen and phosphorous are dissolved and transported downwards through a soil profile. The rate at which these nutrients are dissolved depends on a number of factors such as temperature, soil type, contact time/area, the amount of nitrogen and phosphorous in soluble form, the rate of application, and the rate of water flow (www.gardenwithinsight.com. 1998). One study that focused on the movement of nitrogen in the soil concluded that nitrate-nitrogen is greatest when 1) high annual rates of nitrogen are applied; 2) infrequent and heavy applications of soluble inorganic nitrogen are made; 3) irrigation or rainfall is heavy, and 4.) the soil is light and sandy (Long Island Report 208, 1978). Conventional commercial fertilizers are all water soluble, whereas organic fertilizers also lose water-soluble nutrients but at a slower and smaller rate. The leach rate is a measure of the amount of dissolution that occurs as water and nutrients move downward through the soil-the higher the rate the greater the loss of soluble nutrients.

Leach rates have historically encompassed a wide range, due in part to site specificity. The Long Island Report (Koppleman, 1978) employed a leaching rate varying between 55.5%-60% that is based on studies of soil samples. Brown *et al.* (1982), after conducting similar studies, found a leach rate of 22%. Petrovic, as a result of his 1990 controlled leaching experiments, presented leach rates ranging from 0-56.1%

depending on application rate, soil type, and nitrogen content (Eichner and Cambereri, 1992). The afore mentioned Yarmouth Report used a leach rate of 60% based on the Long Island Report, and historically the CCPEDC and then the CCC have done the same in their studies. Recently however, the CCC has determined that the 60% leach rate is excessive, and instead now uses a rate of 25%, acknowledging that “controlled applications of fertilizers on healthy turf can substantially reduce leaching rates, sometimes allowing no leaching” (Eichner and Cambereri, 1992). In their study of Buttermilk Bay on Cape Cod, Horsley and Witten assumed a leach rate of 30%, as did Howes and Goehring (1997). Finally Valiela *et al.* (1992) assumed a leach rate of 24% in their Waquoit Bay nutrient enrichment study.

There is increasing agreement among scientists that a more realistic leaching rate may lie between 20% and 30%, which is a more conservative estimate and recognizes the use of controlled fertilizer applications. Because this leaching rate has been utilized in fairly recent nitrogen loading studies that have focused on Cape Cod, the accepted leach rate used in this study will be within this range.

Attenuation

Nitrate, an inorganic form of nitrogen, constitutes the majority of the nitrogen load entering groundwater from non-point sources. The amount of total nitrogen added that is taken up by vegetation, denitrified, or sorbed by aquifer soils is “attenuated”. The proportion not attenuated, i.e. added nitrogen reaching the water table, is that proportion “leached,” and generally passes unaltered to the sediments underlying coastal waters where, as readily available nitrogen, it is taken up by algae and phytoplankton (Nixon, *et*

al., 1982; Ernst, 1996; Howes and Goehring, 1999; Howes and Hampson, 2000). Attenuation may also occur as the nitrogen travels through the aquifer, where it may bind to the sediments it passes through and be removed from the nutrient load as it moves through the watershed. The extent to which nitrate is removed as groundwater discharge is influenced by the geological characteristics of the affected watershed. For example, there is minimal removal in highly permeable watersheds that consist of glaciated or unconsolidated soils (Johannes, 1980; Capone and Bautista, 1985; Valiela and Costa, 1988; Valiela, *et al.*, 1989). These types of terrains are comprised of coarse sand and gravel, which may be mixed with finer sand, silt, and clay which was transported by glacial ice and left behind when the ice retreated (USGS, 2001). The composition of these terrains consists primarily of larger-size particles and is poorly mixed, resulting in loosely consolidated sediments that allow a fairly rapid rate of leaching by water. The attenuation rate specific to an area may be as low as zero or as high as 45 percent depending on the terrain's ability to act as natural filter. Streams, ponds, estuaries, and sediments that are consolidated and high in organics are all efficient in the removal of nutrients from groundwater flow, or flux.

Attenuation is also dependent on the distance the nutrients must cover before reaching receiving waters. Logically, the longer the load is subject to a soil or sediment interface, the higher the likelihood of attenuation. This means that whereas nitrogen that originates from sources in the upper part of the watershed may be subject to a significant degree of removal, there is drastically less attenuation in the lower parts of a watershed, where groundwater discharges directly into the bay. Here, the nitrogen load tends to be much higher, being that much closer to the receiving waters.

Recently, there have been some site-specific studies conducted on Cape Cod which have obtained attenuation rates higher than zero. In a study conducted in Waquoit Bay in 2000, for example, the attenuation rate for that watershed was found to be 35% (Valiela, *et al.*, 2000).

For this study of fertilizer use on Cape Cod, no site-specific studies for attenuation were performed. Since the attenuation value of near zero has been well tested in Cape Cod aquifers, and in order to remain conservative, this value was used in the study.

Figure 1. Study Sites, Cape Cod, Massachusetts



CHAPTER IV

METHODOLOGY

Site Description

Cape Cod, Massachusetts is connected to the mainland by two bridges, and is composed of fifteen towns that cover approximately 410 square miles (1070 square kilometers) within a single county, Barnstable (Stone, 1998). The prehistoric formation of Cape Cod has provided the region with its defining hydrogeological characteristics, of which an understanding is critical when determining nitrogen loading to embayments.

The formation of Cape Cod is mostly a result of glacial debris being deposited over existing bedrock when the lobes of the Laurentide Ice Sheet retreated one million years ago during the last ice age of the Pleistocene Epoch (Howes and Hampson, 2000; USGS, 2001). These deposits range in thickness from 200 to 600 feet and are primarily composed of sand and gravel (USGS, 2002). Broad outwash plains and moraines characterize much of the Cape, and mark the positions of the ice front (USGS, 2001). Both features comprise the principal aquifer on the Cape due to the permeability of the material they are composed of. Moraines are ridges of unconsolidated materials including sand, pebbles, and rocks that was transported and deposited by moving ice, while outwash plains were created as debris deposited by meltwater streams which flowed across the surface of the plains (Strahler, 1966; USGS, 2001). While coarse sand and gravel are the most extensive types of glacial deposit found in these two features, clay, silt, and very fine sand may also be part of the debris composition (USGS, 2001.A). Outwash sand and gravel generally have moderate to high permeability, which allows

rapid infiltration of precipitation and results in rapid recharge of groundwater (Eichner, 1998; USGS, 2002;). Consequently, this aquifer, named the Cape Cod glacial aquifer, has been designated by EPA as a “sole source” aquifer and is the primary source of fresh water on the Cape (Giblin and Gaines, 1990). The Cape Cod glacial aquifer has short groundwater flow paths and water movement through the aquifer is towards Buzzards Bay, the Cape Cod Canal, Nantucket Sound, Cape Cod Bay, and the Atlantic Ocean, as well as towards numerous ocean inlets.

As the number of studies mount, it becomes more evident that increased nutrient loading corresponds to increased housing density, as a growing number of embayments and ponds experience eutrophication in fast-developing areas. Embayments along the Cape shoreline are generally shallow and poorly flushed, with restricted tidal exchange. These systems tend to decrease their ability ecosystems to assimilate the expanding nutrient loads from rapid development within the watersheds. Since nearshore coast salt ponds and embayments are the primary recipients of nutrients carried by surface water and groundwater transport from terrestrial sources, activities within the watershed can have chronic and long-lasting impacts on these fragile coastal environments (Ramsey, 2000). Thus, as the trend of development moves inward, as it is doing on Cape Cod, non-point sources such as fertilizer will strongly influence the current loading of nutrients to the coast (Roman, *et al.*, 2000).

Based on aerial photographic surveys of Cape Cod conducted in 1951 and 1990, it was found that the area of forests, woodlands, and open lands has declined from 71 percent of the total area to fifty percent; urban, residential, and commercial land covers have increased from 10 percent to 31 percent, while the area of agriculture, pasture, and

cranberry bogs has declined from 4.8 percent to 1.5 percent (Stone, 1998). In the coastal zone, most of the residential development is sited on unconsolidated plain of sandy soils. Between 1980 and 1997, Barnstable County had the highest net migration of residents of all 14 Massachusetts counties, and between 1980 and 1990, Cape population grew by 26 percent while Massachusetts' population grew by only 5 percent (Cape Cod Commission, 1998a). The housing inventory in Barnstable County grew by 35 percent during the same ten years, increasing by a total of 35,246 new housing units, while statewide, the housing total grew by only 12 percent. From 1990 to 2000, the County had the third highest growth rate of all Massachusetts counties, behind only Nantucket and Dukes counties (CCC, 1998b.).

Among all the towns on the Cape, Barnstable is the largest, with a total area of 76.26 square miles. The population and density per square mile also leads all Cape Cod towns, at 40,949 people and 682 per square mile respectively. These data are based upon Year 2000 surveys (CCC, 1998b.) While Falmouth and Mashpee are located in the Upper Cape, Barnstable is considered Mid-Cape, and encompasses much of the land area in that part of the region. Falmouth is over half the size of Barnstable, having a total land area of 54.44 square miles. Population and density per square mile are 27,960 people and 632 per square mile, respectively. Mashpee, which lies between Barnstable and Falmouth, is tiny compared to its neighbor on the east. With a total area of only 27.24 square miles, its population is 12,984 residents, with a square mile density of only 551 people (www.BarnstableCapeCod.Com. 2001). The combined area of the three towns in the study represents 33% of the total area of Cape Cod (Cape cod Commission, 1998b).

The current land use and land cover of Cape Cod, based on 1990 figures, is dominated by forested, woody, and open land, which covers 50.3% of the landscape (WHRC, 2001; MAEOEA, 1996). Commercial and residential land uses account for 31% use, while fresh and salt wetlands and water cover 11.3% of the land area. Two point two percent of the Cape land is used for recreation and golf, while gravel mining, agriculture, pasture, cranberry bogs, new ocean, and waste disposal make up the remaining 4.5% of land use (WHRC, 2001; EOEA, 1996). Residential land use accounts for almost one-third of the land use on Cape Cod, and with the current growth trend of new housing construction, threatens to increase its take of available land.

Research Methods

Until now, most studies have based their nitrogen loading rates on assumptions made for fertilizer use, such as the number of houses applying fertilizer, the application rate, the leaching rate, and the degree of attenuation. The focus of this study was to quantify the fertilizer loading from a watershed and from individual sources, specifically households, and to provide more accurate data and/or substantiate existing data. Research concentrated primarily on the quantification of fertilizer application rates per household per year within three Cape Cod sample sites. This quantification involved investigating the following objectives as components of a nitrogen loading table:

1. Number of applications per household per year
2. Amount of fertilizer applied per application
3. Average lawn size

Field surveys were used in three selected towns in order to determine the stated objectives. Surveys were conducted in such a way as to be representative of Cape Cod both demographically and geographically by delineating areas of sampling that incorporated inland, pond, and coastal locations (watershed zones) within each of these three towns. The number of surveys was equally distributed among towns and locations.

Two types of field surveys were conducted: on-site resident interviews and visual assessments.

On-site Resident Interviews

On-site resident interviews were conducted from July 15 to September 15, 2001. These interviews were carried out on a randomly selected sample of households and involved the submittal of a pre-designed and pre-tested questionnaire (Appendix B). The primary objective of the personal interviews was to quantify individual household fertilizer use. A secondary objective was to create an accurate database of fertilizer use information from which to estimate nitrogen in the subsequent loading models. The use of the questionnaire was based on the premise that there are a large number of parameters that may influence residential fertilizer use. The selection of the parameters that were the focus of the primary objective in this study was based on the fact that these parameters are part of the equation used to calculate nitrogen loading. It should also be noted that many of the nitrogen load studies merely cite other people's values. In addition to the predetermined parameters, the possibility existed that other parameters may have an impact on fertilizer use, therefore necessitating the expansion of the questionnaire to include this possibility.

The sample of households was taken within defined watersheds to distinct coastal embayments within three Cape Cod towns: Falmouth, Mashpee, and Barnstable. The watershed surveyed in Falmouth drained into the Great, Green, and Bourne Ponds embayment; the Mashpee watershed drained into the Popponeset Bay embayment, and the Barnstable watershed drained into the Three Bays embayment. Each watershed was divided into three different functional zones based on their physical characteristics: coastal, pond, and inland. Coastal areas were defined as areas within a quarter-mile of coastal or embayment waters. Pond areas were defined as areas within a quarter-mile of a pond. Inland areas were defined as those areas having no body of water within its watershed.

The same questionnaire was used in all interviews. The structure of the questionnaire was designed in such a way as to enable the researcher to acquire as much qualitative and quantitative information on application related nitrogen-loading parameters (e.g. lot size, application frequency, application rate, etc.). There were three parts to the questionnaire, each designed to collect a certain type of data. The first two parts collected quantitative and qualitative data through on-site resident interviews. The third part, physical data, was collected by visual assessments.

Questions used to collect quantitative data focused on the following:

Part I: Quantitative data collected in interviews

- Number of fertilizer applications per household per year (0-4)
- Application by homeowner or commercial enterprise
- Amount of fertilizer applied per application
- Lawn size

In nitrogen loading models for lawn fertilizer, average lawn size is commonly assumed to be 5000ft². In order to verify the accuracy of this figure, residents were asked, as part of the on-site resident interview, the size of their lawn.

It was assumed that a certain percentage of those residents who apply fertilizer do so through a commercial landscaping company. Therefore, it was necessary to compile fertilizer application data specific to these companies in order to derive accurate measurements of nitrogen loading.

Although the principal objective of this study was to quantify residential fertilizer use, a secondary objective was to attempt to carry out trend analyses in order to determine the existence of any relationships between a certain parameter and subsequent fertilizer use. Therefore, the questionnaire included the following:

Part II: Qualitative data collected in interviews

- Business where fertilizer was purchased
- Type of fertilizer used
- Season of purchase (Spring, Summer, Winter, Fall)
- Month (s) of application
- Seasonal or year-round residency
- Occupation of head of household
- Age of head of household
- Age of house
- Length of residency on Cape
- Length of residency in house

The three towns involved in the survey were selected based on the fact that all three have fresh and saltwater systems within their borders, that they vary in size, both geographically and demographically, ranging from small (Mashpee) to large (Barnstable), and that all three are concerned with and are actively managing their coastal ecosystems. These towns are also experiencing an increase in population and housing construction, as more people desire to live permanently in these areas.

Neighborhoods in which the surveys were conducted were selected in each town to represent three regions: pond, inland, and coastal. Streets were randomly selected within these neighborhoods, and each house located on each selected street was approached for sampling. For those houses in which no resident was found at home it was recorded as such, and only physical data was collected. If there was a resident in attendance, a questionnaire was then presented. There were no restrictions on the term “respondent,” meaning that any member of the household was considered qualified to provide answers to the questionnaire.

Each resident was informed about the purpose of the study, who was involved in conducting and supporting the study, and the confidentiality of the answers they provided. Respondents were informed that they were not obligated to answer any or all of the questions. Interview surveys were conducted through a structured interview using the same set of questions for all interviewed. The survey was pre-tested in forty households outside of the study watersheds to check that the interviewee correctly understood the intent of each question. Of the twenty-two questions presented, six were refined to enhance clarity based upon comments by the pre-test respondents. The

responses gathered through the pre-test interviews were not incorporated into the study results.

Visual Assessments

Visual assessments made up the third part of the questionnaire. These data, combined with collected interview data, provided the foundation for the quantitative analysis of residential fertilizer use. Data for visual assessments were not collected as part of the personal interviews but rather were collected prior to each on-site interview and also in a larger visual assessment study. The visual assessment study was conducted to significantly expand the censusing of key parameters that were covered in conjunction with the on-site interviews. Visual lot assessments were used to quantify easily observable parameters and involved the appraisal of both house lot characteristics and lawn conditions. This type of assessment was used in this research in order to compile physical data relating to the characteristics of each house lot. Data collected focused on the following:

- Lot location (inland, pond, embayment zone, town, and street)
- Lot size (square feet)
- House size (square feet)
- Lawn size (square feet)
- Percentage of lawn versus cover
- Proximity to the bay
- Lot description

Lot location was recorded in order to provide demographic and geographic information as well as to insure that there was no duplication of data. Respondents were informed that their replies were strictly confidential and that addresses would not be made public.

House size, lawn size, and lot size were estimated by the researcher based on knowledge of and comparison to actual sizes of houses, lawns, and lots. If possible, these estimates were confirmed or adjusted accordingly as a result of personal interviews with residents.

After an analysis of the pre-test questionnaire survey results, resident responses regarding lawn size were found to be estimates to the best of their knowledge, rather than exact measurements. Consequently, with the purpose of collecting more precise and comparable data, a determination of lawn size for each house lot surveyed was also attained by a measure of estimation by the researcher. This was approached in three ways. The first method was to estimate lawn size by on-site observation. The researcher visually assessed each lawn by measuring the square footage of each lawn component (i.e. front, back, sides) by eye and summing all components for a square foot total. This was done for all house lots as part of the visual surveys. In order to determine the accuracy of the visual site assessment measurements of individual lawns, a number of lawns were measured yet again by means of a second method. This method was to physically measure individual lawn size by measuring the stride of the researcher and then walking the property lines of the lawn for individual lots. This was carried out on a specific number of lawns and the results were compared to the results of measurements conducted of the same lawns as part of the visual assessments.

The third method of measurement was to derive lawn size from an equation involving lot size and percentage of lawn cover. The following equation was used:

$$\text{For each lot: (lot size-house size) x (\% lawn/100)}$$

Individual lot size was measured by the researcher by visually estimating, in square feet, the linear measures of the length and breadth of each lot. To determine house size, the footprint of each house within each lot was visually measured, in square feet, by estimating the length and breadth of each house.

Percentage of lawn versus vegetative cover was also estimated by the researcher. Lawn was typically any area covered by grass, while cover was considered anything other than lawn i.e. trees, bushes, paved areas, flower and vegetable beds, etc. Total percentage was the area of the lot that encompassed everything but the footprint of the house.

Proximity to the bay was noted for those house lots surveyed in coastal or pond regions in each town. Distance was measured in mile increments by odometer.

Lot description data was compiled by the researcher and included lawn condition (patchy, healthy, etc), proximity to wooded areas, type of soil (for example, sand v. loam), existence and location of vegetative borders, etc.

Visual lawn assessments focused on the condition of the lawn for each lot surveyed in order to ascertain fertilizer use. Assessments were based on the following characteristics:

- Grass color
- Grass height
- Evenness of color

- Comparison to recognized fertilizer use/no use conditions

Visual assessments followed by an interview were used to determine the validity of the visual assessment approach. When visual lawn assessments were performed by the researcher for a specific house lot prior to a personal interview, this assessment was subsequently compared to the respondent's yes or no answer when queried concerning fertilizer use.

In order to compile a significant database regarding fertilizer use in the three towns, visual assessments of house lots were conducted by using a more "rapid" method than personal interviews, termed rapid visual assessments. The most important parameter collected in the rapid visual assessments was whether the lawn was receiving fertilizer (regardless of the amount). This determination was made based upon criteria developed and verified by rapid visual assessment linked to personal interviews. This method of data collection was similar to the visual assessments conducted together with the personal interviews in that survey sample areas were randomly selected in each town. However, only physical data were recorded for each house lot surveyed in rapid visual assessments. Randomly selected streets were surveyed by evaluating each house lot as the researcher traversed the area without stopping to conduct personal interviews. Although the amount of demographic data collected for some parameters was thus limited by this survey method, data for the physical parameters was increased two-fold.

Density of housing was also recorded as part of the rapid assessment surveys in order to determine whether or not there is a relationship between density and the use of fertilizer. Because houses located in high-density areas tend to have smaller lawns, density may also affect the degree of lawn care and thus the amount of fertilizer used.

Density was quantified in the following way (Koppleman, 1978):

1. High: > 10 housing units/acre
2. 5-10 housing units/acre
3. 2-4 housing units/acre
4. Housing units/acre
5. Low: estate or rural

CHAPTER V

RESULTS

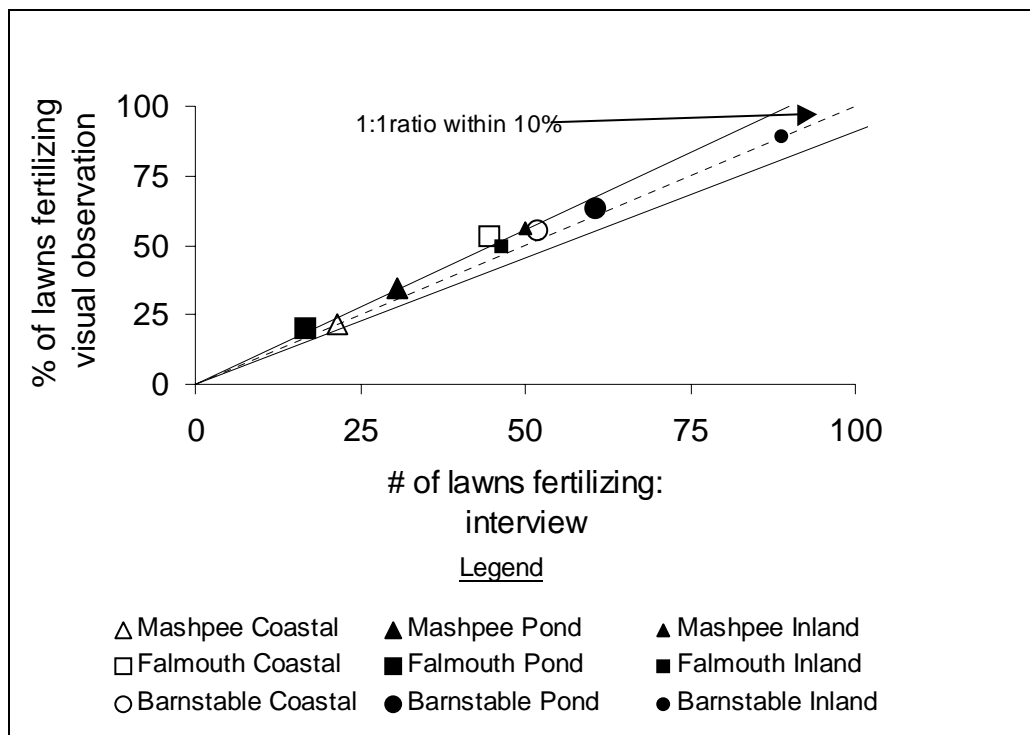
Objective Data

Objective data results are those results derived from data collected to facilitate the quantification of individual household fertilizer use. This quantification involved the determination of the three previously stated objectives.

A total of 323 on-site personal interviews were presented to residents in the towns of Falmouth, Mashpee, and Barnstable. Data collected in these interviews included the number of fertilizer applications per household per year and the amount of fertilizer used per application. Additionally, visual assessments of house lots in the three towns were undertaken in order to collect data concerning individual household fertilizer use and average lawn size, among other parameters.

Visual assessments were made of each house lot surveyed in order to collect physical data as well as to determine whether or not residents applied fertilizer to their lawns. Data collected from these assessments that were completed prior to and in conjunction with on-site interviews served to establish confidence of the rapid visual assessment surveys undertaken in the absence of personal interviews. This was necessary to verify the precision of observations when assessing fertilizer use in these surveys. The success rate for visually assessing fertilizer use was as high as 100% and no lower than 83%, with an average of 94%. As is shown in Figure 2., in a 1:1 ratio of visual observations and actual use, all values between data sets were within 10%.

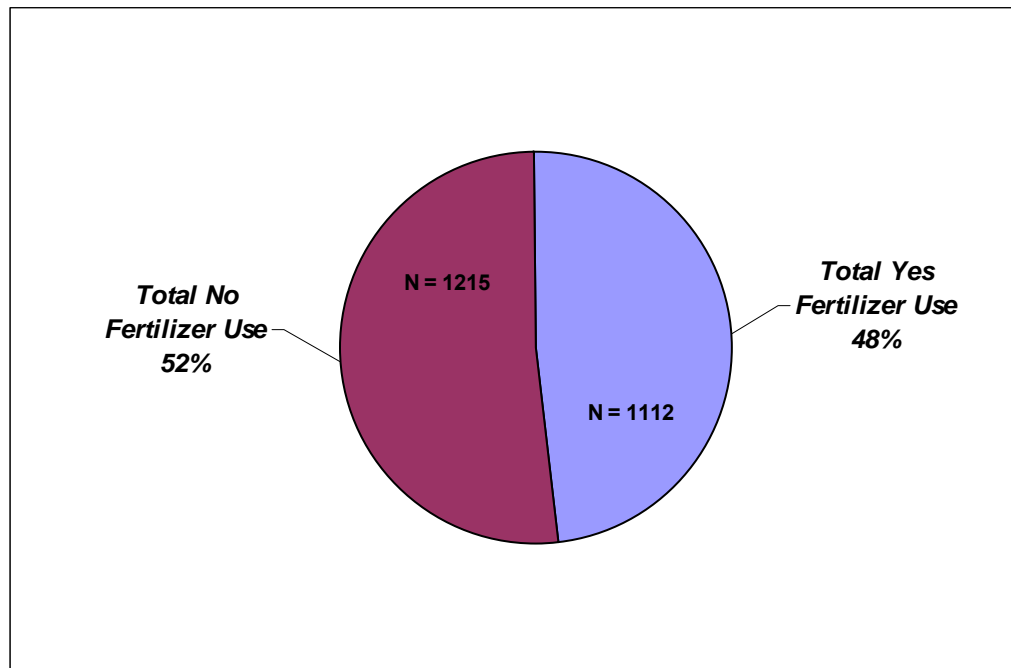
Figure 2. 1:1 Variability Graph for Visual Observations



Overall Percentage of Fertilizer Use

Two thousand and four rapid visual assessments were completed in the three sample towns. Results were combined with those collected from on-site personal interviews (323), for a total of 2327 house lots surveyed for fertilizer use. This was 2% of the combined population of the three sampled watersheds. Of this total, 1112, or 48% of the homes used fertilizer at between 1-4 applications per year (Figure 3).

Figure 3. Percentage of fertilizer use in survey



A Chi square goodness-of-fit statistical analysis was conducted in order to determine whether this observed residential fertilizer use (1112 residents) was significantly different from the residential fertilizer use which might be expected by chance. Results of the analysis revealed that there was a significant difference in observed fertilizer use from what might be expected by chance.

Statistical test results: $X^2 = 4.56$; $p = 0.05$.

Average Number of Applications per Household per Year

Three hundred and twenty-three on-site personal interviews and 2004 rapid visual assessments were completed within the three towns. Data were collected from these surveys regarding the number of fertilizer applications per household per year, ranging from 0-4 applications. A weighted average number of applications per household per year was calculated for total use as well as for each town and each watershed zone (see Appendix B).

The average number of applications per household encompassing all three towns was 1.33 times per year. Individually by town, Falmouth households averaged 1.11 times per year, Mashpee averaged 0.98 times per year, and Barnstable averaged 1.77 times per year. For each watershed zone, coastal households averaged 1.38 fertilizer applications per year, while pond and inland households averaged 1.05 and 1.46 applications per year, respectively.

Percentage of Use by Town and Watershed Zone

A chi square test of contingency statistical analysis was conducted to determine if there was a statistically significant difference between towns regarding the number of residents applying lawn fertilizer. This test compared fertilizer use values between towns (for example, the number of residents applying lawn fertilizer in Falmouth compared to the number of residents applying lawn fertilizer in Mashpee). Results of the analysis revealed that there was a highly statistical significant difference ($\alpha = .001$) in the number of residents applying lawn fertilizer in Barnstable compared to the number of

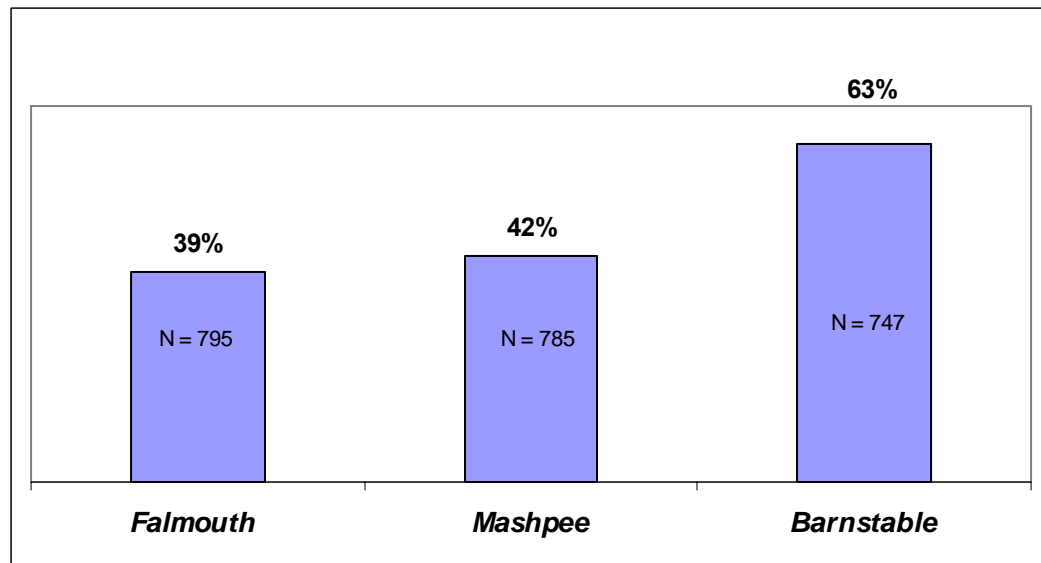
residents applying lawn fertilizer in Falmouth (Appendix D). Analysis also revealed that there was a significant difference in the number of residents applying lawn fertilizer in Barnstable compared to the number of residents applying lawn fertilizer in Mashpee (Appendix D).

Table 1. A breakdown of fertilizer use by Town and watershed zone

EMBAYMENT	WATERSHED ZONE	# surveyed		
		TOTAL	# FERTILIZE	% FERTILIZE
Falmouth	Coastal	293	136	46
Falmouth	Pond	259	69	27
Falmouth	Inland	243	107	44
Falmouth	Total	795	312	39
Mashpee	Coastal	256	67	26
Mashpee	Pond	292	132	45
Mashpee	Inland	237	128	54
Mashpee	Total	785	327	42
Barnstable	Coastal	238	145	61
Barnstable	Pond	237	138	58
Barnstable	Inland	272	190	70
Barnstable	Total	747	473	63
# surveyed				
TOTAL	# FERTILIZE	% FERTILIZE		
2327	1112	48		

Categorizing percentage of fertilizer use by town illustrates that Barnstable had the highest percentage of fertilizer use (63%), followed by Mashpee (42%) and Falmouth (39%) (Table 1, Figure 4).

Figure 4. Percentage of surveyed residents applying fertilizer within each Town



A chi square test of contingency statistical analysis was conducted to determine if there was a significant difference between locations regarding the number of residents applying lawn fertilizer. This test compared fertilizer use values between locations (for example, the number of residents applying lawn fertilizer in inland locations compared to the number of residents applying lawn fertilizer in pond locations). Results of the analysis revealed that there was a highly statistically significant difference ($\alpha = .001$) in the number of residents applying lawn fertilizer in inland locations compared to the number of residents applying lawn fertilizer in coastal locations (Appendix D). Analysis also revealed that there was a significant difference in the number of residents applying lawn fertilizer in inland locations compared to the number of residents applying lawn fertilizer in pond locations (Appendix D).

For locational fertilizer use, the data illustrates that inland respondents had the highest fertilizer use, at 57%, whereas in coastal and pond locations, 44% and 43% of the residents fertilized respectively (Table 2, Figure 5). Fertilizer use in inland locations is above the overall average of 48%, whereas both coastal and pond areas have similar averages that are below the overall average.

Table 2. A breakdown of fertilizer use by watershed zone

WATERSHED ZONE	# Surveyed	# FERTILIZE	% FERTILIZE
	TOTAL		
Coastal	787	348	44%
Pond	788	339	43%
Inland	752	425	57%

Figure 5. Percentage of surveyed residents applying fertilizer within each watershed zone

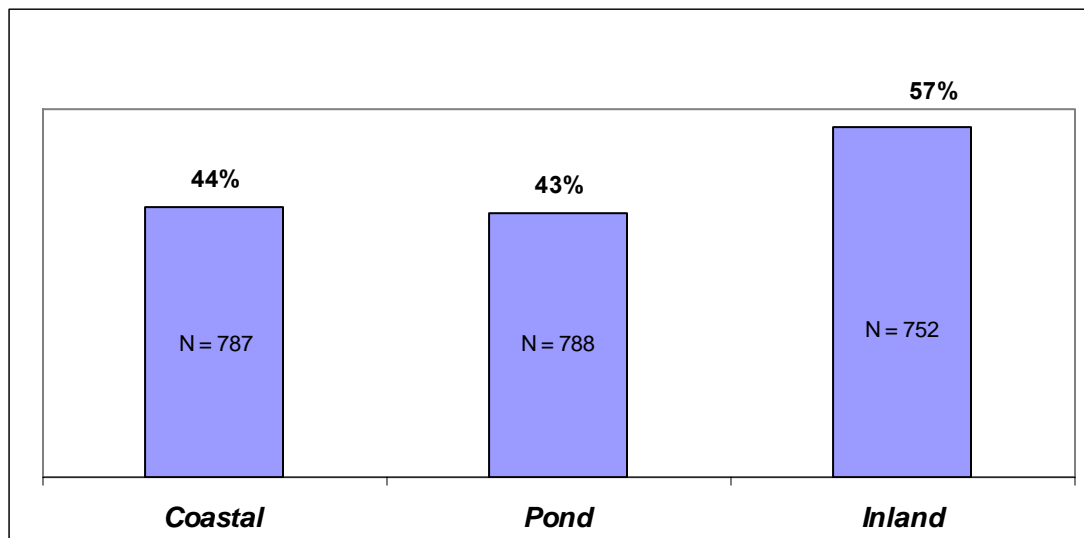
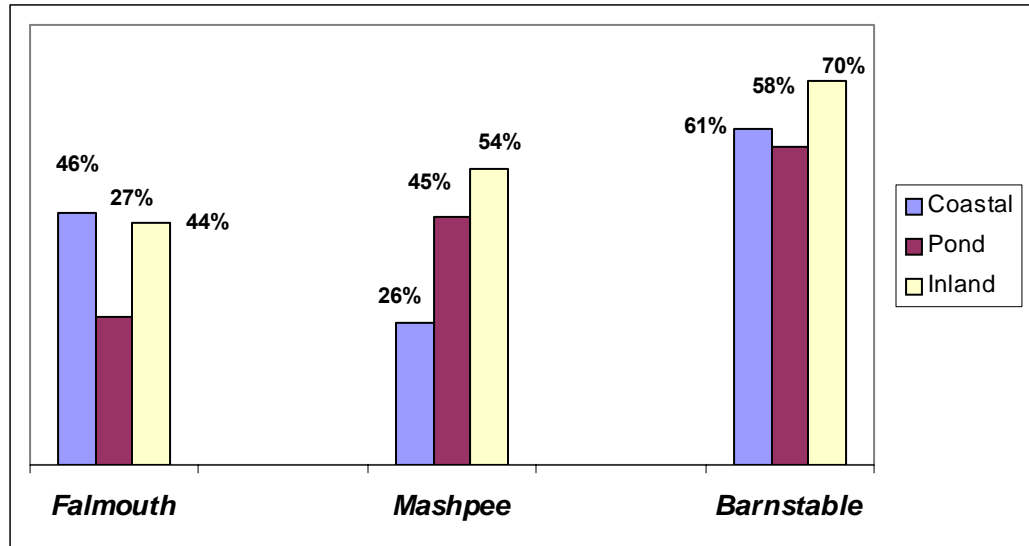


Figure is a breakdown of the percentage of fertilizer use in each watershed zone for each town. This data mirrors the results overall, showing a high percentage of use in inland locations

Figure 6. Percentage of fertilizer use within each watershed zone within each Town



Application Rate

In general, the application rate can be defined as the amount of nitrogen applied as part of fertilizer by a homeowner each year, or the mass load per square footage. This is measured in pounds of nitrogen per 1000ft² lawn per year, or lbsN/1000ft²/yr. Data is derived from information gathered in personal interviews as well as from information found on each bag of fertilizer. In the interviews, residents were asked how much fertilizer they applied to their lawn for each application. Ninety-eight percent of the residents said that they followed application instructions found on each bag of fertilizer. Looking at the application rates suggested by a number of fertilizer brands (see Appendix

B), the data shows an average application rate of 3.2lbsN/1000ft²/year. Each fertilizer brand recommended four applications per year. This results in 0.75lbs of nitrogen per application per year for each household. A review of the literature regarding application rates in nitrogen studies reveals a current application rate of 3lbsN/1000ft²/year. For the purposes of this study, an application rate of 3lbsN/1000ft²/year was used based on both observed use and literature data, and which is consistent in sources of fertilizer use information.

Average Lawn Size

Three methods were used to measure individual lawn size, each with the purpose of collecting a comparable data set of values that would serve to crosscheck the values of the other two data sets. Resident responses regarding lawn size were found to be estimates to the best of their knowledge, rather than exact measurements. Because of the lack of robustness of on-site resident interview data regarding lawn size, this data set was not utilized in this study. No statistical analyses were conducted on this data due to the fact that this method of collection was recognized as lacking robustness after performing pretest surveys. The question regarding lawn size remained within the on-site personal interview questionnaire for future analysis.

A determination of lawn size for each house lot surveyed was also attained by a measure of estimation by the researcher. This was approached in two ways: visual assessments and physical measurements. The data collected as part of the visual assessment surveys was compared to the data collected for corresponding lawns through physical measurements. A linear regression model was conducted in order to determine

the relationship between the two methods of lawn size measurement. Results of the analysis demonstrated a coefficient of determination near one (0.98), with a sample size (N) of 46. This data revealed a high positive correlation between visually measured lawn size and physically measured lawn ($R^2 = 0.95$).

During the process of visual assessment of lawn size and lot size, the accuracy of this method of measurement was deemed uncertain by the researcher. Due to the irregularity of the Cape Cod landscape, land boundaries and borders were hard to define, stemming from property irregularities and unclear lot lines, and resulting in difficulty calculating lot and lawn sizes, as well as percentage of lawn. The end result was a lack of confidence by the researcher in the accuracy of the determinations of lawn and lot size, and percentage of lawn. As a consequence, although statistical analysis demonstrated that the visually lawn size measurement method and the physical lawn size measurement method were robust in comparison to each other, neither method was able to satisfactorily fulfill the study objective of accurately assessing individual lawn size.

The third method of measurement was to derive lawn size from an equation involving lot size and percentage of lawn cover using a formula based on visual assessments of lawn size, house size, and percentage of lawn. However, data collected for each parameter in this formula is based on visual assessment methods that are considered not to be robust. Lawn size inaccuracies have been previously mentioned. Individual house size data was collected in two ways. The first method was to gather data as part of the on-site personal interviews. Residents were asked how large their house was, in square feet. A large number of residents were uncertain of the size of their house, resulting in an incomplete data set due to the small number of accurate responses. The

second method was visual measurement by the researcher as part of the visual assessment surveys. However, due to the lack of experience by the researcher in this endeavor, a large level of inaccuracy was assumed for this data set. As a consequence, this data was not considered robust and hence was not included in the study. Therefore, this third method of individual lawn size measurement is also considered to lack accuracy.

Since at present there is no process to determine which approach may be correct, and due to the lack of accuracy of the data collection methods, the data collected for each of the methods was not used. Instead, this study incorporated in its final load model results the average lawn size of 5000ft², which is an assumption currently accepted in most nitrogen load models.

A statistical analysis was conducted on visual assessment data collected for individual lawn size and fertilizer use, with the intent to explore possible relationships for further study. Data sets were analyzed within the confines of their robustness, and final test results were also considered within these confines.

Student t tests were conducted in order to determine if there were differences in lawn size for those residents who applied fertilizer at least one time per year (Appendix D). Analyses were performed using a 0.05 level of significance. Comparisons were carried out between each of the three towns and each of the three locations.

Test results revealed that there were significant differences in individual lawn size between all towns for those residents applying fertilizer at least once a year, with Barnstable having the largest average lawn size among all three towns for those residents who apply fertilizer.

Test results also revealed that there were significant differences in individual lawns size between coastal and pond locations for those residents who apply fertilizer at least once per year, as well as between coastal and inland locations. In addition, test results illustrated that there was not significant difference in individual lawn size between pond and inland locations.

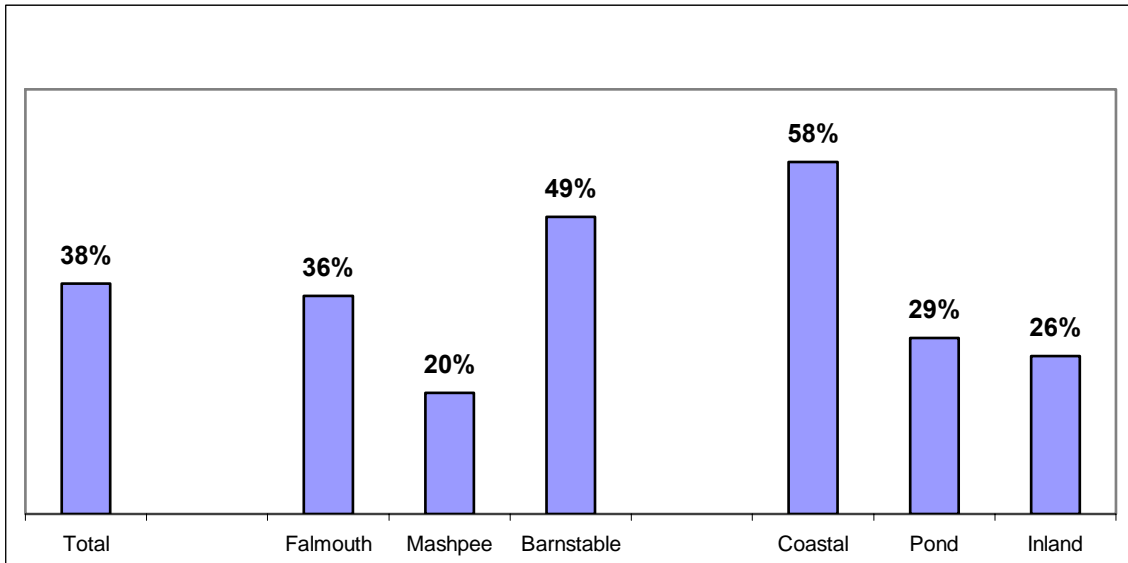
Secondary Parameters

Data from a number of additional parameters were collected from both on-site personal interviews and visual assessments. These parameters were researched for this study in order to collect as much information as possible regarding residential fertilizer use. Datasets from each of these parameters provided background information from which lawn fertilizer use in these three towns can be evaluated as well as provide a database from which future studies may be developed. Many of these parameters were also not included in the present study since these data sets were incomplete due to the small number of responses. These parameters include the respondent's age and occupation, the number of years the respondent resided on the Cape and whether s(he) had lived in that particular residence, and the location and month of purchase of fertilizer. More complete data sets are presented for a range of other parameters where the result is either a better response rate (the use of commercial application, house age, seasonality), or as products of visual assessment surveys (house size, housing density). The results of the surveys for these parameters are as follows:

Percentage of Residents Using A Professional Lawn Care Company

When analyzing tendencies of fertilizer use, it is important to note the role of professional lawn care companies among those residents who use fertilizer. These companies may contribute more nitrogen to the load than self- applied fertilizer strictly because they tend to apply fertilizer more often compared to the average homeowner. Commercial lawn companies usually apply fertilizer four to five times a year. This may elevate the average number of applications per year for residential use and may also enlarge the impact of fertilizers on the total nitrogen load rate to watersheds. In this regard, differentiating between self-application of fertilizer and application by a professional lawn care company may be important when determining the total load rate of nitrogen to a watershed and therefore is a vital parameter to measure.

Figure 7. The percentage of residents employing a professional lawn care company in each of the Towns within each of the watershed zones.



Overall use of a professional lawn care company among the three towns was 38%, while 62% of the residents chose to apply fertilizer themselves. Figure 7 also depicts commercial fertilizer use for each town and each location.

House Age

Three hundred and six residents responded to the question of the age of their house. Of these responses, approximately half were given by those who knew the exact age of their house, while the other half of the residents offered estimations. The average house age inclusive of all three towns was 35 years, and most of the houses were less than 50 years old. One hundred and forty-two of the respondents used fertilizer, and the average house age for this group was 33 years. The average house age for those residents who did not fertilize was 36 years.

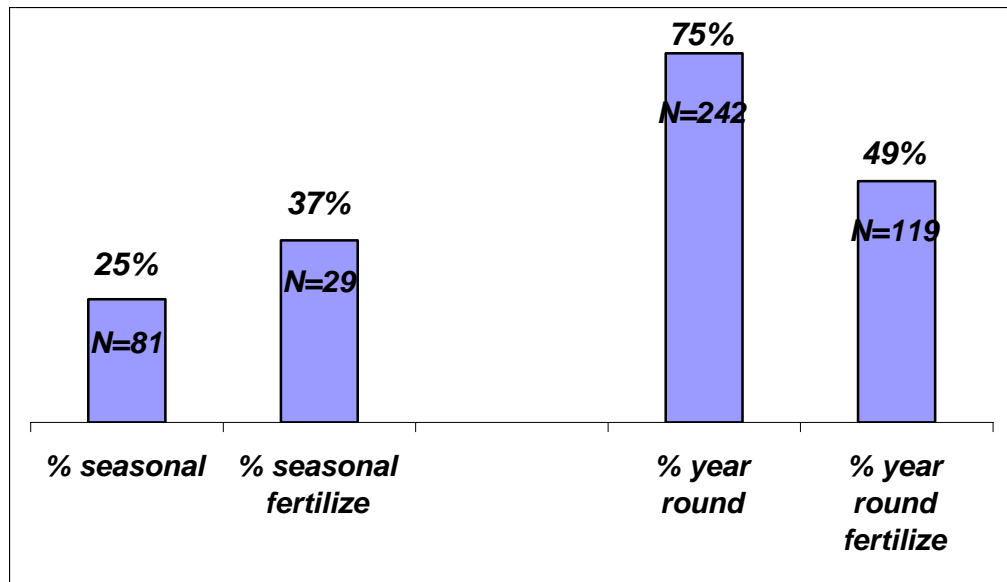
Seasonality

Like most of the nearshore regions up and down the East coast, Cape Cod is increasingly becoming the permanent place of residence for more and more people. Always a popular summer destination, the Cape is experiencing a building boon, not only in new housing but also in the conversion of summer homes to year-round dwellings. With more people settling on the Cape permanently, there is increasing concern that the contribution to the nitrogen load by these additional people living in this area may accelerate and magnify the adverse impacts on coastal embayments. Residents were

asked whether they were a 12-month per year resident, which is considered permanent, or a summer, or part-time, resident residing on the Cape for no more than 4 months a year.

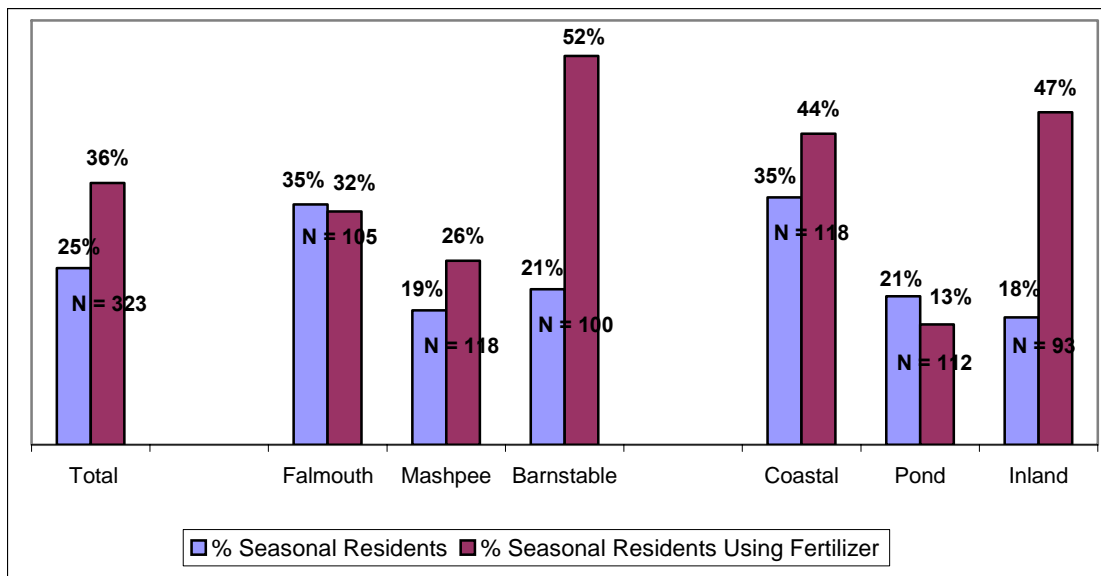
Three hundred and twenty-three residents responded to the question of residency. The percentage of seasonal residents and the percentage of year-round residents are illustrated in Figure 8. Also depicted is the percentage of seasonal residents and year-round residents that apply lawn fertilizer.

Figure 8. Percentage of Seasonal and Year-round Fertilizer Use



The percentage of part-time residents overall, for each town, and for each location is shown in Figure 9. This graph also portrays a breakdown of fertilizer use by part-time residents in each of these areas.

Figure 9. Percentage of seasonal residents applying lawn fertilizer.



Housing Density

Housing density was recorded as part of the 2327 visual assessment surveys completed, and was measured in housing units per acre (hu/a). Based on these assessments, 86% of the households surveyed resided in areas where the housing density was 2-4 housing units per acre. The remaining 14% resided in areas ranging from 0-2 hu/a.

CHAPTER VI

DISCUSSION

Overall Percentage of Fertilizer Use

As seen in this study, less than half the population (48%) surveyed applied fertilizer to their lawns. It appears that this was a smaller proportion of residents who applied lawn fertilizer compared to the assumed fertilizer use rate of 100% found in many historical nitrogen load studies. In order to produce this proportional comparison, it was necessary to qualify these results by stating the margin of error contained in the surveys. Calculation of this error margin was based on the most current number of single-family households within each town. The margin of error determined for these surveys was +/- 2.2% at a 95% confidence interval. Based on this proportional comparison, the research hypothesis is accepted: That the percentage of households that apply fertilizer is significantly different than the assumed figure of 100% that is currently used in nitrogen loading models.

While the exact percentage may not be accurate, this broad view data set immediately demonstrates a decrease in the extent to which fertilizer contributes to the nitrogen load to watersheds. In addition to providing essential database information, the determination of overall percentage of fertilizer use has proven to be a generalized indicator of use due to the ease and simplified nature of its data collection and analysis. In other words, while subsequent conclusions, such as locational use data, require more in-depth data collection and analysis, overall percentage of fertilizer use reveals a preliminary picture of the weight of the impact of fertilizer use on the nitrogen load, and the significance of such fertilizer use.

Nitrogen Load to Groundwater

The ultimate objective of all fertilizer use studies, including all nitrogen source studies, is the development and completion of a nitrogen load model. This model is comprised of a number of parameters which seek to determine the contribution of nitrogen to groundwater in pounds per year. The values for each parameter are formulated into a load equation for which the product is a measure of the contribution by a specific nitrogen source to groundwater per year. This nitrogen load rate is an integral part of nitrogen load modeling and management analyses. The annual nitrogen load model utilized in this study focuses on the contribution of nitrogen fertilizer from individual households in one year. Subsequently, each of the parametric terms incorporated in the load equation relate to this focus and have been researched and analyzed in this study. Figures for average lawn size (5000ft²) that appear in current nitrogen load studies have been accepted in this study, as have leach rate (20%) and attenuation (0%). However, the observed average number of applications per household per year as evidenced from the study data does not concur with current data, as can be seen in Table 3.

Table 3. Summary of estimated nitrogen load from residential lawn fertilizer

	Avg. Lawn Size(Ft²)	Application Rate lbN/1000ft²	# Appl/Yr	% Leach Rate	LbsN to Groundwater/yr
Literature	5000	0.75	4	0.2	3
Observed	5000*	0.75	1.33	0.2*	1
% Change	0	0	67%	0	67%

* = assumed

The final results for both literature data and observed data, pounds of nitrogen reaching groundwater per year (lbsN/yr), is the product of the four nitrogen load parameters: average lawn size, application rate, number of applications per year, and leach rate.

It can be concluded from the data in Table 3 that the average number of applications per year is the driving variable in the nitrogen load formula. Whereas the assumed or forecasted average number of applications is four times per year, the average number of applications per year derived from the data is only 1.33.

A small-sample one-tailed t test was performed in order to determine if there is a significant difference in the observed number of applications and the forecasted number of applications used in literature. The results of the test showed that the observed average number of fertilizer applications per household per year is significantly less than the forecasted average number of fertilizer applications per household per year (Appendix D). This results in a significant decrease in pounds of nitrogen per year contributed by household fertilizer, from 3.0 lbN to 1.0 lbN. The end result is a 67% reduction in nitrogen being contributed to the load to watersheds by household fertilizer application. Consequently, the research hypothesis can be accepted, which states that there is a significant difference between the observed nitrogen load figures for those towns located in the study area and the projected nitrogen load figures currently used in nitrogen loading models.

Table 4 presents an analysis of annual nitrogen load by town and location. The annual household contributions of nitrogen in each town and each location are all similarly reduced.

Table 4. Nitrogen Loads within each Town and within each watershed zone

Location	Lawn Size (ft ²)	Application Rate lbsN/1000ft ²	% Leach Rate	Predicted # appl/yr	Observed # appl/yr	Predicted lbsN to Groundwater/year	Observed lbsN to Groundwater/year	% Reduction
Falmouth	5000	0.75	0.2	4	1.11	3	0.83	72%
Mashpee	5000	0.75	0.2	4	0.98	3	0.74	76%
Barnstable	5000	0.75	0.2	4	1.77	3	1.33	56%
Coastal	5000	0.75	0.2	4	1.38	3	1	66%
Pond	5000	0.75	0.2	4	1.05	3	0.79	74%
Inland	5000	0.75	0.2	4	1.46	3	1.1	64%

Taken as a whole, the data generated as a result of this study regarding the number of residents applying fertilizer illustrates that residential fertilizer use is less than historically projected in nitrogen loading studies. This is the “message” that can be drawn from this study in terms of research application. The actual data may be applied to other towns that possess similar conditions, such as soil type and geography. However, this message can be applied almost anywhere there is concern regarding nitrogen loading. In addition, a further outcome of this data is the finding of an overall reduction in the contribution of fertilizers when considering all major sources of nitrogen to the total annual load to watersheds.

The average number of applications per household per year was derived from data collected during on-site personal interviews. Residents were first asked whether or not they currently applied fertilizer to their lawn. If the reply was affirmative, residents were then asked how many times fertilizer was applied each year. It was assumed in this study

that the respondent was knowledgeable regarding household fertilizer use, and there were few instances in the course of presenting the questionnaires where the respondent was unsure of the exact number of fertilizer applications for that household. Because of the rarity of uncertain responses, the reliability of the responses was not questioned or analyzed in this study. However, there does exist a vulnerability in the accuracy of the responses regarding fertilizer application because of the possibility of uncertain responses. Future fertilizer studies should consider refining the survey questions regarding the number of fertilizer applications by requiring that the resident actually applying (or not applying) fertilizer be the sole respondent to these questions.

Percentage of Use by Town and Location

Lawn fertilizer use was analyzed not only by considering the sample population as a whole, but also by considering use among distinct groups of residents. When analyzed by town and by location, the data demonstrated that, within the population sampled, it appears that fertilizer use was highest among residents in Barnstable and highest among residents in inland locations. While this data may be specific to these towns and these locations, it illustrates the possibility that fertilizer use differs geographically. Further study would be required to determine if these differences are a result of socio-economic factors or environmental factors, or both.

Average Lawn Size

This study attempted to determine average lawn size of residents in study area by visually assessing each individual lawn as part of the survey process. However, after

considering the uncertainties of this method of data collection, it was concluded that the data collected regarding lawn size lacked robustness, and therefore was not incorporated into the final load model. However, preliminary statistical tests were conducted to determine if there was a difference in lawn size between towns and locations for those residents who applied fertilizer at least once a year. Although the test result values may not be robust, they did put forward the possibility of a relationship between lawn size and fertilizer use. This possibility should be included for consideration in future surveys regarding fertilizer use.

Because of the lack of accuracy in determining house size, data collected for this parameter was not included in this study. However, the investigation of possible relationships between fertilizer use and house size should be undertaken in future studies, as well as the investigation of possible relationships between lawn size, house size, and fertilizer use.

In order to undertake the investigation of relationships between parameters, accurate measures of house size, lawn size, and lot size should be undertaken. There are a number of ways to obtain accurate measurement figures: GIS-plotted maps, aerial photographs, and land survey data found in most town records are just a few ways to insure accuracy of measurement. This would result in a refinement in the data and an increase in the robustness of analysis results. Future studies concerned with nitrogen loading should incorporate data from one or all of these measurement methods for lawn size, lot size, and house size.

Secondary Parameters Discussion

Commercial Applications

Residents who choose to apply fertilizer to their lawn have the option of applying it themselves or hiring a professional lawn care company to apply it. As part of the on-site interviews, those residents whose lawns were fertilized were asked if they hired a commercial company to apply it or if they applied it themselves. This parameter is important in the determination of residential fertilizer contribution to groundwater because commercial applications may have an impact on the average number of applications per household per year. Commercial lawn care companies may fertilize a residential lawn more than four times a year, or they may apply fertilizer less than four times a year. For the purposes of this study, it was assumed that professional landscape companies applied fertilizer four times a year. These companies were not included in the survey process in this study due to the lack of cooperation, so no accurate data was collected regarding the number of fertilizer applications each company carried out per household. This uncertainty may result in a lack of confidence in the assumption of four applications per household per year. In order to accurately determine the number times commercial companies apply fertilizer per household, these companies should be surveyed by presenting them with a questionnaire regarding their lawn fertilizer practices. By doing so, the data will reveal if these companies fertilize more often or less often than what is assumed.

House Age

House age data was collected as part of the on-site resident interviews.

Although a large number of residents responded, an incomplete data set was the final result due to the small number of accurate responses. Many residents were uncertain of the exact age of their house, and responded to the best of their knowledge. No statistical analyses were conducted utilizing house size data due to time constraints. This data was collected with the intent of establishing a database of information concerning residential fertilizer use. It may also be included in future studies, where it may be incorporated or expanded on.

Seasonality

The question of whether a resident lived on the Cape year-round or part-time was relevant to this study because Cape Cod is experiencing a building boom, not only in new housing construction but in the conversion of summer homes to year-round homes as well. Seventy-five percent of those residents surveyed lived on the Cape year-round, and almost half of these residents applied fertilizer. At the same time, thirty-seven percent of seasonal residents applied fertilizer to their lawns. Based on the sample surveyed, it appears that year-round residential fertilizer use is higher than the frequency of fertilizer application by seasonal residents. In order to produce this proportional comparison, it was necessary to qualify these results by stating the margin of error contained in the surveys. Calculation of this error margin was based on the most current number of single-family households within each town. The following are the margins of error for

each town: Falmouth: +/- 9.8% at a 95% confidence interval; Mashpee: +/- 9.2% at a 95% confidence interval; and Barnstable: +/-10.0% at a 95% confidence interval.

As the Cape becomes the destination for a growing population of year-round residents, a corresponding increase in fertilizer use may magnify the amount of nitrogen from residential fertilizers reaching groundwater. Research regarding this possibility is critical in the development of build-out models and in the projection of future ecological impacts from sources of nitrogen to embayment waters.

Housing Density

Housing density was a parameter that was measured as part of the visual assessment surveys. Most of the lots surveyed were situated in areas where housing density was 2-4 housing units per acre. Because of this constancy, no statistical analyses were conducted using this data.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The primary focus of this study was to attempt to determine the contribution of lawn fertilizer to the nitrogen load to groundwater within the study area. The final outcome of the research was that the observed mass load of nitrogen to groundwater per household per year was significantly less than the mass load figure currently utilized in nitrogen loading studies. However, because the possibility of uncertainty exists within the data sets for particular parameters, there remains an uncertainty in the preciseness of the observed mass nitrogen load figure.

A number of assumptions were made in this study that regarding the parameters involved in the nitrogen load model. Some were inherent in the questions presented to residents as part of the on-site personal interviews. Others, such as leach rate and attenuation, were accepted based on literature review and lack of site-specific data.

A number of assumptions were made by the researcher regarding the responses of the residents to the on-site personal interview questions. For example, it was assumed that residents applied fertilizer according to the size of their lawn. In this study, it was found that most residents applied fertilizer according to instructions printed on the bag of the brand of fertilizer that was being applied. These instructions provide applications rates per square feet of lawn. Inherent in these instructions is the assumption, which is the same assumption used in this study, that the resident applying the fertilizer can accurately assess the size of his or her lawn. The weakness of this assumption is that the resident may miscalculate the size of his or her lawn, which may lead to the application

of too much or too little fertilizer. Therefore, there exists the prospect of an inaccurate measurement of the amount of nitrogen from fertilizer used per application per household¹.

In order to minimize the risks of this assumption, or to eliminate it altogether, it is recommended that the question of amount of fertilizer used per application be refined to increase accuracy. This may be accomplished by comparing the resident's response to the survey question of lawn size to the application rates recommended by the specified brand of fertilizer used by the resident. This would result in a more exact measurement of the amount of fertilizer actually being applied by each homeowner. In this case, although the response to the question of lawn size may not be accurate in itself, it is the perceived lawn size held by the respondent that is the important parameter. This comparison may act to verify the actual amount of fertilizer per application for each household, and consequently refine not only the questionnaire presented to residents, but also the database collected as part of the survey.

Two assumptions were made in this study regarding the number of applications per household per year. The first assumption was that the resident responding to the personal survey question of the number of lawn fertilizer applications per year was knowledgeable in this regard. The possibility exists that this was not always the case, as not all respondents applied the fertilizer themselves. However, the researcher was confident that the responses regarding this question were accurate.

¹ Most applications of fertilizer utilize applicators which require the user to apply settings on the applicator which will release the fertilizer in accordance with the manufacturer's recommendations. Over time the homeowner is likely to learn how large his or her lawn is and purchase the proper number of fertilizer bags to accomplish the goal of applying the fertilizer.

In order to minimize the inaccuracy of this assumption, or to eliminate it, it is recommended that the question regarding the number of applications per year, as part of the on-site resident interviews, be refined so that is directed only to the resident responsible for the application of lawn fertilizer.

One other assumption was made concerning the number of applications made by professional lawn care companies of four times per year. The possibility exists that this may not always be true. The weakness of this assumption is that lawn care companies may apply fertilizer more or less than four times a year. As a result, the average number of applications per household per year may vary from what has been assumed. Therefore, in order to increase the accuracy of the data set for this parameter, and to eliminate this assumption, it is recommended that professional lawn care companies be interviewed as part of the lawn fertilizer use survey. Although this may require a large investment in time and resources, this method of data collection is important to ensure the accuracy of the database and the refinement of the survey.

The leach rate and attenuation rate used in this study were based on assumptions presented in current and past nitrogen load studies, as site-specific data was lacking. Undertaking site-specific research as part of future studies regarding nitrogen loading would increase the accuracy of these two parameters. The determination of leach rates and attenuation for a particular geographic area would require a large investment in time and resources, but would be essential to refine the specificity of the nitrogen load model.

A number of questions contained in the questionnaire presented to residents as part of the on-site personal surveys had the potential for inaccuracy, such as questions regarding lawn size, lot size, and house size and house age. The collection of such

parametric data in this way presumes that each resident interviewed has accurate knowledge of these measurements. It has been illustrated in this study that this method of data collection provides, at best, data that can be used as ranges rather than final figures. Because of this, alternate methods of measurement for these parameters were utilized in this study. It was found however, that these methods contained degree of inaccuracy that was not acceptable, and as a result, these data were not utilized. However, preliminary analysis between datasets collected for lawn size and fertilizer use revealed a possible relationship between the two parameters. It is recommended that these relationships be explored in future studies in order to substantiate this conclusion and provide greater accuracy. Accuracy would be enhanced by the use of reliable sources in the determination of individual household lawn size. It is recommended that, in order to determine accurate figures in the measurement of such parameters as lawn size, lot size, house size, and age of surveyed residences, dependable sources be utilized from which accurate information can be drawn. This includes GIS mapping, aerial photography, and assessors' maps and data. This would enable the refinement of the data collected and result in greater accuracy of the data collected. Other parametric relationships should be explored in future research endeavors, such as the average lawn size of those households that apply lawn fertilizer versus the average lawn size of those households that do not, lawn size versus house size, and lawn size versus lot size.

The assumptions regarding lawn fertilizer use and lawn size were variables in the parametric data involved in the nitrogen load model. Although the accuracy of these assumptions may have reduced the accuracy of the final load figure, they were a necessary part of this study in order to facilitate data collection and to stay within the

parameters set by access to available resources. It is not believed that their addition not minimized the overall result of the research. It is concluded that the contribution of nitrogen by fertilizers to the groundwater load is less than what had been previously thought. The exact difference may change as surveys and data are further refined and nitrogen load models are reworked. It is also acknowledged that final load figures will also vary among study areas. There is no doubt that as the number of surveys researching lawn fertilizer use increases, the degree of accuracy of the databases and the final figures will improve as well. This particular study has sought to answer a critical question regarding the contribution of nitrogen by fertilizer to the nitrogen load to Cape Cod embayments. In addition, it not only has served to act as a blueprint for future studies, but also presents further possibilities for research and brings to light a number of future questions that should be posed regarding lawn fertilizer use.

Secondary Conclusions and Recommendations

An additional outcome of this study was the accumulation of residential lawn fertilizer use data involving parameters that were not the primary focus of the research. These datasets may have an integral role in the establishment of a database of information concerning residential lawn fertilizer use.

Possible relationships between a number of parameters were illustrated in this study, revealing potential for further research. For example, the comparison of individual household lawn fertilizer use among the three geographic locations. Research revealed a significant difference in use between coastal, pond, and inland locations within the study area, as well as among each of the three towns. This conclusion is potentially important

as it presents to environmental managers and planners the possibility of micro-managing the input of nitrogen from fertilizers by focusing on specific areas where loads appear to be larger when compared to other areas. It also demonstrates a trend of use that may be integrated into build-out models and ecological scenario models. It is recommended that further research should explore possible socio-economic parameters within each location and within each town, such as resident income and age, to determine their effects on residential lawn fertilizer use.

Data collected for a number of secondary parameters were not analyzed in depth and consequently these datasets produced no significant numerical results. However, they should be considered for their contribution towards the refinement of future surveys. The inclusion of socio-economic parameters in the investigation of trends of use, such as resident age and occupation, is vital for the establishment of significant and accurate results and conclusions. An outcome of this study regarding these parameters was the conclusion that, in order to establish a reliable, adequate database, the population sample size for the on-site personal interviews should be expanded. Such an expansion would allow for uncertain or inaccurate responses from residents that could be eliminated without compromising the size of the database. Utilizing a variety of personal interview data collection methods in addition to on-site interviews is also recommended. These may include such things as phone interviews, interviews conducted during public events and at public venues such as garden centers, and questionnaires sent by mail. It is also recommended that the questionnaires require that responses be made only by the resident responsible for the application of household lawn fertilizer. This would eliminate a number of inherent assumptions and increase the accuracy and reliability of the data.

In conclusion, the research involved in this study produced a number of constructive outcomes; the primary one being that the contribution of lawn fertilizers to the nitrogen load to watersheds is less than previously thought. Secondly, this study clarified a number of refinements in the way the data was collected and in the survey design which is likely to improve future lawn fertilizer studies. And finally, this study demonstrated that there were a number of components involved that would require further research, such as trend analyses among parameters.

CHAPTER VIII

FINAL CONCLUSION

There is no denying that fertilizer use on Cape Cod should be of concern to scientists, planners, town managers, and residents when creating nitrogen loading models for the environmental management of coastal ponds and embayments. Fertilizers, septic systems, and surface runoff all contribute to the nitrogen load to watersheds and all have a potential role in the eutrophication of numerous Cape embayments. Historically, it has been generally accepted that of all these three major sources of nitrogen, fertilizers contributed considerably to the total annual load, and is second only to septic systems. Prior to this study, management strategies have focused on limiting fertilizer use among Cape Cod residents based on the assumption of a significant contribution by fertilizer to the load. Much time and money has been spent in an effort to educate the public about the deleterious impacts of fertilizer use on coastal waters. However, after analyzing the data collected in this study, it is clear that the contributions of fertilizer to the nutrient load to watersheds is significantly less than what has previously been thought. It is acknowledged that fertilizer use does have an impact on the environmental quality of coastal waters, and that irresponsible application is a practice that must be regulated. It is also critical that residents be made aware of the consequences of their actions regarding fertilizer use as well as the possible impacts resulting from such use. Education and common sense remain the best components of a management strategy to control fertilizer use, requiring minimal effort of residents while advocating shareholder responsibility. At the same time, there ought to be recognition and acknowledgement that household use of

fertilizers should not be considered a major source of nitrogen and therefore does not justify such a large investment of resources. The result of such a large reduction in fertilizer contribution should be a shift in the focus on nitrogen sources, either to one of the other two major contributors or to the investigation of “other” sources. Investment in management strategies should be refocused on and increased for septic systems and sewerage to wastewater treatment plants, for example. Denitrifying technology is currently being developed for septic systems, both individual and shared. In addition, the implementation of tertiary treatment, which promotes nitrogen removal from wastewater, has been pursued by numerous wastewater treatment plants. In addition, constructed wetlands have been and continue to be a successful method for removing nitrogen from wastewater. Some other options that should be considered are: rezoning or protecting sensitive areas, preserving land areas from development, specifying allowable future land uses, increasing the minimum size for new house lots, limiting new construction, creating natural buffer zones, and increasing embayment flushing by dredging, spur removal, etc.

The effective management of nitrogen inputs to embayments requires a regional watershed-embayment assessment approach, whereby load rates are determined for each source contributing nitrogen in an entire watershed, and an evaluation of ecological conditions is completed for the adjacent embayment. Existing and future load rates of nitrogen from the land surrounding an embayment can be calculated using worksheets that include standard load rates from nitrogen sources (BBP, 1992), with the end result being a total mass load determination of nitrogen into a particular embayment. The sensitivity or assimilative capacity of the embayment is necessary in order to determine the tolerance of the embayment to nitrogen inputs. Since each embayment has site-

specific flushing and watershed land uses, each embayment requires its own nitrogen management scheme adjusted to its tolerances (Howes and Goehring, 1997). Nitrogen loading rate limits are established based on these tolerance levels in order to prevent critical impacts to the ecological health of an embayment (Howes and Goehring, 1997). The load rates for each nitrogen source can effect the assessment of an embayment and as a result may over or underestimate the loads that a system can tolerate.

Build-out analyses, which estimate potential future growth and the resulting nitrogen inputs, also incorporate load rates for each nitrogen source, and it is essential that scientists have accurate and current data from which to extrapolate and “plug into” their nitrogen load models. Fertilizer use must be considered when generating these build-out models, and data from this survey will allow managers to establish a base of reference from which to analyze present fertilizer use and project future fertilizer use. This in turn will not only help remedy existing environmentally-detrimental conditions but will aid scientists in the construction of possible future ecological scenarios so that proactive mitigation and remediation can be introduced.

The growth trend for upper and mid-Cape towns is a shift from seasonal residents towards year-round residency. As year-round residency continues to climb in Cape communities, it follows that fertilizer use will climb as well, pushing the percentage of fertilizer use beyond the present 48%. Subsequently, this expansion in fertilizer use will amplify the contribution of fertilizer to the nitrogen load to watersheds and ultimately to Cape Cod embayments. This data trend can be employed in the projection of potential nitrogen loading models and build-out scenarios and may help determine the scope of future impacts of nitrogen on the ecology of the receiving waters. Thus it is critical that

nitrogen management plans regarding residential fertilizer consider residency and other socio-economic variables in these estimates.

By facilitating the minimization of assumptions and concurrently providing real, hard data, this fertilizer use study may provide the foundation for an accurate nitrogen load database and load model which environmental planners and managers can utilize in their development of watershed management strategies. By establishing an acceptable, communal model, the appropriate focus can be concentrated on the most critically impacted areas, utilizing environmental policies that compliment each other at all levels of management.

The methods utilized in the assessment of nitrogen inputs to embayments and the impacts of these inputs on the ecological health of these estuarine ecosystems have been evolving at a steady pace. It seems that advancements and investments in nitrogen management research accelerate as the degeneration of environmental conditions accelerate. However, recent developments in the application of nitrogen management methodologies have been created with the potential to outpace the rate of degeneration and thus facilitate the movement of a more proactive approach to nitrogen management.

One such example of this is the Massachusetts Estuaries Project, a collaborative effort between MA. DEP and the School of Marine Science and Technology (SMAST) at the University of Massachusetts in Dartmouth. Also involved is the USEPA, EOEA, the Cape Cod Commission, and numerous coastal communities. The Estuaries Project was created to “provide technical guidance to DEP in support of policies regarding nitrogen loading to embayments and to determine TMDLs (Total Maximum Daily Loads) (MA. Estuaries Project, 2003). In a paper focusing on nitrogen management, it was

recommended by the Buzzards Bay Project (1992) that, “to supplement local efforts, MADEP could regulate cumulative impacts of nitrogen from non-point sources by developing nitrogen-specific criteria for state water quality standards. To achieve this objective, it will be necessary for DEP to amend the Water Quality Standards...to include embayment specific TMDLs from both point and non-point sources.” The Estuaries Project has both expanded and refined the nitrogen management models by incorporating a number of parameters that have historically been overlooked or over-generalized. These parameters include benthic regeneration, site-specific flushing rates, and attenuation, as well as an increase in ecological indicators for use in the determination of TMDLs. In conjunction with this expansion of the nitrogen loading database is an increase in the accuracy and efficiency of embayment evaluations and the development of more relevant nitrogen management plans. Precise source load data not only substantiates these end results, but also provides dependable figures for forecasting nitrogen loading from future growth. Further, these figures will allow environmental managers to create various load scenarios in order to determine the results of reducing nitrogen loading from one or more sources. Would it be more feasible, for example, to purchase land to act as buffer zone along a certain embayment rather than to limit growth in that area, both of which are viable options.

The ability to accurately determine nitrogen loads from fertilizers, septic systems, and runoff in these scenarios figures prominently in both the economic and environmental arenas. Public awareness, as well as scientific research and investments in nitrogen management, does not only lend itself to improving the ecological conditions of the coastal environment. Tourism, recreation, commercial fishing, retail, and industry all

benefit from clean and healthy waters as well. Cooperation between towns, citizens groups, environmental managers, stakeholders, and scientists will facilitate the process of developing water quality protection standards that address ecological concerns. Succinctly put, “Because of the changing land use patterns..., environmental management must be directed not only at current demands and problems, but also toward resolving accumulated impacts from the past and to anticipate future demands, which may either protect or harm coastal resources”(National Biological Service, 1996). Prioritizing the sources of nitrogen and accurately quantifying the contribution of nitrogen to coastal waters from these sources should be considered a major step in the process of ecological protection and pollution mitigation. Proper and effective environmental management demands accurate, relevant, and applicable information. A more precise measurement of household fertilizer use answers a number of questions and provides definitive information that will enable the design of effective environmental policy decisions.

APPENDIX A

ACRONYMS

BBP: Buzzards Bay Project

CCC: Cape Cod Commission

CCPEDC: Cape Cod Planning and Economic Development Commission

CPD: Coastal Programs Division

CWA: Clean Water Act

CZARA: Coastal Zone Act Reauthorization Amendments

CZM: Office of Coastal Zone Management

CZMP: Coastal Zone Management Program

DEP: Department of Environmental Protection

DIN: Dissolved Inorganic Nitrogen

EOEA: Executive Office of Environmental Affairs

EPA: Environmental Protection Agency

ISDS: Individual Sewage Disposal System

K: Potassium (Potash)

N: Nitrogen

N_{2g}: Nitrogen Gas

NH₄⁺: Ammonia

NO₂⁻: Nitrite

NO₃⁻: Nitrate

NOAA: National Oceanic and Atmospheric Administration

NPSP: Non-point Source Pollution

NWQAP: National Water Quality Assessment Program

OCRM: Office of Ocean and Coastal Resource Management

P: Phosphorous

RIDEM: Rhode Island Department of Environmental Management

SMAST: School of Marine Science and Technology

TMAL: Total Maximum Annual Limit

TMDL: Total Maximum Daily Load

USGS: United States Geological Survey

WHRC: Woods Hole Research Center

APPENDIX B-1

PARTICIPANT LETTER

The University of Rhode Island Department of Marine Affairs
Washburn Hall Kingston, R.I.
The Contribution of Fertilizer to the Nitrogen Loading of Cape Cod Embayments

Dear Participant:

You have been asked to take part in the research project described below. If you have any questions, please feel free to call Betsy White, the person mainly responsible for this study.

The purpose of this study is to determine the contribution of fertilizer to the nitrogen load entering Cape Cod bays. Responses to these items will be collected as answers to a questionnaire conducted anonymously. The names of the participants will not be solicited and addresses will be kept separate from the data sheets and used only to site the areas of survey.

YOU MUST BE AT LEAST 18 YEARS OLD to be in this research project.

If you decide to take part in this study, your participation will involve answering a questionnaire pertaining to your use of fertilizer for lawn care.

The possible risks or discomforts of the study are minimal.

Although there are no direct benefits of the study, your answers will help increase the knowledge regarding nitrogen management for Cape Cod towns.

Your part in this study is anonymous. That means that your answers to all questions are private. No one else can know if you participated in this study and no one else can find out what your answers were. Scientific reports will be based on group data and will not identify you or any individual as being in this project.

The decision to participate in this research project is up to you. You do not have to participate and you can refuse to answer any question. Participation in this study is not expected to be harmful or injurious to you. However, if this study causes you any injury, you should write or call Betsy White or Professor Niels West at the University of Rhode Island at (401) 874-2596.

If you have any more questions or concerns about this study, you may contact the University of Rhode Island's Vice Provost for Graduate Studies, Research and Outreach, 70 Lower College Road, Suite 2, URI, Kingston, **RI**, (401) 874-4328.

You are at least 18 years old. You have read the consent form and your questions have been answered to your satisfaction. Your filling out the survey implies your consent to participate in this study. Thank you.

Betsy White

APPENDIX B-2

FERTILIZER USE QUESTIONNAIRE

Hi. I'm doing my graduate thesis on watershed management and I am censusing the neighborhood for information. I was wondering if you had a few minutes to answer some questions? All answers will be kept anonymous and confidential.

My name is Betsy White and I'm a graduate student in the department of Marine Affairs at the University of Rhode Island. For my thesis, I am studying the contribution of nutrients, specifically fertilizer, to Cape Cod embayments. Fertilizers are the least well-known contributor to these embayments, yet many towns on the Cape are basing management plans on data that may be incorrect or incomplete. I hope to provide more accurate data so that more comprehensive management plans can be developed.

I would like to ask you twenty-three questions, which should only take about 5 minutes of your time.

1. Do you maintain this house or does someone else? **Myself** **Someone else**
2. How long have you lived on the Cape? _____ In this House? _____
3. How old is this house? _____ **years old**
4. Are you a seasonal or year-round resident? **Seasonal** **Year-round**
5. What is your occupation? _____
6. Could you tell me if you have a college or post-college degree? **Yes** **No**
7. What is your age? (**circle one**) **20-35** **36-50** **51-65** **66-older**
8. Is fertilizer applied to your lawn? **Yes** **No**
9. Is it applied by you or a commercial company? **Myself** **Company**
10. If it is applied commercially, which company do you use? _____
11. If you apply it, where do you generally purchase the fertilizer? (**circle one**)
lawn and garden center such as Mahoney's or Agway, a **hardware store**, such as True Value, or a **large retail store** such as Sears, Wal-Mart, or BJ's?
12. What type of fertilizer do you use? **Liquid** **Solid**
13. When do you buy the fertilizer? (**circle all that apply**)
Spring **Summer** **Fall** **Winter**
14. How often is fertilizer applied? _____ **times per year**
15. Which time(s) of the year is it applied? (**circle all that apply**)
Early Spring **Late Spring** **Early Summer** **Late Summer** **Fall**

16. How much fertilizer is used per application? _____
17. How often do you water your lawn? _____
18. Do you water immediately after applying fertilizer? **Yes No**
19. Do you water immediately before applying fertilizer? **Yes No**
20. Have you used more, less, or the same amount of fertilizer in the past 5 years?
More Less Same (circle one)
21. If this study shows that fertilizer is a major contributor to the nutrient load of Cape embayments, would this alter your current use of fertilizer? **Yes No**
22. On a scale of one to five, how much would you be willing to change your use of fertilizer, with 1 being no changes and 5 being total change? **(circle one)**
1 2 3 4 5
23. Do you know what watershed your house is in? (and which embayment this watershed feeds into?)

Thank you very much and I appreciate the time you have taken to help me gather data for my thesis.

NOTES:

APPENDIX B-3

PHYSICAL DATA SURVEY

DATE:

TIME:

SITE ID:

HOUSE SIZE (SQ FT):

NUMBER OF BEDROOMS:

LAWN SIZE (SQ FT):

GARDEN SIZE (SQ FT):

LOT SIZE (SQ FT):

% OF LAWN VS. COVER:

HOUSING DENSITY: A.) High:> 10 housing units/acre B.) 5-10 hu/acre
C.) 2-4 hu/acre D.) 0-1 hu/acre E.) Low: estate or rural

PROXIMITY TO BAY (miles):

IF COASTAL:

ON WATER OR WATER VIEW?:

DEEDED BEACH RIGHTS?: Y N

LOT DESCRIPTION (trees, topography, site location, etc.):

NOTES:

APPENDIX B-4

RAPID PHYSICAL DATA SURVEY

DATE: SITE ID:
ADDRESS:
PROXIMITY:

HOUSE SIZE: LOT SIZE: LAWN SIZE:

% LAWN VS. COVER: HOUSING DENSITY:

LOT DESCRIPTION:

DATE: SITE ID:
ADDRESS:
PROXIMITY:

HOUSE SIZE: LOT SIZE: LAWN SIZE:

% LAWN VS. COVER: HOUSING DENSITY:

LOT DESCRIPTION:

DATE: SITE ID:
ADDRESS:
PROXIMITY:

HOUSE SIZE: LOT SIZE: LAWN SIZE:

% LAWN VS. COVER: HOUSING DENSITY:

LOT DESCRIPTION:

DATE: SITE ID:
ADDRESS:
PROXIMITY:

HOUSE SIZE: LOT SIZE: LAWN SIZE:

% LAWN VS. COVER: HOUSING DENSITY:

LOT DESCRIPTION:

APPENDIX C-1

Typical Brands of Fertilizer and Application Rates

Brand	Type	Ratio N-P-K	Suggested Application Rate lbN/1000ft²/appl.
<i>Scott's</i>	Turf Builder	29-3-4	0.9
	Turf Builder with Plus 2 Weed Control	28-3-3	0.8
	Turf Builder Summer Guard	28-3-8	0.7
	Starter	20-27-5	0.7
<i>Vigaro</i>	Starter	20-27-5	0.7
	Ultra Starter	20-27-5	0.7
	Ultra Turf	29-3-4	0.9
	Ultra Turf Weed + Feed	28-3-3	0.9
<i>Lesco</i>	Weed and Feed	18-2-9	0.8
	Professional Turf	24-5-11	1
	Professional Landscape and Ornamental	12-12-12	0.5
	Summer/Winter	18-2-18	0.8
<i>Springer</i>	Lawn Restore	10-2-6	1
<i>Milorganite</i>	Organic	6-2-0	1
<i>Gro Green</i>	Triple Ten	10-10-10	1
	Gro-Organic	6-2-0	0.8

APPENDIX C-2

Number of Fertilizer Applications per Year: Personal Interviews

Town/Location	0 Appl/Year	1 Appl/Year	2 Appl/Year	3 Appl/Year	4 Appl/Year	N
<i>Falmouth</i>	63	8	13	0	21	105
<i>Mashpee</i>	78	5	21	1	13	118
<i>Barnstable</i>	33	9	20	4	34	100
<i>Coastal</i>	68	9	8	0	33	118
<i>Pond</i>	70	4	23	3	12	112
<i>Inland</i>	36	9	23	2	23	93
<i>Total</i>	174	22	54	5	68	323

APPENDIX C-3

Weighted Mean Survey Data

Town/Location	Type of Survey	0	1	2	3	4	Total # Households
3-Town Total	On-Site Interview	174	22	54	5	68	323
	Rapid Visual Assessment	1041	NA	NA	NA	NA	2004
	Total (Interview + RVA)	1215	NA	NA	NA	NA	2327
	Adjusted On-Site Interview¹	168.6	22.7	55.7	5.2	70.2	322.4
Falmouth	On-Site Interview	63	8	13	0	21	105
	Rapid Visual Assessment	420	NA	NA	NA	NA	690
	Total (Interview + RVA)	483	NA	NA	NA	NA	795
	Adjusted On-Site Interview¹	63.8	7.9	12.8	0	20.7	105.3
Mashpee	On-Site Interview	78	5	21	1	13	118
	Rapid Visual Assessment	380	NA	NA	NA	NA	667
	Total (Interview + RVA)	458	NA	NA	NA	NA	785
	Adjusted On-Site Interview¹	68.8	5.7	23.8	1.1	14.7	114.2
Barnstable	On-Site Interview	33	9	20	4	34	100
	Rapid Visual Assessment	241	NA	NA	NA	NA	647
	Total (Interview + RVA)	274	NA	NA	NA	NA	747
	Adjusted On-Site Interview¹	36.7	8.1	18.0	3.6	30.6	97
Coastal	On-Site Interview	68	9	8	0	33	118
	Rapid Visual Assessment	371	NA	NA	NA	NA	669
	Total (Interview + RVA)	439	NA	NA	NA	NA	787
	Adjusted On-Site Interview¹	65.8	9.3	8.3	0	34.1	117.5
Pond	On-Site Interview	70	4	23	3	12	112
	Rapid Visual Assessment	379	NA	NA	NA	NA	676
	Total (Interview + RVA)	449	NA	NA	NA	NA	788
	Adjusted On-Site Interview¹	63.8	4.4	25.2	3.3	13.2	109.9
Inland	On-Site Interview	36	9	23	2	23	93
	Rapid Visual Assessment	291	NA	NA	NA	NA	659
	Total (Interview + RVA)	327	NA	NA	NA	NA	752
	Adjusted On-Site Interview¹	40.4	8.0	20.5	1.8	20.5	91.2

APPENDIX D-1

Chi Square Test of Contingency Statistical Analysis: Lawn Fertilizer Use Comparisons Between Towns Lawn Fertilizer Use Comparisons Between Locations

Data Collected

Town/Location	Yes Fertilizer Use	No Fertilizer Use	Total
Falmouth	312	483	795
Mashpee	327	458	785
Barnstable	473	274	747
Coastal	348	439	787
Pond	339	449	788
Inland	425	327	752
Total	1112	1215	2327

Statistical Test Results

Test	Power	χ^2	P value
Falmouth v. Mashpee v. Barnstable	1.000	107.31	<0.001
Falmouth v. Barnstable	1.000	88.355	<0.001
Falmouth v. Mashpee	0.141	0.856	0.355
Mashpee v. Barnstable	1.000	71.132	<0.001
Coastal v. Pond v. Inland	1.000	34.157	<0.001
Coastal v. Inland	0.999	22.773	<0.001
Coastal v. Pond	0.067	0.184	0.668
Pond v. Inland	1.000	27.498	<0.001

Power: Depicts test robustness

χ^2 : Chi Square value

P value: Level of Significance

APPENDIX D-2

Small-Sample t Test Statistical Analysis:
Observed Average Number of Fertilizer Applications per Household per Year Compared
to Projected Average Number of Fertilizer Applications per Household per Year
Statistical Test Results

N	t Test value	Level of Significance (P)	Critical Value
323	29.7	0.05	1.645

Student t Test Statistical Analysis
Lawn Size Comparison Among Residents Applying Fertilizer

Sample Groups	N	Confidence Level (p)	Critical Value (α)	t Observed
Falmouth v. Mashpee	312	0.05	1.960	3.21
Falmouth v. Barnstable	327	0.05	1.960	1.96
Mashpee v. Barnstable	473	0.05	1.960	4.7
Coastal v. Pond	348	0.05	1.960	3.65
Coastal v. Inland	339	0.05	1.960	3.84
Pond v. Inland	425	0.05	1.960	0*

* $\xi_1 = \xi_2$

BIBLIOGRAPHY

- AllAboutLawns.com. 2000. All About Lawns. <http://www.allaboutlawns.com/fertilizing.htm> March 25, 2001.
- Anderson, Donald M., Patricia M. Gilbert, and JoAnn M. Burkholder. August 2002. Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition, and Consequences. Estuaries. Vol.25, no. 4b. p.704-726.
- Ashumet Plume Citizens Committee. 2001. Ashumet Nitrogen Plume Offset Program.
- BarnstableCapeCod.com.1991. <http://www.barnstablecapecod.com/demographics.htm> April 9, 2001.
- Behnke, J. 1975. A Summary of the Biogeochemistry of Nitrogen Compounds in Groundwater. Journal of Hydrology. 27:155-167.
- Bolcourt, William C. 1993. Estuaries-Where the River Meets the Sea. Oceanus. Vol.36, N.2: 29-37.
- Breitburg, D.L., T. Loher, C.A. Pagey, and A. Gerstein. 1997. Varying Effects of Low Dissolved Oxygen on Trophic Interactions in an Estuarine Food Web. Ecological Monographs 67: 489-507.
- Brown, K.W., J. C. Thomas, and R.L. Duble. 1982. Nitrogen Source Effect on Nitrate and Ammonium Leaching and Runoff Losses From Greens. Journal of Agronomy 74: 947-950.
- Buzzards Bay Project. 1987. Buzzards Bay Comprehensive Conservation and Management Plan. U.S. Environmental Protection Agency and Massachusetts Executive Office of Environmental Affairs. Marion, MA.
- Buzzards Bay Project. 1991. Buzzards Bay Comprehensive Conservation and Management Plan Volume I: Management Recommendations and Action Plans. U.S. Environmental Protection Agency and Massachusetts Executive Office of Environmental Affairs. Marion, MA.
- Buzzards Bay Project. 1992. Managing Nitrogen to Sensitive Embayments. Fact sheet.
- Cambareri, T.C., E. Eichner, C.A. Griffith. April,1993. Hydrogeologic Evaluation for the Waquoit Bay Land Margin Ecosystem Research Project. Draft Final Report. Cape Cod Commission, Barnstable, MA.
- Cape Cod Commission. 1998a. Cape Trends. Fifth Edition. Barnstable, MA.

- Cape Cod Commission. 1998b. Cape Cod Land Statistics by Town, 10/7/98. <http://www.capecodcommission.org.html>. March 25, 2001.
- Cape Cod Commission/Water Resources Office. 1998. Cape Cod Coastal Embayment Project. Interim Final Report. Barnstable, MA.
- Capone, D.G., and M.F. Bautista. 1985. A Groundwater Source of Nitrate In Nearshore Marine Sediments. *Nature*. 313: 365-373.
- Chesapeake Bay Program. 1995. The State of Chesapeake Bay. Washington, D.C.: U.S. Government Printing Office.
- Cochran, Kellie M. 1998. Coastal Nonpoint Source Pollution Awareness and Behavior: Considering Socio-Economic Attributes In Environmental Education Program Development. Masters of Arts Thesis. Marine Affairs Program, University of Rhode Island. Kingston.
- Costa, J.E., B.L.Howes, and E. Gunn. 1996. Report of the Buzzards Bay Citizens' Water Quality Monitoring Program 1992-1995. Coalition for Buzzards Bay, P.O. Box 268, Buzzards Bay, Ma. 67pp.
- Costa, Joseph E., B. Howes, D. Janik, D. Aubrey, E. Gunn, A.E. Giblin. 1999. Managing Anthropogenic Nitrogen Inputs To Coastal Embayments: Technical Basis and Evaluation of Management Strategy Adopted For Buzzards Bay. Buzzards Bay Technical Report.
- Culliton, Thomas J., M.A. Warren. 1989. 50 Years of Population Change Along the Nation's Coasts, 1960-2010. NOAA National Ocean Service. Rockville, MD.
- Culliton, Thomas J., John J. McDonough III, Davida G. Remer, and David M. Lott. 1992. Building Along America's Coasts: 20 Years Of Building Permits 1970-1989. Office of Ocean Resources and Assessment, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. Rockville, MD.
- Deegan, Linda A. August 2002. Lessons Learned: The Effects of Nutrient Enrichment on the Support of Neckton by Seagrass and Salt Marsh Ecosystems. *Estuaries*. Vol. 25, no. 4b. p. 727-742.
- De Simone, L.A., and Brian L. Howes. 1998. Nitrogen Transport and Transformations In A shallow Aquifer Receiving Wastewater Discharge: A Mass-Balance Approach. *Water Resources Research*.
- Devore, J. 1987. Probability and Statistics for Engineering and the Sciences. Second Edition. Brooks/Cole Publishing Company, Belmont, CA.

Diaz, R.J and R. Rosenberg. 1995. Marine Benthic Hypoxia: A Review of the Ecological Effects and Behavioral Responses of Benthic Macrofauna. *Oceanography and Marine Biology: An Annual Review* 33: 245-303.

Eichner, E.M., K. Livingston, B. Smith, and V. Morrill. 1988. Pleasant Bay Nitrogen Loading Analysis. Final Report. Cape Cod Commission. Barnstable, MA.

Eichner, E.M., and T. Cambereri. 1992. Nitrogen Loading. Technical Bulletin #91-001. Water Resources Office, Cape Cod Commission. Barnstable. MA.

Environmental Protection Agency. 2001. Total Maximum Daily Load (TMDL) Program. Water Quality-Based Decision Guidance Report, Office of Water. Washington, D.C.

Ernst, L. 1996. Cumulative Impacts of Management Decisions On Nitrogen Loading. Master of Arts Thesis. Marine Affairs Program, University of Rhode Island. Kingston.

The Fertilizer Institute. 2001. Fertilizer: Fuel for Growing Plants. Washington, D.C.

Garden within Sight. 1998. <http://www.gardenwithinsight.com>. March 12, 2001.

Giblin, A.E., and A Gaines. 1990. Nitrogen Inputs To a Marine Embayment: The Importance of Groundwater. *Biogeochemistry* 10: 309-328.

Gold, A.J., W.R. DeRagon, W.M. Sullivan, and J.L. Lemunyon. 1990. Nitrate-Nitrogen Losses to Groundwater From Rural and suburban Land Uses. *Journal of Soil and Water Conservation* March-April: 305-310.

Howarth, Robert W., Andrew Sharpley, and Dan Walker. August 2002. Sources of Nutrient Pollution to Coastal Waters in the United States: Implications for Achieving Coastal Water Quality Goals. *Estuaries* Vol. 25, no.4b, p.656-676.

Horsley and Witten Hegeman, Inc. 1991. Quantification and Control of Nitrogen Inputs to Buttermilk Bay. Volume I. Buzzards Bay Project Technical Report. January. Barnstable, MA.

Howes, Brian L. and Dale D. Goehringer. 1996. Nitrogen Inputs to Buzzards Bay and Management Considerations. *Environment Cape Cod* Vol. 1, N. 1.

Howes, Brian L., and George Hampson. 2002. Water Quality and Habitat Health of the Three Bays Estuarine System. Progress Report From the 1999 Field Season. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA.

Howes, Brian L., George Hampson, and Betsy White. 2001. Watershed Nitrogen Management and Water Quality of Barnstable's Coastal Embayments. Proposal to the

Town of Barnstable. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA.

IEP, Inc. 1988. Yarmouth Report. Water Resources Protection Study. Town of Yarmouth, MA. Sandwich, MA.

Jaworski, N.A., R.A. Howarth, and L. J. Hetling. 1997. Atmospheric Deposition of Nitrogen Oxides Onto the Landscape Contributes to the Coastal Eutrophication In the Northeast United States. Environmental Science and Technology 31: 1995-2004.

Jewell, P. R. 1995. The National Estuaries Program's Watershed Protection Approach: An Analysis of Local Governments, Constituency Organizations, and Watershed Residents In Addressing Nonpoint Source Pollution in the Buzzards Bay Project. Master of Arts Thesis. Marine Affairs Program, University of Rhode Island. Kingston.

Johannes, R. E. 1980. The Ecological Significance of Submarine Groundwater Discharge of Groundwater. Marine Ecologic Prog. Ser. 3: 365-373.

Jones, C., and J. Jacobson. 2001. Nitrogen Cycling, Testing and Fertilizer Recommendations. Montana State University Extension Service Nutrient Management Program.

Koppleman, L. 1978. The Long Island Comprehensive Water Treatment Management Plan. Nassau-Suffolk Regional Planning Board. Hauppauge, N.Y.

Kranzer, J. H. 2003. Statistics for the Terrified Third Edition. Prentice Hall. New Jersey.

Massachusetts Executive Office of Environmental Affairs. 1996. MassGIS Database.

Massachusetts Office of Coastal Zone Management. 1994. The Coastal Nonpoint Pollution Control Program in Massachusetts. Boston, MA.

National Biological Service. September, 1996. U.S. Department of the Interior. Biological Report 31. Ecology of Buzzards Bay; An Estuarine Profile. Washington, D.C.

National Oceanic and Atmospheric Administration/Environmental Protection Agency. 1988. Strategic Assessment of Near Coastal Waters. Northeast Case Study. NOAA/EPA Team on Near Coast Waters. Washington, D.C.

Nixon, S.W. 1995. Coastal Marine eutrophication: A definition, Social Causes, and Future Concerns. Ophelia 41: 199-219.

Nixon, Scott W. 1993. Nutrients and Coastal Waters-Too Much of a Good Thing? Oceanus Vol. 36, N. 2: 38-47.

Nixon, S.W. 1990. Quantifying the Relationship Between Nitrogen Input and the Productivity of Marine Ecosystems. In: Ecological Management of the Marine Environment: Proceedings of the Eighth Marine Technology Symposium. Tokyo, Japan.

Nixon, S. W., B.N. Furnas, R. Chinman, S. Granger, and S. Hefferman. Nutrient Inputs to Rhode Island Coastal Lagoons and Salt Ponds. Final Report to Rhode Island Statewide Planning. Graduate School of Oceanography, University of Rhode Island. Kingston.

Nixon, S.W. 1995. Coastal Marine Eutrophication: A Definition, Social Causes, and Future Concerns. *Ophelia* 41: 199-219.

Nixon, S.W. and M. Q. Pilson. 1983. Nitrogen in Estuarine and Coastal Marine Ecosystems. In Nitrogen in the Marine Environment. Carpenter, E.J. and D.G. Capone, ed. Academic Press.

Northeast Organic Farming Associations of Connecticut and Massachusetts. 2002. Organic Land Care. Informational Pamphlet.

Office of Coastal Zone Management. 2002. Celebrating 30 Years of the Coastal Zone Management Act. National Ocean Service, National Oceanic and Atmospheric Administration. Washington, DC.

Paerl, Hans W., Robin L. Dennis, and David R. Whitall. August 2002. Atmospheric Deposition of Nitrogen: Implications for Nutrient Over-enrichment of Coastal Waters. Estuaries. Vol. 25, no. 4b. p.677-693.

Peckol, P. and J.S. Rviers. 1996. Contribution of Macroalgal Mats to Primary Production of a Shallow Embayment Under High and Low Nitrogen-Loading Rates. Estuarine, Coastal, and Shelf Science 43: 311-325.

Persky, J.H. 1986. The Relation of Groundwater Quality to Housing Density, Cape Cod, Massachusetts. United States Geological Survey, Water Resources Investigation Report 86-4093. Washington, D.C.

Peterson, G. 2001. Scientists Pinpoint Nitrogen Source. The Falmouth Enterprise. Falmouth, MA.

Petrovic, A.M. 1989. Golf Course Management and Nitrates in Groundwater. Golf Course Management, September: 54-64.

Puckett, L.J. 2000. Nonpoint and Point Sources of Nitrogen In Major Watersheds of the United States. Water Resources Investigations Report 94-4001. United States Geological Survey, National Water Quality Assessment Program.

Rainer, S.F. and R.C. Fitzhardinge. 1981. Benthic Communities in an Estuary With Periodic Deoxygenation. Australian Journal of Marine and Freshwater Research 32:227-243.

Ramsey, J.S., S. Kelley, and B.L. Howes. 2000. Water Quality analysis of Great, Green, and Bournes Ponds, Falmouth, MA. Report to the Town of Falmouth.

Rhode Island Department of Environmental Management. July, 1995. Rhode Island's Coastal Nonpoint Pollution Control Program. Providence, R.I.: R. I. Department of Environmental Management, Coastal Resource Management Council. Department of Administration Division of Planning.

Roman, C.T., N. Jaworski, F.T. Short, S. Findlay, R.S. Warren. 2000. Estuaries of the Northeastern United States: Habitat and Land Use In Signatures. Estuaries, Vol. 23, Number 6: 743-764.

Ryther, John H., and W.M. Dustan. 1971. Nitrogen, Phosphorous and Eutrophication in the Coastal Marine Environment. Science Vol. 171: 1008-1013.

Schueler, T. R. 1994. Homeowner Survey Reveals Lawn Management Practices In Virginia. Watershed Protection Techniques 1: 85-86.

South Jersey RC&D Council, Inc. 2000. Nonpoint Pollution Prevention-Homeowner. Public Announcement Handout.

Stone, T.A. 1998. The Land Cover and Land Use of Cape Cod, 1951-1990. Environmental Cape Cod_Vol. 1, No. 4.

Strahler, Arthur N. 1966. A Geologist's View of Cape Cod. The Natural History Press. Garden City, New York.

Suffolk County Department of Environmental Control (SCDEC). 1974. Twelve Pines Study. Medford, New York.

The Massachusetts Estuaries Project. 2003. Embayment Restoration and Guidance for Implementation Strategies. MA. Department of Environmental Protection. Boston.

The Woods Hole Research Center. 2001. Cape Cod Atlas-Current Landcover. Falmouth, Ma.

Thorne-Miller, B., M.M. Harlin, G.B. Thursby, M.M. Brady-Campbell, and B.A. Dworetzky. 1983. Variations on the distribution and Biomass of submerged Macrophytes in Five Coastal Lagoons in Rhode Island, U.S.A.. Botanica Marina 26: 231-242.

United States Department of Commerce and U.S. Environmental Protection Agency. 1993. Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance. USEPA Publication #EPA-841-93-003. Washington, D.C.

United States Environmental Protection Agency. 1995. Watershed Protection: A Project Focus. Publication # EPA-841-R-95-003. Office of Water. Washington, D.C.

United States Environmental Protection Agency. 2002. Polluted runoff (Nonpoint Source Pollution)-Clean Water Act Section 319. Office of Wetlands, Oceans, and Watersheds. Washington, DC.

United States Environmental Protection Agency. 2002. A. Polluted Runoff (Nonpoint Source Pollution)-Coastal Zone Act Reauthorization Amendments Section 6217. Office of Wetlands, Oceans, and Watersheds. Washington, DC.

United States Environmental Protection Agency. 2003. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. Office of Wetlands, Oceans, and Watersheds. Washington, DC.

United States Geological Survey. 2000. Nonpoint and Point Sources of Nitrogen In Major Watersheds of the United States. Water Resources Investigations Report 94-4001. National Water Quality Assessment Program.

United States Geological Survey. 2001. Geologic History of Cape Cod, Massachusetts. United States department of the Interior.

United States Geological Survey. 2001.A. Cape Cod Drainage Basin-Bedrock Geology. United States Department of the Interior.

United States Geological Survey. 2002. Groundwater Atlas of the United States. HA 730-M Surficial Aquifer System. Cape Cod Glacial Aquifer Text.

Valiela, I. And J. E. Costa. 1988. Eutrophication of Buttermilk Bay, a Cape Cod Coastal Embayment: Concentration of Nutrients and Watershed Nutrient Budgets. Environmental Management 12: 539-553.

Valiela, I., C. D'Avanzo, J. Kremer, K. Lajtha, P. Peckol, C.H. Sham, and D. Aubrey. 1989. Coupling of Watershed and Coastal Waters: Waquoit Bay Land Margin Ecosystem Project. National Science Federation, U.S. Environmental Protection Agency, and NOAA.

Valiela, I., J. Costa, K. Foreman, J. Teal, B. Howes, and D. Aubrey. 1990. Transport of Groundwater-Borne Nutrients From Watersheds and Their Effects on Coastal Waters. Biogeochemistry 10: 177-197.

Valiela, I., K. Foreman, M. LaMontagne, D. Hersh, and J. Costa. 1992. Couplings of Watersheds and Coastal Waters: Sources and Consequences of Nutrient Enrichment In Waquoit Bay, Massachusetts. Estuaries 15: 443-447.

Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C.H. Sham. 1997. Nitrogen Loading From Coastal Watersheds to Receiving Estuaries: New Methods and Application. Ecological Applications 7: 358-380.

Valiela, I., M. Geist, J. McClelland, and G. Tomasky. 2000. Nitrogen Loading From Watersheds to Estuaries: Verification of the Waquoit Bay Loading Model. Biogeochemistry 49: 277-293.

Weiskel, P.K., and B.L. Howes. 1991. Quantifying Dissolved Nitrogen Flux Through a Coastal Watershed. Water Resources Research 27, NO. 11: 2929-2939.

Weiskel, P.K. and B.L. Howes. 1992. Differential Transport of Sewage-derived Nitrogen and Phosphorous Through a Coastal Watershed. Environ. Sci. Technol. 26: 352-360.

Williams, S. 2001. Fertilizers: The Basics. Department of Horticultural Science, Division of Extension and Community Relations and the Department of Horticultural Science. University of Saskatchewan, CDA.

World Resources Institute. 1994. World Resources 1994-95, A Guide to the Global Environment. In conjunction with the United Nations Environment Program and the United Nations Development Program. New York: Oxford University Press.