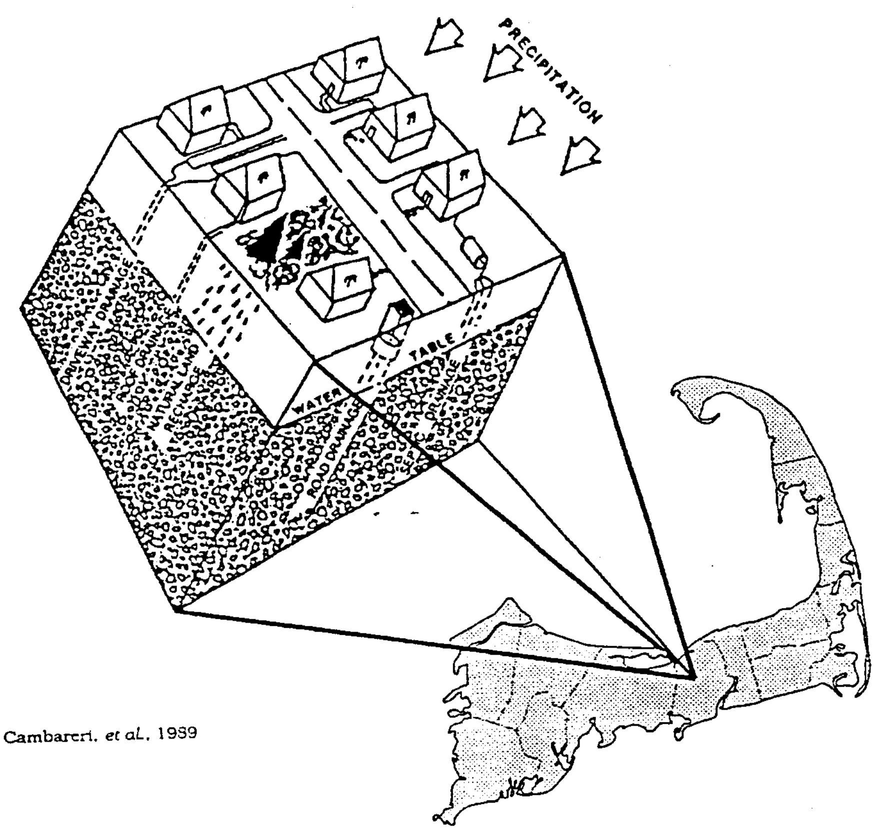
Technical Bulletin 91-001 (FINAL)

NITROGEN LOADING

April, 1992



From Cambareri, et al. 1989

Cape Cod Commission
Water Resources Office
3225 Main Street
P.O. Box 226
Barnstable, MA 02630
(508)362-3828

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Prepared by

Water Resources Office

Eduard M. Eichner
Water Resources Planner/Environmental Scientist
Thomas C. Cambareri
Water Resources Coordinator/Hydrogeologist

Armando J. Carbonell
Executive Director

Cape Cod Commission
3225 Main Street
P.O. Box 226
Barnstable, MA 02630
(508)362-3828

A. INTRODUCTION

The protection of groundwater resources on Cape Cod is crucial. The almost complete dependence of the population on groundwater as a drinking water supply was officially recognized by the US Environmental Protection Agency (USEPA) in 1982, when the Cape Cod aquifer was designated as a Sole Source Aquifer (47 FR 30282). Because the groundwater lenses of Cape Cod also receive wastewater and stormwater discharges, introduction of contaminants needs to be monitored to ensure that the water remains safe for drinking water purposes. One of the primary contaminants of concern on Cape Cod is nitrate-nitrogen (NO_3-N).

Nitrogen loading is important to monitor for several reasons. High drinking water nitrate-nitrogen levels have been shown to cause methemoglobinemia (a potentially lethal decreased ability of the blood to transport oxygen) in infants and have been correlated with progeny malformations (NRC, 1977; Dorsch, *et al.*, 1984). High NO_3-N concentrations in groundwater have also been correlated with higher concentrations of regulated drinking water contaminants, such as volatile organic compounds (VOCs) (Eckhardt, *et al.*, 1986). However, the link of high nitrate levels to methemoglobinemia is the most well established and extensive research has led to the calculation of a 10 ppm NO_3-N concentration as a "no-observed-adverse-effect level" (NOAEL) for most infants (NRC, 1977; Fan, *et al.*, 1987).

In response to the concerns pointed out by research, the USEPA established an interim maximum contaminant limit (MCL) in drinking water of 10 ppm NO_3-N in 1975 (USEPA, 1975). This standard has been reproposed by the USEPA a number of times and is scheduled to be adopted permanently in July, 1992 (56 FR 3526). In addition, USEPA , based on recent research linking high nitrate concentrations to carcinogenic effects, has proposed that the Unreasonable Risk to Health (URTH) level for NO_3-N be set at 10 ppm, along with additional monitoring requirements for public supply wells which exceed 5 ppm NO_3-N (USEPA, 1990). Adoption of this proposed standard means that a well which exceeds the 10 ppm NO_3-N MCL concentration could not obtain a variance or an exemption and would be shut down.

The health concerns about nitrate are compounded by its environmental persistence; once it reaches groundwater, it is not substantially removed by chemical reactions. In addition, most nitrogen introduced to aerobic subsurface environments, such as those encountered in the unconfined aquifers of Cape Cod, is converted to nitrate. Thus nitrogen added to the groundwater system is not attenuated and concentrations can only be lowered by dilution or by limiting the nitrogen introduced to the system.

A number of studies have attempted to quantify and understand nitrogen loading to groundwater systems. The Nassau-Suffolk Regional Planning Board (NSRPB) of Long Island, New York conducted extensive literature reviews and presented nitrogen loading levels from a number of sources, including wastewater, fertilizer applications, and domestic animals, as part of the *Long Island Comprehensive Waste Treatment Management Plan* (also known as the Long Island 208 study) (NSRPB, 1978). The forerunner of the Cape Cod Commission (CCC), the Cape Cod Planning and Economic Development Commission (CCPEDC), developed a wastewater nitrogen loading methodology as part of the *Draft Environmental Impact Statement and Proposed 208 Water Quality Management Plan for Cape Cod* (also known as the Cape Cod 208 study) (CCPEDC and USEPA, 1978). In 1979, CCPEDC modified the methodology to also include nitrogen inputs from fertilizers (CCPEDC, 1979). A 1986 study of nitrate concentrations on Cape Cod found a significant positive correlation between nitrate concentrations in groundwater and housing density (Persky, 1986). In 1988, IEP Inc. presented a nitrogen loading model, as part of their contract to assess the water resources of the Town of Yarmouth, to attempt to understand the observed concentrations at two public supply wells (IEP, 1988). Also in 1988, Frimpter, *et al.* presented a detailed nitrogen loading methodology for determining nitrogen loading within zones of contribution (ZOCs) to public drinking water supply wells. In 1991, the Buzzards Bay (BBP) recommended nitrogen management actions, which involved a synthesis of the methods in many of the previous studies, for “nitrogen sensitive embayments” in their Comprehensive Conservation and Management Plan (CCMP) (USEPA and MA EOEA, 1991). Planning boards and boards of health in many of the towns on Cape Cod have adopted density restrictions, water quality report requirements for new developments, and nitrogen loading methodologies based on the information included in these studies.

Nitrogen loading methodologies used on Cape Cod have based their conclusions and recommendations on various assumptions about nitrogen loading parameters (e.g., wastewater flows, nitrogen concentrations in wastewater, lawn sizes, etc.). As more research has been done and more papers have been published, a certain level of confusion has developed over which values and methods are the most proper to use when performing nitrogen loading calculations. This bulletin presents the methodology which is used by the Water Resources Office (WRO) of the Cape Cod Commission to review Developments of Regional Impact (DRIs) and to evaluate cumulative nitrogen loading to Water Resource Areas as described in the Regional Policy Plan (RPP) (Section 2.1).

B. VALUES

All nitrogen loading methodologies involve a certain number of assumptions. This methodology will assume that the recharge (e.g., wastewater, stormwater runoff, precipitation) and nitrogen sources (e.g., septic wastes, fertilizers, nutrients in runoff) within the boundaries of the development site are well mixed prior to their mixing with the groundwater. While this assumption is not an accurate representation of actual contaminant plume behavior, it is an assumption which simplifies the nitrogen loading calculations and is appropriate in most cases where wastewater quantities are fairly low. An assumption is also made that no nitrogen is lost from the system once it is introduced to the groundwater. This assumption also is an approximation of actual nitrogen contamination behavior, but is appropriate in lieu of definitive research about the level of denitrification reactions at depth within the aquifers of Cape Cod.

B.I. 5 ppm NO3-N

A statistical analysis, conducted by Porter and presented in the Long Island 208 study, of 865 NO_3-N observations from 54 wells in Nassau County on Long Island attempts to establish how often the 10 ppm NO_3-N USEPA MCL would be violated given a mean NO_3-N concentration (NSRPB, 1978). Porter found that a well with a mean NO_3-N concentration of 6.0 ppm would violate the 10 ppm MCL 10% of the time. Additional analysis of the same observations has indicated that a mean concentration of 3 ppm NO_3-N will violate the MCL one time out of a hundred (1% of the time) (LIRPB, 1986). Based, in part, on Porter's work, the Long Island 208 study recommended that in areas that exceeded a 6 ppm NO_3-N concentration, sewering be undertaken to protect future drinking water supplies (NSRPB, 1978).

After reviewing the Long Island 208 study, CCPEDC adopted a 5 ppm NO_3-N standard as a planning guideline (CCPEDC and USEPA, 1978). This concentration promises to keep violations of the USEPA MCL to less than one in 10 samples and "allows for a margin of safety during times of high loading with low recharge" (CCPEDC, 1979).

Although the 5 ppm NO_3-N guideline gives some level of protection to drinking water supplies, the level of protection afforded by this concentration may be inadequate to protect the ecosystems of nitrogen limited coastal embayments on Cape Cod. Nitrogen loading limits for recharge areas to embayments (Marine Water Recharge Areas in the RPP) are referred to as critical nitrogen loading rates, i.e., maximum annual loadings without producing negative ecosystem changes, such as eutrophication. Each embayment has a unique critical nitrogen loading rate, as determined by an analysis of its morphology and tidal exchange or flushing rate. Although available analyses of critical loading based on flushing rates within coastal recharge areas are not extensive, most have identified critical nitrogen loading rates, which when converted to loading concentrations are less than the 5 ppm NO_3-N guideline. K.V. Associates (1983) identified critical loading concentrations of 1.5 and 8.5 ppm NO_3-N for Bournes Pond and Hamblin Pond, respectively, in Falmouth. Horsley Witten Hegemann (HWH) (1991) identified 3.68 ppm NO_3-N as the critical loading concentration for Buttermilk Bay, and identified 3.8 and 2.0 ppm NO_3-N as the critical loading concentrations for Oyster Pond and Mill Pond, respectively, in Chatham (HWH, 1990). The unique characteristics of nitrogen sensitive embayments will require additional studies, including flushing rate determinations, to ascertain critical loading rates.

The CCC WRO believes that the 5 ppm NO_3-N guideline is appropriate for use on Cape Cod and will protect the largely undefined potential future water supply areas, private wells, and the small volume community and noncommunity supply wells, and, in the absence of recharge area specific studies establishing critical nitrogen loading limits, will provide some protection for coastal resources. Lower NO_3-N loading rates based on flushing characteristics, will be necessary within the recharge areas to certain identified nitrogen sensitive embayments.

B.2. Sewage Flows and Concentrations

In the Commonwealth of Massachusetts, wastewater systems are required to be designed based on wastewater flows in 310 CMR 15 *Minimum Requirements for the Subsurface Disposal of Sanitary Sewage,* which is commonly referred to as "Title 5." The flow design criteria for wastewater disposal systems are purposely inflated to ensure that the systems avoid hydraulic failure and "assimilate maximum daily flows" (310 CMR 15.02 (13)). For example, all bedrooms are assumed to have two people per bedroom, with a resultant flow of 55 gallons per capita per day (gpcd) (310 CMR 15.02). In contrast, average residential wastewater flows found in a number of studies averaged approximately 44 gpcd and occupancy levels found in a number of Cape Cod towns do not approach the two people per bedroom level (Bennett, *et al*., 1974; Witt, *et al*., 1974; NSRPB, 1978; Cambareri, *et al*., 1989; Belfit, *et al*., 1990). In spite of the obvious overestimation of usual wastewater flows. Title 5 wastewater flows have been used for analysis of nitrogen loading in most cases, including the Cape Cod 208 study and the analysis presented in Frimpter, *et al*. (1988).

Nitrogen concentrations reaching groundwater have also been assumed at a variety of levels. The literature search conducted for the Long Island 208 study resulted in a conservative estimate of average per capita nitrogen load in wastewater of 10 pounds per year, with a concentration of 41 ppm nitrogen reaching the groundwater (NSRPB, 1978). The Cape Cod 208 study assumed a concentration of 35 ppm NO_3-N reaching groundwater (CCPEDC and USEPA, 1978). A modeling effort conducted by IEP, Inc. in Yarmouth found that a calibrated concentration of 33.9 ppm NO_3-N reaching groundwater produced the closest fit for historic nitrogen concentrations within a specified study area (IEP, 1988). The BBP in their CCMP and guidance documents is using a loading rate of 5.86 lbs / person / year (USEPA and MA EOEA, 1991; Costa *et al.*, in preparation).

Actual studies of leaching field concentrations have found different results depending on the soil characteristics, percolation rate, loading rate, distance to impervious strata, and the distance to the water table (Canter and Knox, 1985). Andreoli, *et al*. (1979), in a study on Long Island, found that an average of 36% of total nitrogen applied to soil is removed after two feet of travel through sandy soil. Andreoli, *et al*. (1979) also found that nitrification (the conversion of ammonium to nitrate) occurs within 2-4 feet of vertical travel through the soil. A study by the Suffolk County Department of Health Services (SCDHS) found that nitrogen concentrations varied depending on the time of year and depth below the leaching field (SCDHS, 1983). Concentrations of total nitrogen varied between 15 and 49 ppm, with an average concentration of 34.7 ppm (SCDHS, 1983). A recent study by Robertson, *et al*. (1991) of two septic systems in sandy soils found NO_3-N concentrations within the contaminant plumes averaging 33 and 39 ppm.

Wastewater flows and expected nitrogen concentrations from nonresidential land uses have not been the subject of comparable research. Wastewater flows and nitrogen concentrations from other uses are more varied in character and quantity, even between similar uses. Frimpter, *et al.* (1988) has a more extensive list of flows from nonresidential uses than Title 5, but does not reference the additional flows. The same lists also have similar concentration ranges for both residential and nonresidential land uses (Frimpter, *et al.*, 1988). Wastewater from facilities which have mostly black water (i.e., toilet) flows tend to have higher NO_3-N concentrations because lower NO_3-N grey water flows, i.e., sinks and showers, are not mixed in for dilution. *The Yarmouth Water Resources Protection Study* model found that a calibrated nitrogen concentration of 50.8 ppm for wastewater flows from restaurants provided the best fit for historical nitrogen concentrations (IEP, 1988). Large corporations, such as McDonald's Corporation, with many similar facilities may have fairly accurate estimates of the expected flows from their facilities (P. Landry, McDonald's Corporation, 1991, oral communication).

Although the staff of the WRO acknowledges that the Title 5 flows are, by design, overestimates of usual wastewater flows, these flows will be utilized by the WRO staff to calculate nitrogen loading. The inclusion of actual town occupancy levels in nitrogen loading calculations for residential developments (see Section B.3.) will correct for some of the overestimation inherent in the use of these wastewater flows. Additionally, 35 ppm NO_3-N has historically been used by the staff of the WRO as the concentration of nitrogen reaching groundwater from septic systems. While this concentration may overestimate concentrations in certain cases, it is also probably an underestimation in others, especially in the case of most commercial wastewater flows. The staff believes that the 35 ppm NO_3-N concentration is an accurate number for all nitrogen loading calculations.

B.3. Occupancy Rates

As was stated in the Section B.2., Title 5 assumes that each bedroom is occupied by two people. The Cape Cod 208 study of nitrogen loading assumed that each housing unit was occupied by three people (CCPEDC, 1979). Frimpter, *et al.* (1988) made no implicit assumptions about occupancy, but demonstration calculations and wastewater flows included in the paper are based on Title 5 flows.

The WRO staff again acknowledges the overestimation inherent in the use of Title 5 flows for nitrogen loading analysis and, as such, requests that future nitrogen loading calculations on residential developments submitted for review include both Title 5 occupancy levels and occupancy levels based on the levels that exist in the town of the proposed development. Regulatory reviews of residential developments will use the mean of the two resulting nitrogen loading values. Nonresidential developments will continue to be reviewed based on Title 5 flows, unless substantial documentation of wastewater flows from similar land use can be presented to the staff.

B.4. Lawns

The Long Island 208 study conducted a survey of lawn fertilizer usage and lawn sizes in an attempt to understand potential nitrogen inputs from lawns. This survey, which contacted 460 households in 7 communities, found that rates of fertilizer application ranged between 1.70 and 3.75 lbs of nitrogen per 1,000 ft^2 per year (NSRPB, 1978). The survey also found that fertilizer application rates were positively correlated with household income levels. Other research cited in the Long Island 208 study had found lawn nitrogen application rates between 2.2 and 3 lbs N / 1,000 ft^2 / yr.

The nitrogen loading calculations adopted by CCPEDC in 1979 included fertilizer inputs. Based on tables in the Long Island 208 study and consultation with the Barnstable County Extension Service, CCPEDC selected 3 lbs N / 1,000 ft^2 / yr as the appropriate fertilizer application rate for nitrogen loading calculations on Cape Cod (CCPEDC, 1979).

Application rate surveys vary widely, depending on the population being surveyed. A study of four golf courses on Cape Cod found overall yearly application rates ranging between 1.7 and 3.1 lbs N / 1,000 ft^2 / yr, with rates of up to 9.6 lbs N / 1,000 ft^2 / yr for greens (Eichner and Cambareri, 1990). A survey of golf course turf managers cited in Petrovic (1989) found typical application rates ranged between 1 and 1.5 lbs N / 1,000 ft^2 / yr. A lawn care consultant, who works extensively on Cape Cod, contacted for the *Yarmouth Water Resources Protection Study* typically applied 4.65 lbs N / 1,000 ft^2 of lawn (IEP, 1988). However, the model developed for the same study calibrated to historical nitrate concentrations found a best fit with an annual application rate of 2.8 lbs N / 1,000 ft^2 and a leaching rate of 60%.

Nitrogen leaching rates have been subject to more study than application rates. The Long Island 208 study presented tables with gross estimates of nitrogen leaching; based on gross estimates of nitrogen application and nitrogen reaching groundwater, leaching rates of 55.5% and 60% were determined (NSRPB, 1978). CCPEDC apparently selected a 60% leaching rate based on the estimates in the Long Island 208 study.

Research on golf courses over the last decade has provided some insights into actual nitrogen leaching rates. Brown, *et al*. (1982) fertilized bermudagrass at a rate of 3 lbs N / 1,000 ft^2 of turf and found a leaching rate of 22%. Petrovic (1990) summarized 33 leaching studies conducted in sandy soil and found leaching rates which ranged between 0 and 56.1%. Leaching rates vary with soil type, application rate, precipitation, temperature, turf type, and applied nitrogen forms.

Average lawn sizes are also important to determine when application rates are presented in terms of pounds per unit area. The Long Island 208 study of application rates also included a section on lawn sizes, along with surveyors checks of a certain percentage of respondents. This survey found that lawn sizes were fairly constant, averaging 36-40% of total lot size in all categories except extremely low and extremely high densities (NSRPB, 1978). CCPEDC recognized that comparable information was not available for Cape Cod and selected a standard size lawn of 5,000 ft^2 based on a lot size of between 10,000 and 15,000 ft^2 (CCPEDC, 1979). Lawn sizes averaged 4,350 ft^2 in a survey conducted for the *Yarmouth Water Resources Protection Study* (IEP, 1988).

Historically, the WRO staff has used a fertilizer application rate of 3 lbs N / 1,000 ft^2 / yr with a leaching rate of 60% off an average lawn of 5,000 ft^2. The application rate and standard lawn size seem to be appropriate in light of the lack of definitive information. However, the research which has been done on leaching rates seems to indicate that the 60% leaching rate figure is too conservative. Petrovic's work has indicated that controlled applications of fertilizers on healthy turf can substantially reduce leaching rates, sometimes allowing no leaching. Although Petrovic's work indicates that a percentage lower than 60% can reasonably be chosen, the CCC WRO believes that the objective of protecting groundwater quality should be the main criteria when selecting a standard leaching rate. Therefore, the CCC WRO will use a leaching rate of 25% in all nitrogen loading analyses. This rate recognizes the results of most of the controlled leaching experiments summarized in Petrovic's work, while acknowledging that fertilizer is often applied to unhealthy turf in an uncontrolled fashion. In summary, future nitrogen loading calculations submitted to the CCC WRO should use an application rate of 3 lbs N / 1,000 ft^2 / yr and a leaching rate of 25% off an average lawn area of 5,000 ft^2.

B.5. Recharge

Recharge from precipitation is the only way to dilute NO_3-N loading on an aquifer-wide basis and provides an important source of dilution for NO_3-N concentrations on smaller scales. Approximately 45% of annual precipitation on Cape Cod becomes recharge (LeBlanc, *et al.*, 1986). The remainder is either transpired by plants or evaporates back to the atmosphere. Precipitation that falls on impervious surfaces (e.g., roofs, parking lots, roads) may be recharged to the water table at a much higher percentage.

Two methods of analysis have been used to estimate the average recharge on Cape Cod. LeBlanc, *et al.* (1986) used the Thornthwaite and Mather method, which is based largely on precipitation measurements, to calculate average recharge rates of 22 inches per year on western Cape Cod and 18 in/yr on eastern Cape Cod. Recharge at Otis Air Force Base has been estimated as 21 in/yr using the same method (LeBlanc, 1982). G. J. Larson of Michigan State University used a radioisotope method to estimate recharge in Truro at between 11 and 16 in/yr, while the Thornthwaite and Mather method calculated a recharge of between 17.3 and 19.4 in/yr (Knott and Olimpio, 1986; Delaney and Cotton, 1972).

Prior nitrogen loading methodologies have been based on conservative recharge rates to ensure a margin of safety when determining concentrations. The original CCPEDC loading methodology assumed a recharge rate of 16 in/yr across all of Cape Cod (CCPEDC and USEPA, 1978). Subsequent loading formulas have also used the same recharge rate (CCPEDC, 1979; Frimpter, *et al.*, 1988). The use of this value may be appropriately conservative for use in calculations on sites in eastern Cape Cod, but is certainly too conservative for western Cape Cod. In consideration of the above studies and the wish to adopt appropriately conservative rates, the CCC WRO staff have decided to utilize the following recharge rates for natural and lawn areas in the following towns: 21 in/yr (Bourne, Falmouth); 19 in/yr (Mashpee, Sandwich); 18 in/yr (Barnstable, Dennis, Yarmouth); 17 in/yr (Brewster, Harwich); 16 in/yr (Chatham, Orleans, Eastham, Wellfleet, Truro, Provincetown).

The WRO staff considered not using recharge associated with wastewater flows in areas which receive drinking water supplies from private wells, because water is not imported from a public supply well. The public health concern of so called “short circuiting” between wells and septic systems is a more crucial concern than site specific nitrogen loading in these areas. The wastewater in private well areas is not recycled back to a supply well, but flows with the groundwater from its recharge point towards the groundwater discharge area. Thus, the private drinking water wells downgradient of numerous wastewater recharge points may intercept the contaminant load from the upgradient contaminant sources. Therefore, proposed developments under CCC review in areas which receive drinking water from private wells will be reviewed based on both the documentation of no negative effects on the nearby private wells, as indicated by Section 2.1.1.3 of the Regional Policy Plan, and the nitrogen loading components of the Regional Policy Plan.

Frimpter, *et al.* (1988) introduced the concept of atmosphere nitrogen loading to calculations done on Cape Cod. Frimpter, *et al.* (1988) assumed a concentration of 0.05 ppm NO_3-N for loading from precipitation to groundwater. This concentration was chosen based on analysis by the Barnstable County Health and Environmental Department of 5,559 groundwater samples from shallow private wells throughout Cape Cod between 1980 and 1986. Thirty percent of these samples had concentrations of less than 0.05 mg NO_3-N/1, which was the detection limit for the analytical method used by the laboratory (Frimpter, *et al.*, 1988). Literature reviews have established a range of 0.14-1.15 ppm NO_3-N for precipitation in the United States (Loehr, 1974). A study of precipitation in Truro found an average NO_3-N concentration of 0.26 ppm (Frimpter, *et al.*, 1988). Frimpter has proposed that nitrogen concentrations up to those found in Truro are removed by the soil zone prior to reaching the water table (M.H. Frimpter, 1991, oral communication). Nitrate-nitrogen concentrations in precipitation on Long Island from 1969 to 1974 ranged between 0.33 and 0.67 ppm (NSRPB, 1978). Regardless of the concentration chosen for natural recharge, the nitrogen load from natural recharge is small enough in comparison to loading from wastewater and fertilizers to ignore it when performing nitrogen loading calculations on individual parcels.

By comparison, nitrogen loading off of impervious surfaces is more significant than natural loading. Howie and Waller (1986) conducted a study of two highway runoff sites in Florida and found concentrations of 1.4 and 0.58 ppm total nitrogen reaching groundwater. IEP, Inc (1988) conducted a literature review of impervious surface runoff concentrations and found ranges of 0.41 to 1.75 ppm NO_3-N and 1.13 to 10 ppm total nitrogen. The calibration of the nitrogen loading model detailed in the *Yarmouth Water Resources Protection Study* produced values of 1.5 ppm N reaching groundwater in recharge off pavement and 0.75 ppm N in recharge off roofs (IEP, 1988). The values chosen in the *Yarmouth Water Resources Protection Study* are also used by the BBP in their nitrogen loading calculations (USEPA and MA EOEA, 1991; Costa, *et al.*, in preparation).

Conventionally, previous nitrogen loading calculations performed by the CCC WRO staff have assumed that 90% of recharge off impervious surfaces and 40 in / yr reaches the groundwater. This percentage assumes that precipitation falls on Cape Cod at an average rate of 44.44 in / yr. Average amounts of precipitation have not been studied across Cape Cod. LeBlanc, *et al.* (1986) summarized National Oceanic and Atmospheric Administration (NOAA) weather station precipitation data for Cape Cod between 1947 and 1976. Although the data from the 10 stations provided the data for the determination of the recharge patterns discussed previously, a few of the stations annual average precipitation figures do not fall into the smooth gradient across Cape Cod that the recharge rates seem to follow (LeBlanc, *et al*., 1986).

The 90% recharge rate off of impervious surfaces has been used in a number of other studies on Cape Cod (e.g. IEP (1988). CCPEDC and USEPA (1978), and CCPEDC (1979). Origins of this number are obscure, although members of the IEP study team for the *Yarmouth Water Resources Protection Study* state that this recharge rate is based on "the intuitive assumption that smaller, shorter storm events would not generate enough water for runoff to occur" (M.E. Nelson and S.W. Horsley, HWH, 1991, written communication). Stormwater modeling programs, such as TR-55, use a 98% runoff rate for parking lots, roofs, streets and driveways directly connected to catch basins, but these calculations are done on the basis of individual storms, not on annual precipitation data (SCS, 1986).

In light of the lack of definitive values for many of the stormwater and runoff attributes, nitrogen loading analyses submitted to the CCC WRO should utilize the values which have been historically used on Cape Cod: 40 in / yr recharge off of impervious surfaces, 1.5 ppm NO_3-N off of paved surfaces, and 0.75 ppm NO_3-N off of roofs. Nitrate-nitrogen loading from recharge on pervious natural areas can be ignored when performing loading analyses on individual parcels.

C. METHOD

C.1. Site Specific Mass Balance Analysis

The information presented above describes values that will be used to assess nitrogen loading by the WRO staff of the CCC. The staff expects that each development will perform a Mass Balance Analysis (MBA) of the nitrogen and water uses within the boundaries of the development, using the values selected in this bulletin. A MBA will consist of totaling the nitrogen inputs to groundwater and dividing the nitrogen inputs by the water inputs according to the parameters described above. Sample calculations following this section provide examples of the methods to be used for residential and nonresidential developments.

C.2. Cumulative Loading Analysis Methodology

If a proposed development is within one of the recharge zones defined in Section 2.1.1.2 of the Regional Policy Plan (RPP) and has a Title 5 wastewater flow of greater than 2,000 gallons per day (gpd), the proponent may also be required to complete a zone-wide Cumulative Loading Analysis (CLA), similar to those presented by the WRO staff of CCPEDC and CCC, respectively, in *Truro/Provincetown Aquifer Assessment and Groundwater Protection Plan* (Cambareri, *et al.*, 1989) and *Harwich/Brewster Wellhead Protection Project*, (Belfit, *et al.*, 1990) and by Horsley Witten and Hegemann, Inc. in *Quantification of Nitrogen Inputs to Buttermilk Bay* (HWH, 1991).

If the CLA is being completed for a Wellhead Protection Area (RPP, Section 2.1.1.2.A.) or a Potential Public Water Supply Area (RPP, Section 2.1.1.2.F.), the CLA should include, at a minimum, current expected NO_3-N concentrations within the delineated area based on both actual occupancy values and full Title 5 wastewater flows and future expected NO_3-N concentrations within the area at full buildout also using the two wastewater flow estimates. The completed CLA buildout assessment will provide a worst case assessment of projected nitrogen concentrations based on current zoning laws. If the buildout assessment indicates that the critical loading concentration (i.e., 5 ppm NO_3-N) will be exceeded under current zoning, the CCC will work with an applicant and/or appropriate authorities to explore nitrogen limitation options.

If the CLA is being completed for a Marine Water Recharge Area (MWRA) (RPP, Section 2.1.1.2.C.), a mass loading approach, similar to the methodology utilized by the Buzzards Bay Project, will be applied to determine the critical nitrogen loading rate (Costa, *et al*., in preparation). The critical loading limit is an expression of the mass of nitrogen an embayment ecosystem can assimilate without negative changes. This limit is dependent, in some cases, on the period of time it takes the water in the embayment to be completely exchanged (i.e., residence time). Thus, CLA's completed for MWRA's will require an assessment of the flushing characteristics of the embayment to determine the critical nitrogen loading rate. The existing and future nitrogen loading to a given embayment will be compared to the BBP recommended nitrogen loading rate limits for coastal embayments (USEPA and MA EOEA, 1991; see Table 1), unless more precise information about the embayment is available.

Masses for each of the nitrogen loading components, i.e., lawns, wastewater, impervious surfaces, will be determined as previously described, but the cumulative mass will not be divided by the recharge and other water flows. Since the mass loading within the recharge area, rather than the groundwater or surface water concentration, is the determining factor in protecting coastal embayments, the total mass of nitrogen from current land use and future buildout, will be used to assess proposed and future development within the recharge area. If the buildout assessment indicates that the critical loading rate (e.g., 200 $mg/m^3/Vr$) will be exceeded under current zoning, the CCC will work with an applicant and/or appropriate authorities to explore nitrogen limitation options.

Many of the types of recharge areas have already been delineated, although few have had CLA's completed. Development proponents should refer to the studies previously referenced in this bulletin and contact the CCC WRO staff to obtain recharge area delineations and guidance prior to preparing a Cumulative Loading Analysis.

C.3. Additional Guidance

If the site is located within a recharge area for which a CLA has been completed, the site specific MBA nitrogen loading concentration or mass loading for the proposed development will be compared to the critical loading concentration or critical loading rate per unit area of the recharge area. If the MBA loading concentration or mass loading for a proposed development exceeds the critical loading concentration or critical loading rate per unit area for a recharge area, the proposed MBA loading concentration or mass loading from the project will need to be lowered (e.g., decrease the wastewater flows). If a sewer connection is available for the proposed development, MBA nitrogen loading calculations will not be required if the proposed development will connect to the sewer and if the municipal wastewater treatment facility has adequate capacity and is operating within the parameters of its discharge permit. Proposed wastewater treatment facilities will be reviewed cooperatively with the MA Department of Environmental Protection. Projects involving nitrogen loading characteristics or situations outside the scope of those described within this bulletin will be handled on a case by case basis. It should be noted that the CCC discourages the use of excessive impervious surfaces to lower nitrogen loading concentrations and Developments of Regional Impact before the CCC must conform to the minimum performance standards concerning open space in the RPP (Sections 6.1.1.3 and 6.1.1.4).

Table 1

SUMMARY OF NITROGEN LOADING VALUES

TARGET CONCENTRATION:	5 ppm (milligram / liter) NO_3-N		
WASTEWATER			
Residences			
Concentration:	35 ppm NO_3-N		
Flow:	Title 5 (310 CMR 15.02)		
Nonresidences			
Concentration:	35 ppm NO_3-N		
Flow:	Title 5; Frimpter, *et al.* (1988): Documented flows satisfactory to CCC WRO staff		
OCCUPANCY:	Range (Actual town rate to 2 people per bedroom)		
LAWNS			
Area:	5,000 ft^2		
Fertilizer:	3 lbs / 1,000 ft^2 of lawn		
Leaching:	25%		
RECHARGE			
Off of impervious surfaces:	40 inches per year		
Concentrations			
Road runoff:	1.5 ppm NO_3-N		
Roof runoff:	0.75 ppm NO_3-N		
Natural areas			
Barnstable:	18 inches per year	Mashpee:	19 in / yr
Bourne:	21 in / yr	Orleans:	16 in / yr
Brewster:	17 in / yr	Provincetown:	16 in / yr
Chatham:	16 in / yr	Sandwich:	19 in / yr
Dennis:	18 in / yr	Truro:	16 in / yr
Eastham:	16 in / yr	Wellfleet:	16 in / yr
Falmouth:	21 in / yr	Yarmouth:	18 in / yr
Harwich:	17 in / yr		

Recommended Nitrogen Loading Limits for Coastal Embayments

EMBAYMENT	WATERS CLASSIFIED SB	WATERS CLASSIFIED SA	OUTSTANDING RESOURCE AREAS
Shallow			
• flushing: 4.5 days or less	350 mg / m^3 / Vr	200 mg / m^3 / Vr	100 mg / m^3 / Vr
• flushing: greater than 4.5 days	30 g / m^2 / yr	15 g / m^2 / yr	5 g / m^2 / yr
Deep			
• select rate resulting in lesser annual loading	500 mg / m^3 / Vr or 45 g / m^2 / yr	260 mg / m^3 / Vr or 20 g / m^2 / yr	130 mg / m^3 / Vr or 10 g / m^2 / yr

Note: Vr = Vollenweider flushing term

$$Vr = \frac{r}{1 + \text{sqrt}(r)}$$

r = flushing time (yrs)

Source: USEPA and MA EOEA, 1991

EXAMPLE NONRESIDENTIAL LOADING CALCULATIONS

Office Building:

Lot Size: 5 acres (217,800 ft^2)

Impervious Surfaces: Roof Area: 15,000 ft^2; Paving Area: 30,000 ft^2

Natural Area: 172,800 ft^2; Lawn Area: 10,000 ft^2

Title V Flow: 75 gallons / day per 1,000 ft^2

WASTEWATER

$$15{,}000\ ft^2 \left[\frac{75\ gpd}{1{,}000\ ft^2}\right]\left[\frac{3.785\ L}{gal}\right] = 4{,}258.1\ L/d \qquad \left[\frac{35\ mg}{L}\right] = 149{,}034.4\ mg/d$$

IMPERVIOUS SURFACES

$$15{,}000\ ft^2 \left[\frac{40\ in}{yr}\right]\left[\frac{ft}{12\ in}\right]\left[\frac{28.32\ L}{ft^3}\right]\left[\frac{1\ yr}{365\ d}\right] = 3{,}879.5\ L/d \qquad \left[\frac{0.75\ mg}{L}\right] = 2{,}909.6\ mg/d$$

$$30{,}000\ ft^2 \left[\frac{40\ in}{yr}\right]\left[\frac{ft}{12\ in}\right]\left[\frac{28.32\ L}{ft^3}\right]\left[\frac{1\ yr}{365\ d}\right] = 7{,}758.9\ L/d \qquad \left[\frac{1.5\ mg}{L}\right] = 11{,}638.4\ mg/d$$

LAWN

$$10{,}000\ ft^2 \left[\frac{3\ lbs}{1{,}000\ ft^2 * yr}\right]\left[\frac{1\ yr}{365\ d}\right]\left[\frac{454{,}000\ mg}{lb}\right]\left[\ 0.25\ \right] = 9{,}328.8\ mg/d$$

NATURAL

$$5\ acres \left[\frac{43{,}560\ ft^2}{acre}\right] = 217{,}800\ ft^2; \quad 217{,}800\ ft^2 - 45{,}000\ ft^2 = 172{,}800\ ft^2$$

$$172{,}800\ ft^2 \left[\frac{1.5\ ft}{yr}\right]\left[\frac{28.32\ L}{ft^3}\right]\left[\frac{1\ yr}{365\ d}\right] = 20{,}111.1\ L/d$$

SUMMARY

$$\frac{149{,}304.4 + 2{,}909.6 + 11{,}638.4 + 9{,}328.8\ mg}{4{,}258.1 + 3{,}879.5 + 7{,}758.9 + 20{,}111.1\ liters} = \frac{172{,}911.2\ mg}{36{,}007.6\ liters} = \boxed{4.80\ ppm}$$

EXAMPLE RESIDENTIAL LOADING CALCULATIONS

Home (3 bedrooms)

Lot Size: 1 acre (43,560 ft^2)
Impervious Surfaces: Roof Area: 2,000 ft^2; Paving Area: 500 ft^2
Natural Area: 41,060 ft^2; Lawn Area: 5,000 ft^2
Title V Flow: 110 gallons / day per bedroom

WASTEWATER

Title V (2 people per bedroom)

$$3 \text{ bedrooms} \left[\frac{110 \text{ gpd}}{\text{bedroom}}\right]\left[\frac{3.785 \text{ L}}{\text{gal}}\right] = 1{,}249.0 \text{ L/d} \quad \left[\frac{35 \text{ mg}}{\text{L}}\right] = 43{,}716.8 \text{ mg/d}$$

Actual (assume 2.5 people / unit average occupancy within the town)

$$3 \text{ bedrooms} \left[\frac{110 \text{ gpd}}{\text{bedroom}}\right]\left[\frac{3{,}785 \text{ L}}{\text{gal}}\right]\left[\frac{2.5}{6}\right] = 520.4 \text{ L/d} \quad \left[\frac{35 \text{ mg}}{\text{L}}\right] = 18{,}214.6 \text{ mg/d}$$

IMPERVIOUS SURFACES

$$2{,}000 \text{ ft}^2 \left[\frac{40 \text{ in}}{\text{yr}}\right]\left[\frac{\text{ft}}{12 \text{ in}}\right]\left[\frac{28.32 \text{ L}}{\text{ft}^3}\right]\left[\frac{1 \text{ yr}}{365 \text{ d}}\right] = 517.3 \text{ L/d} \quad \left[\frac{0.75 \text{ mg}}{\text{L}}\right] = 387.9 \text{ mg/d}$$

$$500 \text{ ft}^2 \left[\frac{40 \text{ in}}{\text{yr}}\right]\left[\frac{\text{ft}}{12 \text{ in}}\right]\left[\frac{28.32 \text{ L}}{\text{ft}^3}\right]\left[\frac{1 \text{ yr}}{365 \text{ d}}\right] = 129.3 \text{ L/d} \quad \left[\frac{1.5 \text{ mg}}{\text{L}}\right] = 194.0 \text{ mg/d}$$

LAWN

$$5{,}000 \text{ ft}^2 \left[\frac{3 \text{ lbs}}{1{,}000 \text{ ft}^2 \text{*yr}}\right]\left[\frac{1 \text{ yr}}{365 \text{ d}}\right]\left[\frac{454{,}000 \text{ mg}}{\text{lb}}\right]\left[0.25\right] = 4{,}664.4 \text{ mg/d}$$

NATURAL

$$43{,}560 \text{ ft}^2 - 2{,}500 \text{ ft}^2 = 41{,}060 \text{ ft}^2$$

$$41{,}060 \text{ ft}^2 \left[\frac{1.5 \text{ ft}}{\text{yr}}\right]\left[\frac{28.32 \text{ L}}{\text{ft}^3}\right]\left[\frac{1 \text{ yr}}{365 \text{ d}}\right] = 4{,}778.7 \text{ L/d}$$

SUMMARY

$$\text{Title V Flow} \quad \frac{43{,}716.8 + 387.9 + 194.0 + 4{,}664.4 \text{ mg}}{1{,}249.0 + 517.3 + 129.3 + 4{,}778.7 \text{ liters}} = \frac{48{,}963.1 \text{ mg}}{6{,}674.3 \text{ liters}} = 7.34 \text{ ppm}$$

$$\text{Actual} \quad \frac{18{,}214.6 + 387.9 + 194.0 + 4{,}664.4 \text{ mg}}{520.4 + 517.3 + 129.3 + 4{,}778.7 \text{ liters}} = \frac{23{,}460.9 \text{ mg}}{5{,}945.7 \text{ liters}} = 3.95 \text{ ppm}$$

Final Calculation $(7.34 + 3.95)/2 =$ **5.65 ppm**

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