Use of a Geographic Information System to estimate nitrogen loading to coastal watersheds

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Summary

The Buzzards Bay Project, a participant in the U.S. Environmental Protection Agency's National Estuary Program, has developed a management strategy to protect and restore water quality and living resources in Buzzards Bay embayments from excessive inputs of nitrogen from human activities. The implementation of this strategy requires an evaluation of existing and potential future inputs of anthropogenic nitrogen from sources within each embayment's drainage basin, to determine if existing or future inputs will exceed recommended nitrogen loading limits. Such an approach requires an evaluation of each parcel of land within the drainage basin to determine the number of existing housing units and future development potential based on local zoning regulations. In this way, existing and potential future "non-point sources" of nitrogen can be determined.

Because a parcel level land use analysis within a drainage basin can be somewhat costly and time consuming, a simplified GIS land use evaluation process was developed to determine which embayments are most likely to require nitrogen controls. This "first-cut" analysis of nitrogen loading was based on an evaluation of land use data and U.S. Census data stored in the Massachusetts Geographic Information System (MassGIS). The land use database was derived from 1:25,000 scale photographs.

Because, in most cases, the majority of anthropogenic nitrogen added to Buzzards Bay embayments is derived from on-site sewage disposal systems, reasonable estimates of nitrogen loading from land use requires good algorithms to predict housing units. Such a relationship was defined empirically for the four MassGIS residential land use categories that could be used to predict housing units for nearly all subbasins around Buzzards Bay. Once the number of housing units were calculated, loadings from septic systems, lawns, and impervious surface were estimated using standards adopted by the Buzzards Bay Project and US Census occupancy rate data. Loading rates for non-residential land use were adopted from literature sources.

Introduction

The Buzzards Bay Project proposed that local, regional, and state authorities adopt nitrogen loading rate limits to protect Buzzards Bay's more than 30 major coastal embayments from excessive inputs of nitrogen (EPA and EOEA, 1991). It was suggested these limits be based on either tiered limits that incorporate the bathymetry of the receiving waters, hydraulic turnover times, and existing water quality classifications, or be based on some other appropriate site specific scientific information. These nitrogen loading rate limits would be used to establish embayment-specific total maximum annual loads (TMALs) for anthropogenic nitrogen from the surrounding drainage basin (Fig. 1).

To implement the Buzzards Bay Project's management strategy, it is necessary to determine whether nitrogen loading to an embayment's drainage basin currently exceeds the embayments recommended maximum annual nitrogen load, or has the potential to exceed this annual load when the drainage basin reaches its full "build-out" potential. This process requires an evaluation of nitrogen loadings from both point source and nonpoint source discharges. The nonpoint source nitrogen loadings would be evaluated by performing a land use analysis on each individually owned parcel of land in the surrounding drainage basin. Point source loadings would be quantified from state and federal discharge permits to surface or groundwater.

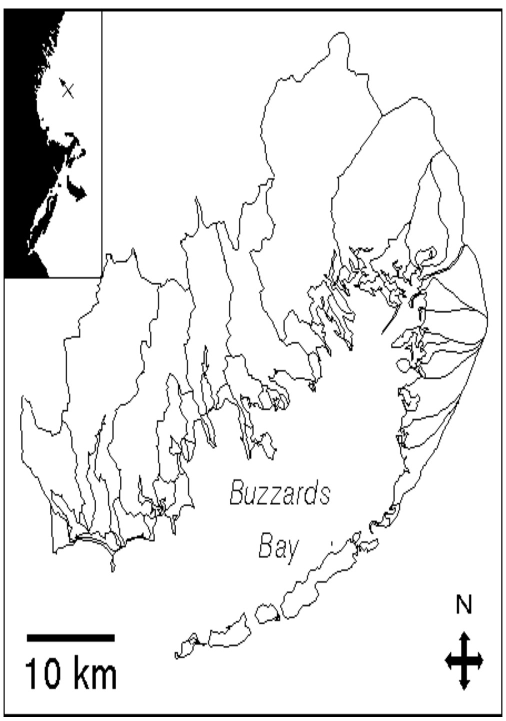

Figure 1. Buzzards Bay basin showing subbasins around 31 major embayments. Inset shows location of Buzzards Bay along Northeast U.S. seaboard.

Although more than 50% of the nitrogen to Buzzards Bay as a whole is discharged by point sources, principally municipal wastewater treatment facility outfalls, in most Buzzards Bay embayments, non-point sources of nitrogen, especially from on-site wastewater disposal systems (septic systems) and fertilizer used on lawns, golf courses, and agricultural land (Kelly *et al.*, 1992; SAIC, 1992) are the principal source of nitrogen. For example in Buttermilk Bay, a typical Buzzards Bay embayment, septic systems alone accounted for more than 70% of anthropogenic nitrogen loading (Horsley Witten and Hegemann, 1991).

Because the parcel level land use analysis that is required to evaluate non-point sources of nitrogen loading within each Buzzards Bay subdrainage basin is somewhat costly and time consuming, a simplified land use evaluation process was developed to determine which embayments are most likely to require management action to control nitrogen. This "first-cut" analysis of nitrogen loading was based on an evaluation of land use data and U.S. Census data stored in the Massachusetts Geographic Information System (MassGIS). The land use database was derived from 1:25,000 scale photographs.

Methods

Land use within 30 Buzzards Bay sub-drainage basins was derived from the Commonwealth of Massachusetts MassGIS Project which employs ARC-INFO™ software. The land use data was compiled by interpreting 1:25,000 scale color infra-red aerial photographs taken in 1984. Features as small as 0.4 ha (1 acre) were interpreted and classified as one of 21 possible land use categories. Among these land use classifications were three agricultural land use categories and four residential categories. The four residential categories were "multi-family" (R0, generally large apartment or condominium complexes), lots smaller than ¼ acre (R1), lots ¼ to ½ acre (R2), and lots greater than ½ acre (R3). Figure 2 shows MassGIS land-use for the Buttermilk Bay watershed, grouped into seven categories for clarity.

For most of these land-use categories, we used nitrogen loading rates typical for that land use from published data and other assumptions described below and elsewhere (see EPA and EOEA, 1991; Costa *et al.*, 1993). Most of our effort, and the focus of this paper, is the estimation of dwelling unit and population density within the four residential land use categories because, as noted above, it is believed that residential land use accounts for the majority of nitrogen inputs to most Buzzards Bay embayments. Once the housing unit densities were calculated, we applied assumed loading rates for septic systems, lawns, and impervious surfaces that were adopted by the Buzzards Bay Project (EPA and EOEA, 1991).

To estimate housing unit density for the four residential land use categories, we counted residential structures (usually single family homes) within randomly selected polygons for each of the four residential land use categories on the GIS system. Residential structures were counted on either USGS 1:25,000 scale quad sheets (photo updated 1972 or 1979), 1981 color photographs, or 1990 black and white orthophotographs. Because the land use evaluation was based on 1984 photographs that were not available for this study, quad sheets were used only to estimate housing unit densities where there

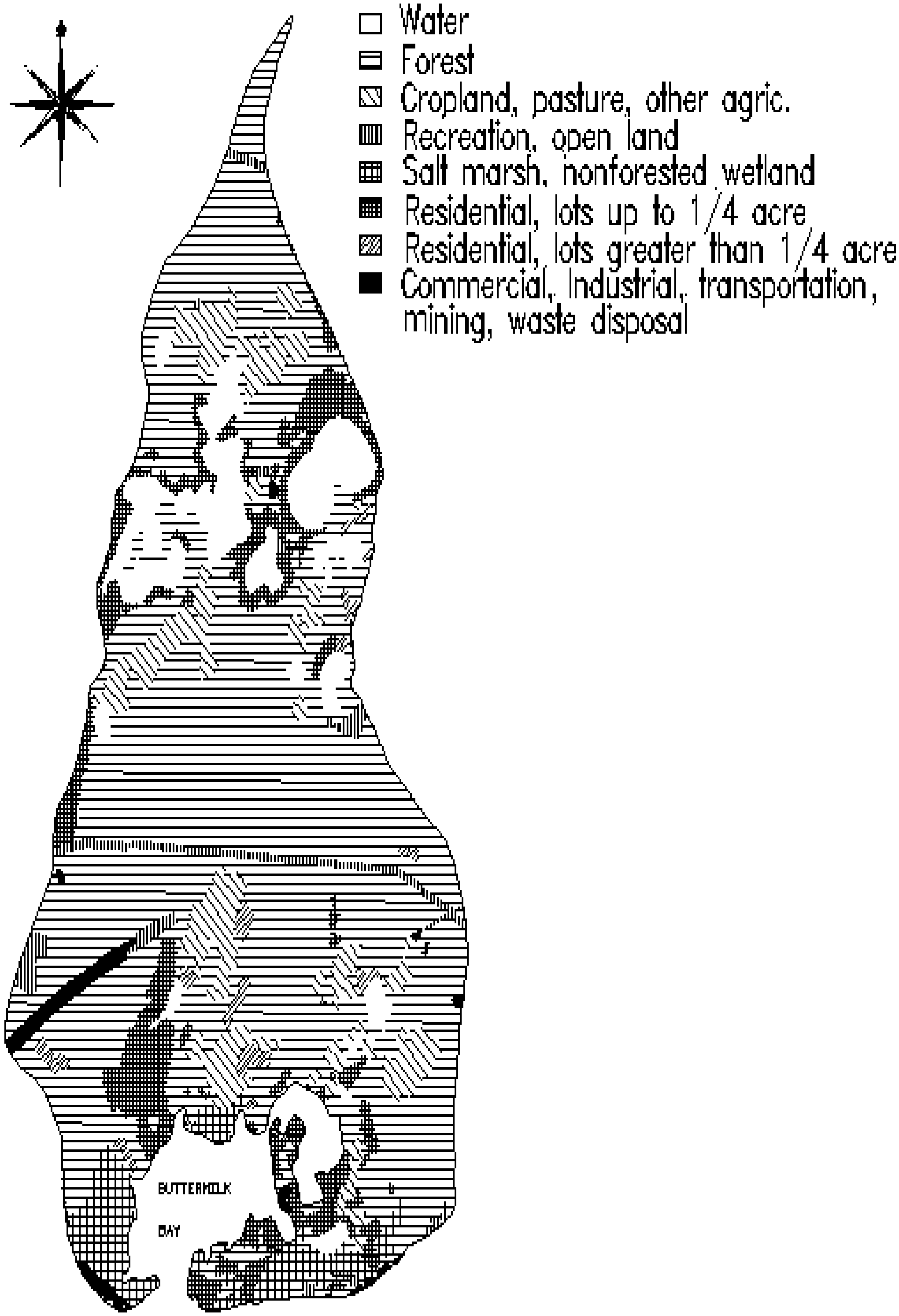

Figure 2. MassGIS 1984 land use for the Buttermilk Bay subbasin aggregated into 7 classes for simplification.

has been little new construction between the time the maps were prepared and 1984. Counts from the 1981 and 1990 photographs were sometimes interpolated. We assumed each house counted was a single family unit (US Census data suggests that in most Buzzards Bay towns, 80% of the dwellings are single family units).

Once the number of units in a subbasin was estimated using the MassGIS land use data, we multiplied this number by the occupancy rate for that subbasin as estimated from US Census data to obtain existing subbasin populations. It was possible to estimate the occupancy rate specific for each embayment subbasin from the U.S. Census data because some of the Census data had also been incorporated into the MassGIS system. Both U.S Census population "block" and housing unit "block group" aggregate polygons have been digitized and registered with the land use data. Within the Buzzards Bay drainage basin, approximately 9,759 population blocks are defined. Since the population of the Buzzards Bay basin is approximately 235,000, this suggests a mean regional block density of 24.0 people. For those blocks that crossed watershed boundaries, we developed an algorithm to divide populations within the block proportionally to the area of the polygon within each subbasin. Approximately 19% of the population blocks were bisected by at least one subbasin boundary.

The process for estimating the number of housing units from the U.S. Census data was somewhat more complicated because the "block group" polygons are large. There are only 350 block group aggregates in the Buzzards Bay basin, but nearly 59,400 housing units, so each block group has an average of 170 units. Since most of these block groups cross at least one subbasin boundary, potential errors would be introduced by assuming housing units densities were uniform over the block group aggregate. To adjust for this source of error, we first estimated the ratio of population of the block group in the basin vs the total for the entire block group. This ratio was than multiplied by the total number of units in the block group to obtain the units of that block group in the subbasin. Errors can be introduced by this methodology if occupancy rate is not uniform over the block group polygon, but overall we felt this approach resulted in the best possible estimates using the available information.

Because some early estimates of nitrogen loading developed by the Buzzards Bay Project were based on a set of *a priori* assumptions relating to unit density in the four residential land use categories, these *a priori* assumptions are described. To evaluate the validity of the estimates of numbers of units and population derived from the land use data (using both *a priori* assumptions and empirical measurements of housing densities), we compared our estimates of dwelling units and population in each subbasin to U.S. Census data, both in town and subwatershed comparisons.

To estimate 1984 units within town boundaries from the U.S. Census statistics, the 1980 and 1990 Census unit data were interpolated. For the embayment level drainage basin comparisons, only 1990 U.S. Census statistics for units and population were available on the GIS system and so only these data were compared to estimates from MassGIS land use. To demonstrate how the loading constants described here can be applied to the MassGIS land use data, we report the annual loading of nitrogen to 28 of 31 Buzzards Bay embayments.

Embayments that included land use within the city of New Bedford were not included in this report because its pattern of development)older urban/industrial development consist of very small lots with many multi-level dwellings)is atypical of the remaining 85% of the Buzzards Bay drainage basin which consists mostly of suburban single family dwellings, mostly on lots 1/3 acre or larger. Also, New Bedford and urban areas like it do not lend themselves to this nitrogen loading analysis because wastewater and stormwater are collected in the sewer system and discharged through outfalls.

We have adopted in our analysis of MassGIS land use data, where possible, the loading assumptions adopted for the Buzzards Bay Project's parcel level land use analysis (see Costa *et. al.*, 1994) including contributions of nitrogen from septic systems, lawns, and impervious surfaces. Below we describe our assumptions on how we translated the MassGIS data into meaningful loading rates, including any variances in our previous assumptions.

Results

Calculating units and population from residential land use

A priori assumptions vs empirical observations

Actual lot size vary widely in the four residential GIS land use categories. In practice, lots most typically conform to minimum lot sizes defined in zoning regulations, the most common of which are 10,000, 15,000, 20,000, 30,000, 40,000 ("1 acre zoning"), 60,000 and 80,000 ft^2. During the past two decades, there has been a trend to increase minimum lot size, and most zoned unsubdivided areas rarely have minimum lot sizes less than 20,000 ft^2.

Previously, the Buzzards Bay Project used a set of *a priori* assumptions to estimate unit density for the four residential land use categories. For R3 (lots greater than ½ acre), we presumed a 40,000 ft^2 typical lot size, for R2 (¼ to ½ acre lots) we presumed 20,000 ft^2 lots typical, and for R1 (<¼ acre lots))mostly areas developed more than 30 years ago)we presumed 10,000 ft^2 lots are most typical. For multi-family classified land-use (R0) we presumed five units per acre. Because the land use classification system did not account for roads, we assumed the land area required for infrastructure such as roads, sidewalks (or road easements), and other non-lot land uses averaged 15% of the polygons for the R1 classifications, and 10% for the two larger lot size land use categories (R2 and R3). These infrastructure percent cover values are often used by planners (e.g. Horsley Witten and Hegemann, 1990). The resultant unit densities for the four residential land use categories using the *a priori* assumptions are shown in Table 1.

Table 1. *A priori* assumptions of resultant unit density in MassGIS residential landuse categories.

MassGIS residential category	**assumed typical lot size (sq. ft.)**	**% infra-structure**	**density (units/ac)**
R0: "multi-family"	NA	NA	5.0
R1: "smaller than ¼ acre lots"	10,000	15	3.7
R2: "¼-½ acre lots"	20,000	10	2.0
R3: "larger than ½ acre lots"	40,000	10	1.0

Table 2. Actual mean unit density (± standard error) in GIS residential land use categories in selected GIS polygons as observed on areal photographs and other sources.

MassGIS residential category	**polygon sample size**	**density (units/ac±SE)**
R1: "smaller than ¼ acre lots"	13	3.75±.37
R2: "¼-½ acre lots"	11	2.19±.27
R3: "larger than ½ acre lots"	62	1.04±.05

Actual unit densities for residential land use classes R1-R3 were similar (Table 2) to the *a priori* housing unit density assumptions and correlated equally well with U.S. Census data (not shown). Consequently we present only the comparisons of the MassGIS algorithms using the empirically derived housing densities to the U.S Census data. Multifamily unit densities were not assessed since they represent such a small portion of the residential development in any watershed.

Estimates of total town housing units (Fig. 3) and population (Fig. 4) from the MassGIS land use data

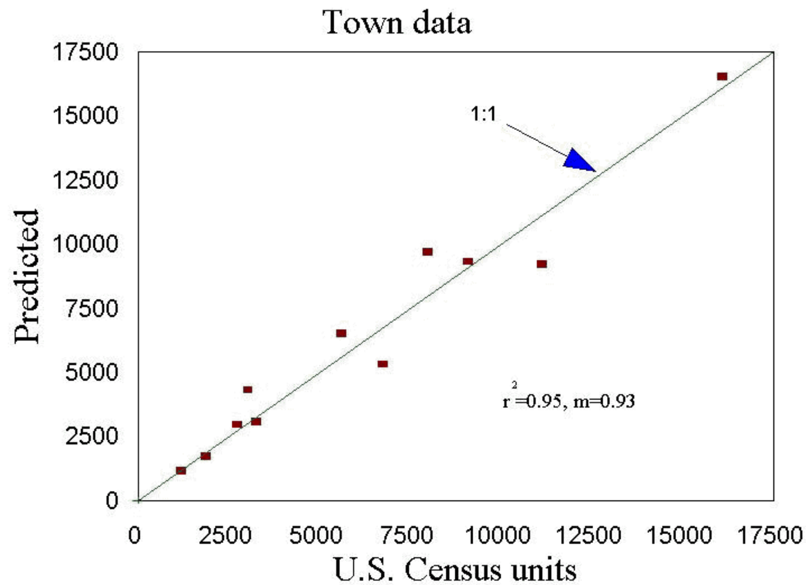

Figure 3. Housing units predicted from 1984 MassGIS land use vs US Census data for 11 Buzzards Bay towns (expected 1:1 relationship shown).

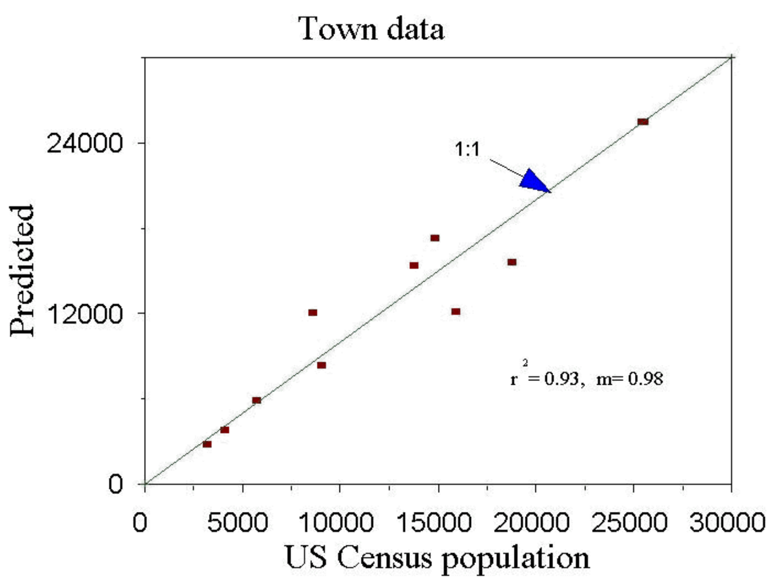

Figure 4. Population predicted from 1984 MassGIS land use vs US Census population data for 11 Buzzards Bay towns.

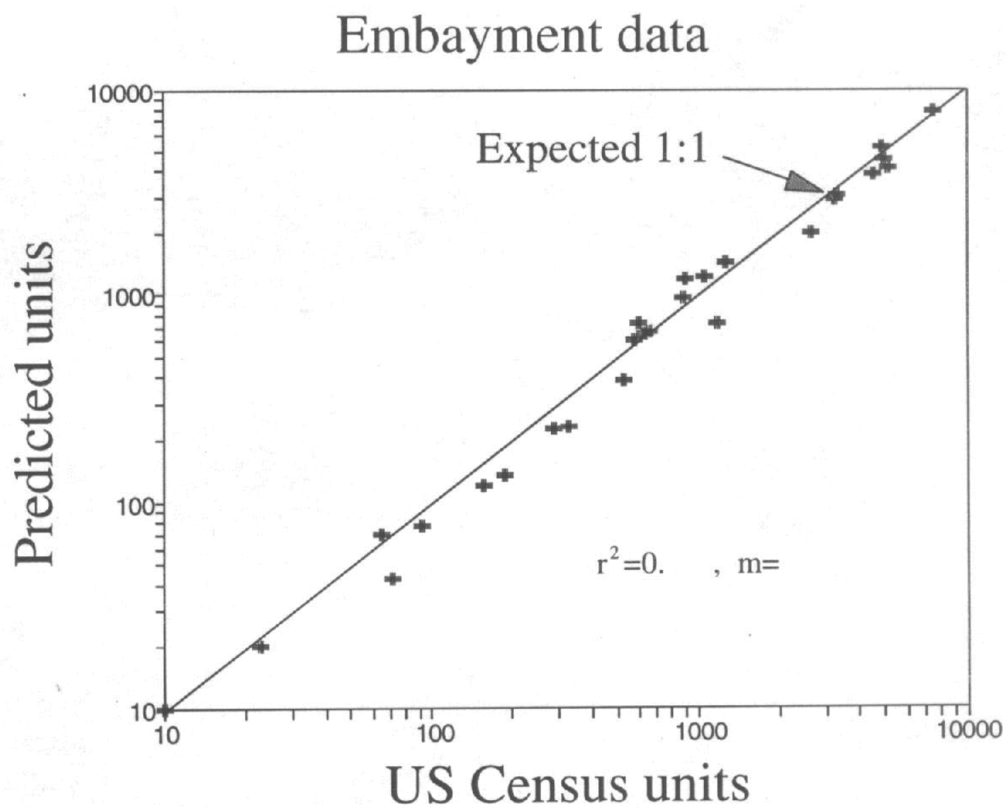

Figure 5. Units predicted from MassGIS land use (using empirically derived unit density assumptions) vs US Census unit data for 26 Buzzards Bay embayments. Slope and correlation coefficient calculated from log transformed data.

correlated well with U.S. Census data. Estimates of housing units in 26 embayments using MassGIS data also correlated well with estimates made from U.S. Census data (Fig. 5, note log scale).

Calculating nitrogen from residential land use

Septic systems

For management action, the Buzzards Bay Project adopted a per capita annual load of 5.9 lb (2.7 kg) capita^{-1} and an occupancy rate of 3 persons per unit for all residential land use classes. Actual U.S Census 1990 occupancy rates (combined rate for both vacant and occupied housing) around Buzzards Bay ranged from a low of 1.7 persons per unit in Falmouth ("off season" occupancy), a tourist resort that experiences a 50% increase in population during summer, to a high of 2.7 in Dartmouth. Some towns have experienced changes in mean occupancy rates over time, and when assessments are conducted to determine historical inputs of nitrogen, or determine existing nitrogen loads, actual occupancy rates should be used.

Lawns

We have assumed that lawn size is proportional to lot size, and have used 140, 279, 465, and 465 m^2 (1500, 3,000, 5,000, and 5,000 ft^2) of lawn sizes per unit for the residential land-use categories R0-R3, respectively. The Buzzards Bay Project adopted 29.3 kg N ha^{-1} (0.6 lb N/1000 ft^2) leaching rates for lawn fertilizer (EPA and EOEA, 1993), this equals 0.4, 0.8, 1.4, and 1.4 kg N $unit^{-1}$ loading rates respectively for the four residential land use classes.

Developed lot impervious surface

We presume there is typically 46.5 m^2 (500 ft^2) in driveways and other paved surfaces on lots of single family homes, and that unpaved impervious surfaces (i.e. roofs) average 140 m^2 (1500 ft^2). The Buzzards Bay Project adopted a loading of 7.3 kg N ha^{-1} (0.15 lb/1000 ft^2) for runoff from impervious surfaces on residential lots, or about 0.14 kg/unit. Contribution of nitrogen from public and private common use road surface area runoff was calculated separately from residential land use areas.

The potential surface water and groundwater nitrogen loading from the 4 residential land use categories for the combined inputs from septic systems, lawns, and impervious surface is shown in Table 3.

Road Surface

The MassGIS stores road locations as dimensionless lines. Four road area classes exist, but for simplification, all were combined, and it was assumed that 8 m (25 ft) was a conservative regional average of secondary road surface. The Buzzards Bay Project adopted a loading rate of 15.1 kg ha^{-1} (0.31 lb/1000 ft^2) for runoff from road surfaces.

For each subbasin we calculated total road area which was multiplied by the loading constant for impervious surface cited above. To illustrate the importance of this contribution, in the Onset Bay drainage basin (mostly R2 and R3 land use classes) there were 80 km of road for an estimated 2087 units. This equaled approximately 307 m^2 per house or an annual nitrogen load of 0.46 kg per house.

Agricultural lands other than cranberry bogs

Application rates of fertilizers to crops other than cranberries range from less than 10 to more than 100 kg N ha^{-1}. Leaching rates generally increase with increased application rates. A large portion of the agricultural land in the Buzzards Bay watershed (other than cranberry bog and pasture) is planted with corn with an application rate 100 kg N ha^{-1}. Assuming a 20% leaching rate, this equals 20 kg N ha^{-1} as the groundwater loading rate for this land use category. For pasture we assumed 10 kg ha^{-1}.

Other categories of land-use

Since we presumed that precipitation on vegetated lands like forests, open spaces, etc. was not an important source of nitrogen reaching groundwater because vegetation is presumed to take up virtually all bioavailable nitrogen in precipitation, these land uses were assigned a nitrogen loading rate of 0. Areas that had lawns with potential of fertilization (golf course, baseball fields, etc.) were given the same loading rate as home lawns (29.3 kg ha^{-1}). For land use categories that lack vegetation (open pit gravel mines), it was presumed that the loading rate was the same as for impervious non-paved surfaces (*e.g.* roof runoff), or 7.3 kg/ha^{-1}. This loading rate was also used to estimate nitrogen loading from deposition, **directly on** the embayment. For commercial land use (typically business strips, restaurants, some apartment buildings, *etc.*) we assumed as high a loading rate for sewage from the multifamily category plus the additional input of stormwater since most of the landscape is covered with pavement and roofs. For industrial, transportation, and waste disposal, we assume the same loading rate as for road surfaces. Although landfills should be additionally included as a point source in this study, because little data was available, and there were few landfills in the drainage basins examined, they were not included. A summary of loading coefficients for all land use categories are shown in Table 3.

In Table 4, we summarize land use for all Buzzards Bay drainage basins evaluated in this study and the relative nitrogen contribution of each land use category. Also included is the nitrogen load by precipitation directly on the embayments. As shown, the residential and commercial land use categories account for 70% of the anthropogenic nitrogen loading to Buzzards Bay embayments.

Table 3. Annual nitrogen loading rates assigned to the 21 landuse categories for the Buzzards Bay drainage basin

Category #	Category Name	Explanation or typical examples	N loading rate (kg ha^{-1} y^{-1})
1	Cropland	corn, nurseries	20.0
2	Pasture	hay, dairy	10.0
3	Forest		0.0
4	Non-forested wetland	freshwater marshes	0.0
5	Mining	sand and gravel pits	7.3
6	Open land		0.0
7	Participatory recreation	golf courses	29.3
8	Spectator recreation	baseball diamonds	29.3
9	Water Based recreation	beaches	0.0
10	R0:Residential-multi-family	condominiums, dormitories	106.5
11	R1:Residential-<¼ acre lots		82.6
12	R2:Residential-¼ - ½ acre lots		46.4
13	R3:Residential->½ acre lots		23.2
14	Salt marsh		0
15	Commercial	business districts	121
16	Industrial		15.1
17	Urban open	parks	0
18	Transportation	interstate highway, medians	15.1
19	Waste disposal	landfills	15.1
20	Water	freshwater ponds and rivers	0
21	Woody perennial	mostly cranberry bogs, some orchards	18.0
NA	Embayment surface	(atmospheric deposition)	7.3

Table 4. Combined landuse statistics and nitrogen loading estimates for 28 Buzzards Bay embayment drainage basins. (*N.B.* embayment loading mean percent of total represents the mean contribution for that land use category in the 28 embayments, not percent of the combined 28 embayment total loading.)

	Landuse category	**Combined area (km^2)**	**% of total**	**combined loading (kg)**	**28 embayment mean % of total**
1	Cropland	3,368	4.0%	67,350	7.6%
2	Pasture	1,582	1.9%	15,820	2.5%
3	Forest	55,106	65.3%	0	0.0%
4	Non-forested wetland	1,870	2.2%	0	0.0%
5	Mining	335	0.4%	2,350	0.3%
6	Open land	2,110	2.5%	0	0.0%
7	Participatory recreation	415	0.5%	12,170	2.5%
8	Spectator recreation	100	0.1%	2930	0.5%
9	Water based recreation	135	0.1%	0	0.0%
10	R0:Residential-multi-family	144	0.2%	15,300	2.7%
11	R1:Residential-<¼ acre lots	1,069	1.3%	88,380	13.4%
12	R2:Residential-¼ - ½ acre lots	3,982	4.7%	206,260	19.9%
13	R4:Residential->½ acre lots	4,103	4.9%	100,920	18.4%
14	Salt marsh	1,702	2.0%	0	0.0%
15	Commercial	517	0.6%	61,990	7.6%
16	Industrial	138	0.2%	2,180	0.4%
17	Urban open	1,195	1.4%	0	0.0%
18	Transportation	1,410	1.7%	21,270	2.2%
19	Waste disposal	181	0.2%	2,860	0.2%
21	Woody perennial (cranberry bogs)	4,872	5.8%	89,165	6.7%
-	ROAD Area	2,020	2.4%	30,900	4.7%
-	Embayment water area	54	0.1%	39,190	11.0%
TOTALS		84,332	100.0%	761,289	100.0%

Point sources and other inputs

For each Buzzards Bay drainage basin, any known significant point sources of nitrogen, such as from sewage treatment facilities, were added to embayment total annual loads.

For two embayment drainage basins with a very large number of dairy cows (Westport Rivers and

Nasketucket Bay) the total number of cows were estimated, and was assumed that of the annual nitrogen load excreted (65 kg N animal^{-1} yr^{-1}; SCS, 1992), 33% would reach the receiving waters. This export rate was used because some of the dairy farms in these watersheds are operated as unconfined feed lots, with animal densities exceeding 5 cows/ac. Under these conditions, sites may be denuded of vegetation so the potential of overland runoff and contamination of groundwater by nitrogen is more pronounced because ground cover on many of these farms is greatly reduced, and because many of the farms are near shore or along tributaries discharging to these embayments, and overland runoff of animal fecal material has been documented as a source of fecal coliform bacteria in each watershed. These animal livestock loadings were calculated as a source separate from the land use loadings. For example, a 20 acre dairy farm (typically pasture) would be considered as a 200 kg N yr^{-1} agricultural land source. If that farm also had 100 cows, the loading rate from manure from cows would included in our loading assessment as an addition 6,500 kg source.

Potential Future Development

To calculate future development in each embayment drainage basin, we presume that 50% of the area defined in the MassGIS "forested land" category is unbuildable because of wetlands[1] or need for infrastructure, open space, protection of drinking water supplies, *etc*. The remainder of the forested land we presume will be built as the residential and commercial/industrial land use classes (categories 10-13, 15-18 on Table 5). We presume that the existing ratio between the area used for residential purposes (R0-R3, categories 10-13) and the commercial/industrial categories (categories 15-18) will remain constant. For the residential categories, we presume that new residential development will be proportional to existing land-use categories R0 (multifamily), R2, and R3. We have omitted the R1 land class (lots less than 1/4 acre) from this formulation because very rarely are such small lot sizes allowed today on unsubdivided parcels of land in the Buzzards Bay area. Agricultural land conversion to residential or commercial industrial land uses were considered in these buildout projections using the same assumptions as forested land.

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[1] The MassGIS land use "forest" category (#19) includes forested wetlands, which are largely unbuidable. Forested wetlands from the state "Wetlands Conservancy Program" maps will eventually be included in the data base and this will enable better estimates of buildable undeveloped land.

Table 5. Comparison of GIS methodology to U.S. Census data and parcel level land use analysis in Buttermilk Bay

Parameter	GIS methodology[1]	US census data[2]	Parcel analysis[3]
Existing units	2772	3314	3049
Population	5961[4]	5575[5]	9255[6]
Buildable land (ac)	4400	NA	4600
Total future units	5329	NA	5316

[1] 1984 landuse using empirically derived unit densities
[2] 1990 data; dwelling units increased 20% in area between 1980 and 1990
[3] 1989 parcel evaluation, from Horsley Witten and Hegemann Inc. (1990)
[4] assumed an subbasin occupancy of 2.2 persons per housing unit (US Census)
[5] population does not account for summer rentals
[6] assumed occupancy of 3 persons per housing unit for planning purposes

Table 6. Comparison of GIS methodology to U.S. Census data and parcel level land use analysis in Waquoit Bay

Parameter	GIS methodology[1]	US census data[2]	Parcel analysis[3]
Existing units	4628	in prog.	4116
Population	8361[4]	in prog.	NA
Buildable land (ac)	2777	NA	2253
Additional future units	4915	NA	

[1] 1984 landuse using empirically derived unit densities
[2] 1990 data
[3] 1990 parcel evaluation from Cape Cod Commission
[4] assumed a probable occupancy of 1.9 persons per housing unit for area (US Census data)

Table 7. Comparison of GIS methodology to U.S. Census data and parcel level analysis in West Falmouth Harbor

Parameter	**GIS methodology**[1]	**US census data**[2]	**Parcel analysis**[3]
Existing units	725	1180	868
Population	1105[4]	1446.[5]	NA
Buildable land (ac)	1842	NA	NA
Additional future units	1065	NA	982

[1] 1984 landuse using empirically derived unit densities
[2] 1990 data
[3] 1990 parcel evaluation from Howes *et al.*, 1992
[4] assumed an occupancy of 1.53 persons per housing unit for area (US Census data times 25% adjustment for seasonal occupancy)
[5] population does not account for summer rentals

Comparison of GIS methodology to parcel level land use analysis

These estimates of annual nitrogen loads from MassGIS data and U.S Census data are an important screening tool, but may not be sufficiently accurate to be used as the basis of decisions on zoning and planning. Instead a parcel level land use analysis may need to be conducted. Nonetheless, even with the inherent limitation of the assumptions made, the MassGIS data is a good preliminary assessment. In Tables 5 and 6, we compare estimates of existing and potential future housing units using our GIS methodology, parcel level analysis, and U.S. Census data for two watersheds.

In the Buttermilk Bay drainage basin, the GIS estimates underestimated existing units by 20%. Part of the discrepancy is probably due to new development which increased 5% between 1984 and 1990, as well as the lack of precision in the GIS land use data. For example, there is a large amount of development around Buttermilk Bay constructed on lots 1/10 to 1/6 of an acre (i.e. effective densities of 5-8 units/acre). Since these areas were classified as "less than ¼ acre" using an effective density of 3.75 units/acre, housing units were underestimated in these polygons.

In estimating future growth potential, our assumptions in the use of the GIS data led to overestimates of future growth potential in Buttermilk Bay. Although there is good agreement in the unbuilt land area in the basin, the higher estimate of potential development from the MassGIS data can be accounted for the fact that large tracts (more that 1700 acres) of land around Buttermilk Bay are classified for tax purpose as managed forests (silviculture), have conservation easements (public and private open space), or have other classifications that preclude any development potential. These areas are of course not distinguished in the MassGIS data set. Because we believe that typically there will not be as large a percentage of land with its development potential reduced as in the Buttermilk Bay subbasin, we did not change our assumptions for future growth potential in other drainage basins. On a case by case basis our algorithms could be adjusted to address special conditions in an embayment.

Application of Methodology

In Appendix A we summarize land use and nitrogen loading for 28 Buzzards Bay embayments. Using the mass loading estimate methodology described here and preliminary flushing estimates for Buzzards Bay embayments (ACI, 1993), the Buzzards Bay Project has conducted a preliminary loading analysis for approximately 30 Buzzards Bay embayments (in preparation) to determine whether they now exceed, or will exceed in the future, the nitrogen loading recommendations contained in the Buzzards Bay Comprehensive Conservation and Management Plan. These results suggest that about half of the embayments in Buzzards Bay may require management action to control nitrogen. Of course, the approach described here is a screening tool. Management action should await a parcel-level land use analysis and better flushing estimates. Ultimately the extent of actions to control nitrogen will be a management decision based on an evaluation of costs and benefits, and the degree of public support.

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