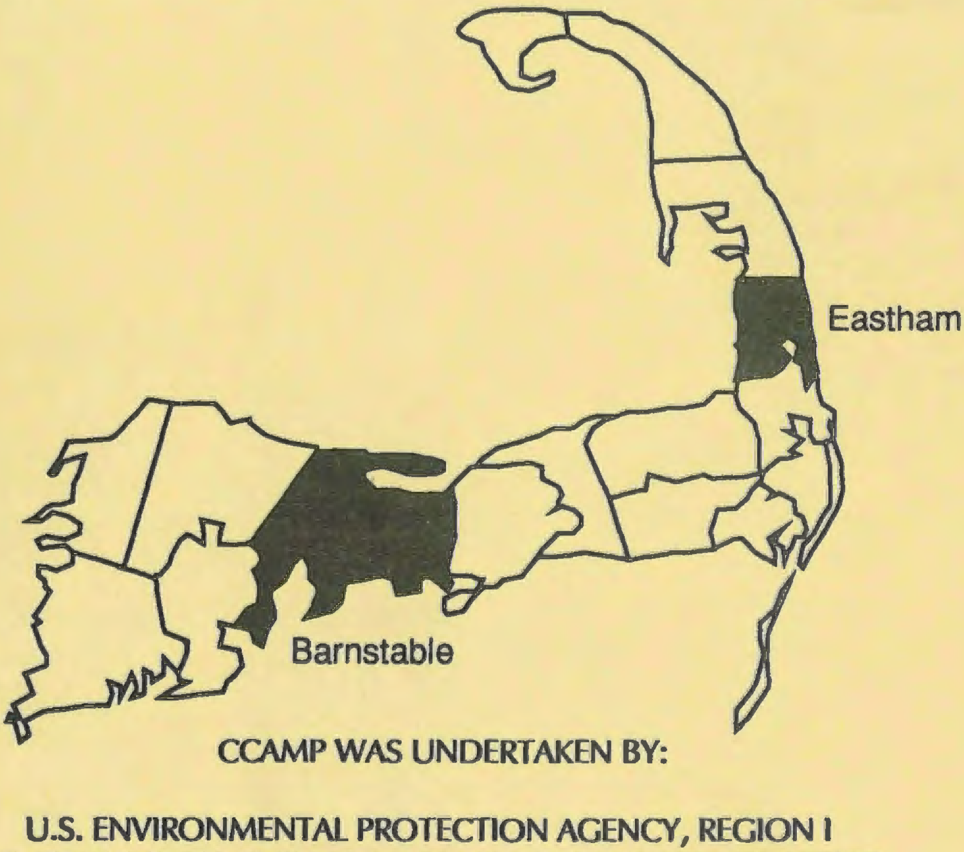
THE CAPE COD AQUIFER MANAGEMENT PROJECT (CCAMP)

A MASS-BALANCE NITRATE MODEL FOR PREDICTING THE EFFECTS OF LAND USE ON GROUNDWATER QUALITY IN MUNICIPAL WELLHEAD PROTECTION AREAS



CCAMP WAS UNDERTAKEN BY:

U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION I
U.S. GEOLOGICAL SURVEY, MASSACHUSETTS DISTRICT OFFICE
MASSACHUSETTS DEPT. OF ENVIRONMENTAL QUALITY ENGINEERING
CAPE COD PLANNING AND ECONOMIC DEVELOPMENT COMMISSION

IN COOPERATION WITH:

THE TOWN OF BARNSTABLE AND THE TOWN OF EASTHAM

JULY 1988

901388007

A Mass-Balance Nitrate Model For Predicting The Effects Of Land Use On Groundwater Quality In Municipal Wellhead Protection Areas

By

Michael H. Frimpter
U.S. Geological Survey
Water Resources Division

John J. Donohue, IV
Massachusetts Department of Environmental Quality Engineering
Division of Water Supply

Michael V. Rapacz
Massachusetts Department of Environmental Quality Engineering
Division of Water Pollution Control

Prepared In Conjunction With
The Cape Cod Aquifer Management Project

July 1988

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

A MASS-BALANCE NITRATE MODEL FOR PREDICTING THE EFFECTS OF LAND USE ON GROUNDWATER QUALITY IN WELLHEAD PROTECTION AREAS

by

Michael H. Frimpter, U. S. Geological Survey, Water Resources Division
John J. Donohue, IV, Massachusetts Department of Environmental Quality Engineering, Division of Water Supply
Michael V. Rapacz, Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control

ABSTRACT

A mass-balance accounting model can be used to guide the management of septic systems and fertilizers to control the degradation of groundwater quality in zones of an aquifer that contribute water to public supply wells. The nitrate nitrogen concentration of the mixture in the well can be predicted for steady-state conditions by calculating the concentration that results from the total weight of nitrogen and total volume of water entering the zone of contribution to the well. These calculations will allow water quality managers to predict the nitrate concentrations that would be produced by different types and levels of development, and to plan development accordingly. Computations for different development schemes provide a technical basis for planners and managers to compare water quality effects and to select alternatives that limit nitrate concentration in wells.

Appendix A contains tables of nitrate loads and water volumes from common sources for use with the accounting model. Appendix B describes the preparation of a spreadsheet for the nitrate loading calculations with a software package generally available for desktop computers.

Introduction

Protection of groundwater quality for public water supply use has become a priority environmental issue. In recent years, one ubiquitous cause of degradation of groundwater quality has been nitrate contributed by subsurface wastewater disposal systems and agricultural activities. In New England, where shallow, unconsolidated aquifer systems provide large quantities of public drinking water and also receive large quantities of wastewater, the potential for water quality degradation is a primary concern. In order for these two potentially conflicting activities to coexist within acceptable limits, the interrelation between withdrawal for water supply and wastewater discharge needs to be accurately defined. This definition requires a characterization of the aquifer system and quantification of the contribution of nitrate to groundwater from land use.

The purpose of this paper is to provide an approach for evaluating the cumulative effects of nitrogen contributing land uses on water quality in public supply wells. The procedure involves the summation of all nitrate sources within a municipal wellhead protection area (Zone II) of a public supply well to predict resultant steady-state nitrate concentrations at the well head.

Specifically, the paper presents a mass-balance accounting equation, tables of nitrate nitrogen concentrations and flow volumes (Appendix A), general model examples and directions for the preparation of a computerized spreadsheet for the mass-balance accounting model (Appendix B).

The proposed approach departs from previous nitrate loading approaches used in Massachusetts, by comprehensively accounting for nitrate inputs to a subset subdivision of the aquifer system the Municipal Wellhead Protection Area (Zone II). Properly applied, this approach will provide the necessary scientific foundation for planning development through land use management, to keep nitrate concentrations at the well head below a chosen threshold value. Anyone intending to apply this approach needs a thorough understanding of the Applications and Qualifications section of this paper.

Nitrate was chosen as the contaminant of concern for several reasons: Nitrate acts as a conservative chemical species in groundwater; it is not sorbed by aquifer materials nor does it enter into most chemical reactions. Although nitrogen may be introduced to groundwater in several dissolved forms, the proposed approach assumes that all nitrogen in groundwater is converted to nitrate before reaching a public supply well. The principal mechanism by which nitrate is attenuated is by dilution. Secondly, two health hazards are related to the consumption of water containing large concentrations of nitrate (or nitrite); induction of methemoglobinemia, particularly in infants, and potential formation of carcinogenic nitrosamines (National Research Council, 1977). Because of these health related concerns, the U.S. Environmental Protection Agency (1975) has established a maximum contaminant level for nitrate as nitrogen in drinking water at 10 mg/L (milligrams per liter). Nitrate, as used hereafter in this report, refers to nitrate as nitrogen. In addition, the results of a study in Australia suggest that the consumption of drinking water containing elevated concentrations of nitrate during pregnancy is associated with a significantly increased risk of malformations in off-spring (Dorsch, 1984). Although nitrate may not be the cause of malformations, it is associated with their presence. It has been demonstrated that nitrate is a geochemical indicator for other more toxic contaminants associated with wastewater (Dorsch, 1984, Dewalle, 1985 and LeBlanc, 1984).

Acknowledgments

The authors express their appreciation to the Cape Cod Aquifer Management Project (CCAMP) project for providing the impetus and forum to research and develop this document. The CCAMP was initiated in 1985 for the purpose of examining the adequacy of groundwater programs at all levels of government and for developing or recommending modifications of these programs. Members of the project included the Cape Cod Planning and Economic Development Commission, the Massachusetts Department of Environmental Quality Engineering, the U. S. Environmental Protection Agency, Region I, and the U. S. Geological Survey. This report is one of several products of the CCAMP intergovernmental collaboration. The authors also greatly appreciate the assistance of Ms. H. Gile Beye in preparing Appendix B, a user's guide to simplify data handling.

Hydrogeologic Setting

Glacial outwash and ice contact deposits of sand and gravel form the most productive aquifers in Massachusetts and New England. These water table aquifers are most commonly less than 25 feet below land surface and less than 100 feet thick. They are typically located either on broad plains or in low valley areas adjacent to the streams of the region. Because these aquifers are recharged from the land immediately overlying them, groundwater quality is highly dependent on local land uses. Massachusetts has developed an approach to managing groundwater quality which focuses management efforts on the land which recharges that part of aquifers which contribute water to wells.

The delineation of the land area that provides recharge to a pumping well is a prerequisite for the application of the methodology set forth in this paper. In Massachusetts, the land surface that contributes recharge to a public supply well is referred to as Zones II and III by the Department of Environmental Quality Engineering. Zone II and Zone III are defined in 310 CMR 24.00 (the Massachusetts Aquifer Land Acquisition Program Regulations, 1983) and shown in Figure 1.

Zone II (the Municipal Wellhead Protection Area) is defined in 310 CMR 24.00 as "The area of an aquifer that recharges a well [the land surface which overlays that part of the aquifer that recharges a well] under the most severe recharge and pumping conditions that can be realistically anticipated. It is bounded by the groundwater divides that result from pumping the well and by the contact of the edge of the aquifer with less permeable materials such as till and bedrock."

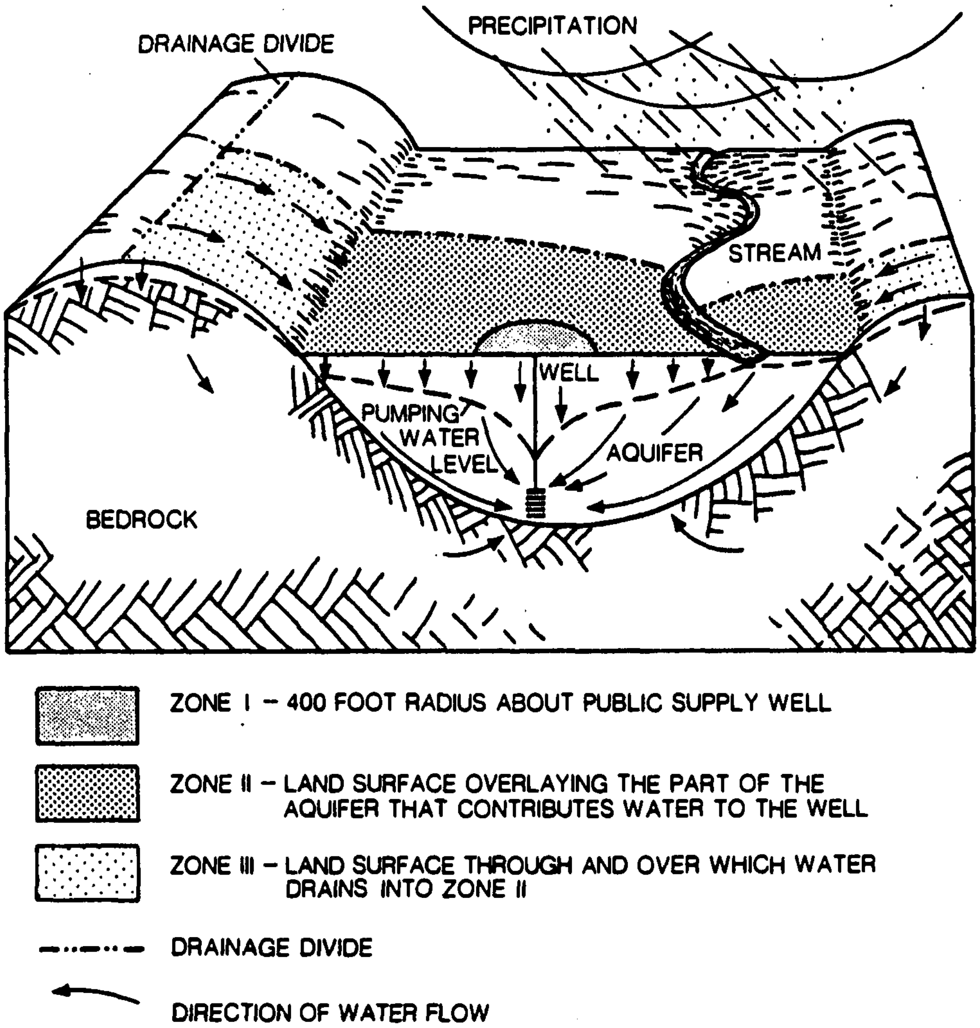


FIGURE 1: Hydrogeologic section of a pumped well in a valley-fill aquifer

Zone III is defined as "That land area beyond the area of Zone II from which surface water and groundwater drain into Zone II. The surface drainage area as determined by topography is commonly coincident with the groundwater drainage area [groundwater divides in the upland materials] and will be utilized to delineate Zone III. In some locations, where surface water and groundwater drainage are not coincident, Zone III shall consist of both the surface drainage area and the groundwater drainage area."

Zone II and Zone III are two-dimensional map projections of a three-dimensional subsurface volume. As such, the proper delineation of Zone II and Zone III should account for significant aspects of the surface water and groundwater hydrogeology: when a well is pumped, the resulting Zone II and associated Zone III represent a state of physical equilibrium. This state of physical equilibrium is reached (after days, weeks, or months), and maintained when the withdrawal from the aquifer because of pumping is balanced by various recharge mechanisms. These mechanisms include: areal recharge from precipitation; recharge from induced infiltration of surface water; recharge from subsurface wastewater disposal systems; and recharge from overland runoff and groundwater that drain from Zone III into Zone II. An accurate delineation of Zone II and Zone III would account for these various recharge mechanisms in their relative proportions. For a more detailed treatment of the determination of Zone II and Zone III see (Massachusetts Department of Environmental Quality Engineering, 1986 and Donohue, 1986).

Within Zone II, all groundwater flow is toward and converges at the well. This results in a complete mixing effect of the water (and associated contaminants) at the well as it is withdrawn from the aquifer.

The mass-balance accounting model presented in this paper is used to predict nitrate concentrations at the municipal wellhead. The concentrations predicted represent steady-state conditions at the wellhead.

In the field, steady-state conditions are reached when physical <u>and</u> dilution equilibrium are attained. Physical equilibrium is attained when the volume of water contributed by the various recharge mechanisms matches the amount of water withdrawn. Dilution equilibrium is attained at the wellhead when the concentration of nitrate nitrogen in the various recharge mechanisms stabilizes, and that recharge (water and associated nitrate nitrogen) has had sufficient time to move from the most distant regions of the Zone II to the wellhead. Steady-state conditions may take tens of years or more to achieve, after nitrate loads to the Zone II have stabilized. The amount of time necessary to achieve steady-state depends on the rate of movement of groundwater in the Zone II being considered.

In summary, the delineations of Zone II and Zone III are important because water of impaired quality recharging the groundwater system within these areas ultimately will affect the quality of water at the wellhead. When steady-state conditions have been reached, the water quality observed at the wellhead represents the sum of the constituents (ratio of nitrate to the volume of water pumped) entering the Zone II. Accordingly, the management of nitrate loading within the Zone II and Zone III areas is an effective approach to prevent contamination of municipal supply wells by nitrate.

Previous Nitrate Loading Approaches: The Relationship Between Nitrate Loading and Housing Density

Previous work on calculating nitrogen loading to ground water for Massachusetts has focused on the determination of the minimum house lot size (Figure 4) that could be allowed on an aquifer recharge area without violating the nitrate limit (10 mg/L nitrate as nitrogen) for drinking water (Cape Cod Planning and Economic Development Commission, 1978). This approach was based on a mass-balance mixture equation described as follows. The average nitrate load and water volume from a septic system were estimated and the average nitrate load from a lawn was estimated using information available in the literature (see Appendix A). To determine the quantity of recharge required to dilute the nitrate to the limit of 10 mg/L, these estimates of water volume and nitrate load were substituted in a mixture equation similar to the one shown below. All nitrogen from the septic system and fertilizer is assumed to be oxidized to nitrate after traveling through the aquifer to the public supply well. Although the nitrate limit for drinking water is 10 mg/L, a planning goal of 5 mg/L was adopted by the Cape Cod Planning and Economic Development Commission to ensure that the health standard would be rarely exceeded (Cape Cod Planning and Economic Development Commission, 1978). The mixture equation could be written as:

$$\text{CONCENTRATION} = \frac{\text{LOAD OF NITRATE}}{\text{VOLUME OF WATER}}$$

or,

$$\text{CONCENTRATION} = \frac{\text{LOAD FROM RECHARGE} + \text{LOAD FROM SOURCES}}{\text{TOTAL VOLUME OF WATER}}$$

Where load from recharge equals recharge volume times nitrate concentration in recharge (0.05 mg/L nitrate as nitrogen) for Cape Cod, Mass.).

The house lot nitrate loads used were 5 pounds per person per year and 9 pounds per year per lawn, or 1090 x 10^4 mg (milligrams) for a 3-person household. The volume of wastewater return flow was 65 gallons per person for 3 persons for 365 days, or 7 x 10^4 gallons (27 x 10^4 liters) per household per day. Solving the equation for recharge volume (in cubic feet), then dividing by the annual recharge rate (1.33 feet per year), a lot size of 59,250 ft^2 (square feet) (Figure 2) was calculated as being required to capture sufficient recharge to dilute the mixture to the 5 mg/L nitrate planning goal.

For the Cape Cod 208 Water Quality Management Plan, this value was adjusted to 43,560 square feet, or 1 acre, for areas zoned for single family housing (Cape Cod Planning and Economic Development Commission, 1979) "after allowing for standard percentages of roads and open space associated with residential development." Land use data for housing and

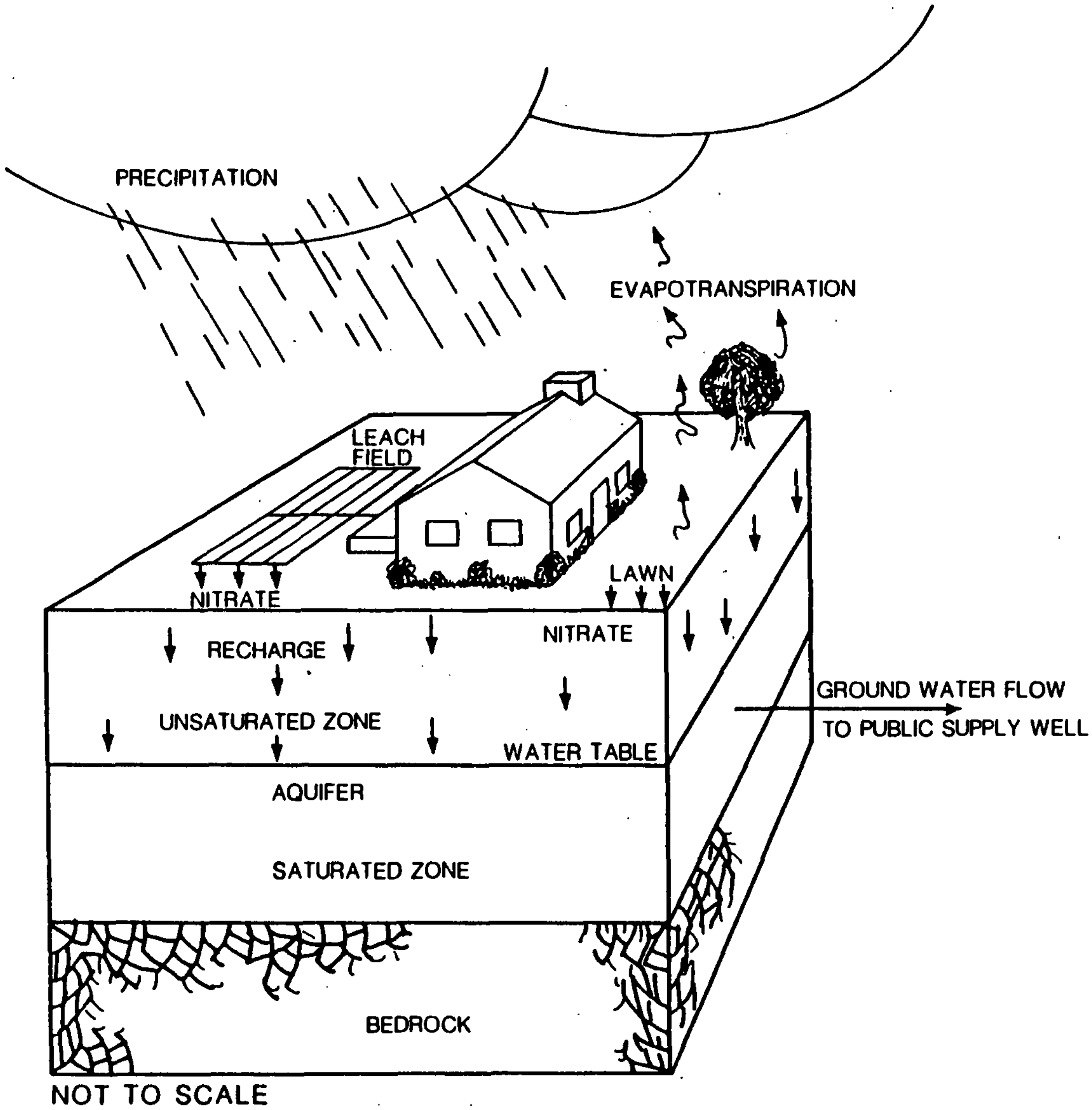


FIGURE 2: Block diagram of house lot showing inflow of nitrate diluted with recharge from precipitation

open space supporting this adjustment were not provided (Cape Cod Planning and Economic Development Commission,1979). With use of the nitrate accounting model described in the next section of this report, the need to provide open space data to justify the adjustment to 1 acre lots is eliminated.

The conclusion that a housing density of one house per acre would meet the planning goal of 5 mg/L nitrate translated into a general planning guideline to protect groundwater quality. This calculation provided an average limit on housing density where groundwater quality is to be protected. For the protection of groundwater quality, this housing density guideline, or some adaptation of it, has been adopted by many towns and incorporated in their land use zoning ordinances and development plans.

Proposed Approach: Nitrate Loading From All Sources In Municipal Wellhead Protection Areas

The intent of this guide and the following equation is to offer a comprehensive approach to limiting nitrate degradation from all sources in the zones that contribute water to public supply wells (Zone II, as defined by the Massachusetts Department of Environmental Quality Engineering, Division of Water Supply (Fig. 3). Nitrogen from all sources is assumed to be oxidized to nitrate before entering a public supply well. The mass-balance accounting model described here is for prediction of future conditions. It is for steady-state conditions in which all of the nitrate and water entering the Zone II are in equilibrium with and equal to that withdrawn for public supply. Currently observed low concentrations of nitrate are not necessarily indicative of future concentrations because many years may be required to reach steady state conditions. On the basis of slow movement of groundwater, as determined in the Cape Cod aquifer (LeBlanc, 1984), the steady-state condition is estimated to take tens of years or more to be approached in most parts of the Cape Cod aquifer. This method also requires that only a small percentage (less than 25 percent) of the water withdrawn is discharged to and recharges groundwater within Zone II. If a large part of the water produced by a public supply well were returned to the zone that contributes water to the well (Zone II), then recycled nitrate would dominate the effects of dilution from precipitation and other recharge sources, and nitrate would increase and exceed 10 mg/L. Wells so affected by recycled nitrate will eventually produce water with more than 10 mg/L nitrate. For these wells, the approach described here is ineffective. For most wells, this approach is effective because most public supply wells serve areas much larger than their Zone II.

Although there are reasons for ground-water quality protection outside of the Zone II , this paper is limited to activities within the wellhead protection area (Zone II) (Fig. 4) that affect nitrate concentration in water from the public supply well. This approach is an expansion of and more complete use of the mass-balance dilution equation used previously to determine a maximum average housing density on Cape Cod. An example of the equation and its accounting for all sources follows:

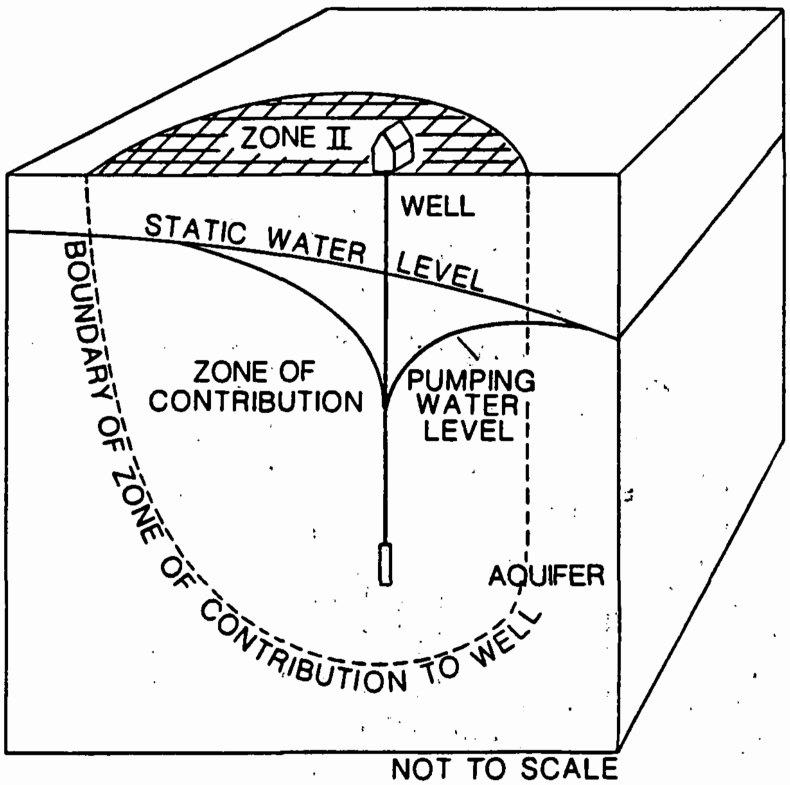


FIGURE 3: Block diagram of a municipal wellhead protection area (Zone II) to a public supply well showing the zone that contributes water to the well

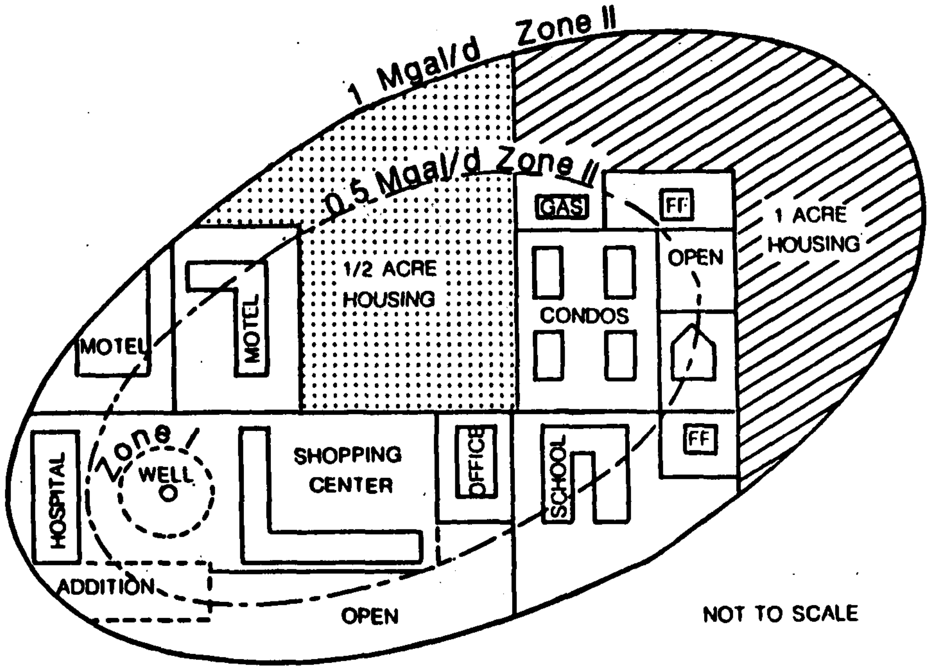


FIGURE 4: Sources of nitrate and zones of contribution to a public supply well pumped at 1 million gallons per day (Mgal/d and 0.5 million gallons per day (Mgal/d)

$$\text{Nitrate concentration in well water} = \frac{\text{Nitrate load from precipitation + nitrate load from sources}}{\text{Total volume of water}}$$

$$C_w = \frac{C_r \times (V_w - 0.9 \times (V_1+V_2+...+V_n)) + (L_1+L_2+...+L_n)}{V_w}$$

where: C_w = nitrate concentration of ground water at the well, in milligrams per liter;

V_w = volume of withdrawal from well in liters (volume must be converted to liters because concentrations are calculated in milligrams per liter;

C_r = nitrate concentration in recharge from precipitation in milligrams per liter;

$L_1+L_2+...+L_n$ = nitrate load in milligrams from individual sources where $L = C \times V$, when load is calculated from the volume and nitrate concentration of effluent from the source;

$C_1+C_2+...+C_n$ = nitrate concentration in individual sources; and

$V_1+V_2+...+V_n$ = volume of water used by each source before discharge to septic system, in liters.

The load of nitrate in recharge from precipitation is the product of nitrate concentration in recharge (C_r) times the volume of recharge derived from precipitation after adjustment for water from other recharge sources (V_w-0.9 x ($V_1+V_2+...+V_n$)). Nitrate concentration in groundwater recharge from precipitation on Cape Cod (C_r) was estimated as 0.05 mg/L on the basis of an analysis of the frequency distribution of nitrate concentration in groundwater. Thirty percent of about 5,000 groundwater samples from Cape Cod had nitrate concentrations of 0.05 mg/L or less.

The term ($L_1+ L_2+...+L_n$) is a summation of the loads of nitrate from all sources within the zone. The term 0.9 x ($V_1+V_2+...+V_n$) represents the quantity of water returned to the aquifer by the septic systems and other return flows and is subtracted from the withdrawal rate to obtain the quantity of recharge from precipitation that will reach the well. The value of the term $V_1+V_2+...+V_n$ would have been determined for delineation of the zone of contribution (Zone II) and therefore would be available for substitution in the mass-balance nitrate calculation. The sum of the volumes of waste water are multiplied by 0.9 to adjust for a 10 percent loss by evapotransporation as estimated in the previous work by CCPEDC. Nitrogen 15 be introduced to the ground in the reduced state (ammonium) but is oxidized to nitrate nitrogen in the well water. For liquid sources, C_1 and V_1 are the concentration of nitrogen in nitrate nitrogen equivalents and volume of water contributed by the first source, respectively, C_2 and V_2 the second source, and C_n and V_n are the last (nth) source. These data are compiled, summed and substituted in the equation to calculate an estimate of the nitrate nitrogen concentration for ground water at the well (C_w). It is recognized that this calculation is an estimate that approximates the concentration of nitrate at a public supply well under several simplifying conditions, none of which are expected to be fully met in an actual situation. The process of denitrification of groundwater has not yet been described in sufficient detail to allow its inclusion in these calculations and is omitted. The resulting influence of this omission on the calculation is expected to be small because of the low rate of the denitrification in groundwater, but the calculation should result in a slightly higher estimate than would actually occur. Other inaccuracies of the calculated concentration may be introduced by the imprecision with which the individual loads are estimated, the imprecision of the mapping of the municipal wellhead protection area (Zone II), and the areal variation of recharge from precipitation over the Zone. The nitrate concentrations calculated by this approach are intended to be a guide for broad decisions on limiting land uses that increase nitrate nitrogen in water supply wells. The significance of nitrate as a contaminant and an indicator of contamination for public health in drinking water is described in the introduction to this report.

Applications

The prediction of nitrate concentration at a well by the dilution accounting approach can be used to evaluate the potential for exceeding nitrate concentration health limits or planning goals. Dilution accounting calculations also can be used to assess the relative effects of various specific land uses or levels of development on water quality. In these applications, nitrate dilution accounting is a water quality planning and management tool that can be used to guide decisions. To calculate nitrate concentrations in milligrams per liter, the water volumes and nitrate weights given in many references and in Appendix A of this report must be converted to the metric units. Some examples of calculations and discussion of their potential use for planning and management of groundwater quality follow.

Example No. 1: Effects of existing and proposed land uses on the nitrate concentration for a well pumped at 1 million gallons per day (Fig. 4)

Table No. 1 - Summary of nitrate loads* from septic systems for average one day period for a well pumped at 1 million gallons per day (in liters and milligrams per day)

	SOURCE	FlOW (gallons/d)	UNITS (variable)	VOLUME (liters/d)	CONCENTRATION** (mg/L)	LOAD (mg/d)
1.	1/2 acre housing	65/person	400 people	98,410	40	3,936,400
2.	High school	20/student	1,000 students	75,700	40	3,028,000
3.	Fast food Restaurant (table seat)	150/seat	70 seats	39,740	40	1,589,700
4.	Fast Food Restaurant (counter seat)	350/seat	10 seats	13,250	35	463,750
5.	One acre housing	65/person	200 people	49,210	40	1,968,400
6.	Condominium	65/person	120 people	29,520	40	1,180,800
7.	Shopping center	60/employee	50 employees	11,360	40	454,400
8.	Office building	15/employee	25 employees	1,420	40	56,800
9.	Gas station	500/island	2 islands	3,785	40	151,400
10.	Church	3/seat	200 seats	2,270	40	90,800
11.	Motel A	75/person	40 people	11,355	35	397,425
12.	Motel B	75/person	160 people	45,420	35	1,589,700
13.	Hospital	200/bed	60 beds	45,420	35	1,589,700
Totals	$(V_1+V_2+...+V_{13})$			426,860	$(L_1+L_2+...+L_{13})$	16,497,275

*Note: Values are selected from Appendix A, nitrate concentrations in effluent were increased by 5 mg/L based on the assumption that public water supply would not exceed the 5 mg/L planning goal, the 453,592 milligram per pound conversion was rounded to 454,000 milligrams per pound, and a conversion factor of 3.785 liters per gallon was used. Volume was rounded to nearest 5 liters.

Table No. 2 - Summary of solid nitrate loads in milligrams per day

	SOURCE	UNITS	NITRATE (pounds/d)	MILLIGRAMS/POUND	LOAD (mg/d)
14.	Lawns (5,000 ft^2)	100 lawns	0.025*	454,000	1,135,000
15.	Horses @ 1,200 lb each	6 horses	0.027/100 lb of animal	454,000	882,580
	Total	$(L_{14}+L_{15})$			2,017,580

*Note: Based on 9 lbs/yr of nitrate leaching into the groundwater system from 5,000 ft^2 of lawn (Cape Cod Planning and Economic Development Commission, 1979)

$(V_1 + V_2 +\ldots+V_{13})$ = 426,860 liters

$(L_1 + L_2 +\ldots+L_{15})$ = 2,017,580 + 16,497,275 = 18,514,855

By substituting the calculated total volume and total load in the mixture equation described above, the concentration of nitrate at the pumped well can be calculated as follows:

Calculation No. 1

$$C_w = \frac{C_r \times (V_w - 0.9 \times (V_1 + V_2 + \ldots + V_n)) + (L_1 + L_2 + \ldots + L_n)}{V_w}$$

$$C_w = \frac{0.05 \times (3{,}785{,}000 - 0.9 \times (426{,}860)) + 18{,}514{,}855}{3{,}785{,}000}$$

$$C_w = \frac{18{,}684{,}896}{3{,}785{,}000}$$

where:

V_w is in liters per day (1 Mgal/d x 3.785)

C_r is the nitrate concentration in groundwater recharge in undeveloped areas of Cape Cod

C_w = 4.94 mg/L = Nitrate concentration at the well

Example No.2: Prediction of the effect of a proposed forty bed addition to the hospital in Example No.1.

The predicted 4.94 mg/L concentration is close to the planning goal of 5 mg/L. The advisability of permitting a proposed 40-bed addition to the hospital (fig. 6, table 3) in the zone of contribution can be determined by predicting its effect on nitrate concentration in the well. To calculate the nitrate concentration that would result with the hospital addition, the estimated additional water volume and additional nitrate load can be added to the previously determined totals and the new totals substituted in the equation.

Table No. 3 - Increase in nitrate load due to proposed hospital addition

SOURCE	FLOW (gal/d)	UNITS (variable)	VOLUME (liters/d)	CONCENTRATION (mg/L)	LOAD (mg/d)
16. Hospital addition	200/bed	40 beds	30,280	35	1,059,800

Calculation No. 2

$(V_1+V_2+...+V_{14}) + V_{16} = 457,140$ liters

$(L_1+L_2+...+L_{16}) = 19,574,655$ milligrams

$$C_w = \frac{C_r \times (V_w - 0.9 \times (V_1+V_2+...+V_n)) + (L_1+L_2+...+L_n)}{V_w}$$

$$C_w = \frac{0.05 \times (3,785,000 - 0.9 \times (457,140)) + 19,574,655}{3,785,000}$$

$C_w = 5.22$ mg/L (nitrate)

Calculation No. 2 includes the water volume and nitrate load that would be caused by the hospital addition, and exceeds the planning goal of 5 mg/L. If the planning goal is to be upheld, then the conclusion must be to deny approval of the hospital addition as proposed. In this way, the nitrate accounting equation becomes a decision-making tool for limiting the amount of nitrate discharged to the wellhead protection area. It can also be used to compare various potential development plans and to select future development alternatives. For example, the effect of sewering could be predicted by subtracting the load of nitrate that would be sewered rather than discharged within the Zone II.

<u>Example No. 3: Effects of existing land uses in Example No.1 on nitrate for the same well with pumping reduced to 0.5 million gallons per day</u>

This example considers a nonuniform distribution of nitrate sources and a reduced pumping rate. Because a well may not be pumped at the same rate every year and because there is no guarantee that the sources of nitrate will be uniformly distributed within the zone of contribution, additional calculations are advisable. If a lower pumping rate is assumed, then the predicted zone of contribution to the well will be correspondingly smaller and closer to the well. See Figure 4 which shows the zone of contribution for a well pumped at 1 million gallons per day and a smaller zone of contribution for the same well when pumped at 0.5 million gallons per day. By summing the water volume and nitrate load produced by the sources within the smaller zone and solving the equation to predict the nitrate concentration at the well, it is possible to determine whether the 5 mg/L planning goal would be exceeded at a lower pumping rate. Comparison of the two nitrate concentration predictions under different pumping rates would also indicate whether the sources of nitrate are uniformly distributed within the larger wellhead protection area, or whether they are concentrated close to or far from the well.

Table No. 4 - Summary of nitrate loads from septic systems for average one day period - 0.5 million gallon per day public supply well

	SOURCE	FLOW (gallons/d)	UNITS (variable)	VOLUME (liters/d)	CONCENTRATION (mg/L)	LOAD (mg/d)
1.	1/2 acre housing	65/person	300 persons	73,807	40	2,952,300
2.	High school	20/student	1,000 students	75,700	40	3,028,000
3.	Condos	65/person	120 persons	29,523	40	1,180,920
4.	Shopping center	60/employee	50 employee	11,355	40	545,200
5.	Office building	15/employee	25 employee	1,419	40	56,760
6.	Gas station	500/island	2 island	3,785	40	151,400
7.	Motel B	75/person	160 persons	45,420	35	1,589,700
Totals		$(L_1 + L_2 + \ldots + L_7)$		241,009	$(V_1 + V_2 + \ldots + V_7)$	9,504,280

Table No. 5 Summary of solid nitrate loads for average one day period - 0.5 million gallon per day public supply well

	SOURCE	UNITS (variable)	NITRATE (pounds/d)	MILLIGRAMS/POUND CONVERSION	LOAD (mg/d)
8.	Lawns ($5,000\ ft^2$)	50	0.025	454,000	567,500

Calculation No. 3

$(V_1+V_2+\ldots+V_7)$ = 241,010 liters

$(L_1+L_2+\ldots+L_8)$ = 10,071,780 milligrams

$$C_w = \frac{C_r \times (V_w - 0.9x(V_1+V_2+\ldots+V_n)) + (L_1+L_2+\ldots+L_n)}{V_w}$$

$$C_w = \frac{.05 \times (1{,}892{,}500 - 0.9 \times (241{,}010)) + 10{,}071{,}780}{1{,}892{,}500}$$

C_w = 5.37 mg/L nitrate

In this example, because the loading sources were more heavily concentrated close to the well, the nitrate concentration predicted for the smaller zone of contribution is higher than that calculated for the larger zone, violating the 5 mg/L planning goal. Similarly, calculations of load can be expanded to account for larger areas of contribution if additional pumping is planned.

Example No. 4: Application to glacial-valley aquifers

Most public supply wells in New England are in glacial-valley aquifers bounded by less permeable till and bedrock uplands and by streams. To account for nitrate loading in these aquifers, some additional components must be added to the dilution accounting equation. Where a well derives part of its yield from induced infiltration from a stream (figs. 1 and 5), the quantity of water (V_s) and nitrate concentration (C_s) of the stream water must be entered into the accounting. Similarly, where water drains from beyond the aquifer into the zone that contributes water to the well (Figs. 1 and 5), the volume of that water (V_{III}) and the nitrate concentration of that water C_{III} must be entered in the accounting. These considerations result in the following expansion of the dilution accounting equation:

$$\text{Concentration at public supply well} = \frac{\text{precipitation load + source load + stream load + Zone III load}}{\text{total volume of water pumped}}$$

or,

$$C_w = \frac{C_r \times (V_w - V_s - V_{III} - 0.9 \times (V_1 + V_2 + \ldots + V_n)) + (L_1 + L_2 + \ldots + L_n) + (V_s \times C_s) + (V_{III} \times C_{III})}{V_w}$$

Where the new terms are:

V_s = Volume of induced infiltration from streams, in liters;

V_{III} = volume of drainage from Zone III into Zone II, in liters;

C_s = nitrate concentration in induced infiltration, in milligrams per liter; and

C_{III} = nitrate concentration of drainage from Zone III to Zone II, in milligrams per liter.

The volume of water from streams and the volume of water from Zone III are essential ingredients for the determination of the zone of contribution to a well (Donohue, 1986 and Morrissey, 1987) and, therefore, must be available wherever the zone of contribution (Zone II) has been determined.

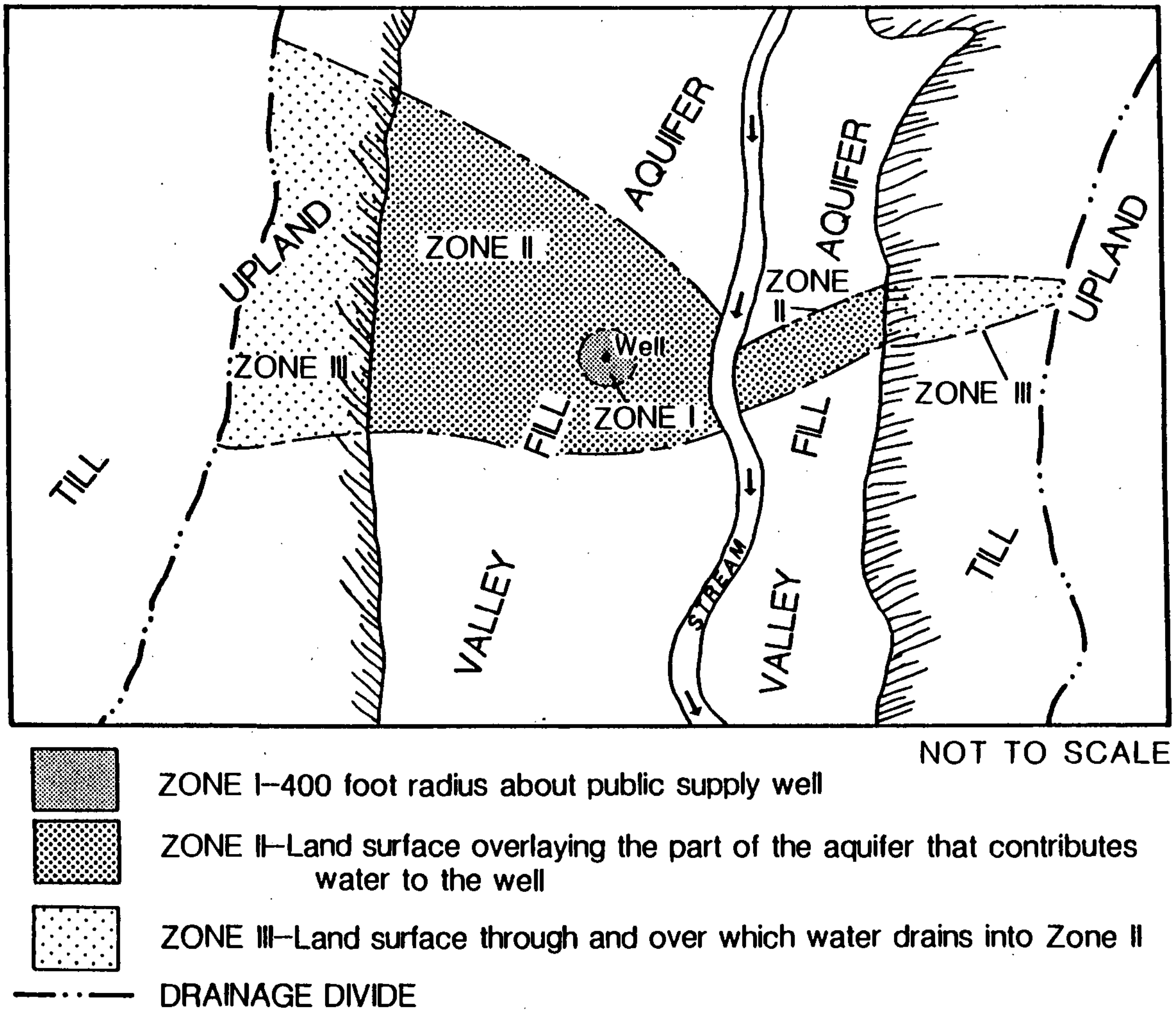


FIGURE 5: Idealized map view of glacial-valley aquifer showing the zones and stream which contribute water to a public supply well

In Massachusetts, nitrate concentration data for streams may be available from the Division of Water Pollution Control or samples may have to be collected for chemical analysis. Estimates of the nitrate concentration of water draining from Zone III could be made from a dilution accounting calculation for that zone, or chemical analysis of representative water samples might be used.

Appendix B is a computer spreadsheet for applying this accounting approach to a public supply well in the most complicated case where there are contributions from surface water and from Zone (III) outside of the aquifer. If no water is contributed from these sources, as on Cape Cod, then zeros are entered for V_s, C_s, V_{III}, and C_{III}.

From inspection and comparison of the calculated nitrate loads from various sources, a relative ranking of the importance of the sources can be developed. Once the nitrate loading data are entered into an automatic spreadsheet, such as shown in Appendix B of this report, only minor modifications are necessary to make sensitivity analyses to test for the consequences of different development levels or scenarios. Assessment and comparison of the potential effects of all sources through the nitrate accounting process described here assists in the recognition of greatest threats to water quality and corresponding selection of priorities and scale of groundwater quality management efforts.

ASSUMPTIONS AND QUALIFICATIONS

1. The nitrate accounting approach described here provides the necessary information for land use decisions that will limit groundwater contaminants in the wellhead protection area of wells completed in water table aquifers. The approach is appropriate for contaminants that are attenuated predominantly by dilution and that may be tolerated in the 1-to 500-mg/L range of concentration, such as nitrate, chloride, and total dissolved solids. The approach should not be used to manage or evaluate threats from other types of contaminantion, such as solvents and fuels. The nitrate predictions that result are approximations of long-term average concentrations, which are imprecise in that actual concentrations may be expected to be above and below the average. For this reason, a planning standard, or goal, of 5 mg/L, which is lower than the 10 mg/L health standard, has been advocated by the Cape Cod Planning and Economic Development Commission and is used in the examples in this guide.

2. The approach assumes that, under steady-state withdrawal conditions, all of the water and nitrate withdrawn from the well are derived from the zone of contribution for the well, and that only some of the water withdrawn is returned to the zone of contribution as return flow. In those situations where a well derives some of its yield from induced infiltration from streams or other surface water bodies, the quantity and quality of induced infiltration need to be entered in the accounting. The quantity of water derived from induced infiltration would

have been computed in order to delineate the zone of contribution and, therefore, would be available for nitrate calculations. In those situations where a well derives some of its yield from an area of till upland beyond the boundary of the aquifer from which ground and surface water drain (Zone III), the quantity and quality of such drainage need to be entered in the accounting.

3. The formula predicts concentration at the well under steady-state conditions where all of the water from the zone of contribution is mixed. Individual plumes with elevated concentrations of contaminants would be expected to emanate from septic systems and other sources within the zone of contribution. Therefore, the prediction should not be used to determine contaminant concentration at other points within the aquifer, or to determine the concentration in any smaller (private domestic supply) wells within the zone of contribution.

4. The contaminant (nitrate) is considered to act conservatively. It is not absorbed or adsorbed by aquifer materials. Attenuation is assumed to occur only through the process of dilution. Some diminishment of nitrate through other processes is known to occur, but the quantities affected are not large enough to be considered in these gross calculations.

5. The zone of contribution to the well is assumed to remain constant in size and shape for application of the nitrate accounting approach described here. Actually, the size of the zone is expected to become smaller as more return flow from septic systems recharges the zone of contribution, but additional recalculations of the zone of contribution would most likely be expensive and have an unacceptably high cost to benefit ratio. Therefore, this assumption results in protection in a zone slightly larger than may actually contribute water to the well and is therefore considered conservative if sources are uniformly distributed. Recharge to the aquifer is assumed to be uniform over the zone of contribution. Where variations of aquifer properties or surface drainage characteristics cause irregular distribution of recharge, both the delineation of the zone of contribution and the calculation of contaminant concentration would have to take those variations into account. Under such conditions, the predictive approach described in this guide may not be accurate.

6. For the examples shown here, return flow of public supply water is estimated to be 10 percent less than the quantity of water supplied because of evaporation and transpiration from outdoor uses and from septic system leach fields. Future research may indicate that the return flow from septic systems is somewhat different. The 10 percent value is based on the findings of Cape Cod Planning and Economic Development Commission and estimates for Long Island, New York. Soil conditions over other aquifers will most likely allow different rates of evaporation and transpiration.

7. On the basis of nitrate analyses of about 5,000 water samples from shallow wells on Cape Cod, the nitrate concentration of groundwater recharge was estimated to be 0.05 mg/L for the examples in this guide. The concentration of nitrate in recharge may vary considerably from region to region primarily because of differences in quality of precipitation, soils, and geology. Application of the nitrate accounting approach described here needs to take these local geochemical and hydrologic conditions into consideration.

8. It is necessary to demonstrate that the sources of nitrate are relatively uniformly distributed within the zone of contribution by using the technique for predicting nitrate concentrations at the well for lower withdrawal rates. Without application of the prediction for lower withdrawal rates, it would be possible for land uses to be concentrated about a well in such a pattern that although the nitrate planning goal is not exceeded at the maximum withdrawal rate, it might be exceeded at some lower withdrawal rate. This is a significant consideration, because withdrawal rates from an individual well are commonly changed from time to time.

CONCLUSION:

This nitrate accounting approach can be used to predict nitrate concentrations in public supply wells. These predictions will allow planners and managers to recognize what level of incremental development will cause violations of nitrate planning goals thereby signaling the need to cease further development of nitrate loading activities within the zone of contribution. Alternatively, predictions may be used to indicate the level of development at which sewering within the zone of contribution would be needed to limit nitrate contamination of a public supply well. Most importantly, this nitrate accounting approach provides a technical basis for evaluating future alternative development plans and for comparing tradeoffs between various land uses and development proposals in groundwater quality protection areas.

REFERENCES CITED

1. Bear, Jacob, 1979, Hydraulics of Groundwater: New York, N.Y., McGraw-Hill, Inc., 569 p.

2. Cape Cod Planning and Economic Development Commission (CCPEDC) 1978, Environmental Impact Statement and 208 Water Quality Management Plan for Cape Cod, Vol. 1 and Vol. 2, 340 p.

3. Cape Cod Planning and Economic Development Commission (CCPEDC) 1979, Water Supply Protection Project - Final Report: Barnstable, Bourne, Brewster, Dennis, Yarmouth, 20 p.

4. Dewalle, F.B. Kalman, D.A., Norman, 6., Plews, 6., 1985, Determination of toxic chemicals in efflment from household septic tanks: U.S. Environmental Protection Agency, Water Engineering Research Laboratory EPA/600/S2-85/050, 9 p.

5. Donohue, J. J. IV, 1986, "Zone II Determination: A Case Study of Two Hydrogeological Investigations," Proceedings of the Third Annual Eastern Regional Ground Water Conference, National Water Well Association, Dublin, Ohio. pp. 54-63.

6. Dorsch, M.M., 1984, "Congenital Malformations and Maternal Drinking Water Supply in Reval, South Australia, American Journal of Epidemiology, Vol. 119, No. 4, pp. 473-486.

7. LeBlanc, D.R., 1984, "Sewage Plume in a Sand and Gravel Aquifer, Cape Cod, Massachusetts," U.S. Geological Survey Water Supply Paper 2218: Washington,D.C., Government Printing Office, 28 p.

8. LeBlanc, D.R., Guswa, J.H., Frimpter, M.H. and Londquist, C.J. 1987, "Ground-Water Resources of Cape Cod, Massachusetts," U.S. Geological Survey Hydrologic Atlas 692, Washington, D.C., U.S. Government Printing Office, 4 pls., scale 1:48,000.

9. Massachusetts Aquifer Land Acquisition Program Regulations (310 CMR 25.00), 1983, Massachusetts Department of Environmental Quality Engineering, Division of Water Supply, Boston, Massachusetts, 4 p.

10. Massachusetts Department of Environmental Quality Engineering, Division of Water Supply, 1986, Hydrogeologic Study Requirements for the Delineation of Zone II and Zone III for New Source Approvals, Boston, MA, 11 p.

11. National Research Council, 1977, "Drinking Water and Health", Washington, National Academy of Sciences, 939 p.

12. U. S. Environmental Protection Agency, 1975, Water programs, national interim primary drinking water regulations, V. 40, No. 248, Wednesday, December 24, 1975, Part IV, p. 59566-59587.

GENERAL REFERENCE LIST

1. Anderson - Nichols and Co., Inc., 1985, Edgartown Water Resource Protection Program - Final Report

2. Bear, Jacob, 1979, Hydraulics of Groundwater: New York, N.Y., McGraw-Hill, Inc.

3. Belfit, G., 1986, Personal communication concerning fertilizer application rates to golf courses on Cape Cod: Cape Cod Planning and Economic Development Commission (CCPEDC).

4. Bennett, E.R., Leach, L.E., Enfield, C.G. and Walters, D.M., 1985, Optimization of nitrogen removal by rapid infiltration: U.S. Environmental Protection Agency, EPA/600/S2-85/016.

5. Cape Cod Planning and Economic Development Commission (CCPEDC), 1979, Water Supply Protection Project - Final Report: Barnstable, Bourne, Brewster, Dennis, Yarmouth.

6. Cape Cod Planning and Economic Development Commission (CCPEDC), 1978, Environmental Impact Statement and 208 Water Quality Management Plan for Cape Cod, Vol. 1 and Vol. 2.

7. Clark, B., 1986, Communication concerning fertilizer application rates, leaching rates and grass types on Cape Cod: Barnstable County Extension Service - personal communication.

8. Cooper, R., 1986, Communication concerning fertilizer components, application rates, potential for leachability or uptake, and fertilization rates: UMASS, Amherst, MA, Dept. of Plant and Soil Sciences.

9. Cornell University, 1974, Nitrogen utilization by crops: Cornell Field Crops Handbook.

10. Deubert, K.H., 1986, Communications concerning nitrogen loading in the form of fertilizers for cranberry bogs: Wareham, MA. Cranberry Experiment Station - personal communication.

11. Dewalle, F.B., Kalman, D.A., Norman, G., Plews, G., 1985, Determination of toxic chemicals in effluent from household septic tanks: U.S. Environmental Protection Agency, Water Engineering Research Laboratory, EPA/600/S2-85/050.

12. Dickey, E.C. and Vanderholm, D.E., 1981, Vegetative filter treatment of livestock feedlot runoff: J. Environ. Quality., Vol. 10, No. 3.

13. Douglas, D.F. 1986, Literature Review of the Cumulative Impact of On-Site Sewage Disposal Systems on Nitrate - Nitrogen Concentrations in Ground Water: Ground Water Management Section. Department of Water Resources and Environmental Engineering, State of Vermont.

14. Dorsch, M.M., 1984, "Congenital Malformations and Maternal Drinking Water Supply in Rural South Australia: A Case-Control Study," American Journal of Epidemiology, the John Hopkins University of Hygiene and Public Health.

15. Eckenfelder, W.W. Jr., 1970, Water quality engineering for practicing engineers: Boston, MA, Cahner Books International, Inc.

16. Edwards, W.M., Chister, F.W. and Harrold, L.L., 1971, Management of barnlot runoff to improve downstream water quality: International Symposium on Livestock Wastes pp. 48-50, 1971.

17. Gerhart, J.M., 1986, Ground-water recharge and its effects on nitrate concentrations beneath a manured field site in Pennsylvania: Groundwater, Vol. 24, No. 4, July-August.

18. Harper, J., 1983, Turf and garden fertilizer handbook: Washington, D.C., The Fertilizer Institute.

19. Hem, J.D., 1970, "Study and Interpretation of Chemical Characteristics of Natural Water," U.S. Geological Survey Water Supply Paper 2218: Washington, United States Government Printing Office.

20. Heufelder, G., 1986, Barnstable County Board of Health, Personal communication.

21. Hinisk, W.W., 1978, Forty questions and answers on manure: Pennsylvania State University, College of Agriculture, Leaflet No. 213.

22. Holyoke, V., 1981, Manure is not an evil: New England Farmer. October 1979.

23. LeBlanc, D.R., 1984, "Sewage Plume in a Sand and Gravel Aquifer, Cape Cod Massachusetts," U.S. Geological Survey Water Supply Paper 2218: Washington, United States Government Printing Office.

24. Litchfield, J.H., Meat, fish, and poultry processing wastes: Water Pollution Control Federation, Volume 56, Number 6.

25. Livestock waste facilities handbook.

26. MacQueen, M., 1986, Pilgrim Resource Conservation and Development Council, Middleboro, MA, personal communication.

27. Metcalf & Eddy, Inc. 1972, Wastewater: collection, treatment, disposal: New York, McGraw Hill.

28. National Research Council, 1977, "Drinking Water and Health," Washington, National Academy of Sciences.

29. North Carolina State University, 1978, Best management practices for agricultural nonpoint source control: Biological and agricultural engineering department, North Carolina State University, Raleigh, N.C..

30. Tchobanoglous, G., rev., 1979, Wastewater engineering: treatment disposal, reuse: New York, McGraw-Hill.

31. Tchobanoglous, G., Theisen, H., and Eliasses, R., 1977, Solid wastes: engineering principles and management issues: New York, McGraw-Hill Book Company.

32. U.S. Environmental Protection Agency, 1977, Process design manual for land treatment of municipal wastewater: U.S. Environmental Protection Agency, Office of Water Program Operations, EPA 625/-77-008 (COE EM1110-1-501).

33. U.S. Environmental Protection Agency, 1984, Handbook for septage treatment and disposal: U.S. Environmental Protection Agency, Environmental Research Laboratory, Ohio, EPA 625/6-84-009.

34. U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Interior, U.S. Department of Agriculture, 1981, Process design manual for land treatment of municipal wastewater: U.S. Environmental Protection Agency, Center for Environmental Research Information, EPA/625/1-81-013 (COE EM1110-1-501).

5. U.S. Environmental Protection Agency, 1977, Alternatives for small wastewater treatment systems, EPA/625/4-77-011.

36. U.S. Environmental Protection Agency, October 1975, Process design manual for nitrogen control: U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, D.C.

37. U.S. Department of Agriculture, U.S. Environmental Protection Agency, 1979, Animal waste utilization on cropland and pastureland: USDA Utilization research report No. 6, EPA - 600-2-79-069.

38. United States Geological Survey, 1986, Personal communication concerning water quality analysis for public water supply wells on Cape Cod; Water Resources Division - Boston, MA.

39. Wehrmann, A.E., 1983, Potential nitrate contamination of groundwater in the Roscoe area, Winnebage County, Illinois: Champaign, Illinois: Illinois State Water Survey.

40. Wells, R.G., 1986, Communications concerning the appropriate application rates for fertilizers: Washington, D.C., The Fertilizer Institute.

41. Young, R.A., Huntrods, T. and Anderson, W., 1980, Effectiveness of Vegetated buffer strips in controlling pollution from feedlot runoff: Journal of Environmental Quality, Vol. 9, No. 3, 1980.

APPENDIX A

NITROGEN CONCENTRATIONS ASSOCIATED WITH DIFFERENT LAND USES

TABLES

Section 1. Sewage Flow Volumes and Nutrient Concentration

The following Table 1A is a list of sewage flow volumes commonly discharged from commercial, recreational and domestic land uses. The nitrate nitrogen figure presented is the concentration of nitrate nitrogen expected to be generated, assuming ammonia nitrogen has been bacterially oxidized and is in the nitrate form.

Table 1A - Sewage Flow Volumes and Nitrate Concentrations

Land Use	Unit	Flow-GPD/ Person or Unit	Concentration of NO_3-N mg/l	lbs. NO_3-N/ 1000 gallons of Wastewater	
				Conc. in mg/l	lbs. NO_3-N
1) Restaurants					
A. food service-lounge tavern	seat	35	35-40		
B. thruway service area	table seat	150	35-40		
thruway service area	counter seat	350	30-35	10	0.08
C. short order	person	4	35-40	30	0.25
D. bars, cocktail lounge	person	2-20	35-40	35	0.29
E. average type	seat	35	35-40	40	0.33
average type	meal	7	35-40	45	0.38
F. cafeteria	seat	150	30-35	50	0.42
G. mess hall	person	15	30-35	100	0.83
H. coffee shop	person	250	30-35		
2) Schools					
A. day/cafeteria	person	10-15	35-40		
B. day/cafeteria showers	person	20	30-35		
C. day	person	10	35-40		
D. high school	person	20	30-35		
E. elementary	person	10	35-40		
F. boarding	person	75	30-35		

Table 1A - Sewage Flow Volumes and Nitrate Concentrations

Land Use	Units	Flow-GPD/ Person or Unit	Potential Concentration of NO_3-N mg/l
3) Parks/Campgrounds			
A. developed campground	person	25	35-40
B. camp/mess hall	person	15	35-40
C. day camp/no meals	person	10	35-40
D. luxury camp/private bath	person	75-100	30-35
E. trailer/toilet/bath	2 1/2 persons	125-150	30-35
F. trailer village	person	35	35-40
G. trailer dump station	per site	50	35-40
H. lodge/cabin	person	50	35-40
I. picnic parks/toilets	person	5-10	35-40
J. park/shower/toilet	person	10	35-40
K. swimming pool/beaches	person	10-15	35-40
4) Hospitals			
A. hospital	bed	200	30-35
B. hospital	person	125-200	30-35
C. prison	person	175	30-35
5) Recreation			
A. fairgrounds/daily	person	1	35-40
B. assembly halls	person	2	35-40
C. theatre/auditorium/inside	person	3-5	35-40
D. theatre/outside/food stand	car	3-5	35-40
E. gymnasium	person	3-25	30-35
F. country club-resident type	person	20-100	30-35
G. country club-transient/meals	person	17-30	35-40
H. church	seat	3	35-40
I. bowling alley	alley	100-200	35-40
J. skating rink (3000 gpd+)	seat	5	30-35

Table 1A - Sewage Flow Volumes and Nitrate Concentrations - continued

Land Use	Units	Flow-GPD/ Person or Unit	Potential Concentration of NO_3-N mg/l
6) Commercial			
A. gas stations	island	300-500	35-40
B. gas stations	vehicle	10	35-40
C. office building	person	10-15	35-40
D. office building	1000 $ft.^2$	75	35-40
E. barber shop/beauty parlor	seat	100	30-35
F. dry good store	100 $ft.^2$	5	35-40
G. stores -	1st 25 ft. of frontage	450	35-40
H. stores	additional 25 ft.	400	35-40
I. shopping center	employee	60	35-40
7) Dwellings			
A. private - pub/priv. water supply	person	50-70	30-35
B. apartments/private wells	person	75-100	30-35
C. single/multiple	per bedroom	110	30-35
D. general	person	55	30-35
E. hotels	person	50-100	35-40
F. motels	person	50-75	30-35
G. boarding house	person	50-75	30-35
H. mobile home park	site	200	35-40
I. colleges, boarding schools	person	50-65	35-40
J. residence homes/apartments	person	75	35-40
K. dormitory, bunkhouse	person	50	35-40
L. construction camp	person	50	35-40
M. private dwellings	110 gal	10-15,000 ft^2	30-35

Some of the flow/unit values appearing in the above table have been taken from "310 CMR 15.00" The State Environmental Code-Title 5 Minimum requirements for the subsurface disposal of sanitary sewage." Title 5 provides flow estimates for varying land uses. These values are to be used when sizing a leaching area as part of a subsurface wastewater disposal system.

The potential concentration of NO_3-N mg/1 values have been taken from planning documents and sampling date collected by the Massachusetts Department of Environmental Quality Engineering. The values will vary depending on water use practices. For example, a business that employs strict water conservation techniques and hardware will have a higher concentration of NO_3-N when measured as milligrams per liter.

Section 2 - Animal Feedlot Nitrogen Production

Table 2A presents the nitrogen production potential common to animal feedlot waste products:

TABLE 2A - FEEDLOT WASTES

Animal	lbs/day of nitrogen per 100 lbs of animal without loss
Dairy Cattle	0.040
Beef Cattle	0.034
Finishing pig	0.045
Sow and litter	0.060
Sheep	0.045
Horses	0.027
Chickens	0.087
Ducks	0.142

Generally one ton (2000 lbs) of manure is composed of 1380 lbs. solid and 620 lbs. of liquid. The liquid portion of manure is immediately available for plant uptake. Only a small percentage of the solid portion is available the first year, prior to bacteriological breakdown of solids in the soils. The potency of manure is greatly decreased because of failure to utilize the liquid portion and excessive nitrogen loss from solids by ammonia volatilization, due to volatilization and evaporation.

TABLE 2B - INFLUENCE OF TIME AND WIND SPEED ON NITROGEN LOSS

	Percent Total nitrogen lost	
Manure spread	No wind	8 1/2 mph wind
12 hrs. @ 68°F	7.7 percent	25 percent
36 hrs. @ 68°F	23 percent	31 percent
7 days @ 68°F	36 percent	37 percent

Manure that is not collected and applied promptly and properly has very limited value. Ten tons of potent manure (20,000 lbs) is comparable in nutrient value to 500 pounds of a 10-6-10 (nitrogen-phosphorous-potash) commercially available fertilizer.

Section 3 - Nutrient Utilization by Crops, Trees, and Ground Cover

When considering the amount of nitrogen available to leach throughout vegetated top soils and surficial deposits, the nitrogen uptake potential of the ground cover must be considered. Table 3A presents values from the literature describing the nitrogen uptake potential for several crops and ground covers.

TABLE 3A - NITROGEN UTILIZATION BY CROPS AND COMMONLY-OCCURRING GROUND COVER *

Vegetative Type	pounds of nitrogen per acre per year
corn	250
grass-legume hay	300
oats	60
summer annuals	200
pines (trees)	27-62
mixed coniferous	36-71
deciduous (trees)	44-88
alfalfa	450
bromegrass	165
coastal bermuda grass	500
reed canary grass	
rye grass	210
sweet clover	157
tall fescue	118
barley	62
cotton	66
milomaize	81
soybeans	94
kentucky bluegrass	178-240
quackgrass	210-250
orchardgrass	225-310
grain sorghum	120
potatoes	205
wheat	143

* Values used are approximations from current literature. The values presented include the nitrogen fixed from the air as N and nitrate nitrogen in soils. To achieve these values the plant must be harvested.

Different levels of sanitary wastewater treatment provide varying levels of nitrogen compound removal. Nitrogen remaining after treatment will presumably be converted to the nitrate form some distance from the subsurface discharge point. Water quality analysis conducted for municipal wells on Cape Cod supports this presumption. Most samples collected contain nitrate but very limited nitrogen in the ammonia form.

The Massachusetts regulatory agencies consider primary treatment of effluent to be removal of at least 25% of the five day Biological Oxygen Demand (BOD_5) 55% of the suspended solids and 85% of the floating solids and solids that settle out. Secondary treatment is considered to be removal of at least 85% BOD_5 and suspended solids and removal of all settleable and floating solids. Advanced treatment is considered any treatment form exceeding secondary treatment. Examples of advanced treatment would be the addition of a nitrification/denitrification stage for nitrogen removal or carbon filtration or an air stripper for the elimination of volatile organic chemicals.

TABLE 4A - NITROGEN REMOVAL VARIATIONS

Treatment Process	Nitrogen Removal Potential %	Total Nitrogen Concentration of Untreated Effluent mg/l	Total POST Treatment Nitrogen Concentration mg/l
primary	no removal 0-10%	40	35-40
secondary	none-slight 0-30%	40	25-40
advanced (denitrification)	70-95%	40	6-10

In the Commonwealth of Massachusetts treatment plant discharges to ground-waters are required to discharge at or below the drinking water standard for nitrates or total nitrogen (10 mg/l) if they are an industrial discharger, discharge over 150,000 gallons per day of sanitary wastewater or are considered by the regulatory agency to be in an environmentally sensitive area. The use of treatment plants is required for all industrial discharges and sanitary wastewater discharges over 15,000 gallons per day. It is highly unlikely that the State of Massachusetts would permit the construction of a municipal scale wastewater treatment plant within the delineated Zone II of a public supply well. Location of commercial and large scale residential wastewater treatment plants is evaluated on a case by case basis with drinking water supplies being considered the most important potentially impacted resource.

Section 5 - Septage Pits and Sanitary Lagoons

Although great effort has been made by regulatory authorities to phase out "septage pits" as a disposal option, several municipal and private pits/lagoons exist throughout the Commonwealth. Because of the less-dilute nature of septage the nitrogen levels (organic nitrogen and ammonia-nitrogen) available for conversion to nitrate greatly exceed sanitary wastewater. The ammonia nitrogen levels commonly observed in septage exceed 100 mg/l. EPA documents reviewed suggested that 150 mg/l would be an appropriate design figure although total nitrogen concentrations observed in septage samples often approach 400 mg/l. One thousand gallons of septage has the potential to generate between 0.83 and 1.25 pounds of nitrate nitrogen.

Section 6 - Cranberry Bogs and Their Fertilization

Massachusetts is this countries highest bulk producer of cranberries. This requires the use of thousands of acres of land for cultivation and the use of tons of fertilizer to stimulate plant growth. Between ten and forty pounds of nitrogen/acre/year are applied to cranberry bogs. Thirty lbs/acre/year is assumed to be the average application rate. Nitrate applications are monitored carefully because the plants will sprout leaves rather than berries if excessive quantities of nitrogen are applied. It is therefore probable that a large percentage of the nitrogen applied to the bogs is utilized by the plant. Since the plant is harvested, very little plant decay matter is available for bacteriological breakdown. Very acidic, low pH environments associated with bogs do not stimulate bacteriological activity necessary for the conversion to nitrate. Surface water runoff via drainage ditches, flood channels or tributary streams associated with bogs sometimes have elevated nitrate nitrogen concentrations.

Section 7 - Fertilizer and Lawns

Fertilizers are applied to ground covers and crops to stimulate growth and productivity. The following table describes the lawn fertilizer application rates suggested by the National Fertilizer Institute in their publication "Turf and Garden Fertilization Handbook". The rates of application suggested should stimulate maximum plant growth under most circumstances. The grasses listed are common ground covers found throughout Massachusetts and the fertilizers are readily available commercial products.

Table 7A

Common Grass Types - Recommended Fertilizer Application

Grass Type	Fertilizer	lbs/nitrogen $1000\ ft^2$/year	Recommended Number of Applications
Kentucky Blue	regular	2-3	3
Kentucky Blue	slow release	3-4	2
Rye	regular	3-5	3
Rye	slow release	4-6	2
Tall Fescue	regular	3	2
Tall Fescue	slow release	3-4	2
Leafy Fescue	regular	2	2
Leafy Fescue	slow release	4	2

Most cultivated lawns include these grass types in varying percentages. For example, an attractive, durable, well-maintained lawn may include 40% Kentucky Blue grass, 30% fescue and 30% rye grass.

Section 8 - Nutrient Input from Lawn Fertilizers

The Long Island Cooperative Extension Service presented in a 1978 planning study, fertilizer application rates thought to be typical for lawns on Long Island. It was assumed that:

- 3 lbs of nitrogen are applied per 1000 ft^2/yr of lawn
- most lawns are 5000 ft^2
- 1000 ft^2 x 5 x 3 lbs nitrogen = 15 lbs nitrogen/5000 ft^2/yr
- 60% of nitrogen applied (15 lbs) leached into groundwater
- 60% x 15 lbs = 9 lbs
- nitrogen converted to nitrate form
- 9 lbs nitrate nitrogen /5000 ft^2 lawn/yr leaches to groundwater

Many factors play a part in determining the quantity of nitrogen that leaches into groundwater. When considering lawns the following factors appear to be of primary importance:

- o fertilizer application rate
- o type of fertilizer
- o soil type
- o precipitation/rates
- o type of plant/uptake potential
- o stage of plant growth
- o frequency of harvesting - cut and remove
- o nitrate in precipitation
- o conversion from nitrogen to nitrate
- o depth to water table

Conversations with several life long residents of Cape Cod suggest that the 3 lbs/1000 ft^2/yr figure utilized in the Long Island 208 study might be excessive when discussing the average lawn on Cape Cod. Golf courses on Cape Cod, meticulously maintained apparently apply on the average between 3 and 4 pounds of nitrogen per 1000 ft^2 per year. It is highly unlikely that the <u>average</u> lawn on Cape Cod is maintained to such rigorous standards. For arguments sake we'll assume that the <u>average</u> lawn of Cape Cod receives more than half the fertilizer per unit area than that of a professionally maintained golf course. In this case a volume of 2 lbs/1000 ft^2/yr could be used as an average, stretching the application rate to 3 lbs for green lawn enthusiasts.

Section 9 - Nitrate Leachability

Following a literature review and consultation with people working in the agricultural disciplines, it appears that there is a probable range of values representing the percent of nitrate leaching into groundwater through vegetative cover and soils. Nitrogen applied to the land surface from various fertilizers is presumed to be converted to nitrate and from <u>10-60%</u> of the volume initially applied will reach the groundwater as nitrate. This large range of leaching nitrate is dependent on the factors listed above. Values in the neighborhood of 45-50% might be most representative of the Cape Cod environment. For the sake of argument several scenarios concerning fertilizer applications are presented below:

Table 9A
Nitrogen Leachability

Application Rate ($lbs/1000\ ft^2/yr$)	X	Average Lawn Size (ft^2)	X	Nitrogen leaching (%)	=	Nitrate nitrogen volume available to groundwater (lb/yr)
2		6000		10		1.0
3		6000		10		1.5
2		6000		45		4.5
3		6000		45		6.75
2		5000		60		6.0
3		5000		60		9.0
6		5000		10		3.0
6		5000		45		13.50
6		5000		60		18.00

Assuming average lawn sizes to be approximately 5000 ft^2 (CCPEDC, 1979) these are the probable ranges of nitrogen likely to leach into groundwater. The application rate of 6 $lbs/1000\ ft^2/yr$ was used to demonstrate volumes that are generated by over-zealous or incorrect applications of lawn fertilizer. As was mentioned earlier, grasses are most productive when a specific quantity of fertilizer is applied (per Table 7A). Over fertilization may be harmful to the plants and results in excess nitrogen available to leach into groundwater. In this case, more is definitely not better.

Lawn sizes and fertilizer application rates vary greatly from region to region and from home to home. Local conditions should be evaluated to accurately predict the effects of lawns on groundwater quality.

Section 10 - Golf Courses

Fertilization rates for two golf course settings were available for review. Both courses are situated on Cape Cod.

Fertilization Rates For Two Golf Courses on Cape Cod

Area	Application Rate lbs nitrogen/1000ft^2/yr
fairways	3.1-4.0
greens	4.3-6.0
tees	3.8
rough	0-2.0

Since fairways generally constitute close to 90% of a golf course's total land area, the fertilizer application rates assigned to fairways can be used to represent an overall application volume:

lbs of nitrogen/acre/yr =

3.1-4.0 lbs/1000 ft^2 X 43560 ft^2/acre = between 135-17-lbs/acre/yr

Section 11 - Recharge from precipitation

Thirty percent of about 5,000 groundwater samples from Cape Cod had nitrate notrogen concentrations of 0.05 mg/L or less. These nitrate concentrations are interpreted to result from recharge of precipitation in undeveloped areas without anthropogenic sources in the recharge area. Therefore, a recharge concentration, C_r, of 0.05 was used to calculate the nitrate load derived from precipitation for Cape Cod. This value is significantly lower than the 2 year nitrate nitrogen average concentration of 0.26 mg/L measured in precipitation at Truro on Cape Cod. The reduction of nitrogen concentration between precipitation and groundwater is apparently caused by biological activity in the soil zone and at land surface. Nitrogen loads in precipitation, soil, and vegetative conditions vary greatly from place to place and nitrate concentrations values for recharge need to be developed from emperical data representative of the region for which the mass balance nitrate calculations are being made.

APPENDIX B

Directions for the Preparation of a Computerized Spreadsheet for Automated Calculation of Nitrogen Loads

by H. Gile Beye

A spreadsheet to calculate nitrogen loads can easily be set up with Lotus 1-2-3 or similar software packages.[1] A working knowledge of the software package is prerequisite to use of the spreadsheet. The example, shown on p. B2 and described below, uses Lotus 1-2-3. The spreadsheet is set up in seven parts. Each part generates values to ultimately be used to solve the nitrate-loading mass-balance equation.

The first part of the spreadsheet, summary of liquid nitrate loads, contains data necessary to calculate the sum of liquid nitrate load from different land uses and also to calculate the total volume of water contributed by the sources (V1 + V2+...+Vn). The spreadsheet software package does not accommodate subscripts, so the terms in the formula are modified from those presented in the text. The calculations are based on long-term averages for an arbitrary period of 1 day. The first column in part 1 of the spreadsheet is labeled SOURCE. Listed in this column is the land use source of nitrate. The next column is labeled FLOW. The flow is the discharge from the source in gallons per day per person, seat, employee, or other unit. The next column is labeled UNITS; it lists the number of units in each land use category. The names of the units can be included to clarify the FLOW and UNITS columns, as shown in the example. To do this, set up a separate column for the names (Lotus does not allow letters to be listed in the same column as numbers that will be used for calculations). The next column is labeled VOLUME; the volume is calculated by multiplying FLOW, UNITS and a conversion factor of 3.7853 (liters per gallon). To set up this equation, type an opening (left) parenthesis, the cell address of the first value in the FLOW column, an asterisk (*), the cell address of the first value in the UNITS column, another asterisk, 3.7853, and the closing (right) parenthesis. The resultant value appears in the first cell of the VOLUME column. It represents the volume of discharge per land use, in liters per day. Copy the formula into the other cells in the VOLUME column (use the copy procedure in the Lotus menu). If data are missing from the FLOW and UNITS column, a zero will appear in the VOLUME column. This will be automatically replaced by a value when the data are entered in those columns. The next column is labeled CONCENTRA TION. It is the concentration of nitrate for each land use listed. The final column is labeled LOAD. It is the total nitrate load per land use per day. This is the product of the VOLUME and the CONCENTRATION columns. To compute the load, type an opening (left) parenthesis, the cell address of the first value in the VOLUME column, an asterisk, the cell address of the first value in the CONCENTRATION column, and then a closing (right) parenthesis. Copy this formula into each cell of the LOAD column. Then, total the VOLUME column by typing at the bottom "@SUM (cell address of first value in column..cell address of last value in column)." Type only the information

----

[1] Use of product or trade names does not consitute endorsement by the authors or their agencies.

within the quotation marks, for example @SUM(G9..G22). This will give the value for (V1 + V2+...+Vn) in the final nitrate loading mass balance equation. To total the LOAD column, follow the same procedure.

The second part of the spreadsheet, summary of solid nitrate loads, solves an equation which computes the load of solid nitrate, in milligrams per day. The procedure for setting up this equation is the same as that used for the liquid nitrate equation, except there will not be a FLOW column. When the LOAD values have been calculated, total the column using the @sum procedure. The total solid nitrate load is added to the total liquid nitrate load for a total load (L1 + L2 +...+ Ln). Set this up as an equation on a separate line in the spreadsheet. The equation is "(cell address of total liquid nitrate load + cell address of total solid nitrate load)".

The third part of the spreadsheet is the nitrate concentration in recharge from precipitation (Cr). This varies from case to case. Enter on this line the value to be used for the current case.

The fourth part of the spreadsheet converts the volume of pumpage from well (Vw) from English (inch, pound) to Metric units (meter, gram). Set up the equation with gallons per day in one column and the conversion factor (3.7853) to change gallons to liters in the next column. In the third column, type "(cell address of the gallons per day value * cell address of the conversion factor). The resultant value, pumpage in liters per day, will appear in the cell.

Part five of the spreadsheet, nitrate load of induced infiltration from streams, is the product of the volume of induced infiltration from streams (Vs) and the nitrate concentration of the induced infiltration (Cs).

Part six of the spreadsheet, nitrate load of drainage from Zone III to Zone II, is the product of the volume of drainage from Zone III to Zone II (VIII) and the nitrate concentration of the drainage (CIII).

Part seven of the spreadsheet, concentration at well, is the final equation. The equation using the variables defined in this spreadsheet looks like this:

Cw = [Cr * [Vw-Vs-VIII -(0.9 * (V1 + V2+...+Vn))] + [(L1 + L2 +...+Ln) + (Vs * Cs) + (VIII * CIII)] /Vw.

Set this up by typing an opening (left) parenthesis, the cell addresses of the values that correspond to the variables in the equation, and a closing (right) parenthesis. In Lotus syntax it looks like this: "C39*(F46-(0.9*I22)) + (I35+C53+C60)/F46." The result is the concentration of nitrate in mg/L at the well.

The advantage in using a spreadsheet to solve this equation is that the effects of additional or different land uses can be easily evaluated. If additions are anticipated at the time of spreadsheet generation, set up extra rows for them. When changes are made, test to be sure that accuracy in the solution of the equations is preserved.

The software package Lotus 1-2-3 was used for this example. However, a similar spreadsheet can be designed with any software package that has the capability to perform mathematical functions. This appendix describes a general format for structuring data to solve equations by means of a spreadsheet. The format can be modified to meet the requirements of other spreadsheet software.

SUMMARY OF WATER VOLUMES AND NITRATE LOADS CALCULATED PER DAY IN THE ZONE OF CONTRIBUTION

1) Summary of liquid nitrate loads (mg/day)

SOURCE (Land use)		FLOW (gallons/day)		UNITS (varies)			VOLUME (liters)		CONCENTRATION (mg/L)		LOAD (mg)
1/2 Acre housing	-	65.00 /people	-	400	people	-	98417.80	-	40.00	-	3936712.00
High School	-	20.00 /people	-	1000	people	-	75706.00	-	40.00	-	3028240.00
Fast Food table seats	-	150.00 /seat	-	70	seats	-	39745.65	-	40.00	-	1589826.00
Fast Food counter seats	-	350.00 /seat	-	10	seats	-	13248.55	-	35.00	-	463699.25
1 Acre housing	-	65.00 /people	-	200	people	-	49208.90	-	40.00	-	1968356.00
Condominiums	-	65.00 /people	-	120	people	-	29525.34	-	40.00	-	1181013.60
Shopping Center	-	60.00 /employee	-	50	employees	-	11355.90	-	40.00	-	454236.00
Office Building	-	15.00 /employee	-	25	employees	-	1419.49	-	40.00	-	56779.50
Gas Station	-	500.00 /island	-	2	islands	-	3785.30	-	40.00	-	151412.00
Church	-	3.00 /seat	-	200	seats	-	2271.18	-	40.00	-	90847.20
Motel	-	75.00 /people	-	40	people	-	11355.90	-	35.00	-	397456.50
Hotel	-	75.00 /people	-	160	people	-	45423.60	-	35.00	-	1589826.00
Hospital	-	200.00 /bed	-	60	beds	-	45423.60	-	35.00	-	1589826.00
					Total VOLUME (V1 + V2 +...Vn) =		426887.21		Total liquid LOAD=		16498230.05

2) Summary of solid nitrate loads (mg/day)

SOURCE		UNITS (varies)			NITRATE (lbs)		CONVERSION (mg/lb)		LOAD (mg)
Lawns 5000 sq. ft.	-	100	lawns	-	0.025 /lawn	-	454000	-	1135000.00
Horses @ 1200 lb each	-	6	horses	-	0.027 /100 lbs of animal	-	454000	-	73548.00
							Total solid LOAD=		1208548.00

Total Nitrate LOAD, liquid and solid combined (L1 + L2 +...Ln) = 17706778.05

3) (Cr)- Nitrate concentration in recharge from precipitation.

0.05 mg/L

4) (Vw)- Volume of pumpage from well

VOLUME (GPD)	CONVERSION (GPD) x 3.7853	L/day
1000000	3.7853	3785300

5) *Nitrate load of induced infiltration concentration from streams*

(Vs)- Volume of induced infiltration from streams 0.00 L
(Cs)- Nitrate concentration in induced infiltration 0.00 mg/L

(Vs * Cs) = 0.00 mg

6) Nitrate load of drainage from ZoneIII to ZoneII

(VIII)- Volume of drainage from ZoneIII into ZoneII 0.00 L
(CIII)- Nitrate concentration of drainage from ZoneIII to ZoneII 0.00 mg/L

(VIII * CIII) = 0.00 mg

7) (Cw)- Concentration of nitrate at well

$$Cw = [\ Cr * [Vw - Vs - VIII - (0.9 * (V1 + V2 + \ldots Vn))\ ] + (L1 + L2 + \ldots Ln)\ ] + (Vs \times Cs) + (VIII \times CIII) \ / \ Vw$$

Cw= 4.72 mg/L

Appendix C

List of Acronyms, Chemical Formulas and Mathematical Symbols Used

ACRONYMS

BOD:	5 day Biological Oxygen Demand
CCPEDDC:	Cape Cod Planning And Economic Development Commission
GPD:	Gallons Per Day
MGD:	Million Gallons Per Day
MG/L:	Milligrams Per Liter
USEPA:	United States Environmental Protection Agency
WHPA	Wellhead Protection Area

Mathematical Symbols

C_n: Nitrate concentration in individual sources (mg/L)

C_r: Nitrate nitrogen concentration in recharge from precipitation (mg/L)

C_s: Nitrate concentration in induced infiltration (mg/L)

C_w: Nitrate nitrogen concentration at well (mg/L)

C_{III}: Nitrate concentration of drainage from Zone III to Zone II (mg/L)

L_n: Nitrate nitrogen load in milligrams for individual septic systems

V_n: Volume of water used by each source before discharge to septic system (liters)

V_s: Volume of induced infiltration from streams (liters)

V_w: Volume of withdrawal from well (liters)

V_{III}: Volume of drainage from Zone III into Zone II (liters)

Chemical Formulas

N:	Nitrogen
N_2:	Nitrogen (atmospheric)
N_2:	Nitrite Nitrogen
NO_3:	Nitrate Nitrogen
NH_3:	Ammonia Nitrogen
NH_4:	Ammonia Nitrogen (ionized)