A Mass-Balance Nitrate Model for Predicting the Effects of Land Use on Ground-Water Quality

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

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors.

Multiply inch-pound unit	By	To obtain metric unit
	Length	
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09294	square meter (m^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	4.536	kilogram (k)

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ABSTRACT

A mass-balance accounting model can be used to guide the management of septic systems and fertilizers to control the degradation of ground-water quality in zones of an aquifer that contribute water to public-supply wells. The nitrate 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. Tables of nitrate loads and water volumes from common sources for use with the accounting model are given.

INTRODUCTION

Background

Protection of ground-water quality for public water supply use has become a priority environmental issue. In recent years, one ubiquitous cause of degradation of ground-water 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 waste-water, 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 ground water from land use.

Purpose and scope

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 method used computes the sum of all nitrate sources within the recharge area of a public-supply well in order to predict steady-state nitrate concentrations in the well water.

Specifically, the paper presents a mass-balance accounting equation, tables of nitrate as nitrogen concentrations and flow volumes (Appendix A), and general model examples and directions for the preparation of a computerized spreadsheet for the mass-balance accounting model (Appendix B) for application to those areas that recharge the zones that contribute water to a well. The model may be appropriately applied to wellhead protection areas when those areas are derived from delineation of the areas that contribute recharge to a well, as they are in Massachusetts.

The proposed approach departs from previous nitrate loading approaches used in Massachusetts, by comprehensively accounting for nitrate inputs to that part of an aquifer that contributes water to a well. Properly applied, this approach will provide the necessary scientific foundation for planning development through land-use management, to keep nitrate concentrations at the wellhead below a chosen threshold value. Anyone intending to apply this approach needs to examine the Assumptions and Qualifications section of this paper.

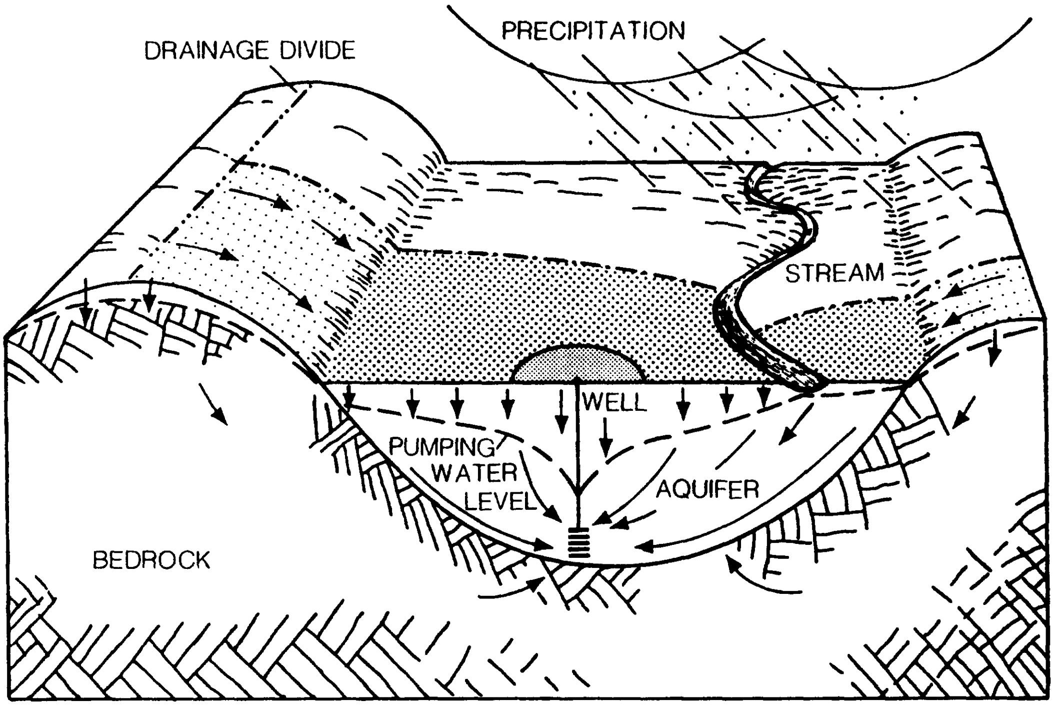
Nitrate was chosen as the ground-water contaminant of concern for several reasons: Dilution is the principal mechanism by which nitrate in ground water is attenuated. Nitrate functions as a conservative chemical species after entering the saturated zone; it is not sorbed by aquifer materials nor is it removed by chemical reactions. Although nitrogen may be introduced to ground water in several dissolved forms, the proposed approach assumes that all nitrogen in ground water is converted to nitrate before reaching a public-supply well. 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 imply that the consumption of drinking water containing elevated concentrations of nitrate during pregnancy is associated with a significantly increased risk of malformations in offspring (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 and others, 1985 and LeBlanc, 1984).

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 ft (feet) below land surface and less than 100 ft 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, ground-water quality is highly dependent on local land uses. Massachusetts has developed an approach to managing ground-water quality that focuses management efforts on the land that recharges the parts of aquifers that contribute water to wells.

The delineation of the land area that provides recharge to a pumped well is a prerequisite for applying 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. Zones I, II, and III are defined in 310 CMR 24.00 (Massachusetts Department of Environmental Quality Engineering, 1983) and shown in figure 1.

Zone I is the protective radius around a public water-supply well or wellfield owned or controlled by the water supplier, as required by the Massachusetts Division of Water Supply.



(Zone I pattern)	ZONE I -- 400 foot protective radius about public-supply well
(Zone II pattern)	ZONE II -- Land surface overlaying the part of the aquifer that contributes water to the well
(Zone III pattern)	ZONE III -- Land surface through and over which water drains into Zone II
—··—··—	DRAINAGE DIVIDE
←—	DIRECTION OF WATER FLOW

Figure 1.--Recharge areas to a pumped well in a valley-fill aquifer.

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 ground-water 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."

Zone III is defined as "That land area beyond the area of Zone II from which surface water and ground water drain into Zone II. The surface drainage area as determined by topography is commonly coincident with the ground-water drainage area (ground-water divides in the upland materials) and will be utilized to delineate Zone III. In some locations, where surface-water and ground-water drainage are not coincident, Zone III shall consist of both the surface drainage area and the ground-water 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 need to account for significant aspects of the surface-water and ground-water 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 ground water 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 ground water flows 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 and 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 in the various recharge mechanisms stabilizes, and that recharge (water and associated nitrate) 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 ground water 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 ground-water 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.

Acknowledgments

The authors express their appreciation to the Cape Cod Aquifer Management Project (CCAMP) 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 ground-water 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 (CCPEDC), 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 simplifying data handling.

DETERMINATION OF NITRATE LOADS

Previous Approach

Previous work on calculating nitrogen loading to ground water for Massachusetts has focused on the determination of the minimum house lot size (fig. 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

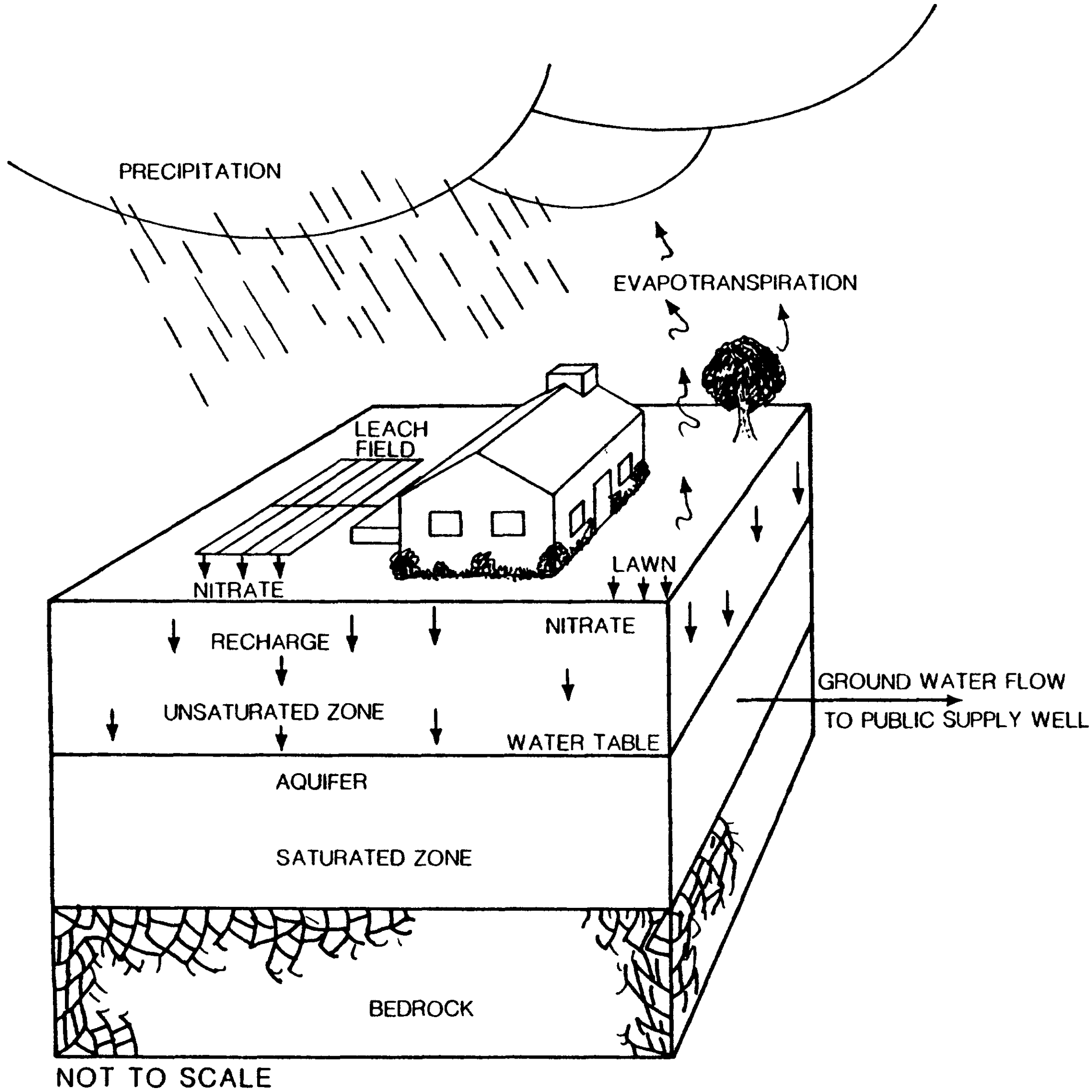


Figure 2.--House lot showing inflow of nitrate diluted with recharge from precipitation.

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 CCPEDC 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:

$$\text{Concentration} = \frac{\text{load of nitrate}}{\text{volume of water}} \qquad (1)$$

or,

$$\text{Concentration} = \frac{\text{load from recharge} + \text{load from sources}}{\text{total volume of water}} \qquad (2)$$

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 $1,090 \times 10^4$ 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 7×10^4 gallons (27×10^4 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) (fig. 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 ft^2, or 1 acre, for areas zoned for single family housing "after allowing for standard percentages of roads and open space associated with residential development" (Cape Cod Planning and Economic Development Commission, 1979). Land-use data for housing and 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 ground-water quality. This calculation provided an average limit on housing density; for the protection of ground-water quality, this 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

The intent of this guide and the following equation is to offer a comprehensive approach to limiting nitrate concentrations from all sources

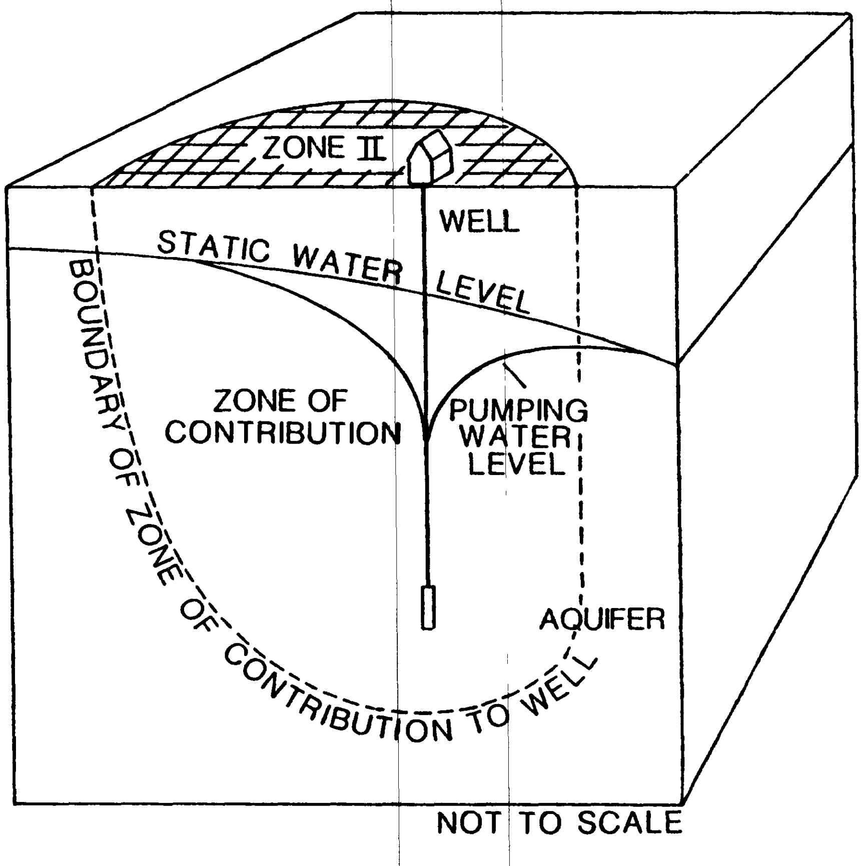


Figure 3.--Municipal wellhead protection area (Zone II) to a public-supply well showing the zone that contributes water to the well.

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 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 ground water, 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 be discharged to and recharged to ground water 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, however, this approach is effective because most public-supply wells supply 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:

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

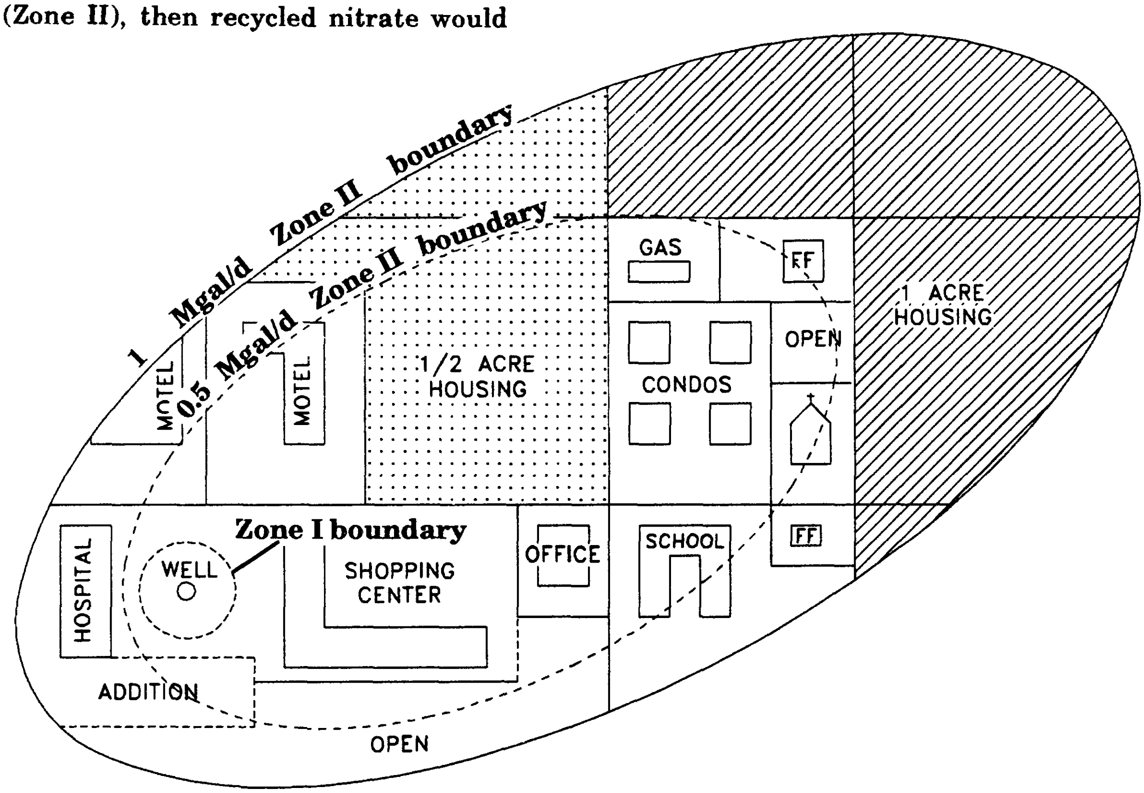


Figure 4.--Sources of nitrate and zones of contribution to a public-supply well pumped at 1 million gallons per day and 0.5 million gallons per day.

$$C_w = \frac{C_r (V_w - 0.9 (V_1 + V_2 + \ldots + V_n)) +}{V_w} \qquad (3)$$

$$\frac{(L_1 + L_2 + \ldots + L_n)}{V_w}$$

where:

C_w is nitrate concentration of ground water at the well, in milligrams per liter;

V_w is volume of withdrawal from well, in liters (volume needs to be converted to liters because concentrations are calculated in milligrams per liter);

C_r is nitrate concentration in recharge from precipitation, in milligrams per liter;

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

$C_1 + C_2 + \ldots + C_n$ is nitrate concentration in individual sources, in milligrams per liter; and

$V_1 + V_2 + \ldots + V_n$ is 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 ($V_1+V_2+\ldots+V_n$)). Nitrate concentration in ground-water 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 ground water. Thirty percent of about 5,000 ground-water samples from Cape Cod had nitrate concentrations of 0.05 mg/L or less.

The term $L_1+ L_2+\ldots+L_n$ is a summation of the loads of nitrate from all sources within the zone. The term 0.9 ($V_1+V_2+\ldots+V_n$) 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 $V_1+V_2+\ldots+V_n$ 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 wastewater are multiplied by 0.9 to adjust for a 10-percent loss by evapotranspiration as estimated in the previous work by CCPEDC. In other climates where evapotranspiration rates and practices of water users may differ, this adjustment value for water loss may be changed. Nitrogen may be introduced to the ground water in several chemical forms, but is assumed to be oxidized to nitrate before reaching the well. For liquid sources, C_1 and V_1 are the concentration of nitrogen, in all its chemical forms, and volume of water contributed by the first source, respectively, C_2 and V_2, the second source, and C_n and V_n, the last (nth) source. These data are compiled, summed and substituted in this equation (3) to calculate an estimate of the nitrate 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 ground water 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 ground water, 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 concentrations 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 need to be converted to metric units. Some examples of calculations and discussion of their potential use for planning and management of ground-water quality follow.

Calculation of the Effects of Existing and Proposed Land Uses

A prediction of the effects of land uses, either existing or possible within zoning restrictions, may be calculated by summing the nitrate

Table 1.--*Summary of nitrate loads[1] from septic systems for an average one day period for a 1 million gallon per day well*

[gal/d, gallons per day; L/d, liters per day; mg/L, milligrams per liter; mg/d, milligrams per day]

Source	Flow (gal/d)	Units (variable)	Volume (L/d)	Nitrate as nitrogen concentration (mg/L)	Load (mg/d)
1. ½ acre housing	65/person	400 people	98,410	40	3,936,400
2. High school	20/student	1,000 student	75,700	40	3,028,000
3. Fast food restaurant (counter seat)	150/seat	70 seats	39,740	40	1,589,700
4. Fast food restaurant (table 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		$(V_1+V_2+\ldots+V_{13}) =$	426,860	$(L_1+L_2+\ldots+L_{13}) =$	16,497,275

[1] Values are selected from Appendix A, nitrate as nitrogen 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 2.--*Summary of solid nitrate loads*

[ft^2, square feet; lbs/d, pounds per day; mg/d, milligrams per day]

Source	Units	Nitrate as nitrogen (lbs/d)	Milligrams/Pound	Load (mg/d)
14. Lawns (5,000 ft^2)	100 lawns	0.025[1]	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

[1] Based on 9 pounds per year of nitrate leaching into the ground-water system from 5,000 ft^2 of lawn (Cape Cod Planning and Economic Development Commission, 1979).

loads from recharge from precipitation and from land-use sources and dividing by the volume of water withdrawn (equation 3 and tables 1 and 2),

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

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

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:

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

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

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

where: V_w is in liters per day (1 Mgal/d × 3.785);

C_r is the nitrate concentration in ground-water recharge in undeveloped areas of Cape Cod;

C_w is 4.94 mg/L =nitrate concentration at the well.

In this example of a well pumped at 1 million gallons per day, the calculated nitrate concentration in the well is 4.94 mg/L, close to the planning goal of 5 mg/L. These predictions can be compared with water-quality limits or planning goals to evaluate land-use, zoning, or well-location decisions.

Calculation of the Effect of an Additional Source

The advisability of permitting a proposed 40-bed addition to the hospital (table 3, fig. 4) 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.

$$(V_1 + V_2 + \ldots + V_{16}) = 457{,}140 \text{ liters}$$

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

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

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

$$C_w = 5.22 \text{ mg/L (nitrate)}$$

Table 3.--*Increase in nitrate load due to proposed hospital development for a 1 million gallon per day public-supply well*

[gal/d, gallons per day; L/d, liters per day; mg/L, milligrams per liter; mg/d, milligrams per day]

Source	Flow (gal/d)	Units (variable)	Volume (L/d)	Nitrate as nitrogen concentration (mg/L)	Load (mg/d)
16. Hospital addition	200/bed	40 beds	30,280	35	1,059,800

The calculation includes the water volume and nitrate load that would be caused by the hospital addition. The resultant prediction exceeds the planning goal of 5 mg/L. If the planning goal is to be upheld, then the conclusion could 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.

Calculation of the Effects of Different Pumping Rates

Changes in pumping rates can result in decreased or increased nitrate concentration. 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. Figure 4 shows the zone of contribution for a well pumped at 1 Mgal/d (million gallons per day) and a smaller zone of contribution for the same well when pumped at 0.5 Mgal/d. 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 (tables 4 and 5), 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.

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

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

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

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

$C_w = 5.37$ 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, exceeding 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.

Table 4.--*Summary of nitrate loads from septic systems for an average one day period for a 0.5 million gallon per day public-supply well*

[gal/d, gallons per day; L/d, liters per day; mg/L, milligrams per liter; mg/d, milligrams per day]

	Source	Flow (gal/d)	Units (variable)	Volume (L/d)	Nitrate as nitrogen concentration (mg/L)	Load (mg/d)
1.	½ acre housing	65/person	300 persons	73,807	40	2,952,300
2.	High school	20/person	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 bulilding	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			$(V_1+V_2 ....+V_7) =$	241,009	$(L_1+L_2+...+L_7) =$	9,504,280

Calculations for 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 need to 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 need to 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}) need to be entered in the accounting. These considerations result in the following expansion of the dilution accounting equation:

$$\text{Concentration at public-supply well} = \frac{\text{precipitation load} + \text{source load} + \text{stream load} + \text{Zone III load}}{\text{total volume of water pumped}} \qquad (4)$$

or,

$$C_w = \frac{C_r\,(V_w - V_s - V_{III} - 0.9\,(V_1 + V_2 + \ldots + V_n)) +}{V_w}$$

$$\frac{(L_1 + L_2 + \ldots + L_n) + (V_s\,C_s) + (V_{III}\,C_{III})}{V_w} \qquad (5)$$

where the new terms are:

- V_s is volume of induced infiltration from streams, in liters;
- V_{III} is volume of drainage from Zone III into Zone II, in liters;
- C_s is nitrate concentration in induced infiltration, in milligrams per liter; and
- C_{III} is 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, need to be available wherever the zone of contribution (Zone II) has been determined.

Table 5.--*Summary of solid nitrate loads for an average one day period for a 0.5 million gallon per day public-supply well*

[ft^2, square feet; lbs/d, pounds per day; mg/d, milligrams per day]

Source	Units (variable)	Nitrate as nitrogen (lbs/d)	Milligrams/pound conversion	Load (mg/d)
8. Lawns ($5{,}000\ ft^2$)	50	0.025	454,000	567,500

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 outside of the aquifer (Zone III). 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 alternatives. Assessment and comparison of the potential effects of all sources through the nitrate accounting process described here assists in the recognition of the greatest potential sources for contamination of water quality and corresponding selection of priorities and scale of ground-water quality management efforts.

ASSUMPTIONS AND QUALIFICATIONS

1. The nitrate accounting approach described here provides the necessary information for land-use decisions that may limit ground-water 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 tolerated in the 1- to 500-mg/L range of concentration, such as nitrate, chloride, and total dissolved solids. The approach is not useful for managing or evaluating sources of other types of contamination, such as solvents and fuels. The nitrate predictions that result are approximations of long-term average concentrations, 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 recommended by the CCPEDC 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 to be computed in order to delineate the zone of contribution and, therefore, be available for nitrate calculations. In those situations where a well derives some of its yield from an area of till

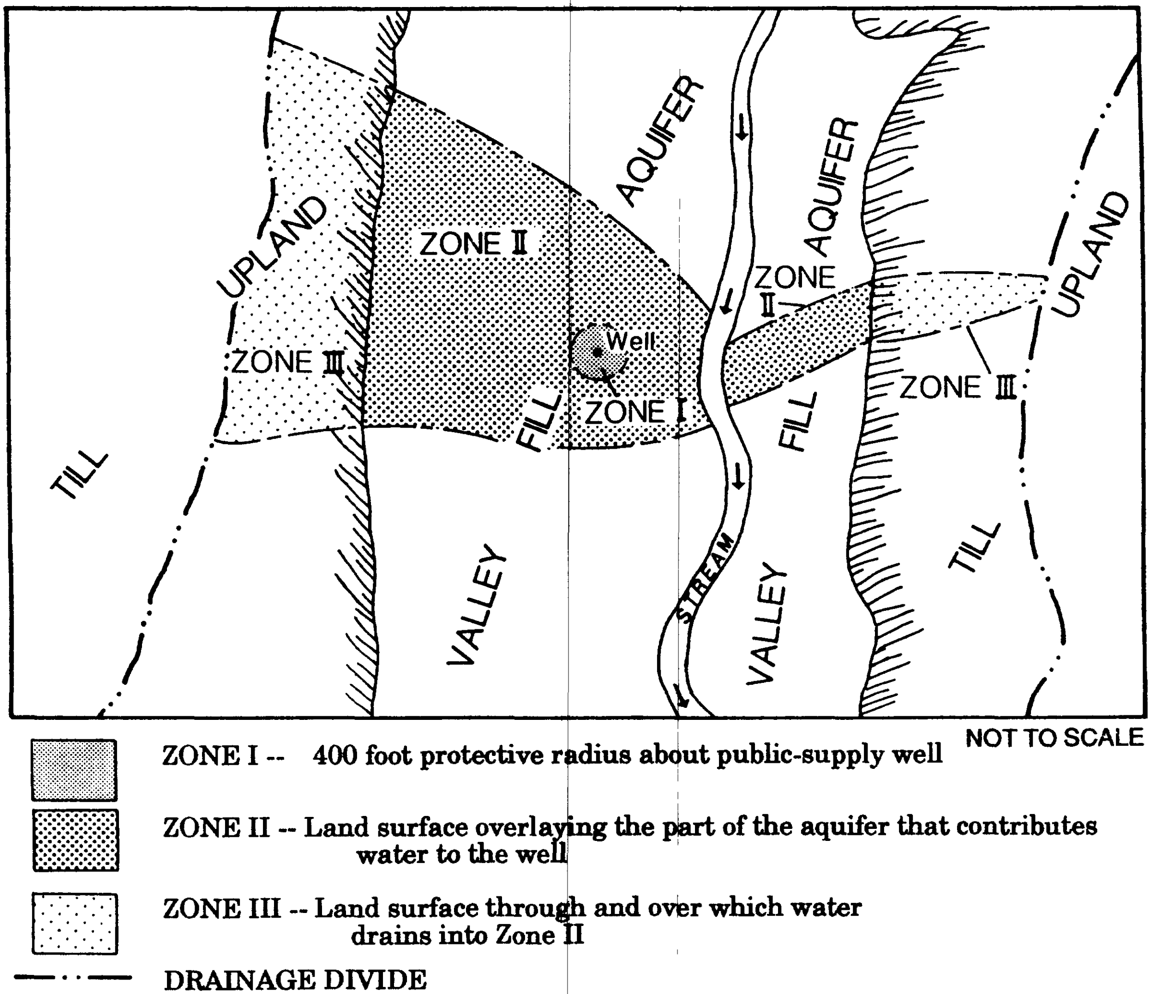


Figure 5.--Glacial-valley aquifer showing the recharge zones and stream which contribute water to a public-supply well.

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 equations are useful for predicting 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 is not appropriate for determining contaminant concentration at other points within the aquifer, or determining the concentration in any smaller (private-domestic supply) wells within the zone of contribution.

4. After entering the saturated zone, the contaminant (nitrate) is considered to be conservative. It is not precipitated or adsorbed by aquifer materials. Attenuation in the saturated zone 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. Any changes in water quality owing to renovation in the unsaturated zone need to be accounted for before load values are input to the mass-balance model. Reduction of source loads from the initial loads given in

appendix A will be dependent on soil type, the thickness of the unsaturated zone and the interaction of the source's variable components, which are specific to each zone of contribution. No renovation is assumed in the examples given in this report because the unsaturated zone is thin (10 to 30 ft) and composed of permeable coarse sand.

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 of 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 CCPEDC and estimates for Long Island, New York. Soil conditions over other aquifers will most likely allow different rates of evaporation and transpiration with proportionate adjustment of the return flow rate.

7. On the basis of nitrate analyses of about 5,000 water samples from shallow wells on Cape Cod, the nitrate concentration of ground-water 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 differ-ences 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. By predicting nitrate loading for different pumping rates and correspondingly different zones of contribution, the effects of irregular distribution of sources may be tested. It would be possible for nitrate sources 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.

CONCLUSIONS

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 ground-water quality protection areas.

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APPENDIX A

Nitrogen concentrations associated with different land uses

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 figure presented is the concentration of nitrate as 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*

[ft, feet; ft^2, square feet; gal, gallons; gal/d, gallons per day; mg/L, milligrams per liter; NO_3, nitrate; N, nitrogen]

Land Use	Unit	Flow[1] in gallons per day per person or unit	Potential[2] Concentration of NO_3 as N in mg/L	Pounds of NO_3 as N per 1,000 gallons of wastewater	
				Concentration in mg/L	Pounds of NO_3 as 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 nitrogen concentrations* -- Continued

Land use	Units	Flow in gallons per day per person or unit	Potential concentration of NO_3 as N in 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 ½ 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 (3,000 gal/d +)	seat	5	30-35

Table 1A.--*Sewage flow volumes and nitrogen concentrations* -- Continued

Land use	Units	Flow gallons per day person or unit	Potential concentration of NO_3 as N in 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 feet of frontage	450	35-40
H. stores	additional 25 feet	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

[1] 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.

[2] The potential concentration of NO_3 as N values have been taken from planning documents and sampling data 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 as N than shown in this table.

Section 2 - Animal Feedlot Nitrogen Production

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

Table 2A.--*Feedlot wastes*

[lbs, pounds; lbs/d, pounds per day]

Animal	lbs/d of nitrogen per 100 lbs of animal without loss[1]
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

[1] Livestock waste facilities handbook (Livestock Wastes Subcommittee, 1985).

Generally one ton (2,000 lbs) of manure is composed of 1,380 lbs of 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 owing to ammonia volatilization and evaporation.

Table 2B - *Influence of time and wind speed on nitrogen loss*

[mi/h, miles per hour]

Manure spread	Percent total nitrogen lost[1]	
	No wind	8 ½ mi/h wind
12 hours @ 68 °F	7.7 percent	25 percent
36 hours @ 68 °F	23 percent	31 percent
7 days @ 68 °F	36 percent	37 percent

[1] Animal waste utilization on cropland and pastureland: USDA utilization research report no. 6 (U.S. Department of Agriculture, U.S. Environmental Protection Agency, 1979).

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 lbs 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 needs to be considered. Table 3A presents values from the literature describing the nitrogen uptake potential for several crops and ground covers. (Cornell University, 1974, Harper, J., 1983 and Wells, R.G., The Fertilizer Institute, oral commun., 1986).

Table 3A.--*Nitrogen utilization by crops and commonly-occurring ground cover* [1]

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

[1] Values used are approximations from current literature. The values presented include the nitrogen fixed from the air as N and nitrate as nitrogen in soils. To achieve these values the plants need to be harvested.

Section 4 - Wastewater Treatment Facilities

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 percent of the five day Biological Oxygen Demand (BOD_5), 55 percent of the suspended solids, and 85 percent of the floating solids and solids that settle out. Secondary treatment is considered to be removal of at least 85 percent 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*

[mg/L, milligrams per liter]

Treatment process	Nitrogen removal potential percent	Total nitrogen concentration of untreated effluent mg/L	Total POST treatment nitrogen concentration mg/L
primary	no removal 0-10 percent	40	35-40
secondary	none-slight 0-30 percent	40	25-40
advanced (denitrification)	70-95 percent	40	6-10

In the Commonwealth of Massachusetts treatment plant discharges to ground waters are required to be at or less than 10 mg/L if the effluent is industrial waste, over 150,000 gallons per day of sanitary wastewater, or is discharged 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 country's 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 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", (Harper, 1983). The rates of application suggested should stimulate <u>maximum</u> 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 and recommended fertilizer application*

[ft^2, square feet]

Grass type	Fertilizer	Pounds/nitrogen 1,000 ft^2/year	Recommended[1] 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

[1] Turf and garden fertilizer handbook (Harper, J., 1983).

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

Section 8 - Nutrient Input from Lawn Fertilizers

The Long Island comprehensive waste treatment management plan (Nassau-Suffolk Regional Planning Board, 1978) presented fertilizer application rates thought to be typical for lawns on Long Island. It was assumed that:

- 3 lbs of nitrogen are applied per 1,000 ft^2/yr of lawn
- most lawns are 5,000 ft^2
- 1,000 $ft^2 \times 5 \times 3$ lbs nitrogen = 15 lbs nitrogen/5,000 ft^2/yr
- 60 percent of nitrogen applied (15 lbs) leached into ground water
- 60 percent $\times$ 15 lbs = 9 lbs
- nitrogen converted to nitrate form
- 9 lbs nitrate nitrogen /5,000 ft^2 lawn/yr leaches to ground water

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

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

Conversations with several life long residents of Cape Cod suggest that the 3 lbs/1,000 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 that are meticulously maintained apparently apply on the average between 3 and 4 pounds of nitrogen per 1,000 ft^2 per year. It is highly unlikely that the average lawn on Cape Cod is maintained to such rigorous standards. For argument's sake, assume that the average 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 ground water through vegetative cover and soils. Nitrogen applied to the land surface from various fertilizers is presumed to be converted to nitrate and from 10-60 percent of the volume initially applied will reach the ground water as nitrate. This large range of leaching nitrate is dependent on the factors listed above. Values in the neighborhood of 45-50 percent 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*

[ft^2, square feet; lbs, pounds; yr, year]

Application rate (lbs/1,000 ft^2/yr)	×	Average lawn size (ft^2)	×	Nitrogen leaching (percent)	×	Nitrate nitrogen volume available to ground water (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 5,000 ft^2 (CCPEDC, 1979) these are the probable ranges of nitrogen likely to leach into ground water. The application rate of 6 lbs/1,000 ft^2/yr was used to demonstrate volumes that are generated by overzealous 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). Overfertilization may be harmful to the plants and results in excess nitrogen available to leach into ground water. 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 ground-water quality.

Section 10 - Golf Courses

Fertilization rates for two golf course settings were available for review (Belfit, G., CCPEDC, oral commun., 1986). Both courses are situated on Cape Cod.

Table 10A.--*Fertilization rates for two golf courses on Cape Cod*

[ft^2, square feet; lbs, pounds; yr, year]

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

Because fairways generally constitute close to 90 percent 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 $ft^2 \times$ 43560 ft^2/acre = between 135-17 lbs/acre/yr

Section 11 --Recharge from Precipitation

Thirty percent of about 5,000 ground-water samples from Cape Cod had nitrate as nitrogen 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 ground water 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 concentration values for recharge need to be developed from empirical 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

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

[1] Use of product or trade names is for identification purposes only and does not constitute endorsement by the authors, the U.S. Geological Survey, the Massachusetts Department of Environmental Quality Engineering, the Cape Cod Planning and Economic Development Commission, or the U.S. Environmental Protection Agency.

lons 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
Motel	75.00/people	160 people	45423.60	35.00	1589626.00
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)
100 lawns @ 5000 ft^2 each	500000 ft^2	0.005/1000 ft^2	454000	1135000.00
6 horses @ 1200 lbs. each	7200 lbs.	0.027/100 lbs. of animal	454000	882576.00
			Total solid LOAD =	2017576.00

Total nitrate LOAD, liquid and solid combined (L1 + L2 + . . . Ln) = 18515806.05

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

0.05 mg/L

4) (Vw) - Volume of pumpage from well

VOLUME (GPD)	CONVERSION (GPD) × 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 Zone III to Zone II

(VIII) - Volume of drainage from Zone III into Zone II 0.00 L

(CIII) - Nitrate concentration of drainage from Zone III to Zone II 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 = 4.94 mg/L

APPENDIX C

List of acronyms, chemical formulas and mathematical symbols used

Acronyms

BOD$_5$: 5 day biological oxygen demand

CCAMP: Cape Cod Aquifer Management Project

CCPEDC: Cape Cod Planning and Economic Development Commission

CMR: Code of Massachusetts Regulations

GPD: gallons per day

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_{II}: volume of drainage from Zone III into Zone II (liters)

Chemical Formulas

N: nitrogen

N_2: nitrogen (atmospheric)

NO_2: nitrite nitrogen

NO_3: nitrate nitrogen

NH_3: ammonia nitrogen

NH_4: ammonia nitrogen (ionized)

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