Oyster Pond: Links between watershed land-use and nitrogen loading rates, and a discussion of management issues

Sarah R. Good

Boston University Marine Progam, Marine Biological Laboratory,
Woods Hole, MA 02543

Abstract

Eutrophication of estuaries, stimulated by anthropogenic nitrogen loading, is of increasing concern on Cape Cod and throughout the world. Land-use surrounding estuaries plays an important role in the amount of nitrogen entering a body of water. Land covers differ throughout the Oyster Pond watershed. A Nitrogen Load Model (NLM) developed for use in rural to suburban coastal watersheds underlain by unconsolidated coarse sediments, was applied to the Oyster Pond watershed. The N load entering this estuary from the watershed was estimated and the relative potential effectiveness of management options for reducing the N load to this estuary were evaluated.

The predicted N load to Oyster Pond was 878 kg N y^{-1}. Wastewater derived nitrogen contributed 69% of the total N load. Wastewater contribution to the N load is correlated to the number of people living in an area. The N load to Oyster Pond is relatively low compared to other estuaries on Cape Cod.

It is possible to decrease the N load even under build-out conditions by installing septic systems with higher retention rates than conventional models. The greatest change in N load (19% decrease from present) was predicted for build-out conditions where new buildings contained RUCK® septic systems and a package treatment plant is installed. Managing fertilizer application has limited potential because fertilizer contributes only 7% to the total N load. It is hoped that these NLM predictions will assist with future decision-making concerning nitrogen loads to this estuary.

Introduction

A major human impact to estuaries results from increasing eutrophication (GESAMP 1990). Eutrophication of estuaries, stimulated by anthropogenic nitrogen loading, is of increasing concern on Cape Cod and throughout the world (GESAMP 1990) because nitrogen supply generally limits growth of phytoplankton and macroalgae in coastal waters (Duarte 1995). As the amount of nitrogen from anthropogenic sources increases, the composition of primary producers and the mosaic of coastal habitats are altered (Valiela et al. 1992). Coastal embayments and estuaries such as those found on Cape Cod are particularly vulnerable to these influences. Nitrogen loading to estuaries has become a primary concern to coastal managers and other stakeholders (Valiela and Bowen 2002). Therefore, it has become increasingly important to identify appropriate land management options (Valiela et al. 1999).

The major sources of nitrogen entering coastal estuarine systems are atmospheric deposition, fertilizer application, and septic wastewater (Valiela et al. 1997). Nitrogen travels to estuaries through groundwater and surface water flows as well as through direct atmospheric deposition. The geology of a watershed determines the relative magnitude of nitrogen transport pathways (Giblin and Gaines 1990).

In areas that are underlain with highly permeable soil, such as those found on Cape Cod nitrogen travels to estuaries through groundwater sources (Emery 1997). High permeability ensures that groundwater is the dominant pathway for freshwater traveling to estuaries (Millham and Howes 1994). This is because rainwater travels quickly through the permeable soil layer, producing little surface run-off (Valiela 1995).

Land-use surrounding estuaries plays an important role in the amount of nitrogen entering a body of water. Oyster Pond is a coastal pond on Cape Cod, Massachusetts. Land in the Oyster Pond watershed has been altered throughout the years (Emery 1997). Signs of declining health such as loss of white perch and water lilies were reported at Oyster Pond in the 1980's. Since that time, managers and stakeholders have been interested in restoring the health of the pond. The nitrogen load and the impact that changes in land-use have on nitrogen loads to Oyster Pond are of great concern (Emery 1997).

Land covers in different areas within the Oyster Pond watershed differ substantially. The different usages furnished the possibility to examine whether rates of land-derived nitrogen loads delivered from specific subsections of the pond varied. The watershed was divided into 7 arbitrary recharge zones (Fig. 1). This makes it possible to measure responses to the different loads by water quality, plants, algae, and fauna to be described in other papers in this volume.

A Nitrogen Load Model (NLM) was developed for use in coastal watersheds in which land use is rural to suburban, and which is underlain by unconsolidated coarse sediments (Valiela et al. 1997). NLM works by estimating inputs of nitrogen by atmospheric deposition, fertilizer use, and wastewater to surfaces of the major types of land use within the landscape of the watershed. Land-uses include natural vegetation, turf, agricultural land, residential areas and impervious surfaces. NLM then estimates losses of nitrogen with these recharge zones and calculates N load to the estuary (Valiela et al. 1997)

Septic wastewater contributes the largest portion of land-derived nitrogen to many estuaries similar to Oyster Pond (Kroeger, 1997). On Cape Cod, 98% of homes are serviced by septic systems (Heufelder and Rask 1996). In the Oyster Pond watershed all the wastewater is treated by septic systems. Therefore, decreasing the amount of nitrogen from septic wastewater should considered when making management decisions.

Altering the effectiveness of the nitrogen retention in septic systems is one way to minimize the impact of increased N load due to new developments, such as those occurring under build-out conditions (Bowen and Valiela submitted). Retrofitting septic systems throughout a watershed is politically daunting and economically unfeasible (Bowen and Valiela submitted). A more cost-effective alternative may be to focus on those septic systems that have not yet been installed.

There are many septic systems with a wide range of nitrogen retention rates. Conventional septic systems can retain an average of 39% of the nitrogen from wastewater (Valiela et al. 1997). RUCK ® septic systems have a higher nitrogen retention rate than conventional models, removing 78% of the total nitrogen from the wastewater. Another possible option designed to decrease the amount of wastewater-derived nitrogen, is the establishment of a septic package plant. Small-scale package treatment plants designed to treat effluent volumes from local neighborhoods are becoming more common (EPA 2000). Particular developments located within the Oyster Pond watershed may be candidates for a package treatment plant as a method for decreasing N loads to the estuary.

In this paper NLM is used to 1) estimate N load entering Oyster Pond from the watershed; 2) estimate the relative contributions of wastewater, fertilizer, and atmospheric deposition to Oyster Pond; 3) compare the magnitude of the N load to nitrogen loads to other Cape Cod estuaries; 4) evaluate the relative potential effectiveness of management options for reducing the nitrogen load to Oyster Pond.

Methods

NLM was used to estimate the N load to Oyster Pond. The watershed was divided into 7 recharge zones. This delineation was based on water table contour maps (Emery 1997). The area for each land-use including natural vegetation, turf, agricultural, residential, and impervious surfaces (roads, driveways, and roofs) were assessed using Geographical Information System (GIS) based on 1998 aerial photographs.

NLM includes average inputs for atmospheric deposition, fertilizer application and septic wastewater based on calculated inputs used in a study of Waquoit Bay (Valiela et al. 1997). In order to determine the effects of inputs from residential areas, houses were counted for each recharge zone. The occupancy rate calculated by Valiela et al (1997) determined the average number of people per house per year for this area of Cape Cod. For particular developments this rate was modified due to seasonal occupancy and living unit divisions.

NLM was used to calculate nitrogen inputs of atmospheric deposition, fertilizer application, and septic wastewater based on loading rates for each land-use. Results from the model were compared to N loads to other local estuaries.

Management options were evaluated for effectiveness and N loads were calculated for the following scenarios. The number of buildable plots remaining within the watershed was assessed in order to run NLM for build-out conditions defined as scenario 1. Scenario 2 estimated the N load at build-out if all new buildings were equipped with high retention septic systems made by RUCK ®. Scenario 3 estimated the N load under present conditions with a package-treatment plant installed to a community located in recharge area 3. Scenario 4 estimated the N load with the same package treatment plant installed for scenario3, under build-out conditions. Scenario 5 estimated the N load under build-out conditions if a package treatment plant were and all new buildings contained RUCK® septic systems. In addition, the NLM was used to determine the effectiveness of decreasing fertilizer use by reducing the number of lawns or decreasing the fertilizer rates on the total N load.

Results and Discussion

The predicted total N load to Oyster Pond was 878 kg N^{-1} (Table 1). The expected total N load for septic wastewater was 610 kg N^{-1} (69% of the total N load), atmospheric deposition contributed 208 kg N^{-1} (24% of the total N load), and fertilizer application contributed 60 kg N^{-1} (7% of the total N load) (Table1). Recharge zone 3 contributed the greatest portion to the N load from the watershed, making up 39% of the total N load (340 kg N^{-1}). 71% of the nitrogen from recharge zone 3 was comprised of wastewater (Table 1).

The input to the watershed from each source reveals that atmospheric deposition contributes the most nitrogen to the watershed (1348 kg N^{-1}) (Table 2). However, atmospheric deposition has a higher loss during its travel from source to estuary than other sources. As a result, atmospheric deposition contributes only 24% of the total nitrogen load entering Oyster Pond. Because it has a smaller loss rate in the watershed, wastewater accounts for 69% of the total nitrogen entering Oyster Pond, even though it contributes less nitrogen to the watershed than atmospheric deposition. Fertilizer contributes relatively small amounts of input into the watershed and the estuary, representing only 7%of the total nitrogen entering the estuary (Table 2).

To show the contribution of nitrogen from various sources, the proportion of the total N load was reported for septic-, fertilizer-, and atmospheric-deposition contributions and compared with the number of people living in each recharge zone (Fig. 3). NLM predictions suggest that wastewater contribution to the N load is directly related to the number of people in a recharge zone (Fig.3). Septic wastewater makes up 69% of the total N load and the contribution to wastewater is correlated with the number of people living in a recharge zone. This suggests that as more developments are built within this watershed, management options targeting septic wastewater may be most successful for altering the total N load to Oyster Pond.

The N load to Oyster Pond appears relatively low compared to other estuaries on Cape Cod (Table 3). The Childs River watershed is much more developed and has a much higher total N load. The watershed surrounding Sage Lot Pond is in near pristine conditions. The N load to Oyster Pond falls between these two estuaries, much closer to the N load values for Sage Lot Pond.

The Oyster Pond watershed is currently at 87% of build-out. As this watershed approaches build-out there is mounting concern for the impact new development will have on the N load entering the estuary. There appear to only be 29 empty, buildable plots within the Oyster Pond watershed that are likely to be built upon. Increasing the number of houses may increase nitrogen entering Oyster Pond, depending upon the future decisions of landowners and managers.

To limit the total N load, it is important to assess management options with the greatest potential form limiting the amount of nitrogen entering the watershed. NLM is a tool with which it is possible to manipulate various management scenarios, indicating what efforts should be undertaken to achieve N loading goals (Valiela et al. 1997).

Under a build-out scenario (Table 3, scenario 1) the predicted N load would increase 11% if all the septic tanks were traditional (39% N retention), however, if the new homes were equipped with RUCK ® septic systems, there would only be a 3.8% increase from today's N load (Table 3, scenario 2). It appears as though increasing the effectiveness of septic systems may be a feasible way to minimize the impact of wastewater nitrogen under build-out conditions.

Installing a package plant in a development located in recharge zone may be another effective option for decreasing the N load to Oyster Pond. The Treetops development is an appropriate candidate for a package treatment plant due to its size and location in recharge zone 3. If the Treetops development were equipped with a package treatment plant, the total N load would decrease by 25% (Table 3, scenario 3). If a package treatment plant were installed at this development under build-out conditions, the N load would be reduced from the present conditions by 13% (if new homes had traditional septic systems installed) and by 19% (if new homes had RUCK ® systems installed) (Table 3, scenario 4 and 5). These simulations suggest that it is possible to maintain current N loads, even under build-out conditions by changing to septic systems that have increased nitrogen retention for new homes and/or by implementing a package treatment plan at a development in recharge zone 3.

In addition to increased wastewater inputs, an increase in houses under build-out conditions also has a potential impact on the number of lawns fertilized. Fertilizer use within the Oyster Pond watershed is primarily due to lawn use. Lawns receive fertilizer at a rate of 122 kg N ha^{-1} y^{-1}, and it is estimated that 34% of homes use fertilizer (Giblin and Gaines 1990). Management options designed to decrease the impact of fertilizer application to the total N load were investigated.

There are two ways to lower potential fertilizer nitrogen inputs to estuaries. The amount of land that receives fertilizers can be limited, or the rate that fertilizer is applied can be limited (Bowen and Valiela submitted). Implementing either of these options have a direct effect on the total N load (Fig. 3). These simulations suggest that it is possible to decrease the N load by limiting the number of lawns that are fertilized and/or by limiting the amount of fertilizer used on the lawns that are fertilized within the Oyster Pond watershed. However, decreasing fertilizer use in the Oyster Pond watershed will have a limited impact on the total N load because fertilizer nitrogen represents only 7% of the total N load (Table 3).

Looking at various management options allows us to see ways in which it is possible to not only maintain the current N loads, but that it is possible to decrease the total N load to Oyster Pond even under build-out conditions. There have already been many management options implemented within the Oyster Pond watershed. It is hoped that these NLM predictions will assist with future decision-making concerning nitrogen loads to this estuary.

Literature Cited

Bowen, J.L. and I. Valiela. 2001. The ecological effects of urbanization of coastal watersheds: historical increases in nitrogen loads and eutrophication of Waquoit Bay estuaries. Canadian Journal of Fisheries Aquatic Sciences 58:1489-1500.

Duarte, C. M. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. Ophelia 41:87-112.

Emery, K.O. 1997. A Coastal Pond Studied by Oceanographic Methods. Oyster Pond Environmental Trust, Inc., Woods Hole, Massachusetts.

Environmental Protection Agency. 2000. Wastewater Technology Fact Sheet: Package Plants. Office of Water US EPA, Washington D.C. EPA 832-F-00-016.

Giblin, A.E. and A.G. Gaines. 1990. Nitrogen input to a marine embayment and the importance of groundwater. Biogeochemistry 10:309-328.

GESAMP. 1990. State of the Marine Environment. Reports and Studies No. 39. Joint Group of Experts on the Scientific Aspects of Marine Pollution. United Nations Environment Programme.

Heufelder, G., and S. Rask. 1996. Alternative Septic System Update #9. Barnstable County Department of Health and the Environment, Barnstable, Massachusetts.

Kroeger, K.K., J.L. Bowen, D. Corcoran, J. Moorman, J. Michalowski, C. Rose, and I. Valiela. 1999. Nitrogen loading to Green Pond, Falmouth, MA: sources and evaluation of management options. Environment Cape Cod 2: 15-26.

Millham, N.P. and B.H. Howes. 1994. Freshwater flow into a coastal embayment: groundwater and surface water inputs. Limnology and Oceanography 39: 1928-1944.

Ryther, J.H., and W.M. Dunsten. 1971. Nitrogen, phosphorous, and eutrophication in the coastal marine environment. Science 171: 1008-1013.

Valiela, I., K. Foreman, M.LaMontagne, and others. 1992. Couplings of watersheds and coastal waters: sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts. Estuaries 15: 443-457.

Valiela, I. 1995. Marine Ecological Processes, 2nd ed. Springer-Verlag, New York.

Valiela, I., and J.L. Bowen. 2002. Nitrogen sources to watersheds and estuaries: Role of land cover mosaics and losses within watersheds. Environmental Pollution 118:239-248.

Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C.H. Sham. 1997. Nitrogen loading from coastal watersheds to receiving estuaries: New method and application. Ecological Applications 7: 358-380.

Valiela, I., M. Geist, J. McClelland, and G. Tomasky. 2000. Nitrogen loading from watershed to estuaries: Verification of the Waquoit Bay nitrogen loading model. Biogeochemistry 49: 277-293.

Unpublished Materials

Bowen, J.L., I. Valiela. submitted. Nitrogen loads to estuaries: Using loading models to assess the effectiveness of management options to restore estuarine water quality.

Table 1. Nitrogen loads expressed as kg N y^{-1} and as % of the total load of atmospheric deposition, septic wastewater, and fertilizer application for each recharge zone within the Oyster Pond watershed, and for the entire watershed.

Recharge Zone	Atm N		Septic N		Fert N		Total N	
	kg N y^{-1}	%	kg N y^{-1}	%	kg N y^{-1}	%	kg N y^{-1}	%
1	32	24	96	71	9	7	136	15
2	35	23	106	70	11	7	152	17
3	98	29	242	71	24	7	340	39
4	33	28	75	65	8	7	116	13
5	9	12	60	80	6	8	74	9
6	14	31	28	62	3	7	45	5
7	3	42	4	53	0	4	7	2
Entire watershed	208	24	610	69	60	7	878	100

Table 2. Contributing sources of nitrogen to Oyster Pond. The input to the watershed (kg N y-1) from each source and the losses within the watershed (kg N y-1) are shown. The total N load to the estuary and the proportion each source contributes to the total N load as calcuated using NLM.

N source	Inputs to watershed	Losses within watershed	Input to Oyster Pond	
			N load	Proportion of total
	(kg N y^{-1})	(kg N y^{-1})	kg N y^{-1}	%
Atmospheric N			208	24
Natural veg.	1348	118	114	68
Turf	138	13	13	6
Roofs, drive	69	6	6	3
Roads	52	13	15	7
Ponds	21	6	6	3
other impervious	9	2	2	1
wetlands	111	24	24	12
Wastewater N	1707	610	610	69
Fertilizer N	383	60	60	7
Total N	1726	848	878	100

Table 3. Comparison of the magnitude of the modeled nitrogen load to Oyster Pond with loads to other Cape Cod estuaries. N load is calculated as total load (kg N y^{-1}) and N loading rate (kg N y^{-1}) for the estuaries.

Estuaries	Area (ha)	Modeled N load (kg N y^{-1})	Modeled N load rate (kg N y^{-1} ha^{-1})
Childs River[1]	13.5	5536	410
Quashnet River[1]	28	8406	300
Oyster Pond	27.7	878	32
Sage Lot Pond[1]	70	361	5

[1] adapted from Kroeger et al. (1999)

Table 4. Nitrogen load determined by NLM for various wastewater management scenarios; build-out (scenario 1), build-out with new homes using RUCK ® septic systems (scenario 2), current conditions with a package treatment plant at Treetops development (scenario 3), build-out conditions with package treatment plant at Treetops development (scenario 4) and build-out conditions with new homes using RUCK ® septic systems and package treatment plant at Treetops development (scenario 5).

Scenarios	Total N load ($kg\ N\ y^{-1}$)	Change % from present
1 Build-out	974	11
2 Build-out with RUCK ® for new building	911	3.8
3 Package plant at Treetops under present conditions	662	-25
4 Package plant at Treetops under build-out conditions	758	-13
5 Build-out conditions with RUCK ® for new buildings and package plant at Treetops	695	-19

Figure Legends

Figure 1. Map of the Oyster Pond watershed on Cape Cod, Massachusetts. The outside polygon represents the land withiin the watershed. Subdivisions within the watershed represent recharge zones indicated with numbers.

Figure 2. The percent total N load of wastewater, atmospheric, and fertilizer predicted in comparison to the number of people residing in the watershed recharge zones. the percent N load increases as the number of people living within a recharge zone incrase for wastewater-, fertilizer-, and atmospheric-deposition.

Figure 3. The reduction in nitrogen loads predicted as a result of decreases in the percent of land that receives fertilizer (top), and the fertilizer application rates (bottom). The dotted lines represent present conditions.

Figure 1.

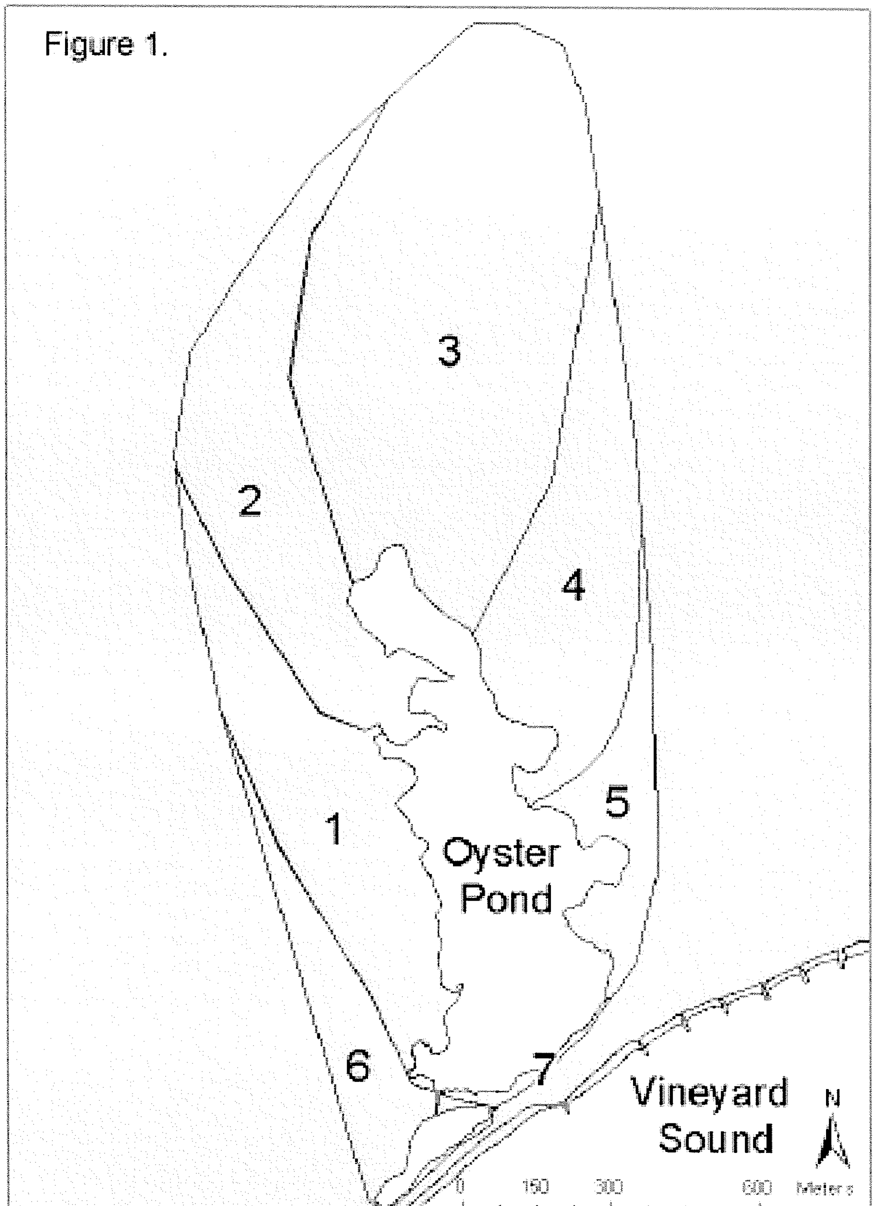
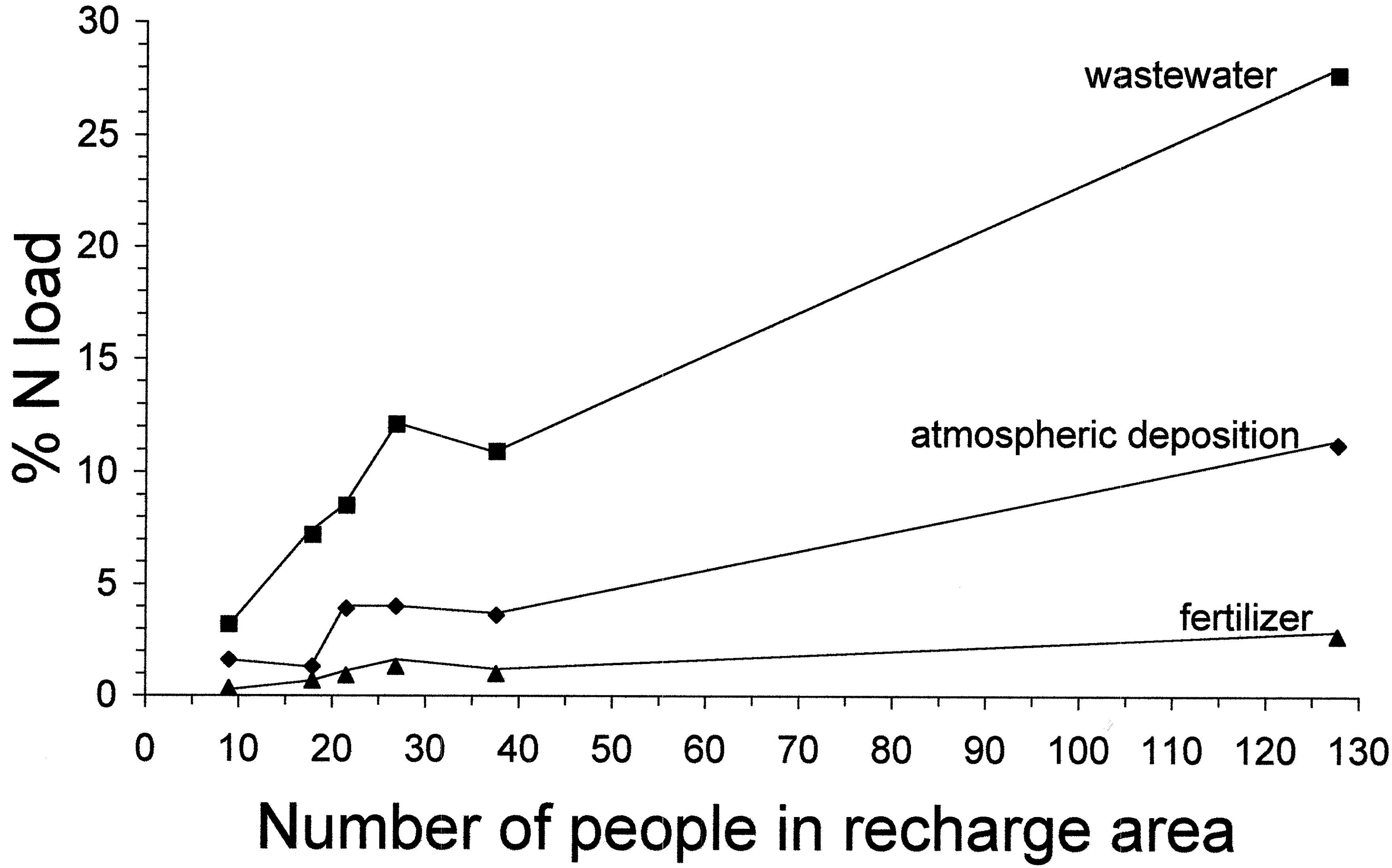
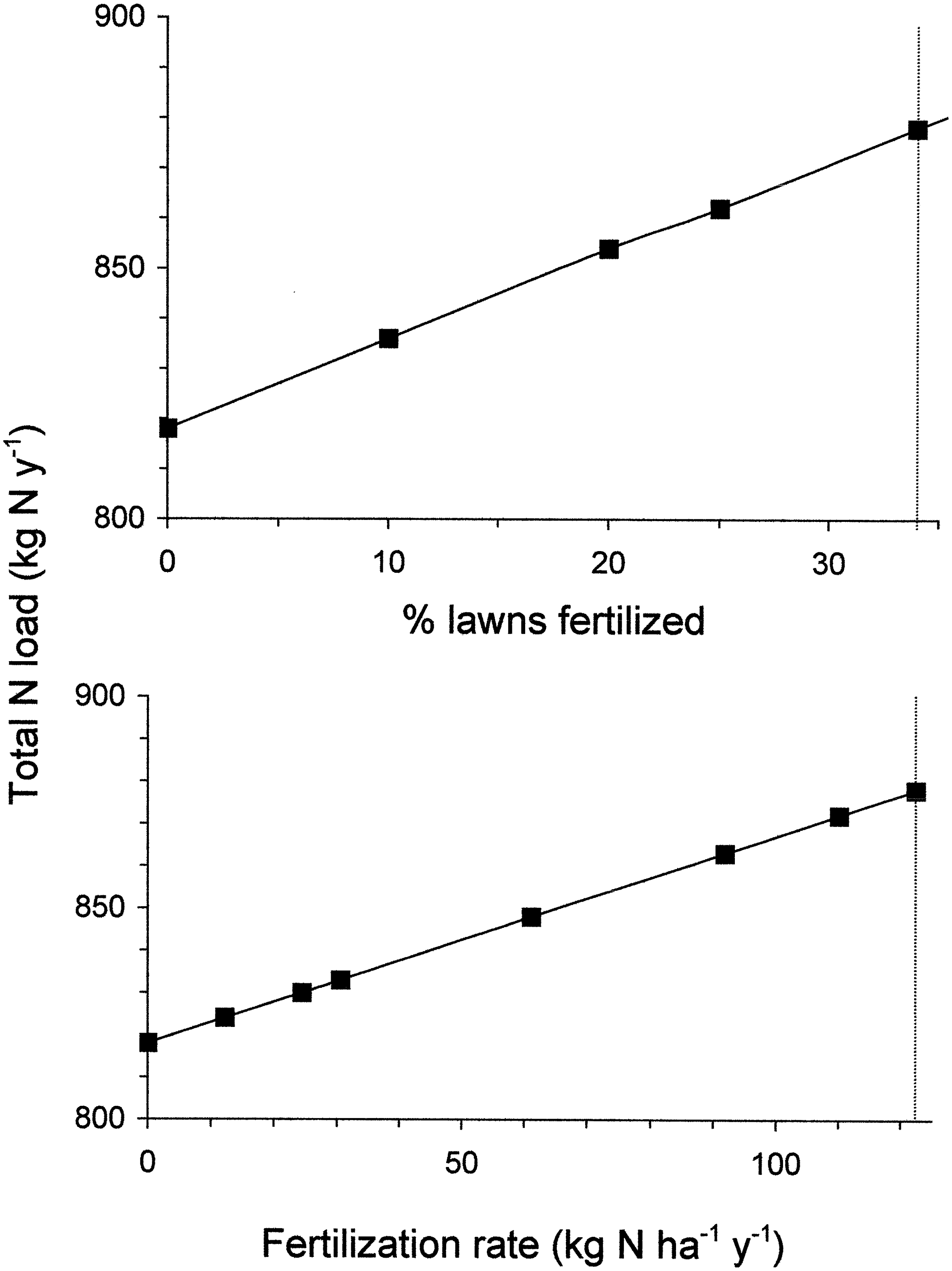


Figure 2



wastewater
atmospheric deposition
fertilizer
% N load
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Number of people in recharge area

Figure 3



Total N load (kg N y-1)
900
850
800
0
10
20
30
% lawns fertilized
900
850
800
0
50
100
Fertilization rate (kg N ha-1 y-1)