THE RELATION OF GROUND-WATER QUALITY TO HOUSING DENSITY, CAPE COD, MASSACHUSETTS

By James H. Persky

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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	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Housing Density	
housing unit per acre (house/acre)	247.1	housing unit per square kilometer (house/km^2)

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ABSTRACT

Correlation of median nitrate concentration in ground water with housing density for 18 sample areas on Cape Cod yields a Pearson correlation coefficient of 0.802, which is significant at the 95-percent confidence level. In five of nine sample areas where housing density is greater than one unit per acre, nitrate concentrations exceed 5 milligrams of nitrogen per liter (the Barnstable County planning goal for nitrate) in 25 percent of wells. On the other hand, nitrate concentrations exceed 5 milligrams of nitrogen per liter in 25 percent of wells in only one of nine sample areas where housing density is less than one unit per acre. Median concentrations of sodium and iron, and median levels of pH and specific conductance, are not significantly correlated with housing density.

A computer-generated map of nitrate shows a positive relation between nitrate concentration and housing density on Cape Cod. However, the presence of septage- or sewage-disposal sites and fertilizer use are also important factors that affect the nitrate concentration. A map of specific conductance also shows a positive relation to housing density, but little or no relation between housing density and sodium, ammonia, pH, or iron is apparent on the maps.

Chemical analyses of samples collected from 3,468 private- and public-supply wells between January 1980 and June 1984 were used to examine the extent to which housing density determines water quality on Cape Cod—an area largely unsewered and underlain by a sole-source aquifer.

INTRODUCTION

Background

Barnstable County, Massachusetts, better known as Cape Cod (fig. 1), is the fastest growing county in New England. The popularity of Cape Cod as a resort and retirement area has caused a rapid increase in the county's population. The estimated winter population rose from 97,450 in 1970 to 147,925 in 1980, while the estimated peak summer population in 1980 was 439,803 (Cape Cod Planning and Economic Development Commission, 1978a, table 2.3; 1982, tables 6, 9). By the year 2000, a winter population of 230,000 and a peak summer population of over 600,000 (Cape Cod Planning and Economic Development Commission, 1982, tables 6, 9) are expected. Nearly 4,000 new houses were built on Cape Cod in 1983, including 18 percent of all single-family houses built in Massachusetts that year (O'Brien, 1985, p. 111).

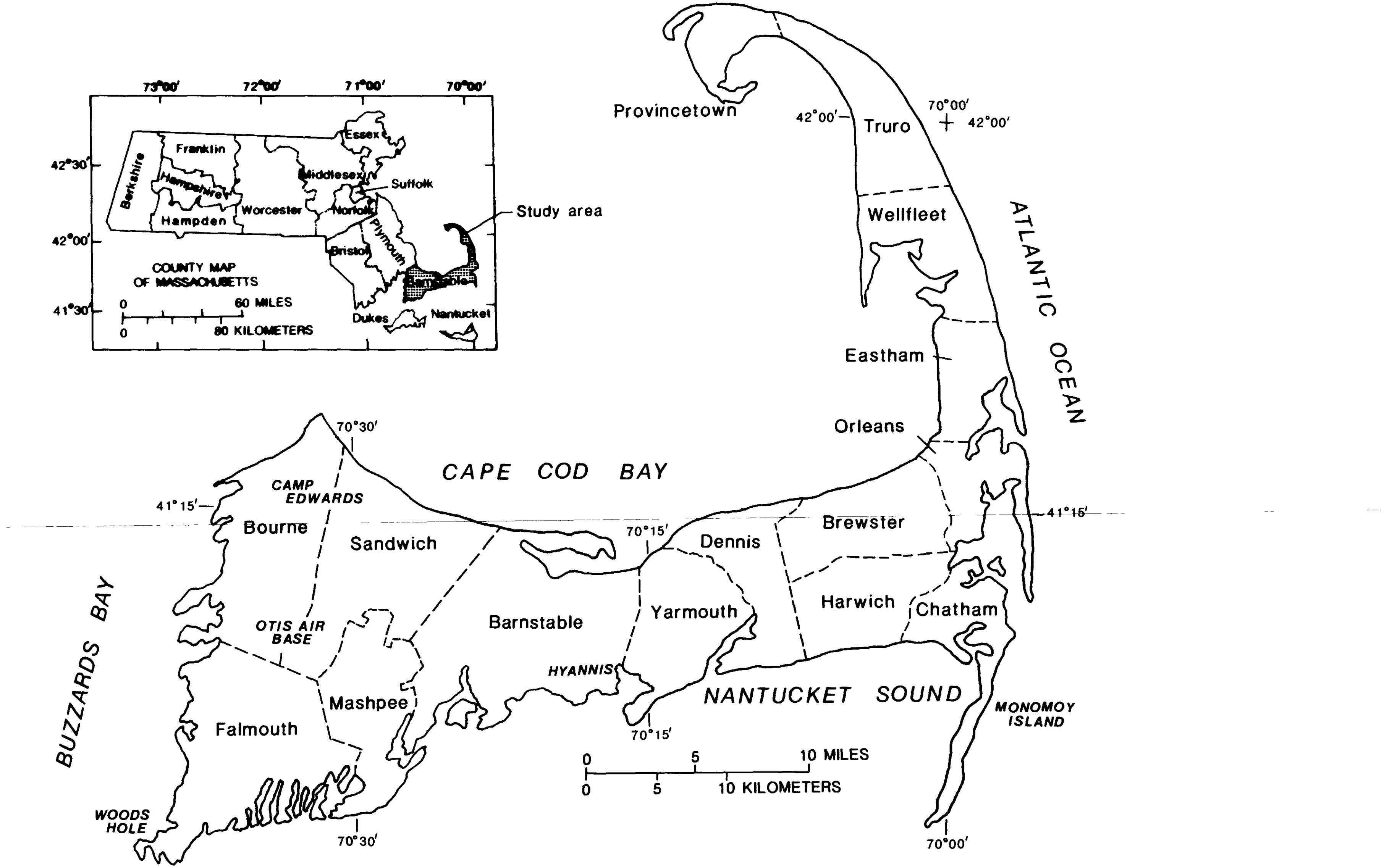

Figure 1.--Index map of study area.

The Cape Cod aquifer, which underlies all of Cape Cod, is the sole source of drinking water. The aquifer is hundreds of feet thick and consists of unconsolidated glacial-moraine and outwash deposits of sand and gravel containing some silt and clay. The upper 100 feet of these deposits, in most areas, consists primarily of permeable sand and gravel. The aquifer provides ground water to 128 municipal wells and more than 20,000 private wells (Cape Cod Planning and Economic Development Commission, written commun., 1986). Kettle-hole ponds, which are a surficial expression of the saturated zone of the aquifer, also contribute to the Cape's water supply.

Ground water on Cape Cod is generally of good chemical quality and suitable for domestic use (Frimpter and Gay, 1979, p. 1); however, some water-supply wells have become contaminated. The most common ground-water contaminants on Cape Cod are nitrate and sodium chloride. The major potential sources of nitrate contamination are septic-system effluent, leachate from landfills and sewage-disposal sites, and fertilizer from lawns or golf courses. Road salting, saltwater intrusion, and coastal flooding are the primary causes of sodium-chloride contamination (Frimpter and Gay, 1979, p. 1).

The disposal of human waste is a major concern for water-supply planners on the Cape. Only a few small areas on Cape Cod are sewered, and the majority of private homes, motels, restaurants, and businesses rely on septic systems and cesspools. All public sewage systems on the Cape rely on land disposal, except for a small system serving the Woods Hole section of Falmouth. Municipal landfills on Cape Cod (fig. 2) include septage-disposal facilities (septage is the septic-system equivalent of sewage). Dissolved contaminants from septage and sewage, including nitrate, sodium, chloride, sulfate, and phosphate, eventually seep downward into the aquifer. Of these, nitrate and, to a lesser extent, sodium are the contaminants of greatest concern because of their potential effects on health at relatively low concentrations.

Local officials are concerned that the population expansion will result in widespread degradation of ground-water quality. The Cape Cod Planning and Economic Development Commission has estimated acceptable average housing densities in zones of contribution to public-supply wells. A drinking-water standard and planning goal of 5.0 mg/L (milligrams per liter) of nitrate has been set for Barnstable County (Cape Cod Planning and Economic Development Commission, 1978b, p. 2-3). All concentrations given for nitrate and ammonia in this report refer to milligrams per liter of nitrogen.

Although many studies have related water quality to various types of land use, few studies have specifically involved population or housing density. Morrill and Toler (1973) found a relation between housing density and specific conductance of ground water discharged to streams in northeastern Massachusetts. Wehrmann (1983) concluded that housing densities should be limited to less than 1.0 house per acre in some areas of northern Illinois to prevent nitrate concentrations in domestic-well water from exceeding the U.S. Environmental Protection Agency drinking-water standard of 10 mg/L (U.S. Environmental Protection Agency, 1983, p. 233). Quadri (1984) attributed increased nitrate-nitrogen concentrations in some public-supply wells on Cape Cod to increased septic-system density.

A study of Cape Cod's ground-water resources was conducted by the U.S. Geological Survey from 1982 to 1985, in cooperation with the Cape Cod Planning and Economic Development Commission. This part of the study assessed the effect of the population increase on ground-water quality. Housing density was used as an index of population density because population data were not available at the desired geographic scale, and because housing density could be assumed to equal septic-system density in unsewered areas.

Purpose and Scope

This report presents the results of a study of the relation of ground-water quality to housing density on Cape Cod. The study also evaluated two methods to determine such relations using an extensive water-quality data base: A system-mapping procedure to

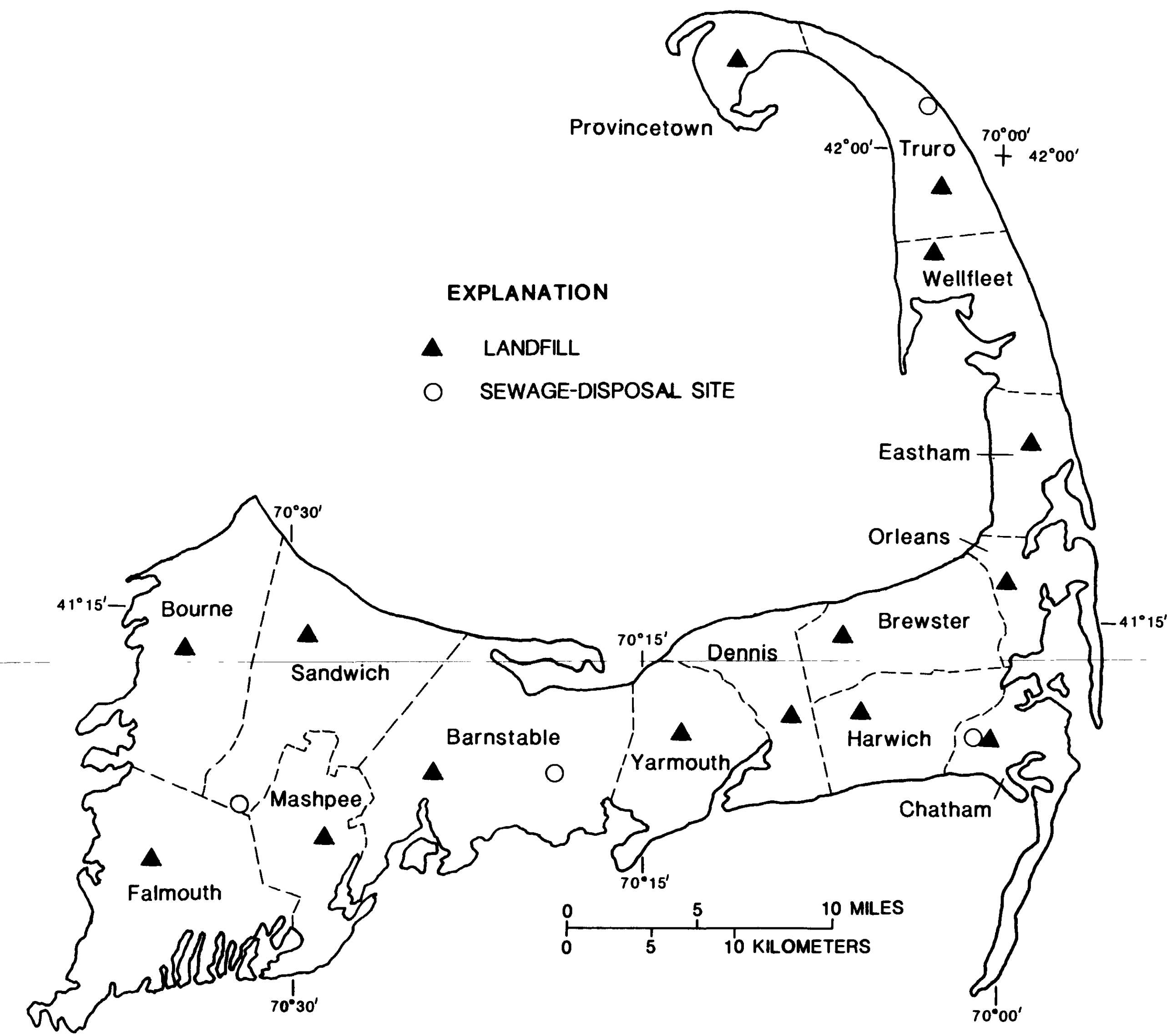

Figure 2.--Landfills and sewage-disposal sites on Cape Cod.

display general relations of ground-water quality to housing density throughout Cape Cod, and a statistical analysis to display quantitative relations of ground-water quality to housing density based on data from selected sample areas.

Thousands of analyses of ground-water samples from public- and private-supply wells throughout Cape Cod were entered into WATSTORE, the U.S. Geological Survey's National Water Data Storage and Retrieval System. Ground-water-quality contour maps of the Cape were generated from these data using a computerized mapping procedure, QWSYMAP, and were compared with a map of housing density. In addition, the housing density was determined in 18 selected sample areas on the Cape. Water-quality data for samples from wells within these areas were retrieved, and statistical correlations between water quality and housing density were determined.

Acknowledgments

The Barnstable County Health Department provided latitude, longitude, and ground-water-quality data for water samples from approximately 4,000 private-supply wells. The Cape Cod Planning and Economic Development Commission provided ground-water-quality data for water samples from public-supply wells and provided extensive assistance in coding water-quality data for entry into the data base. Samples of public-well water were analyzed by the Massachusetts Department of Environmental Quality Engineering. Access to housing data was provided by the Assessors' Offices of the Towns of Barnstable, Brewster, Chatham, Eastham, Falmouth, Sandwich, and Wellfleet, and by the Town of Yarmouth Planning Board. The National Park Service provided housing data for the Newcomb Hollow sample area in Wellfleet.

GROUND-WATER-QUALITY DATA BASE

Analyses of private-well water samples by BCHD (Barnstable County Health Department) and analyses of public-well water samples by DEQE (Massachusetts Department of Environmental Quality Engineering) are stored in WATSTORE as part of an ongoing program to maintain a water-quality data base for Cape Cod. The private-well analyses generally include coliform-bacteria counts, pH and specific-conductance measurements, and concentrations of nitrate and iron. If the specific conductance is greater than or equal to 100 µS/cm (microsiemens per centimeter at 25°C), the sodium concentration of the sample also is measured. Ammonia, copper, manganese, chloride, methylene-blue active substances (detergents), hardness, and alkalinity are occasionally included in the analyses. The public-well water analyses include pH, specific conductance, alkalinity, nitrate, ammonia, sodium, and chloride. As of April 1985, more than 5,000 analyses from more than 4,000 wells have been entered into the data base.

Analyses of water from private wells make up the great majority of the analyses; all but approximately 100 of the 3,468 wells included in this study (fig. 3) are private-supply wells. Several Barnstable County towns require testing of water from all new domestic-supply wells, and many residents have water samples from existing wells tested. The person requesting the analysis obtains a sterilized sample bottle from BCHD and runs the faucet for at least 5 minutes before collecting the sample. The sample must be brought to the Health Department within 6 hours if the sample is not refrigerated, or within 24 hours if the sample is refrigerated.

Because the water-quality data base contains relatively few data from public-supply wells, the data tend to be clustered in those areas predominantly supplied by private wells. The Towns of Bourne, Orleans, Provincetown, and Yarmouth are supplied mainly by public water (and Provincetown's public-supply wells are located in Truro), so there are relatively few data from these towns. Wellfleet, Eastham, and Truro are supplied entirely by private wells and are well represented in the data base. The remaining towns all have public-water supply in at least the town centers; the sections of these towns that rely on private-water supply are well represented in the data base.

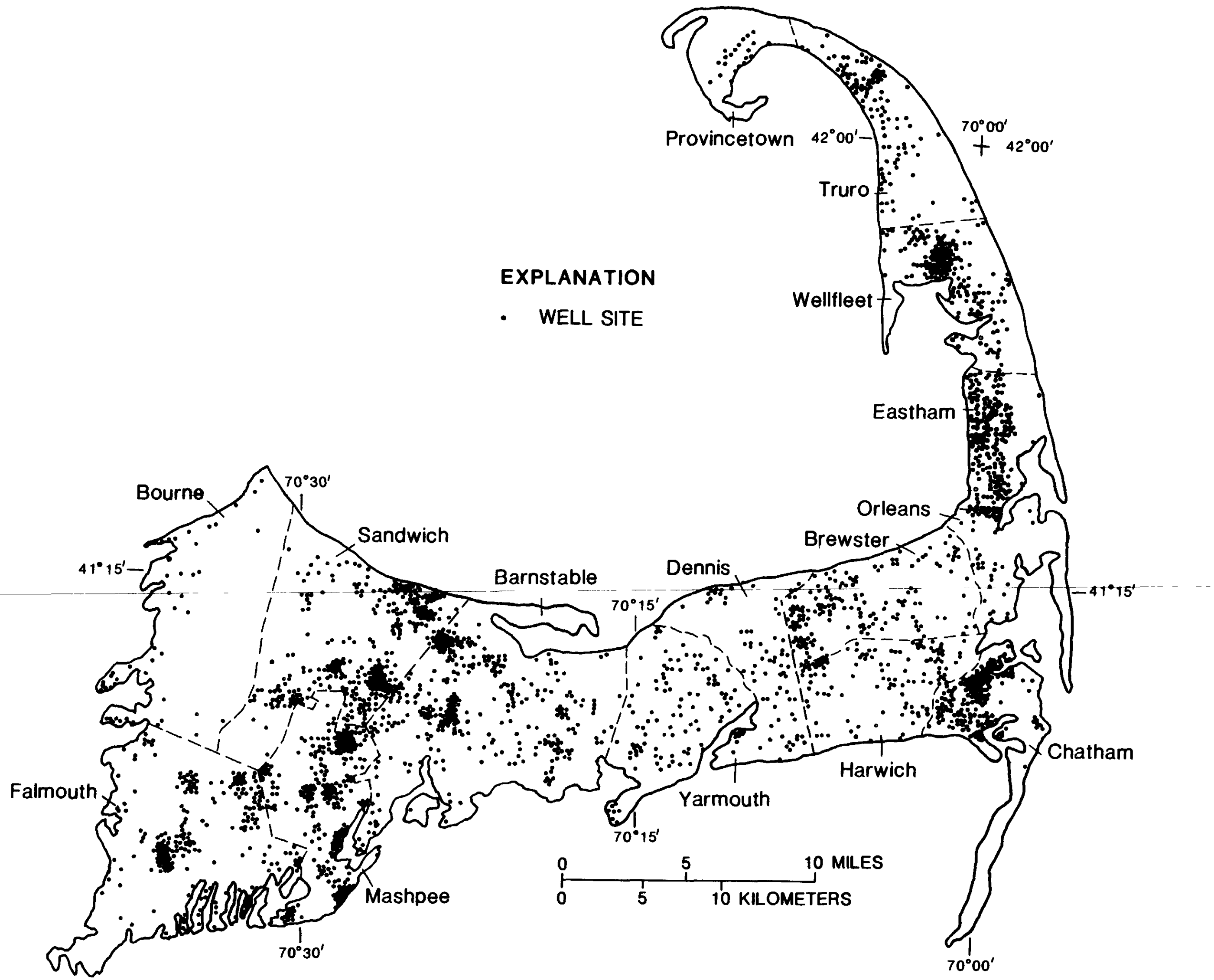

Figure 3.--Location of wells included in the study.

The water-quality data base also may be biased by the reasons for which wells are sampled. Samples from new wells often come from new housing developments, where septic systems have not yet affected the ground water; these samples, therefore, would reflect the natural background water quality. On the other hand, samples from existing wells generally are collected when the owners suspect that water-quality problems exist.

The average sodium concentration of the analyses in the data base is higher than the actual average sodium concentration for Cape Cod, because sodium is only analyzed if the specific conductance of a water sample is 100 μS/cm or greater, and sodium and chloride are the primary contributors to specific conductance on Cape Cod. It is assumed, for the purpose of this study, that the values for sodium are skewed similarly throughout the Cape, and that average concentrations in separate areas, therefore, can be compared. Iron and pH data from the private wells may not reflect the actual chemical quality of the ground water, because pH may change quickly after sampling and iron may either precipitate when the samples become oxygenated or enter the water from the plumbing system.

Private wells on Cape Cod rarely extend more than 20 feet below the water table. Thus, BCHD analyses from the data base provide a good representation of the water quality in the uppermost part of the aquifer, the part likely to be affected by nearby septic systems. Water quality in deeper parts of the aquifer may be different. For example, in northeastern Falmouth, private domestic-supply wells pump uncontaminated water despite the presence of a sewage plume from the Otis Air Base sewage-treatment facility deeper in the aquifer (LeBlanc, 1984, p. 24).

For the purpose of this study, water-quality constituents in a sample that had a concentration below the detection limit were assigned a value of the detection limit. For example, the detection limit for nitrate is 0.04 mg/L. All nitrate concentrations that were stored as "less than 0.04 mg/L" were treated as though they had an actual concentration of 0.04 mg/L. The QWSYMAP procedure uses the value stored in the data base for a constituent, whether or not there is a "less than" code stored with it. For consistency, the "less than" code also was dropped from values used during statistical analysis of data for the selected sample areas.

RELATIONS BETWEEN GROUND-WATER QUALITY AND HOUSING DENSITY BASED ON SYSTEM MAPPING

General relations between ground-water quality and housing density throughout Cape Cod were determined by overlaying computer-generated water-quality contour maps onto a housing-density map of the Cape (fig. 4). The housing-density map is based on a dot map of the Cape Cod summer population in 1975 (Cape Cod Planning and Economic Development Commission, 1978c). A ratio between the number of housing units in 1985 and the summer population in 1975 (Cape Cod Planning and Economic Development Commission, 1978a, table 5.1; 1982, table 2) was determined for each town, and the number of dots in each town on the population map was divided by this ratio and transferred to the housing-density map.

System-Mapping Procedure (QWSYMAP)

Water-quality contour maps of Cape Cod were generated from the water-quality data from analyses by BCHD and DEQE using QWSYMAP, a water-quality system-mapping procedure associated with WATSTORE. QWSYMAP is a computerized system that can produce contour maps of water-quality constituents on a line printer. After water-quality data for an area are retrieved from the WATSTORE Water-Quality File, QWSYMAP assigns the value for the constituent being mapped to a set of location coordinates. Line-printer characters are assigned to data values that fall within ranges pre-set by the user, and QWSYMAP interpolates between data points to produce continuous contour lines through areas where there are no data.

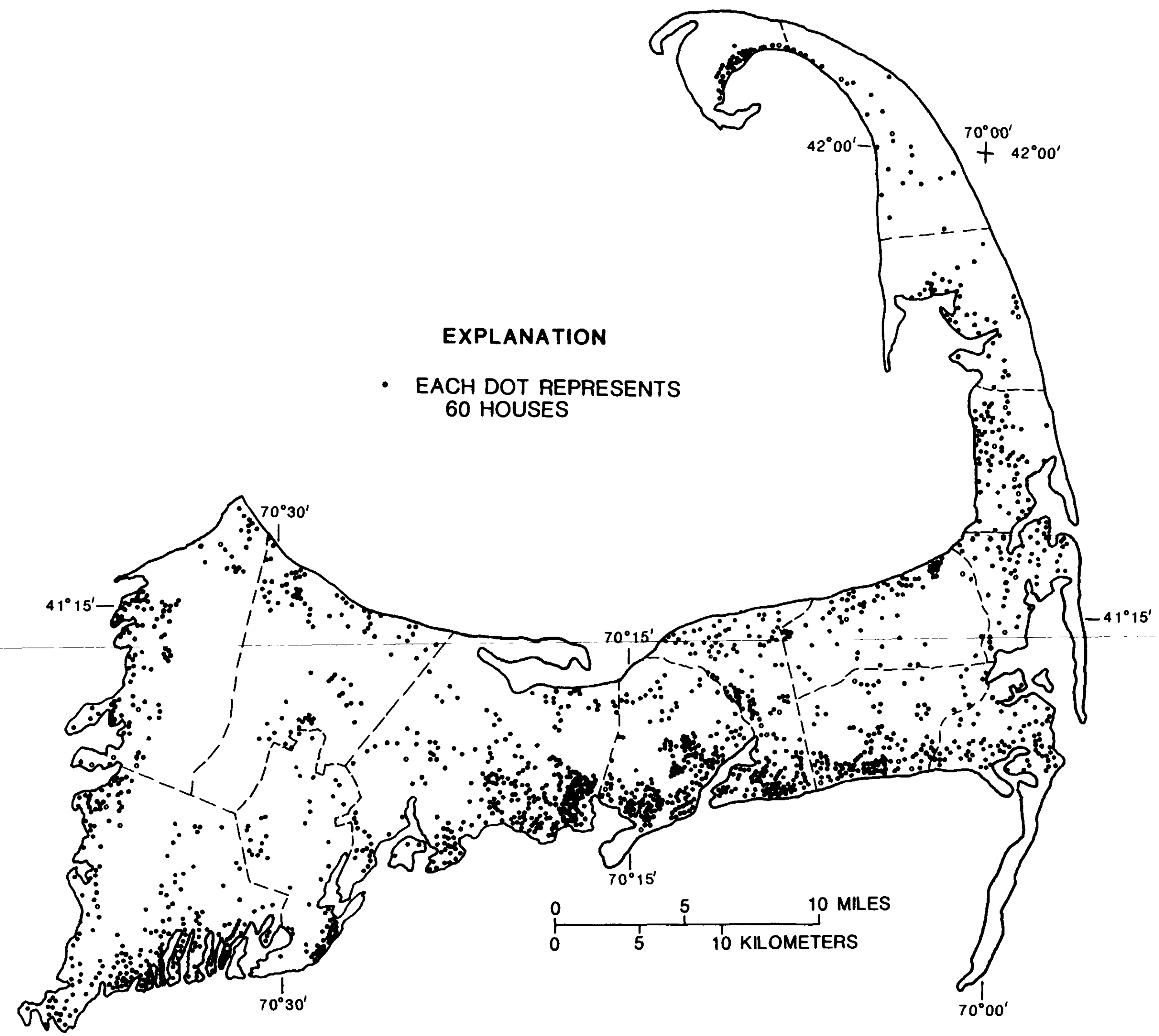

Figure 4.--Housing density on Cape Cod, 1985 (based on data from Cape Cod Planning and Economic Development Commission, 1978a, table 5.1, 1978c, and 1982, table 2).

QWSYMAP maps were generated for nitrate, pH, specific conductance, sodium, iron, and ammonia. Data retrieval was limited to analyses of samples collected between January 1, 1980, and June 20, 1984; the latter was the most recent date of collection for Barnstable County data in the data base at the time of retrieval. A total of 4,498 analyses of samples from 3,468 wells were retrieved. Where more than one analysis existed for a well, the highest concentration or value of the water-quality constituent was used in preparing the map in order to highlight "hot spots."

Retrieval of data also was limited to analyses done by BCHD and DEQE; analyses of samples collected by the Survey for other studies on Cape Cod were not retrieved. This limitation was made to prevent distortion of the sodium and specific-conductance maps by samples collected from the saltwater-freshwater boundary at several sites on the Cape. As a result, analyses of samples collected at the Town of Falmouth Sanitary Landfill and the sewage-treatment facility at Otis Air Base during previous Survey studies were also not retrieved. The presence of these sites are revealed on the water-quality maps produced by QWSYMAP where they affect either nearby private wells from which samples were analyzed by BCHD, or nearby public wells from which samples were analyzed by DEQE.

QWSYMAP is a procedure for interpolating between points with known values; it does not account for the effects of geology and hydrology. Also, there are some blank areas on the maps, such as Woods Hole, because the mapping system uses the WATSTORE pre-set boundaries for Barnstable County, which were taken from a smaller scale map with less detail.

Mapped Consituents and Properties

This section discusses the maps generated by QWSYMAP. Areas of poor water quality are related to known sources of contamination where possible, based on Ryan (1980, plate 1). The cause of poor water quality in other areas is unknown.

The terms "high" and "low" are used in this section to refer to concentrations or values that fall outside of the middle range on the maps. The term "poor" is used here and in the appraisal section to refer to water quality in areas where concentrations or values are high (or low, in the case of pH).

The background nitrate concentration on Cape Cod is less than 1 mg/L (fig. 5). The Barnstable County planning goal of 5 mg/L is exceeded at 273 wells, and the U.S. Environmental Protection Agency drinking-water standard of 10 mg/L is exceeded at 93 wells.

A positive relation exists between nitrate concentration and housing density. Areas of low nitrate concentration have low housing density, except for sections of central Harwich and south-central Yarmouth. Coincidence of areas of high nitrate concentration with areas of high housing density is particularly notable along the densely settled southern shore of the Cape, in Hyannis, Yarmouth, Dennis, southwestern Harwich, and Chatham. High nitrate concentrations also are apparent in the town centers in Wellfleet and Eastham.

Housing density is not the only factor that determines the nitrate concentration in ground water; the presence of sewage- or septage-disposal sites and use of fertilizer have effects, and community age and prior land use also may be contributing factors. Municipal sewage and septage facilities are associated with areas with high nitrate levels in north-central Falmouth, Bourne, central Dennis, west-central Barnstable, northwestern Wellfleet, and Provincetown. Elevated levels in Brewster also may be the result of septage disposal. Fertilizer use at golf courses may be responsible for high nitrate levels in northern Dennis and along the southwestern coast of Barnstable. High levels in central Truro may result from sewage disposal at an Air Force station, fertilizer use at an adjacent golf course, or both. An inactive landfill probably is the cause of high levels in southwestern Falmouth. Elevated nitrate levels at Otis Air Base may be the result of fertilizer application, leaking sewer lines, or both (Frimpter and Gay, 1979, p. 10).

The median specific conductance of ground water on Cape Cod is 106 μS/cm, although the greatest number of values range from 50 to 100 μS/cm (fig. 6). The inner Cape (south and west of Orleans) has a lower background level of specific conductance than the outer Cape (from Orleans north), because the limited width of the outer Cape makes it more susceptible to coastal flooding and deposition of wind-borne salt. The outer Cape also is more susceptible to saltwater contamination caused by pumping, because the fresh ground water is present as lenses that overlie denser saline ground water.

Areas of elevated specific conductance in Truro, Bourne, Sandwich, Barnstable, and Yarmouth coincide with landfills. High specific-conductance levels in Falmouth and north of Hyannis may result from road salting along Route 28. Leaching of stored road salt elevates specific-conductance levels in central Yarmouth (Frimpter and Gay, 1979, p. 7). An area of elevated specific conductance in northwestern Harwich may be caused by a landfill and (or) road salting along Route 6.

There seems to be a slight relation between specific conductance and housing density. Densely settled areas in Hyannis, southern Yarmouth, and Provincetown have high specific conductances, although high-density areas in south-central Yarmouth and south-coastal Mashpee have low specific conductances. Because coastal areas of Cape Cod tend to be more densely populated than inland areas, it is difficult to determine how much of the relation is actually the effect of housing density and how much is the effect of contamination by sea salt. On the inner Cape, however, the lower specific conductances in sparsely settled coastal sections of Barnstable, Sandwich, and Mashpee imply that the relation between specific conductance and housing density is not just an illusion caused by proximity to the coast.

No relation between ground-water quality and housing density was found for the other mapped constituents. Although sodium (fig. 7) is contributed to the aquifer by septage, the effect of septic systems on Cape-wide sodium levels is masked by other factors, particularly saltwater contamination. Sodium concentrations tend to be lower on the inner Cape than on the outer Cape for the same reasons as given for specific conductance. Landfills show as areas of elevated sodium levels in Sandwich, Mashpee, and Truro. An area of high sodium levels in Falmouth lies along Route 28 and is probably caused by road salting. Storage of road salt may be responsible for high sodium levels in southwestern Truro.

Ammonia (fig. 8) has a background level of less than 0.1 mg/L throughout most of the Cape, because it tends to oxidize to nitrate in oxygenated environments. In reducing environments, such as near bogs, the background level will likely be higher. An area of high ammonia concentration in Hyannis is attributed by local officials to the Hyannis sewage-treatment plant. High ammonia levels in northeastern Falmouth are along the path of a plume of contaminated ground water from the sewage-treatment plant at Otis Air Base (LeBlanc, 1984, p. 18-20). A landfill in western Barnstable is probably responsible for the high levels there. Close spacing of septic systems in a ground-water discharge zone causes the high ammonia levels in Wellfleet. High ammonia levels in Provincetown are due to reducing conditions caused by decay of organic material buried by sand dunes (Frimpter and Gay, 1979, p. 8).

The pH of ground water on Cape Cod (fig. 9) usually ranges from 5.5 to 6.5, with a median of 5.8, which is slightly acidic. High pH values often associated with sewage and landfill-leachate plumes—caused by removal of hydrogen ions from ground water in reducing environments to create ammonia (Baedecker and Back, 1979, p. 433)—are not shown on the map. In fact, low pH values are present near the landfills in Barnstable, Yarmouth, Dennis, Harwich, and Provincetown, and near the Hyannis sewage-treatment plant.

Total iron concentrations in Cape Cod ground water (fig. 10) have a median value of 150 μg/L (micrograms per liter). Because iron that collects in the pressure/storage tanks of private-well systems is not completely rinsed out during the 5 minutes that faucets are run prior to collection of private-well water samples (Frederick B. Gay, U.S. Geological Survey, personal commun., 1985), the median for these analyses is much higher than the 41 µg/L median found by Frimpter and Gay (1979, p. 8). Iron levels in southeastern Massachusetts commonly exceed recommended public water-supply standards for aesthetics and taste (Frimpter, 1973, p. 3-8); the element is ubiquitous in the unconsolidated aquifers of the region, occurring in mineral grains and in oxide coatings on sediment particles, from which it dissolves in acidic, reducing environments (Frimpter and Gay, 1979, p. 8). Therefore, the background iron concentration in different areas of the Cape depends on the local chemical conditions in the aquifer.

RELATIONS BETWEEN GROUND-WATER QUALITY AND HOUSING DENSITY BASED ON WATER QUALITY IN SAMPLE AREAS

Although the maps produced by QWSYMAP show qualitative relations between ground-water quality and housing density on Cape Cod, determination of the extent of these relations requires a quantitative method. To quantify the relations, ground-water-quality and housing-density data for 18 sample areas on Cape Cod (fig. 11) were collected. Correlations between the ground-water quality and housing density of these areas were analyzed statistically.

Selection of Sample Areas

Sample areas were chosen from topographic maps using several criteria. Housing densities shown on topographic maps were taken into account so that a wide range of housing densities would be included. Sample areas do not include extensive internal variation in housing density and do not have housing densities markedly different than those of the areas immediately upgradient of them. All sample areas include at least five wells in the data base.

Housing and Building Density

Housing and building data were collected at the town offices of the eight towns that included sample areas. In Yarmouth and Chatham, maps showed the location of buildings on the lots. The Yarmouth maps were color coded to indicate single-family houses, commercial buildings, and so on. Personnel in the Chatham Assessors' Office pointed out which buildings were commercial in the Chatham sample areas. In Eastham and Falmouth, listings of lots were marked with dots to indicate houses; town officials stated that no commercial buildings were likely to be in the sample areas. In the remaining towns, information was obtained using assessors' maps and the tax rolls.

Because of the disparity in the types, number, and frequency of data available in different towns, data were simplified to counts of total housing and total building units. Each house, apartment building, condominium, and mixed residential-and-commercial building was counted as a housing unit, regardless of the number of families living in it (all condominiums in the sample areas were individual buildings). Building units included housing units and all nonresidential buildings other than out-buildings, such as garages and sheds. In some towns, untaxed buildings, such as schools, churches, and municipally owned buildings, were not shown in the assessors' records, preventing an accurate count of the total building units. Housing and building densities were determined by dividing the housing and building unit counts by the acreage of the sample areas, as determined by planimetry of topographic maps.

Housing- and building-density data for each sample area are listed in table 1. Within each sample area, except Wellfleet Center and Hyannis, the housing density and building density were very similar; therefore, except for one example, only housing density is examined in this report.

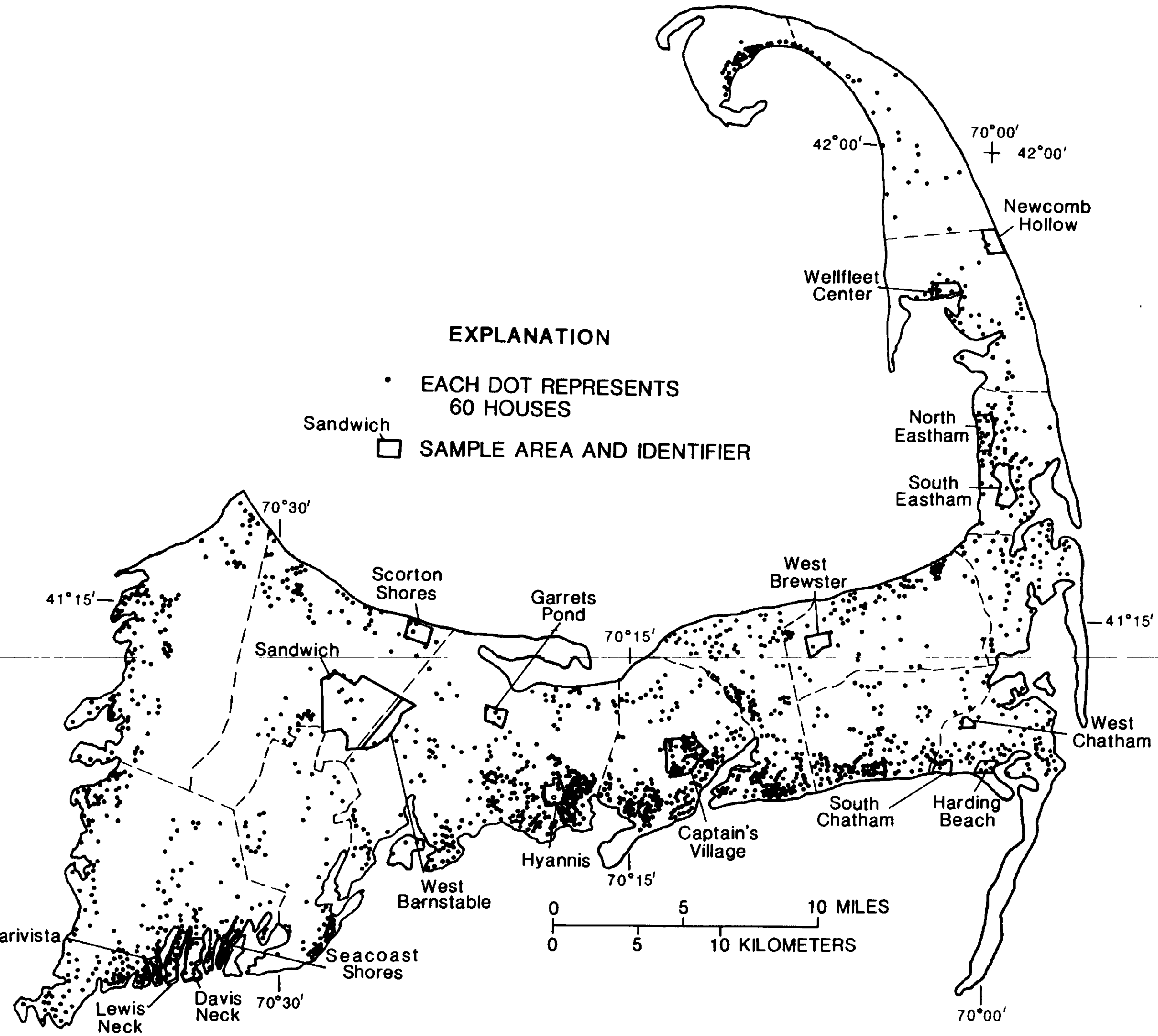

Figure 11.--Location of sample areas.

Table 1.—Housing and building density for sample areas on Cape Cod, 1980-84

(Area, in acres; housing and building density, in units per acre.)

Sample area	Area	Housing units	Building units	Housing density	Building density
Captain's Village	1,202	2,035	2,042	1.69	1.70
Davis Neck	655	532	537	.812	.819
Garrets Pond	315	117	119	.372	.378
Harding Beach	266	308	312	1.16	1.18
Hyannis	433	660	740	1.52	1.71
Lewis Neck	534	907	907	1.70	1.70
Maravista	218	834	834	3.83	3.83
Newcomb Hollow	399	32	32	.128	.128
North Eastham	719	813	813	1.13	1.13
Sandwich	3,012	343	355	.114	.117
Scorton Shores	253	204	204	.806	.806
Seacoast Shores	276	730	731	2.65	2.65
South Chatham	218	384	392	1.76	1.80
South Eastham	541	254	254	.469	.469
Wellfleet Center	284	308	332	1.09	1.17
West Barnstable	844	205	206	.244	.244
West Brewster	315	111	117	.353	.372
West Chatham	200	134	134	.670	.670

Ground-Water Quality

Ground-water-quality data for BCHD and DEQE samples from all the sample areas were retrieved from WATSTORE for the period January 1, 1980, to late December 1984. At the time of retrieval, the most recent samples in the data base were collected on June 20, 1984. If any well had been sampled more than once for a particular constituent or property, the mean of all values for that constituent or property was used. The Captain's Village sample area included two public-supply wells; all the wells in all the other sample areas were private-supply wells. Water-quality data for the sample areas are shown in table 2.

For each constituent, the median value for all wells in each sample area was determined. The housing densities of the sample areas were compared with the median values to determine the extent of correlation between them. The median value was used in place of the mean because the values were not normally distributed, and because extreme high values for some parameters were tens or hundreds of times greater than extreme low values. The 75th-percentile nitrate concentration also was determined because of the importance of nitrate as a potential threat to ground-water quality. Ammonia data were not included because of insufficient data in the sample areas.

Table 2.—Water-quality data for sample areas on Cape Cod

(—, not applicable)

	Captain's Village	Davis Neck	Garrets Pond	Harding Beach	Hyannis	Lewis Neck
Nitrate, in milligrams per liter of nitrogen						
Number of data points	7	10	30	23	17	7
Maximum	3.6	5.8	23	13	19	13
Minimum	.04	.04	.04	.04	.04	.1
Mean	1.3	.98	2.5	2.8	4.5	3.2
Standard deviation	1.4	1.7	4.5	3.8	5.9	4.7
Median	.75	.54	1.2	.9	2.5	1.0
75th percentile	2.5	.96	3.5	4.8	5.8	5.0
pH						
Number of data points	7	10	31	25	17	10
Maximum	6.5	6.1	6.4	7.6	5.8	6.7
Minimum	4.9	4.7	4.8	4.5	4.4	4.9
Mean	5.8	5.5	5.9	6.0	5.4	5.6
Standard deviation	.5	.5	.4	.7	.3	.5
Median	5.7	5.6	6.1	6.1	5.3	5.6
Specific conductance, in microsiemens per centimeter at 25°C						
Number of data points	7	10	31	24	17	8
Maximum	160	230	444	1,800	270	460
Minimum	42	58	60	96	114	75
Mean	104	124	138	332	170	165
Standard deviation	39	50	89	414	42	130
Median	118	112	112	210	174	108
Sodium, in milligrams per liter						
Number of data points	3	2	15	20	7	1
Maximum	15	30	42	390	26	15
Minimum	14	14	8	10	10	15
Mean	14	22	16	62	18	15
Standard deviation	.6	11	9.0	100	4.8	—
Median	14	22	14	29	18	15
Iron, in micrograms per liter						
Number of data points	5	9	29	20	15	5
Maximum	8,100	3,500	5,000	4,900	6,300	280
Minimum	120	50	20	50	50	90
Mean concentration	1,900	510	980	550	920	156
Standard deviation	3,500	1,100	1,500	1,400	1,700	74
Median concentration	350	150	220	92	220	150

Table 2.—Water-quality data for sample areas on Cape Cod (continued)

	Maravista	Newcomb Hollow	North Eastham	Sandwich	Scorton Shores	Seacoast Shores
Nitrate, in milligrams per liter of nitrogen						
Number of data points	5	5	34	136	37	6
Maximum	8.4	2.38	11	22	4.7	2.1
Minimum	.04	.04	.04	.04	.04	.7
Mean	4.0	.94	1.7	1.5	1.2	1.4
Standard deviation	3.9	1.2	2.1	3.1	1.1	.5
Median	3.5	.20	1.0	.29	1.2	1.4
75th percentile	8.0	2.2	2.2	1.4	1.7	1.8
pH						
Number of data points	5	5	36	139	37	7
Maximum	6.1	6.0	6.4	6.7	7.2	5.7
Minimum	4.8	5.7	5.3	5.0	5.6	5.5
Mean	5.5	5.9	5.9	5.8	6.0	5.6
Standard deviation	.6	.1	.3	.6	.3	.1
Median	5.6	5.9	6.0	5.7	6.0	5.6
Specific conductance, in microsiemens per centimeter at 25°C						
Number of data points	3	5	35	138	37	5
Maximum	3,650	240	235	480	180	280
Minimum	162	160	90	34	69	98
Mean	1,650	188	144	93	117	147
Standard deviation	1,800	31	57	60	25	77
Median	1,140	185	130	74	116	110
Sodium, in milligrams per liter						
Number of data points	0	5	21	40	12	0
Maximum	—	35	60	76	25	—
Minimum	—	23	13	5	13	—
Mean	—	28	22	19	17	—
Standard deviation	—	4.4	12	15	3.2	—
Median	—	27	19	16	17	—
Iron, in micrograms per liter						
Number of data points	1	5	32	128	37	2
Maximum	60	650	1,400	3,300	4,800	830
Minimum	60	100	20	10	40	100
Mean	60	240	280	190	510	460
Standard deviation	—	230	330	390	940	520
Median	60	150	150	80	150	460

Table 2.—Water-quality data for sample areas on Cape Cod (continued)

	South Chatham	South Eastham	Wellfleet Center	West Barnstable	West Brewster	West Chatham
Nitrate, in milligrams per liter of nitrogen						
Number of data points	6	37	31	76	9	20
Maximum	6.5	12	27	14	14	10
Minimum	2.0	.04	.04	.04	.04	.04
Mean	3.4	.96	3.6	1.3	3.8	1.4
Standard deviation	2.0	2.1	5.1	2.4	5.8	2.8
Median	2.2	.18	1.8	.4	.62	.38
75th percentile	5.5	.92	5.5	1.5	8.4	1.1
pH						
Number of data points	6	38	30	77	9	24
Maximum	6.2	6.7	7.0	6.4	6.1	8.9
Minimum	5.5	5.1	4.5	4.6	4.9	5.6
Mean	5.7	5.9	6.1	5.6	5.6	6.3
Standard deviation	.3	.4	.6	.3	.4	.7
Median	5.7	5.9	6.1	5.7	5.7	6.1
Specific conductance, in microsiemens per centimeter at 25°C						
Number of data points	6	37	30	76	9	20
Maximum	198	180	5,800	410	280	265
Minimum	115	46	56	41	74	82
Mean	150	119	624	77	131	140
Standard deviation	31	32	1,190	51	69	50
Median	140	120	255	60	105	122
Sodium, in milligrams per liter						
Number of data points	6	22	25	15	6	13
Maximum	25	38	740	63	34	43
Minimum	13	13	13	7	9	12
Mean	20	20	75	19	18	21
Standard deviation	4.7	5.3	150	14	8.6	10
Median	21	20	30	15	16	18
Iron, in micrograms per liter						
Number of data points	6	38	29	69	8	18
Maximum	1,200	4,800	4,200	5,900	2,000	5,000
Minimum	50	20	20	10	80	40
Mean	260	430	490	400	570	570
Standard deviation	460	960	1,100	960	670	1,200
Median	55	100	120	120	260	160

Correlations Between Ground-Water Quality and Housing Density

There is a positive correlation between nitrate concentration and housing density on Cape Cod. Median nitrate concentration and housing density have a Pearson correlation coefficient of 0.802 (fig. 12), which is significantly different from zero at the 95-percent confidence level. Statistical significance at this level means that there is at most a 5-percent probability that a correlation coefficient this high could occur by chance without the existence of an actual relation between the two quantities. The square of the correlation coefficient is called the coefficient of variability, the amount of the variability in the dependent variable (median nitrate concentration) that can be attributed to the independent variable (housing density). Thus, housing density causes 64 percent of the observed variation in median nitrate concentration. If building density is used in place of housing density (fig. 13), the correlation coefficient increases slightly to 0.821, but the graphs of the two correlations are nearly identical.

Other statistical measures of nitrate levels also clearly show the relation between housing density and nitrate levels. Of the nine sample areas with housing densities greater than 1 house/acre, five areas had a nitrate concentration of at least 5 mg/L (the Barnstable County planning goal for nitrate) at the 75th percentile. Of the nine sample areas with housing densities less than 1 house/acre, only one area had a nitrate concentration greater than or equal to 5 mg/L at the 75th percentile.

Correlations between housing density and median values of sodium (fig. 14), pH (fig. 15), and iron (fig. 16) are not statistically significant at the 95-percent confidence level. Housing density and median specific conductance have a significant correlation coefficient of 0.710 (fig. 17), but this reflects the exaggerated influence of the data point for Maravista (in the upper right of the figure), where two of the three wells tested for specific conductance were affected by saline ground water, on the equation for the Pearson correlation coefficient. If this point is excluded from the calculation, the correlation coefficient drops to 0.168, which is not significantly different from zero. Although sodium is an important constituent of septage, and sodium and specific conductance would thus be expected to increase with housing density, other factors such as wind-borne ocean spray, road salting, and saltwater contamination seem to have a greater influence on sodium concentration.

APPRAISAL OF METHODS USED TO DETERMINE RELATIONS

QWSYMAP provides a fast and economical way of displaying large amounts of ground-water-quality data in map format for areal analysis. The procedure is especially useful for pointing out areas where water-quality problems may occur. However, the advantages of the procedure are counterbalanced by several disadvantages. One disadvantage is that the line-printer maps generated by QWSYMAP do not line up exactly with base maps. This makes it difficult to identify probable contaminant sources for areas of poor water quality. The averaging process QWSYMAP uses for values from adjacent sites can be misleading, because for many water-quality consitituents, the most significant ranges of values for analytical purposes are orders of magnitude apart. Maps of these constituents will tend to show artificially large areas of poor water quality.

The interpolation scheme used by QWSYMAP does not account for physical characteristics of the aquifer, such as lithology, or hydrologic characteristics, such as direction of ground-water flow. If a data point does not have other data points near it, QWSYMAP interpolates the same distance from that point in the upgradient direction that it interpolates in the downgradient direction. For this reason, the interpolation procedure in QWSYMAP may produce inaccurate representations in some areas, as in western Wellfleet, where QWSYMAP interpolated between areas that are separated hydrologically by marshes.

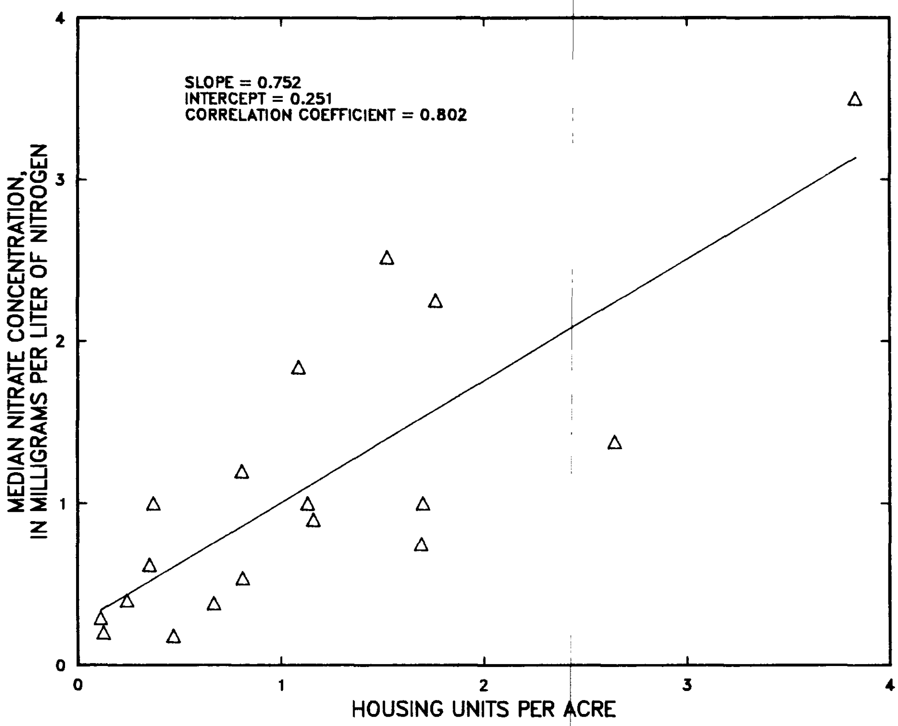

Figure 12.--Median nitrate concentration as a function of housing density.

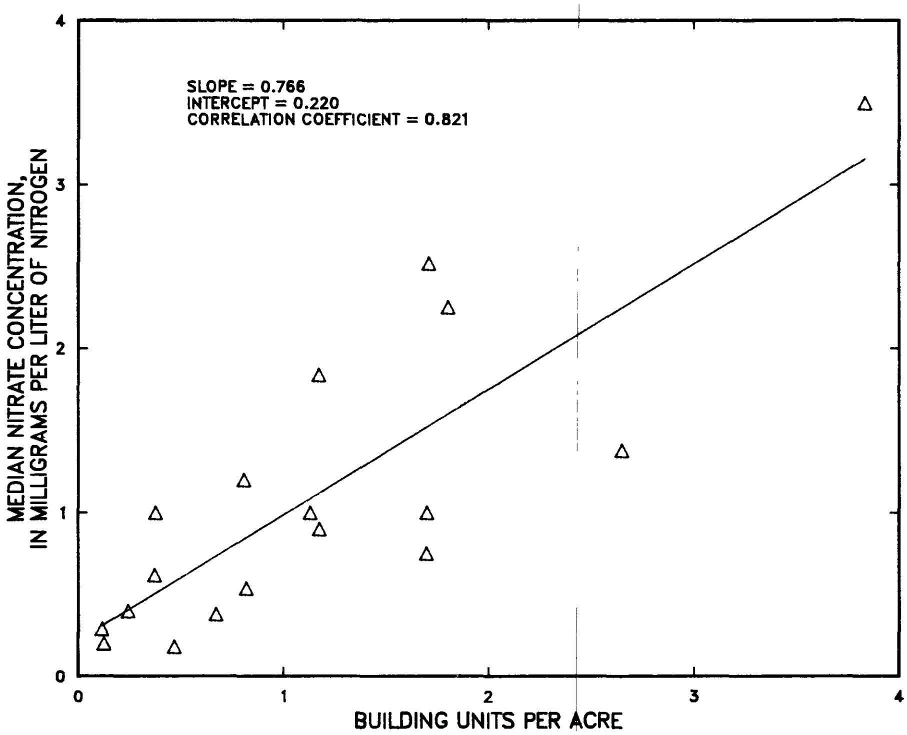

Figure 13.--Median nitrate concentration as a function of building density.

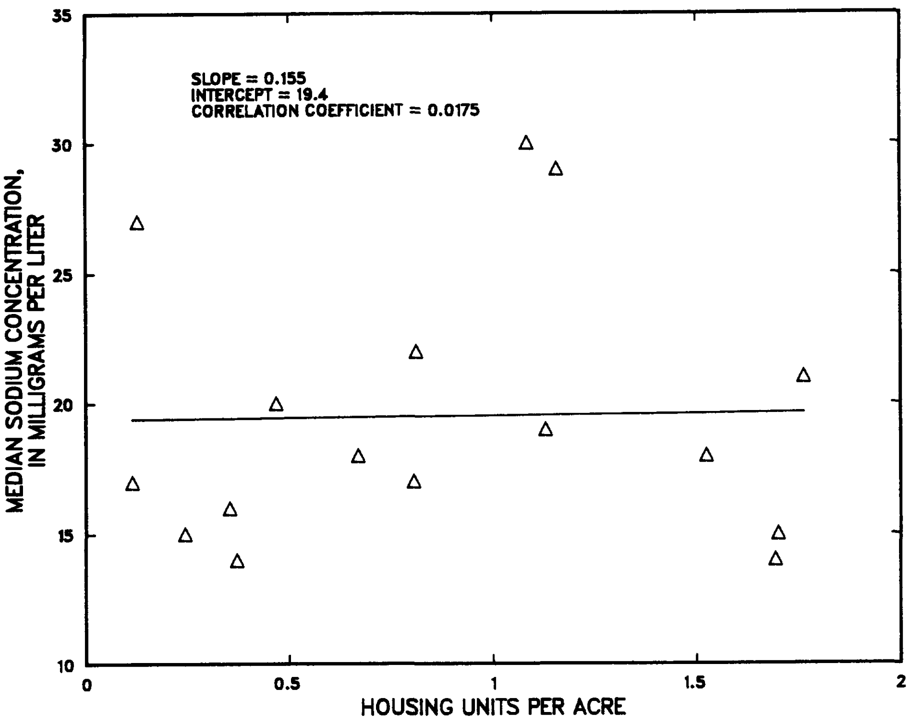

Figure 14.--Median sodium concentration as a function of housing density.

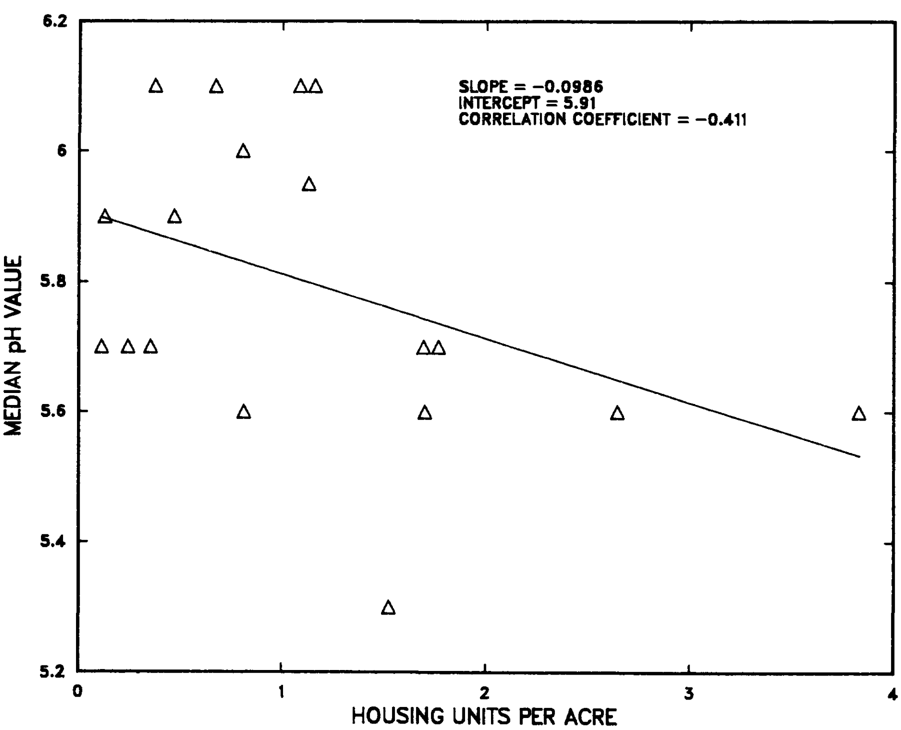

Figure 15.--Median pH as a function of housing density.

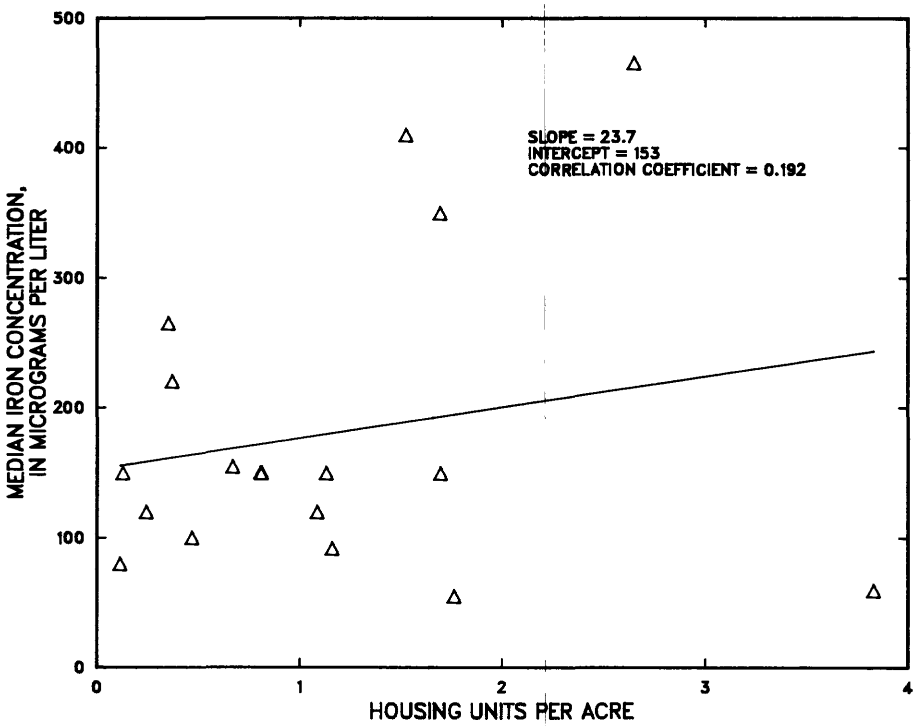

Figure 16.--Median iron concentration as a function of housing density.

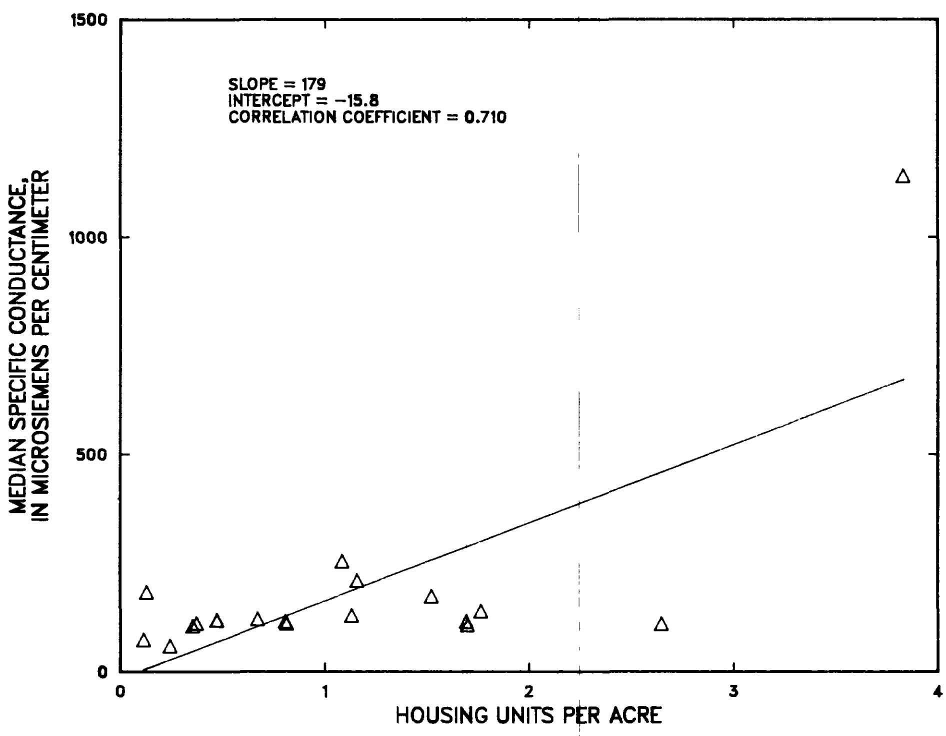

Figure 17.--Median specific conductance as a function of housing density.

The water-quality maps of Cape Cod generated by QWSYMAP can be misleading in areas with few wells, because the system may interpolate large areas of the map from only a few points. This condition occurs in Provincetown, Bourne, and the portion of Sandwich that is occupied by Camp Edwards.

Proper interpretation of QWSYMAP maps is heavily dependent on detailed user knowledge of local sources of contamination and on the idiosyncrasies of both the water-quality data base and the mapping procedure. QWSYMAP allows qualitative relations between ground-water-quality and housing density to be identified; however, the relations cannot be quantified.

Quantitative analysis of ground-water-quality data by the sample-area method is a valid method for calculating the relations between the concentration of selected water-quality constituents and housing density. The method works well for regions like Cape Cod, where numerous water-quality data are available and the hydrogeologic setting is relatively uniform. The preferred method is to select sample areas randomly; however, from a logistical standpoint, this is not possible because the water-quality data tend to cluster in certain areas of the region and because the availability, quantity, and quality of the housing data are highly variable from town to town. One possible solution is to select the sample areas randomly and to install wells in those areas to collect ground-water samples. This method has its own drawbacks: It is costly, time-consuming, and (in the case of Cape Cod) does not take advantage of the extensive water-quality data base already in place.

The next step in quantitative analysis of the water-quality data on Cape Cod is to take advantage of the automated geographic-information systems now becoming available. These systems, of which QWSYMAP is a precursor, have the capability of overlaying different types of geographic information, such as water quality and housing density, onto one map and performing statistical analysis on the data. Different combinations of two or more sets of data can be analyzed in much less time than was possible by previous means. Such a system would combine the primary benefits of QWSYMAP and sample-area analysis—rapid processing of large amounts of data for areal analysis in map format and quantification of relations.

The lack of digitized housing-density data is a problem with no immediate solution. Cape Cod does not contain any U.S. Census Bureau block tracts, for which housing data are available for each city block. Any study of water quality and housing density that uses an automated geographic-information system will have to include the time-consuming process of collecting, quantifying, and digitizing these data.

SUMMARY

Ground-water-quality maps of Cape Cod generated by a computerized mapping procedure show a relation between nitrate concentration and housing density, and a less clearly defined relation between specific conductance and housing density. Maps of sodium, ammonia, pH, and iron show little or no relation between these constituents and housing density.

Quantitative analysis of data from 18 sample areas throughout the Cape shows a statistically significant correlation of nitrate concentrations with housing density. Median nitrate concentration has a Pearson correlation coefficient of 0.802 with housing density, which is significant at the 95-percent confidence level. Of the nine sample areas with housing densities greater than 1 house/acre, five areas had a nitrate concentration of at least 5 mg/L at the 75th percentile; of the nine sample areas with housing densities less than 1 house/acre, only one area had a nitrate concentration at or above 5 mg/L at the 75th percentile. Nitrate levels increase with housing density because of the increase in contaminants being added to the aquifer by septic systems. Sodium, pH, iron, and specific conductance do not significantly correlate with housing density at the 95-percent significance level.

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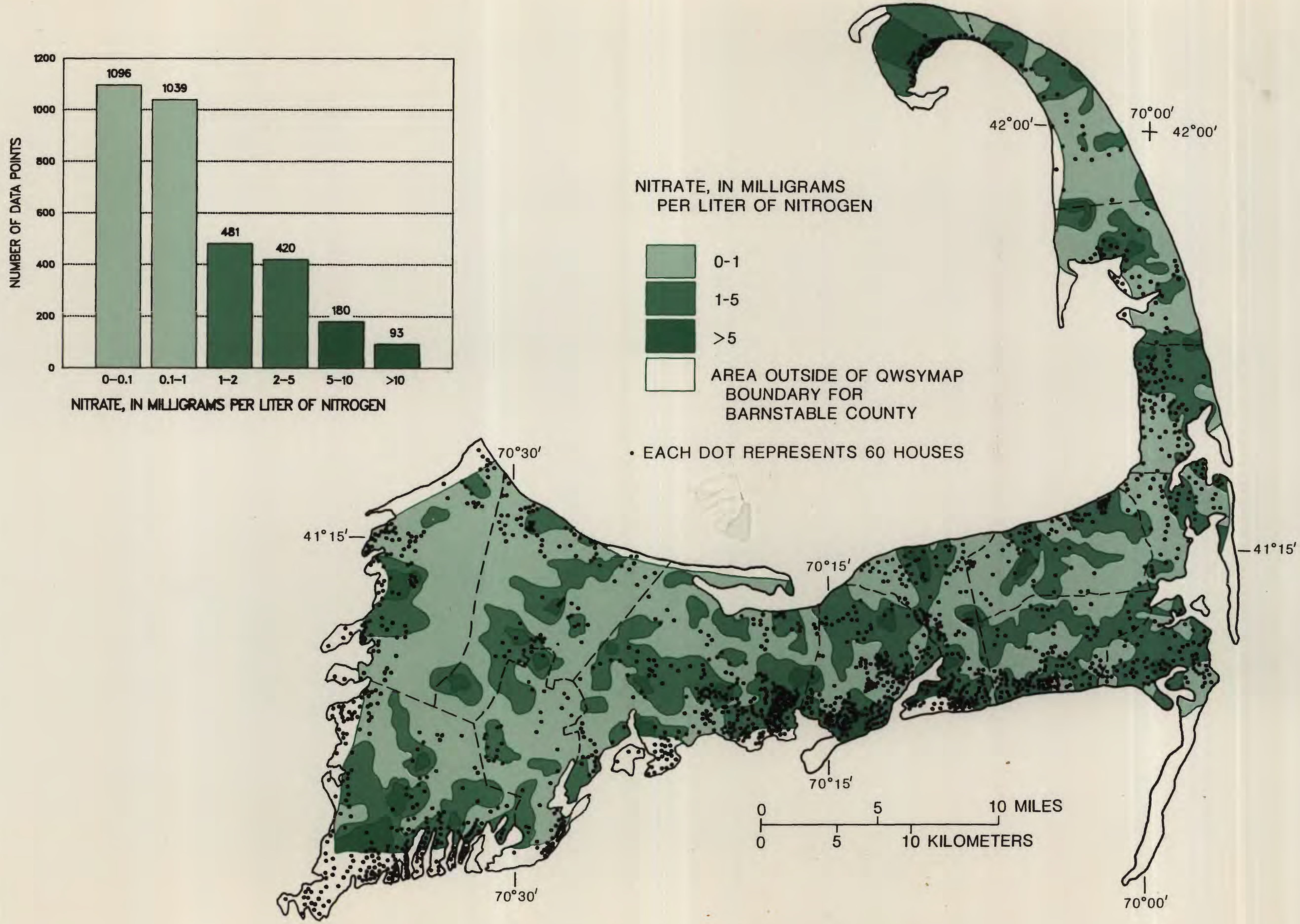
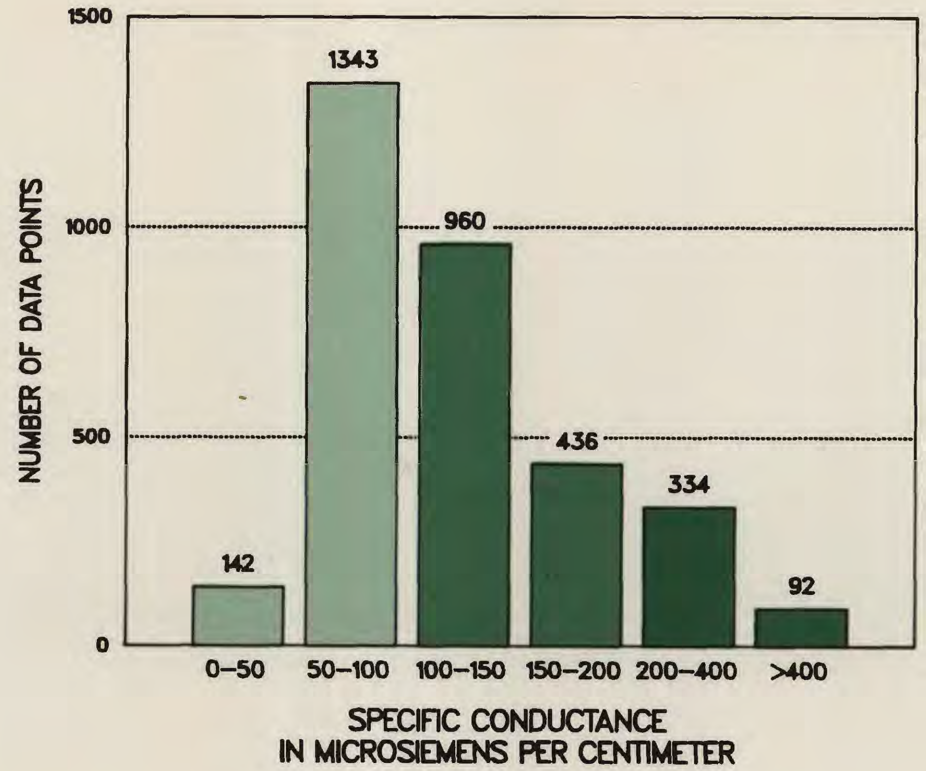


Figure 5.--Nitrate concentrations and frequency distribution on Cape Cod, 1980-84.



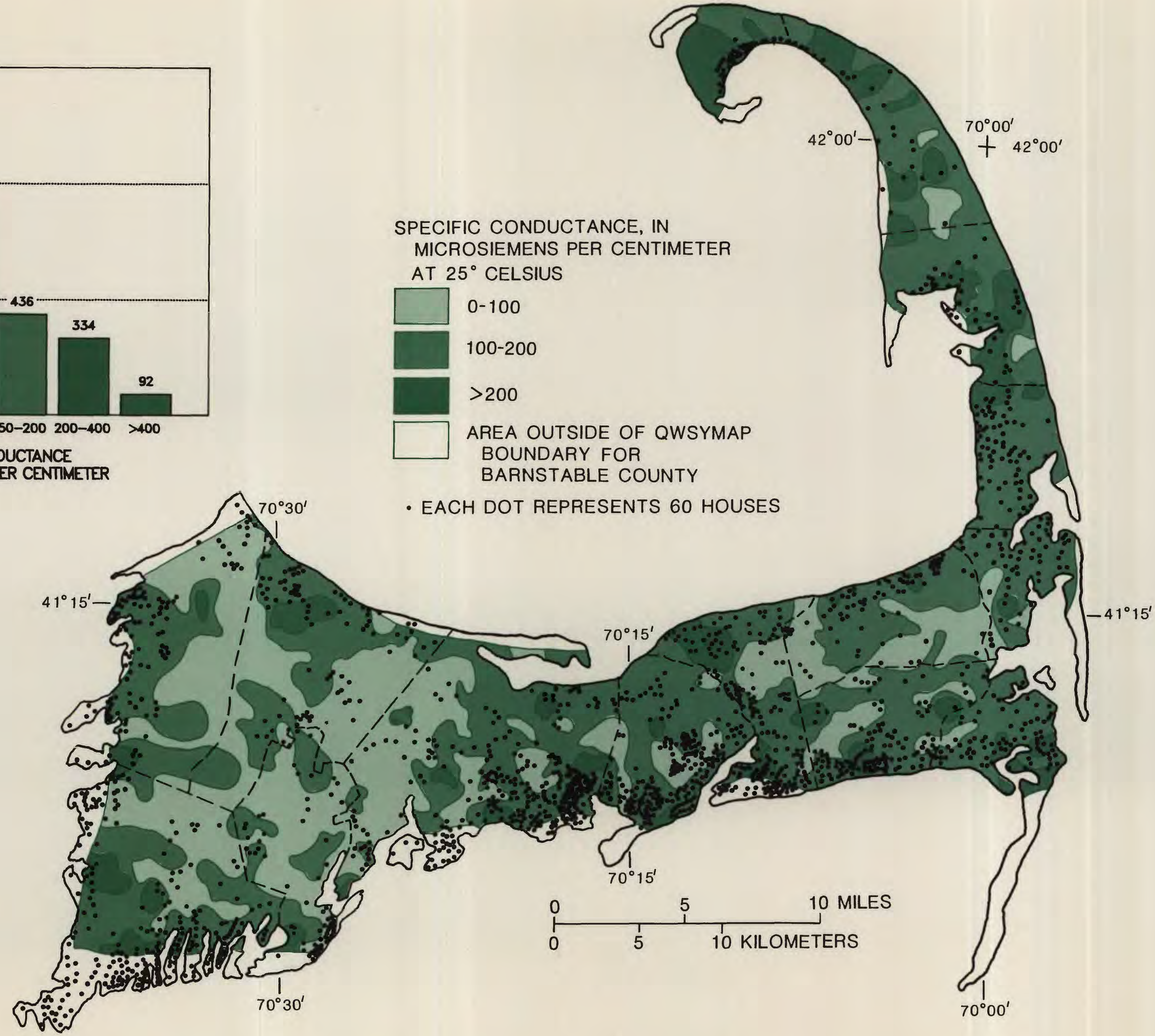


Figure 6.--Specific conductance levels and frequency distribution on Cape Cod, 1980-84.

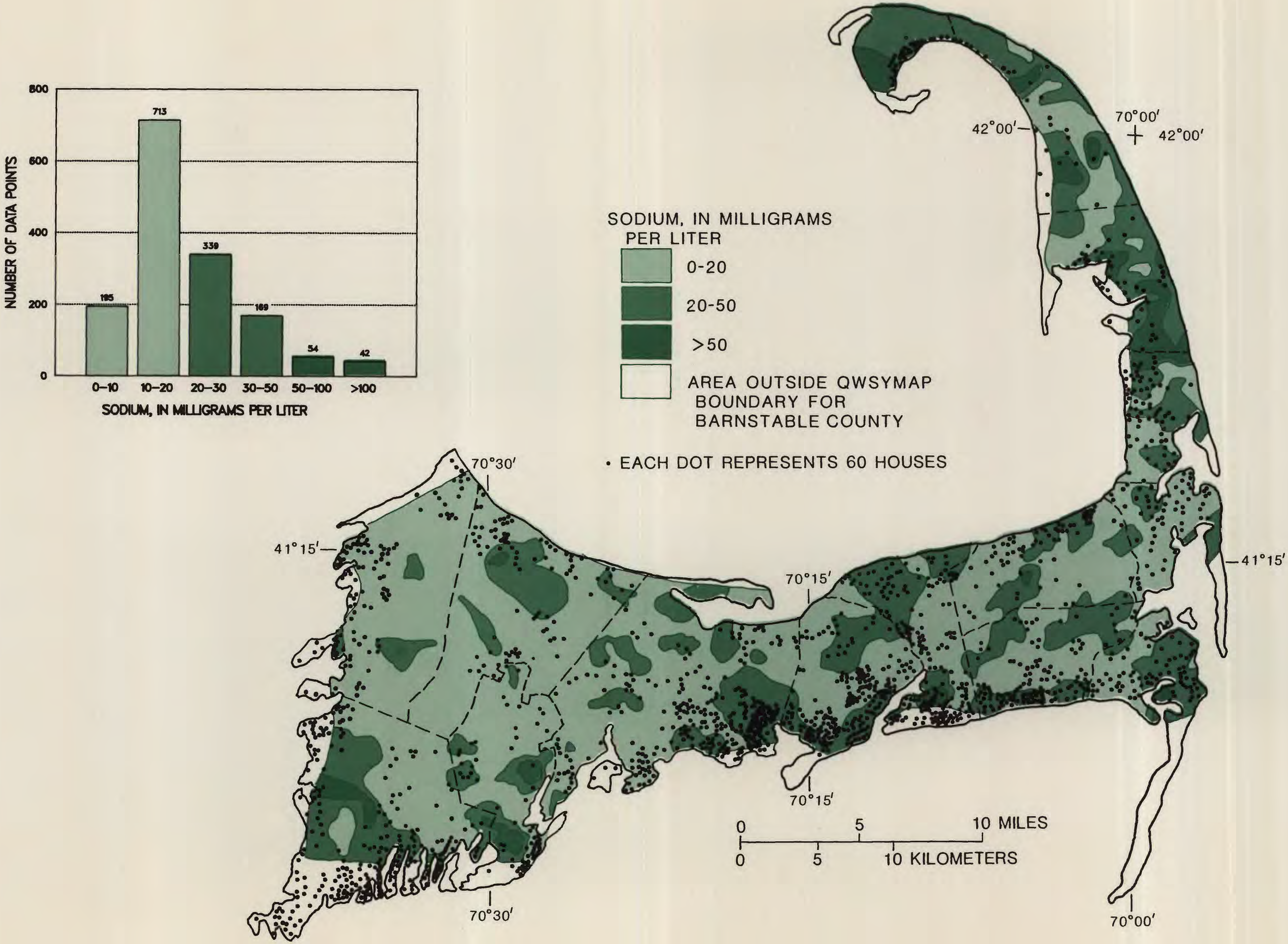


Figure 7.--Sodium concentrations and frequency distribution on Cape Cod, 1980-84.

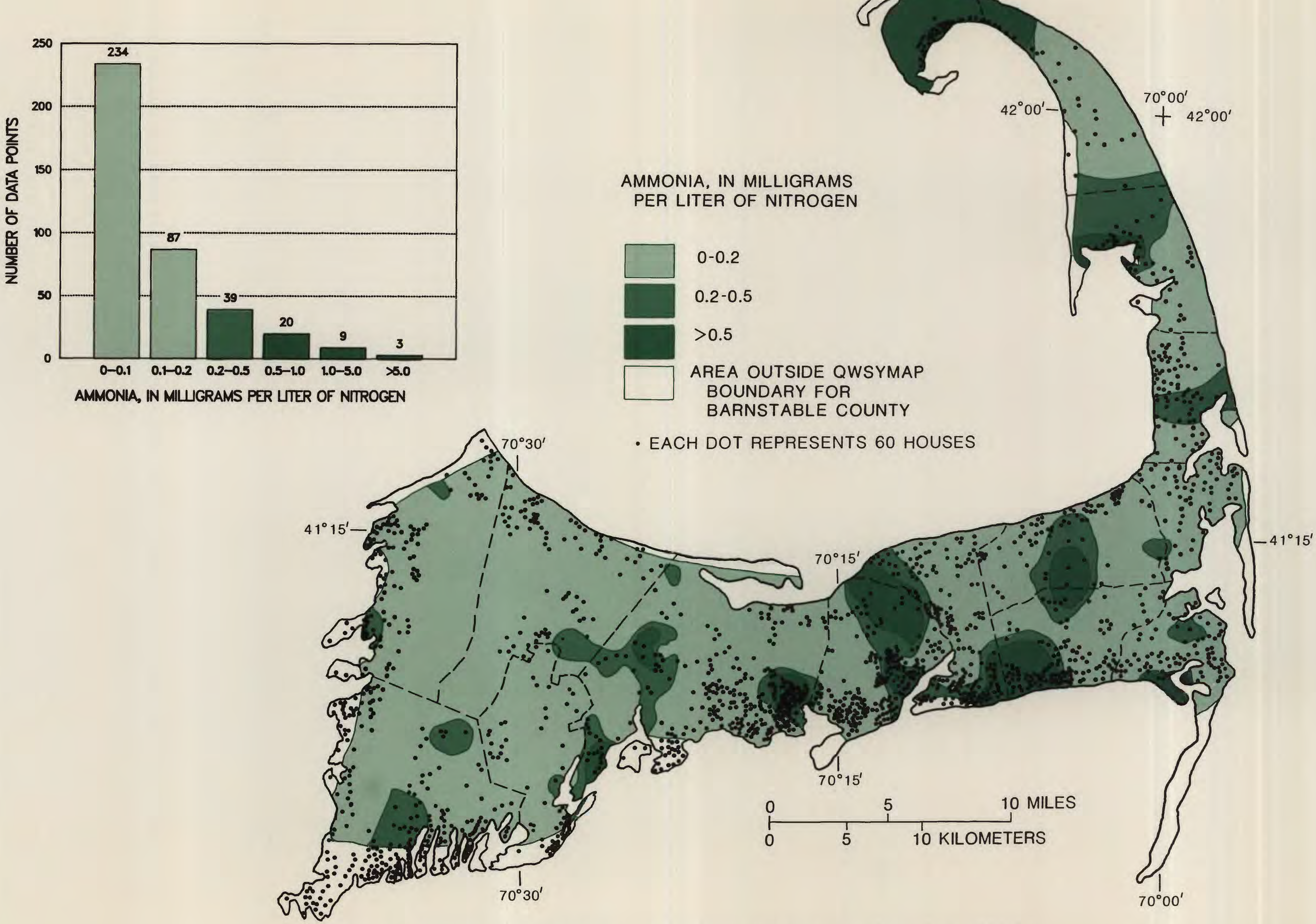


Figure 8.-- Ammonia concentrations and frequency distribution on Cape Cod, 1980-84.

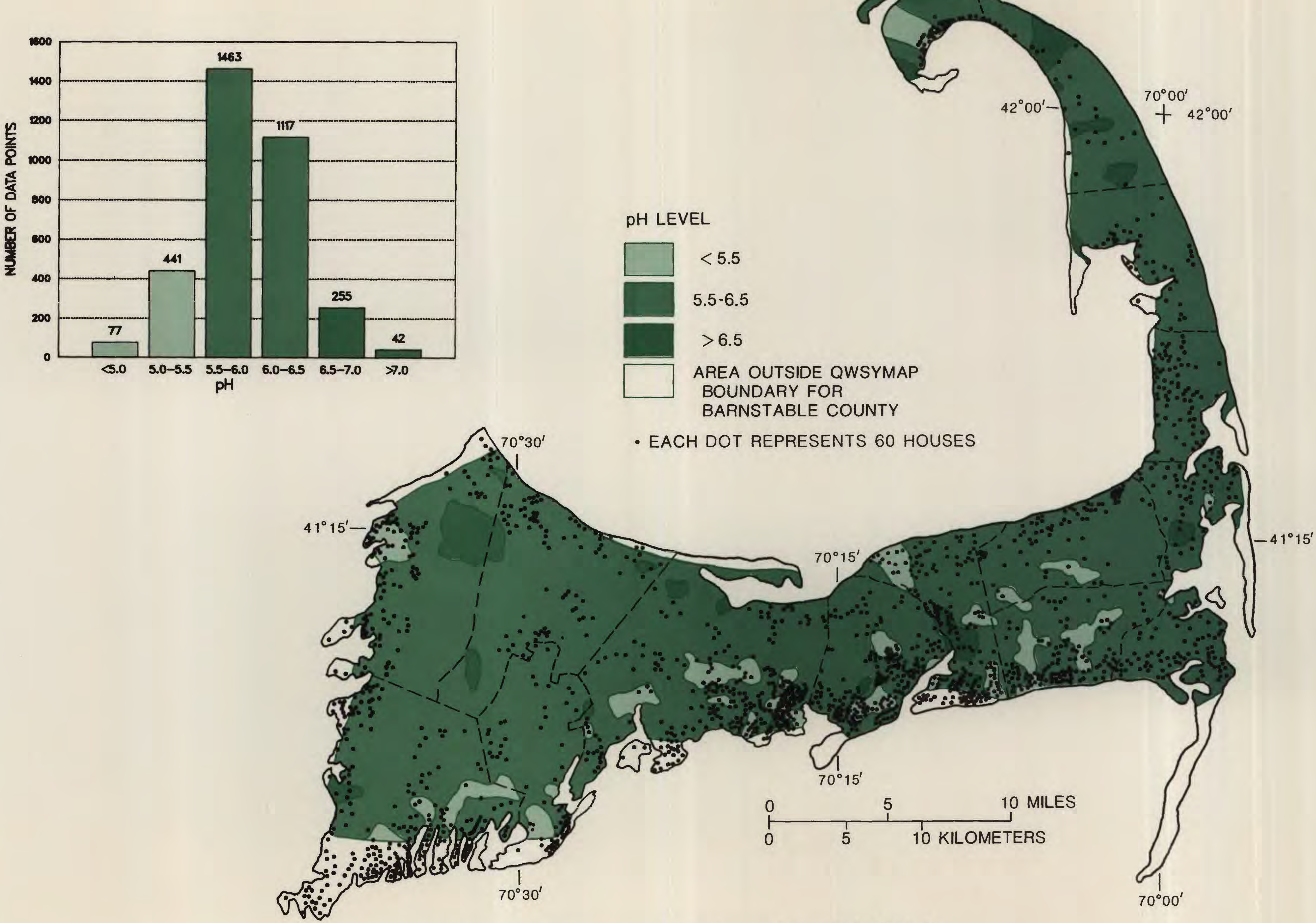
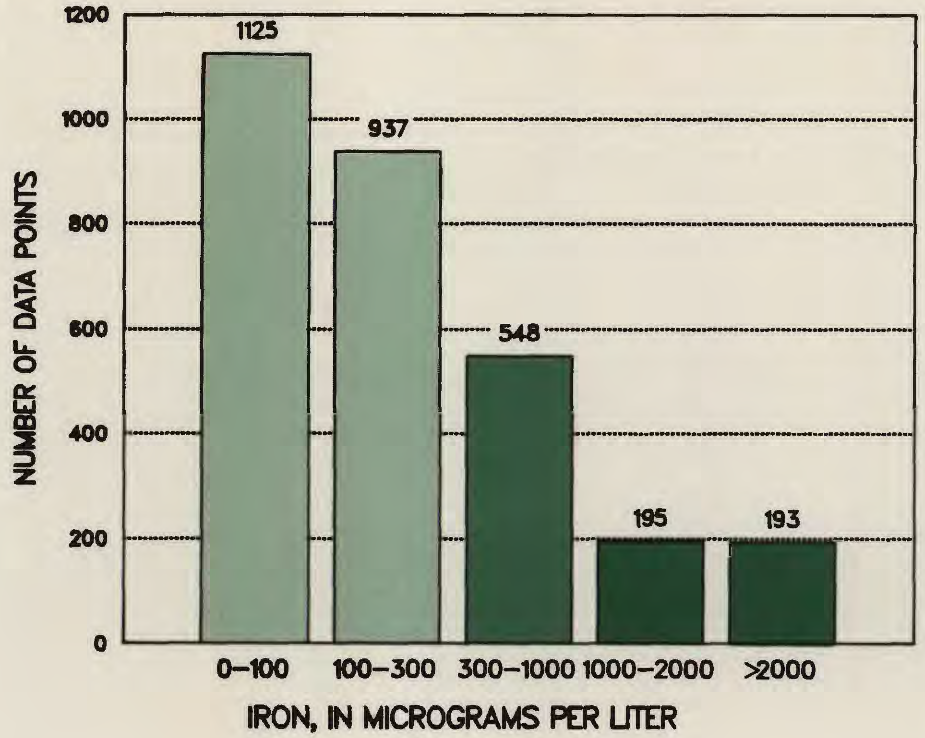


Figure 9.--pH levels and frequency distribution on Cape Cod, 1980-84.



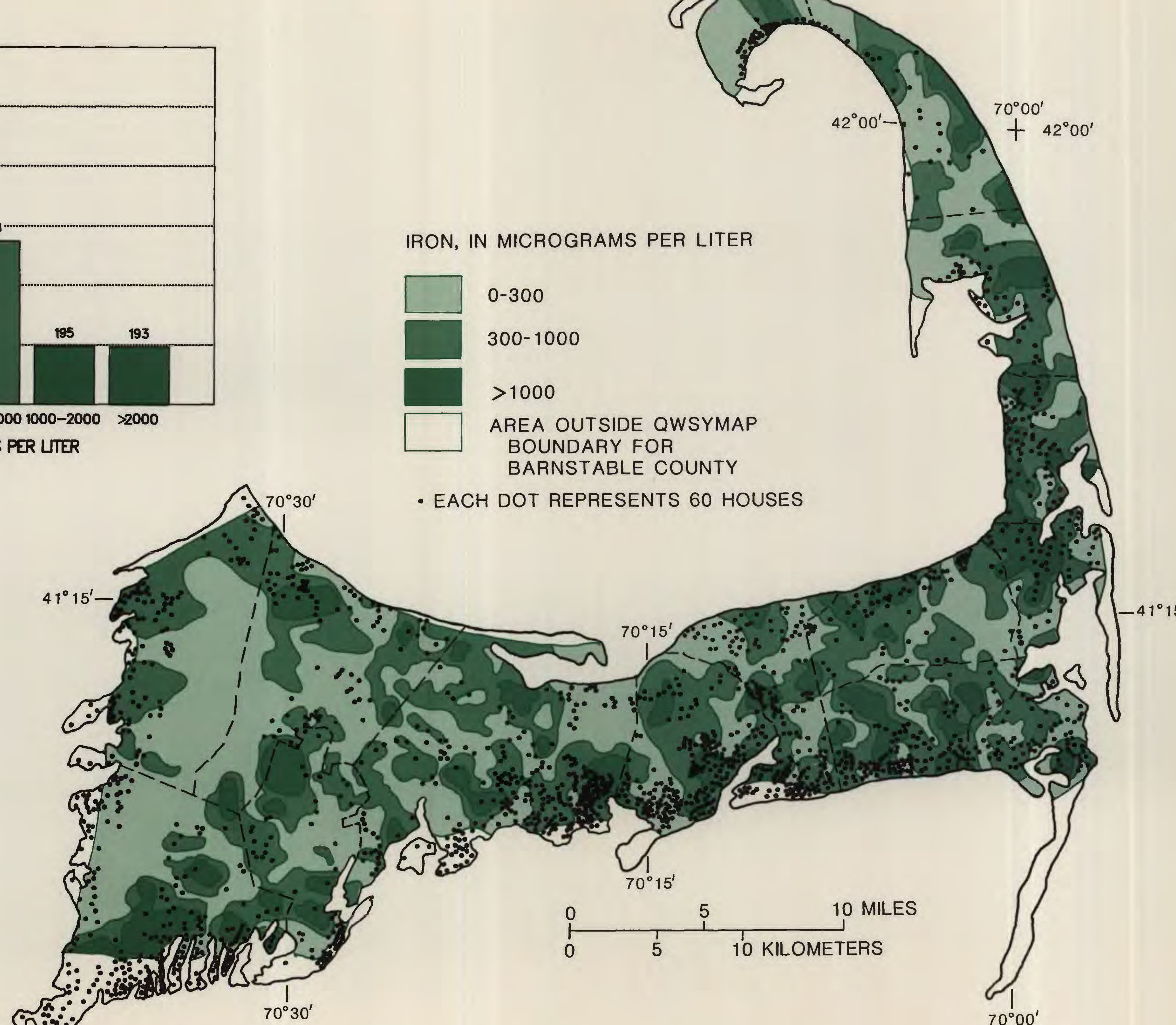


Figure 10.--Iron concentrations and frequency distribution on Cape Cod, 1980-84.