Comparison of Native Ground-Water Quality with Water Quality in Agricultural and Residential Areas of Long Island, New York

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

COMPARISON OF NATIVE GROUND-WATER QUALITY WITH WATER QUALITY IN AGRICULTURAL AND RESIDENTIAL AREAS OF LONG ISLAND, NEW YORK

by Kenneth A. Pearsall

Abstract

Two recent studies on Long Island--one appraising the quality of native ground water (water that is unaltered by the effects of man's activities), and the other assessing the present quality of shallow ground water in five areas of differing land use--provide sufficient data to determine the percentages of sodium, potassium, calcium, magnesium, chloride, sulfate, nitrate, alkalinity, and dissolved solids in residential and agricultural areas that are derived from human activities. The contribution from human activities ranged from 57 percent for alkalinity in residential areas to 99 percent for nitrate in agricultural areas. Differences between estimated native concentrations and current concentrations were statistically significant for all constituents except alkalinity in agricultural areas.

INTRODUCTION

Comparison of data from two recent water-quality studies on Long Island by the U.S. Geological Survey (USGS) allows quantification of the effects of human activities on the concentration of inorganic constituents in ground water.

Purpose and Scope

This report briefly summarizes the pertinent parts of both studies and compares their results to indicate the contribution of human activities to major-ion and dissolved-solids concentrations in shallow ground water in residential and agricultural areas in central and eastern Long Island.

Physical Setting

Long Island extends 120 mi east-northeast from New York City into the Atlantic Ocean and is a little more than 20 mi wide at its widest point (fig. 1). It is surrounded by saltwater. Development on Long Island has proceeded eastward from New York City; thus, the two western counties (Kings and Queens), which are boroughs of New York City, are highly developed and industrialized and densely populated. The central and eastern counties (Nassau and Suffolk) are less developed and more sparsely populated, and eastern Suffolk County retains considerable amounts of agricultural land and some large tracts of undeveloped land. Kings and Queens Counties rely mostly on surface water from the mainland for water supply, whereas Nassau and Suffolk Counties rely entirely on ground water. For this reason, the U.S. Environmental Protection Agency has designated the aquifer system under Nassau and Suffolk Counties as a sole-source aquifer.

The Long Island aquifer system consists of unconsolidated deposits that range in thickness from 0 to 2,000 ft. From the base of the system upward, the system is divided into the Lloyd aquifer, the Raritan confining unit, the Magothy aquifer, the upper glacial aquifer, and other, thin units of limited areal extent (fig. 2). The lowermost aquifer, the Lloyd, which ranges in thickness from 0 to 550 ft, overlies bedrock and is overlain and confined by the Raritan confining unit. Use of the Lloyd aquifer for water supply is usually but not exclusively restricted to nearshore areas. The principal water-supplying aquifer is the Magothy, which provides about three-quarters of the ground-water supply for all of Long Island. The Magothy, which is separated from the underlying Lloyd by the Raritan confining unit and overlain by the upper glacial (water-table) aquifer, ranges in thickness from 0 to 1,050 ft. The upper glacial aquifer ranges from 0 to 650 ft in thickness. The Lloyd and Magothy aquifers and the Raritan confining unit are of Cretaceous age; the upper glacial aquifer is of Pleistocene age. The upper glacial aquifer has largely been abandoned for water supply in western and central Long Island in favor of less contaminated water from deeper in the aquifer system, but, in some parts of eastern Long Island, the upper glacial aquifer is still being developed for water supply. Only the upper glacial and Magothy aquifers are addressed in this report.

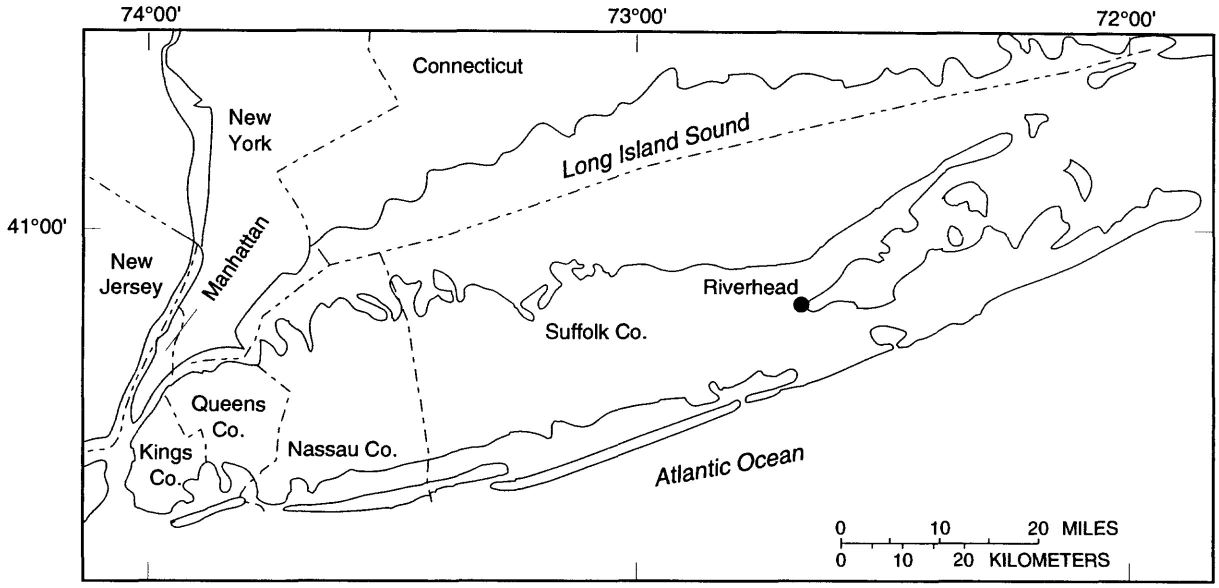

Figure 1. Counties of Long Island, New York.

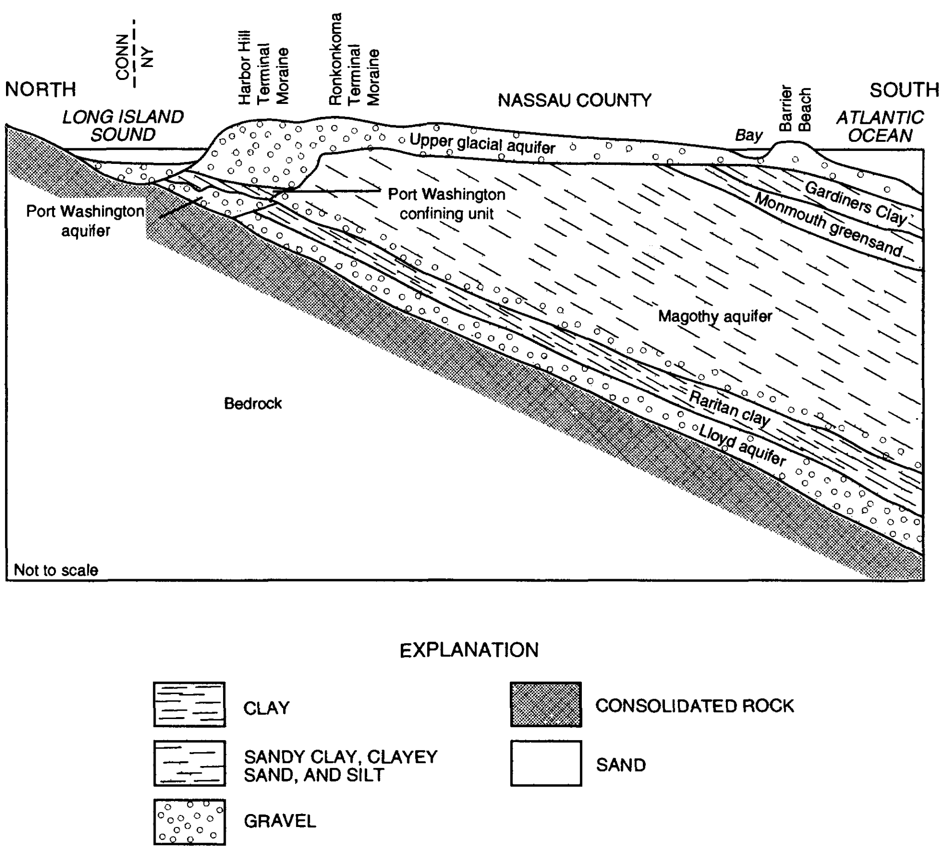

Figure 2. Generalized hydrogeologic section of the Long Island ground-water system. (Modified from Franke and McClymonds. 1972, p. F10.)

STUDY OF GEOCHEMICAL PROCESSES

In 1985 the USGS, in cooperation with the Nassau County Department of Public Works, Suffolk County Water Authority, Suffolk County Department of Health Services, and New York State Department of Environmental Conservation, began a study to investigate natural geochemical processes that affect ground-water quality in the Long Island aquifer system. Examination of these processes required characterization of native or pristine water quality--water unaffected by man's influences. A data base of 8,500 wells on Long Island was screened to identify those at which the water might reflect natural (predevelopment) conditions. The screening criteria were a chloride concentration of 10 mg/L or less and a nitrate concentration of less than 1.0 mg/L. These concentrations were selected because previous studies had concluded that concentrations above these levels indicated contamination from human activities (Perlmutter and Geraghty, 1963, p. 39; Perlmutter and Koch, 1972, p. 228). Of all the wells that met these criteria, more than 200 were selected to provide a three-dimensional distribution of sampling points throughout the aquifer system in Nassau and Suffolk Counties. Additional wells without historical data were added in areas where no wells met the screening criteria or in areas where no historical water-quality data were available.

About 220 wells were sampled, and analyses where chloride or nitrate concentrations exceeded the screening criteria were discarded. The remaining wells were then categorized by aquifer and redox state to form groups representing similar geochemical environments. The Magothy aquifer was divided into upper and lower halves because it is much thicker than the other aquifers. Median concentrations of major constituents were calculated for each group. Data from oxic environments in the upper glacial aquifer, the upper half of the Magothy aquifer, and the lower half of the Magothy aquifer are given in table 1. Water quality in anoxic environments was not addressed in this analysis to avoid considering the potential for

Table 1. Median concentrations of inorganic constituents in ground-water samples collected in two ground-water studies, Long Island, New York

[Concentrations are in milligrams per liter]

	Number of samples	Constituent								
		Chloride	Sodium	Potassium	Calcium	Magnesium	Sulfate	Nitrate	Alkalinity	Dissolved solids
STUDY OF GEOCHEMICAL PROCESSES (1989, data on file at USGS office in Coram, N.Y.)										
Upper glacial aquifer	12	6.4	4.2	0.50	1.5	1.4	6.4	0.022	6	34
Upper half of Magothy aquifer	7	6.2	5.0	.63	3.6	1.7	5.5	.29	16	47
Lower half of Magothy aquifer	30	4.0	3.3	.44	1.2	.56	1.6	.20	7	25
STUDY OF EFFECTS OF LAND USE (Eckhardt and others, 1988)										
Undeveoped area	15	8.3	5.0	.80	4.0	1.6	9.0	.24	6	70
Residential area	60	29	18	3.0	18	3.3	26	5.4	14	163
Agricultural area	15	23	9.0	4.3	31	7.7	59	8.9	9	216

reduction of nitrate and sulfate and changes in the dissolved-solids concentration.

An important feature of the data is the decrease in concentrations with depth--concentrations appear to be higher in the upper half of the Magothy than in the lower half of the Magothy, but no known mineralogic difference between the two units could account for the difference. Other studies of ground-water quality on Long Island, including those by Cohen and others, (1968, p. 50) and Ragone and others (1981, p. 29) have similarly noted a decrease in constituent concentrations with depth. In most aquifer systems the dissolved-solids concentration in ground water increases with depth as the contact time with aquifer sediments increases. The trend observed in this analysis suggests that the well-selection process failed to eliminate some shallow wells that are affected by human-derived influences. The anomalously high concentrations in the upper half of the Magothy are attributed to the large percentage of sampled wells in agricultural areas and the insufficient size of the data set (seven samples).

Data from the lower half of the Magothy aquifer probably represent natural (predevelopment) conditions more closely than the data from the overlying units for two reasons. First, the age of ground water generally increases with depth in the flow system; therefore, water in the deepest part of the Magothy aquifer should be the least affected by human activities. Second, few shallow wells that are definitely unaffected by human influences are available outside the pine barrens area in eastern Suffolk County, one of the few remaining largely undeveloped areas on Long Island (area 1 in fig. 3). The few shallow wells selected from outside the pine barrens, although the best obtainable, nevertheless reflect some effects of human activities.

STUDY OF THE RELATION BETWEEN LAND USE AND GROUND-WATER QUALITY

The second study, by Eckhardt and others (1988) evaluated the quality of shallow ground water in five

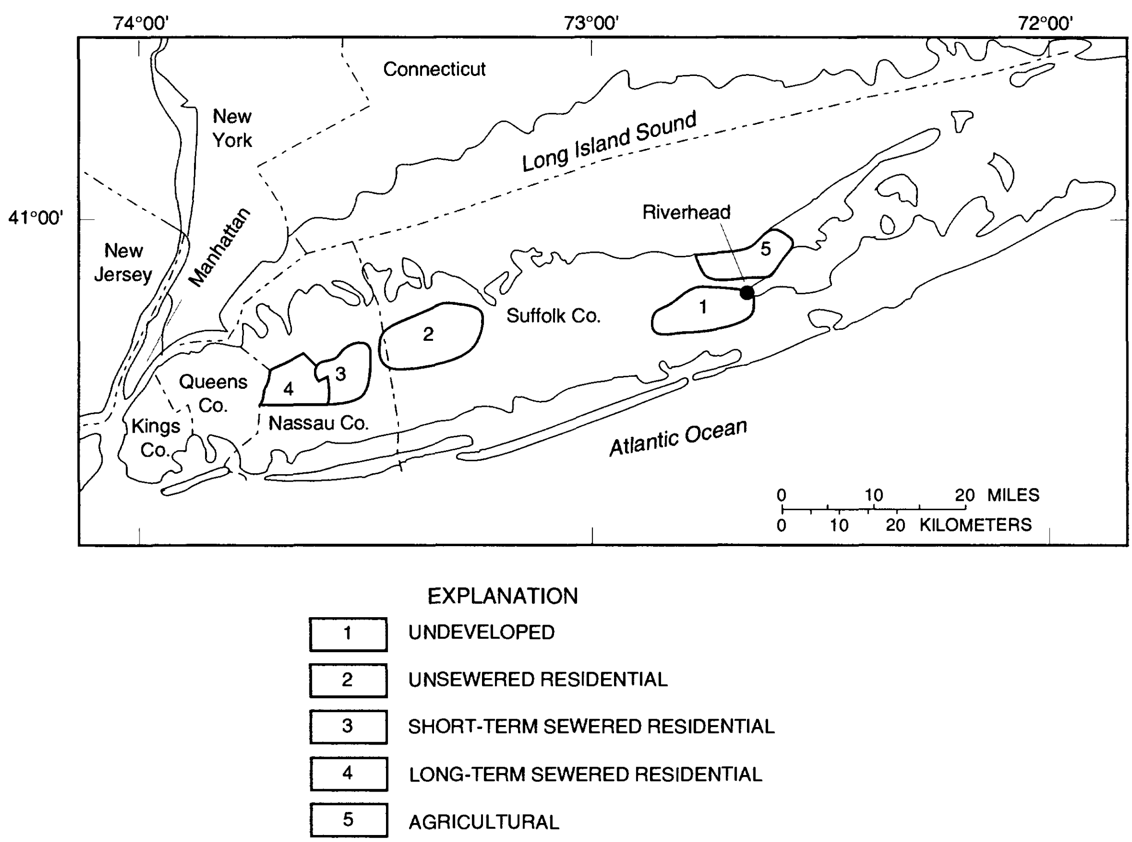

Figure 3. Location of study areas used in land-use study of Eckhardt and others, (1988).

Table 2. Results of multiple-comparison tests of data sets from the studies of geochemical processes and the effects of land use on Long Island, N.Y.

[Groups within each bracket are not significantly different from each other. RESID, residential data; AG, agricultural data; UNDEV, undeveloped data; TPMAG, upper half of Magothy aquifer data; BTMAG, lower half of Magothy aquifer data; UGA, upper glacial aquifer data]

Chloride	Sodium	Potassium	Calcium	Magnesium	Sulfate	Nitrate	Alkalinity	Dissolved solids
RESID	RESID	AG	AG	AG	AG	AG	TPMAG	AG
AG	AG	RESID	RESID	RESID	RESID	RESID	RESID	RESID
UNDEV	UNDEV	UNDEV	UNDEV	UNDEV	UNDEV	UNDEV	AG	UNDEV
UGA	TPMAG	TPMAG	TPMAG	TPMAG	UGA	TPMAG	BTMAG	TPMAG
TPMAG	UGA	UGA	UGA	UGA	TPMAG	BTMAG	UNDEV	UGA
BTMAG	BTMAG	BTMAG	BTMAG	BTMAG	BTMAG	UGA	UGA	BTMAG

areas of differing land use (undeveloped, agricultural, unsewered residential, recently sewered residential, and long-term sewered residential) to relate water quality to land use (fig. 3). The undeveloped area is in the pine barrens in eastern Suffolk County, south of Riverhead. The agricultural area is north of Riverhead. The three residential areas together overlie the deep-recharge area of western Long Island from the Queens-Nassau border to the Nissequogue River in Suffolk County (fig. 3). All five study areas were close to the regional ground-water divide (fig. 1) and avoid upgradient influences from outside the study area. Samples were obtained from wells screened in the upper glacial and Magothy aquifers within 40 ft of the water table. Statistical procedures were used to compare water quality in the five areas to identify significant differences among the data sets. In this report, all three residential areas used in the land-use study (unsewered, long-term sewered, and short-term sewered) are combined into a single group. Median concentrations of major ions in ground water beneath the undeveloped, agricultural, and combined residential land use areas are given in table 1.

COMPARISON OF GROUND-WATER QUALITY

Each land-use area or aquifer zone constitutes a single data group. As is typical of water-quality data, the data within these groups are not normally distributed. To compare groups, an analysis of variance with multiple-comparison tests for significant differences among groups at 95-percent confidence limits (Tukey's studentized range test) was used on ranked data. Results of the multiple-comparison tests are given in table 2 and indicated across the top of each of the box plots (fig. 4). A rule of thumb for determining significant differences among groups is to observe whether the interquartile ranges of the groups overlap; if no overlap occurs, the groups probably differ significantly. Results of this analysis generally are consistent with the results of the multiple-comparison tests.

Calculations of the average contribution from human activities to the concentration of a specific constituent (table 3) are based on the differences between the median concentrations of the native (predevelopment) water-quality data sets (geochemical study) and the current or ambient data sets (land-use study). Except for sulfate, differences between the upper glacial aquifer and the lower half of the Magothy aquifer were not significant, and the data sets were combined to form a native water-quality data set before the median values were calculated for the comparison. Data from the upper half of the Magothy aquifer were not used because many of the concentrations were anomalously high and the data set too small, as mentioned previously.

The error in the estimate of the human-derived component of a constituent concentration depends on several factors. If the analytical technique and the method of estimating native (predevelopment) water quality from contemporary data are considered valid, the error in the estimate depends predominantly on the number of measurements in the data sets and the spread or range of the data. Except for sulfate, for which differences between the upper glacial aquifer and the lower half of the Magothy aquifer were significant, the comparisons are based on 42 samples in the native water-quality data set, 60 samples in the

Table 3. Percentage of constituent concentrations attributed to human activity in residential and agricultural areas, Long Island, N.Y.

[Values are based on median for upper glacial aquifer and lower Magothy aquifer combined, except as noted. Dashes indicate no data available]

	Land-use area	
Constituent	Residential	Agricultural
Sodium	81	62
Potassium	84	89
Calcium	92	96
Magnesium	79	91
Chloride	86	82
Sulfate[1]	75	89
Sulfate[2]	94	97
Nitrate	98	99
Alkalinity	57	--
Dissolved solids	83	88

[1] Based on median for upper glacial aquifer.
[2] Based on median for lower part of Magothy aquifer.

residential area data set, and 15 samples in the agricultural and undeveloped area data sets. Even though the 15 samples from agricultural areas and the 15 samples from undeveloped areas constitute the smallest data sets, the sampling points were carefully chosen, and the study's author has concluded they are sufficient to characterize water quality in these areas.

The data are displayed in box plots (fig. 4) to indicate the magnitude and range of concentrations for each of nine constituents. In these plots, the spread of the native (pristine) data sets is small in relation to that of the residential and agricultural data sets. Thus, the error in the estimate of the contribution from human-derived sources to a constituent concentration in ground water depends mainly on the spread within the residential and agricultural data sets and, possibly, on the number of measurements in the agricultural data set.

In the geochemical processes study, data for the upper glacial aquifer were obtained mostly from southeastern Suffolk County--the same area as the undeveloped area of the land-use study. Of the 10 wells in the geochemical-processes study and 15 wells in the land-use study, only two were used in both studies, and they were sampled separately in each study. Comparison of median concentrations in native (pristine) water from the upper glacial aquifer with those in ground water from the undeveloped area of the land-use study indicates that the estimate of native concentrations of dissolved constituents is lower than ambient (present-day) concentrations in the undeveloped area. This may be because the undeveloped study area contains roads, residences, and some agriculture, and the land around the wells sampled is estimated to be only 74 percent undeveloped (D.A. Eckhardt, U.S. Geological Survey, oral commun., 1988). The differences were statistically significant only for potassium and calcium, however (table 2). Presumably, the samples from the geochemical-processes study also were affected by land use, but to a lesser extent; the amount has not been quantified.

On Long Island, chloride is the ion most likely to reflect human influences because it does not participate in geochemical processes that could complicate interpretation of the data. Chloride has no sources or sinks in the aquifer materials, and its movement is conservative. The only natural source of chloride to the aquifer system is atmospheric deposition of wetfall and dryfall containing chloride, generally of oceanic origin. Input to the aquifer system from this source differs with proximity to saltwater and patterns of air flow, and this could explain the minor difference in chloride concentration between the upper glacial aquifer and the lower half of the Magothy aquifer (the difference was not statistically significant). Water in the lower half of the Magothy originated as precipitation on the central part of Long Island and, thus, would be expected to contain somewhat less chloride than water from the pine barrens, which are closer to the ocean. Human-derived sources of chloride include deicing salts, septic systems, leaky sewers, and fertilizers. Comparison of the estimated chloride concentration in native (pristine) water with that in the residential and agricultural areas indicates that 86 and 82 percent, respectively, of the chloride in ground water in the residential and agricultural areas are derived from human activity (table 3). The spread of chloride data in the residential-area data set (fig. 4A) is about 10 times that of the lower Magothy and upper glacial aquifer data sets combined, strongly suggesting that chloride in the residential area arises from variable or intermittent sources. The spread of the agricultural area data is less than half that of the residential area but is still much larger than the spread in the predevelopment (pristine) data sets, and thus likewise indicates variable or intermittent sources.

Median concentrations of sodium, potassium, calcium, and magnesium (figs. 4B, 4C, 4D, 4E) in the

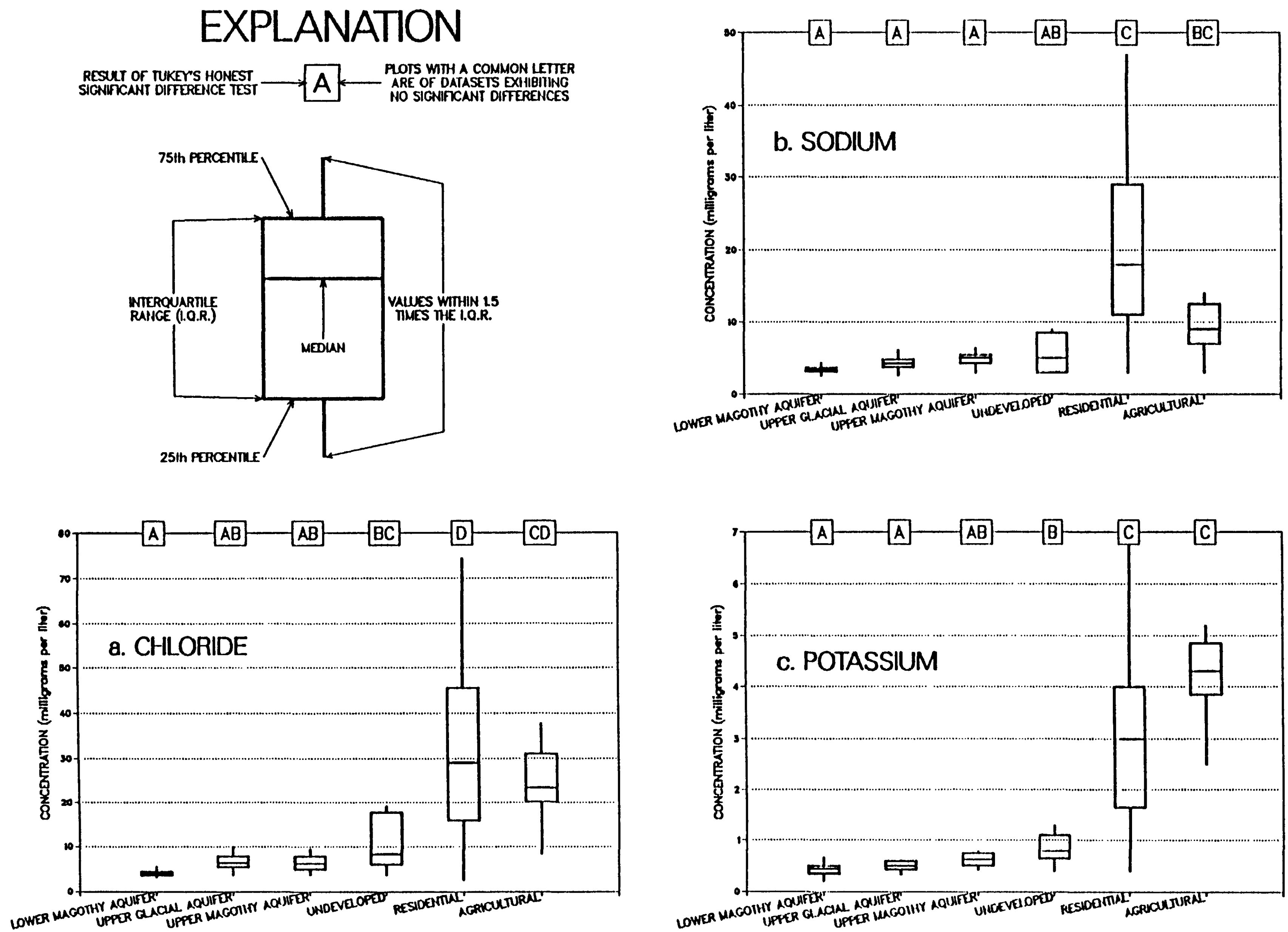

Figure 4. Box plots of native water quality and land use data sets.

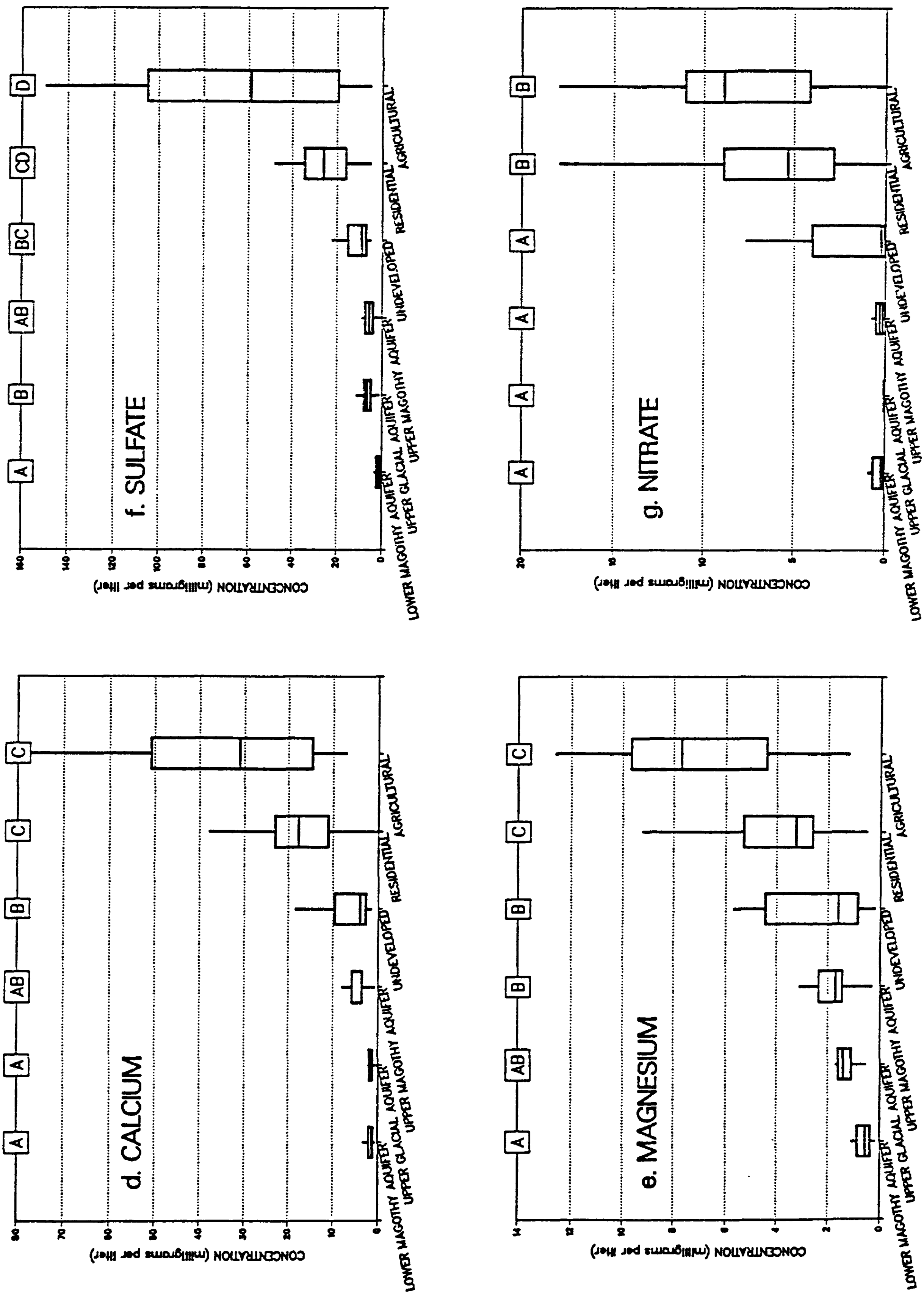

Figure 4. Box plots of native water quality and land use data sets (continued).

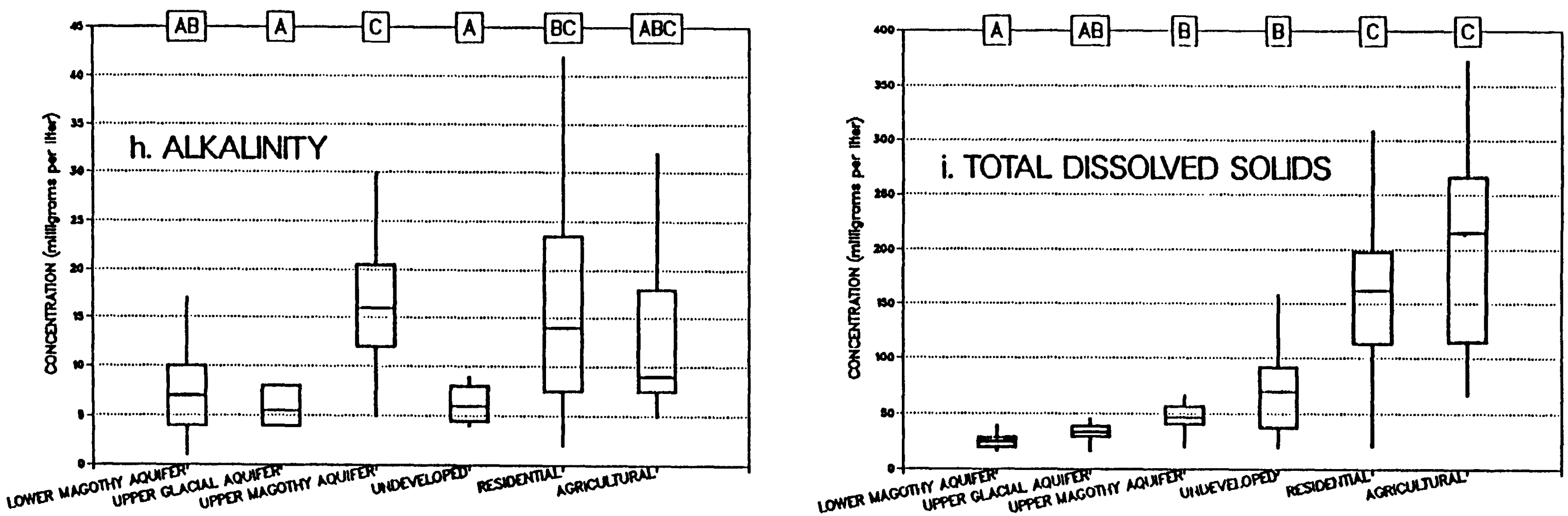

Figure 4. Box plots of native water quality and land use data sets (continued).

upper glacial aquifer are higher than in the lower half of the Magothy aquifer, but the differences are not statistically significant. Each of these constituents is present in seawater; therefore, as with chloride, atmospheric input of sea spray in nearshore areas could partly explain these minor differences. Natural sources of these cations include decomposition of unstable minerals such as feldspars in aquifer material, as well as atmospheric deposition. Human-derived sources include deicing salts, septic systems, leaky sewer lines, fertilizers, pH control chemicals, and so forth. Differences in median concentrations of these cations between either the upper glacial aquifer or the lower half of the Magothy aquifer and those in the residential and agricultural areas were statistically significant. Comparison of the median concentrations for the combined upper glacial aquifer and the lower half of the Magothy aquifer data set with the residential and agricultural area data sets indicates that 81 percent of the sodium in shallow ground water from the residential study area and 62 percent of the sodium in shallow ground water from the agricultural study area, 84 percent of the potassium in the residential area and 89 percent in the agricultural area, 92 percent of the calcium in the residential area and 96 percent in the agricultural area, and 79 percent of the magnesium in the residential area and 91 percent in the agricultural area are derived from the effects of human activity (table 3).

The highest median concentration coincides with the land-use area with the largest data spread for each of these cations except potassium (fig. 4C). Potassium is an essential nutrient and a major component of fertilizers and would be expected to be highest in agricultural areas, where fertilizer use is heaviest. In residential areas, however, decay of organic matter, either of plant matter such as leaf litter or from septic systems, would provide irregular sources that could cause the uneven distribution of potassium concentrations. Sodium concentrations, unlike potassium, calcium, and magnesium, are highest in the residential area (fig. 4B), probably because most sodium sources are nonagricultural. Calcium and magnesium (figs. 4D and 4E) are highest in agricultural areas, probably because lime is used extensively in agriculture for pH control.

The pattern of sulfate concentrations in the upper glacial and lower Magothy aquifers (fig. 4F) is difficult to explain. The median concentration of sulfate in the upper glacial aquifer is four times that in the lower half of the Magothy, and the difference is statistically significant. Both sets of data are from oxic environments, where loss of sulfate by reduction to sulfide would not be expected to occur. Additionally, if authigenic pyrite and marcasite, which are present in oxic parts of the Magothy aquifer, were undergoing oxidation, sulfate concentrations in the Magothy would be higher than those in the upper glacial aquifer. An analysis of 2.5 years of recent precipitation-quality data from central Nassau County indicates a median sulfate concentration of 6.4 mg/L. Loss of half of the precipitation through evapotranspiration could possibly produce a sulfate concentration in shallow ground water of 12.8 mg/L, before plant uptake. Higher concentrations of sulfate in the upper glacial aquifer could possibly be attributed to increasing concentrations in atmospheric deposition, although no historic data are available to test this hypothesis. Johnson (1979) reported data that support this hypothesis for surface waters in New Jersey, however. Other human-derived sources include fertilizers and septic systems. If the sulfate concentrations in the lower half of the Magothy are used as a baseline, 94 percent of the sulfate in the residential study area and 97 percent in the agricultural study area are of human-derived origin. If the concentrations in the upper glacial aquifer are used, the amounts are 75 percent and 89 percent, respectively.

The median nitrate concentration in the lower half of the Magothy aquifer is 10 times that in the upper glacial aquifer (fig. 4G), but the wide spread of concentrations within both groups makes the difference not statistically significant. This variability reflects the difficulty of obtaining water samples of native nitrate concentrations on Long Island. The variability is small, however, in relation to concentrations in samples from the residential and agricultural areas. When compared to the combined native water-quality data set, 98 percent of the nitrate in the residential area and 99 percent of the nitrate in the agricultural area is of human-derived origin.

Alkalinity concentrations showed some variability among the data sets (fig. 4H), but the only differences were those between the upper glacial aquifer or the combined native water-quality data sets and the residential study area. Using the combined native water-quality data set indicates that 57 percent of the alkalinity in the residential study area is of human-derived origin.

The dissolved-solids concentration can be thought of as the sum of all constituents previously described as well as other less abundant constituents, and results of comparison tests among the six groups are similar to the results for constituents previously discussed. The estimated dissolved-solids concentration of native upper glacial aquifer water (fig. 4I) is somewhat higher than that for the lower half of the Magothy, but the difference is not statistically significant. When compared to the combined native water-quality data set, 83 percent of the dissolved solids in the residential area and 88 percent of the dissolved solids in the agricultural area are of human-derived origin. The variability and range of dissolved-solids concentrations among the six groups are typical of most other constituents studied; the narrow range of data from the geochemical processes study contrasts sharply with the wide range of data from the land-use study.

CONCLUSONS

Large proportions of the concentrations of dissolved inorganic constituents in shallow ground water on Long Island are the result of human activity. The contribution of sodium, potassium, calcium, magnesium, chloride, sulfate, nitrate, and dissolved solids from human activity ranges from 62 percent to virtually 100 percent of the inorganic constituent load to the aquifer system in residential and agricultural areas; the contribution of natural geochemical processes to constituent concentrations in these areas is small. A source-apportionment study would provide a useful indicator of the relative importance of the human activities that create these sources. The wide range of data from the land-use study indicates that the percentages derived in this report are applicable only for describing trends and areas for which large amounts of data are available and should not be applied to individual wells or analyses.

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