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LAND-USE IMPACTS ON GROUND-WATER QUALITY IN A FRACTURED BEDROCK AQUIFER

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BY

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ABSTRACT

The impact of land use in sand and gravel aquifers has been studied extensively, but the impact on fractured-bedrock aquifers has not. Many water-supply aquifers are in fractured bedrock and their susceptibility to contamination needs to be better understood. This study was done on Northern Conanicut Island, a small fractured bedrock island in Rhode Island. Ground-water samples were collected from 174 domestic wells in areas with housing lot sizes ranging from 1/8 to >2 acres.

Land-use impacts are common from sources such as septic systems, agricultural fertilizers, road salt, and saltwater intrusion. The most common constituents attributable to these sources are nitrate, chloride, sodium, sulfate, and coliform bacteria. The relative ratios of the constituents in leachate from each of the aforementioned sources can be used to identify probable sources of contamination in ground water. Nitrate-nitrogen to chloride ratios were used to identify septic system and fertilizer impacts. Elevated concentrations of sodium and chloride together with location and well depth were used to identify road salt and saltwater contamination. Of the sites with elevated nitrate for which a specific source could be identified, 37 were indicative of septic leachate, 25 of fertilizer, and 22 were from multiple sources. The areas of greatest septic system impact are found in the part of the island with the highest housing density, where lots are smaller than 1 acre. This leads to the belief that there is inadequate dilution taking place between neighboring wells and septic systems. Of the sites with elevated chloride, 22 were found to have a saltwater impact and 5 were contaminated by road salt. The geochemical data suggest that a minimum of 1 acre is required to protect ground-water quality.

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1. INTRODUCTION

The impact of land use in stratified glacial drift aquifers has been studied extensively (Grady 1989 in Connecticut; and Eckhardt et al. 1989 and Eckhardt and Stackelberg 1995 on Long Island, NY). However, fractured-bedrock aquifers have not received this degree of attention. This lack of attention is important because many water-supply aquifers are in fractured bedrock and their susceptibility to contamination needs to be better understood. The Town of Jamestown, Rhode Island is appropriate for this type of study because it is located on a small fractured bedrock island. Northern Conanicut Island (Figure 1) is 7.2 kilometers (4.5 miles) long by 2.4 kilometers (1.5 miles) wide, encompassing an area of approximately 17 square kilometers (5 square miles).

The objectives of this study were to develop a method to chemically "fingerprint" land-use degradation in ground water, to evaluate the degree of anthropogenic impact in Jamestown, and to determine minimum lot-size criteria to protect ground-water quality.

On the northern end of the island, the residents use private wells and individual sewage disposal systems (ISDS), some on very small lots with soils, such as glacial till, which are marginal for septic system emplacement. Increasing development can stress a ground-water system particularly in areas served by septic systems and private wells. Concern over the present ground-water quality and the impact of future development on water quality prompted this investigation. The Town of Jamestown wants to determine the relationship between land-use and water quality because northern area residents rely on ground water found in the fractured bedrock of the island.

Deviations of dissolved constituents from background levels can be attributed to a limited number of local land-use practices. Jamestown is predominantly a residential community with a few small farms and commercial businesses. By identifying the contaminants and natural constituents in the ground water, the impact to the water quality can be evaluated. Some of the constituents most often considered by researchers (Canter 1997; Canter and Knox 1985; Gold 1990; Miller 1980; and Morton et al. 1988) are nitrate, which can cause methemoglobinemia, or "blue-baby syndrome," (World Health Organization, 1978) and chloride which, at concentrations greater than 250 mg/L, imparts a salty taste to the water. Canter (1997) specifies sources of nitrate in groundwater and the health concerns and problems related to the presence of nitrate in groundwater. Gold (1990) studied various sources of nitrate loss to groundwater from crop coverage to home lawns and septic systems. Morton et al. (1988) studied in Southern New England and Long Island, focusing on overwatering and fertilization of home lawns and the subsequent loss of nitrate to groundwater. Canter and Knox (1985) and Miller (1980) performed general analyses of waste disposal and septic tank system effects on groundwater, including the constituents in septic effluent and the effects of the fate and transport of these constituents in the saturated zone. These constituents can be traced back to sources such as fertilizers and septic systems for the nitrate; and road salt, septic systems, and saltwater intrusion for chloride. Grady (1989) focused on sources that were predominantly beyond the scope of this paper (pesticides, solvents, solid waste disposal sites, and road salt storage) and concluded that commercial areas were those most affected by anthropogenic input. Eckhardt (1989 and 1995) studied glacial till aquifers in Long Island in a traditional method of focusing on sampling wells from particular land-use covers and comparing the results to differentiate the anthropogenic impact.

Potential sources of contamination to the ground water in this study area include abandoned wells, septic systems, road deicing salts, small-scale agriculture, a landfill, and buried storage tanks. Evaluation of leaking storage tanks was beyond the scope of this study. The Jamestown Landfill has been previously studied with regard to possible environmental impact (EA Engineering, 1991). The above-mentioned potential sources can contribute a variety of chemical constituents to the ground water and each was evaluated in terms of the constituents involved and their relationship to the observed chemistry of the island's water.

Most previous hydrologic studies on Conanicut Island [including Goldberg-Zoino & Associates Inc. (1986), Urish (1980), Maguire (1985), and Metcalf & Eddy (1968)] have focused on water availability. Water-quality analyses have been limited. An environmental-impact study was completed at the now closed Jamestown Landfill (EA Engineering, 1991), where some localized volatile organic carbon (VOC) contamination was noted.

The island has not been the subject of a detailed area-wide analysis of the ground-water quality. In this study, ground-water chemistry was analyzed to determine background chemistry and evaluate land-use sources of contamination. This study is similar in concept to a surface-water study in which chemical "signatures" were used to determine nonpoint sources of contamination (Rahn, 1992), but here it is applied to a fractured bedrock aquifer. Gburek (1993) focused primarily on groundwater flow modeling with attention to nitrate concentrations beneath forest and farm crop land use in the layered and fractured aquifer in the Valley and Ridge Province, but in general, fractured bedrock aquifers have not received much attention. This study addresses the issue of land-use impact on a fractured bedrock aquifer and explores the relationship of housing lot size to ground-water quality. Persky (1986) studied the groundwater quality in Cape Cod, MA to determine a minimum housing lot size. In this glacial till aquifer setting, the study concluded a minimum 1 acre lot size was required.

2. SETTING

Conanicut Island is in southern Rhode Island in Narragansett Bay (Figure 1). Jamestown Brook, which drains to the southwest and discharges into Narragansett Bay, is the main drainage system. The land surface consists of gently rolling topography, reaching a maximum elevation of 140 feet at the south-central part of the island. The aquifer is fractured bedrock overlain by glacial till, with some stratified sediment in the Jamestown Brook valley. Average annual precipitation for southern Rhode Island for the period 1995-97 was 50.9 inches, 0.9 inches above the 30-year average. Mean annual temperature for this period was 50°F (10°C), 0.7°F above normal (Kingston weather station, Carl Sawyer). Water-table depths vary between 0 meters (0 feet) and 8.3 meters (30 feet) below land surface in the wet season, with a mean of 3.9 meters (14 feet) (Goldberg-Zoino & Associates, 1986).

Geology

Northern Conanicut Island is comprised of the Pennsylvanian-age Rhode Island Formation (Hermes et al., 1994). The bedrock is predominantly interlayered carbonaceous schist, meta-sandstone, and meta-conglomerate (Hermes et al., 1994). The bedrock is overlain by 6.3 to 15 meters of glacial till (GZA, 1986). The till was deposited during the last glacial period, which ended in this region from approximately 18,000 - 16,000 years ago (Stone and Borns, 1986). Northern Conanicut Island is separated from the rest of the island by a fault that has surface expression as the Great Creek. There are numerous north-south trending fractures lending to the anisotropy of the aquifer. This anisotropy includes north-south striking, east-dipping fractures that seem to be the main fracture orientation (Michaud, 1998).

Hydrology

The aquifer is anisotropic and heterogeneous because of the fractured bedrock. Ground-water flow tends to mimic the land-surface topography and flows toward the perimeter of the island (Figure 2). Ground-water flow consists of horizontal as well as vertical flow components (Figure 3). Ground water also discharges into Jamestown Brook and at several locations where there are depressions in the topography.

Goldberg-Zoino & Associates, Inc. (GZA) reported transmissivity at 3.7 m^2/day (40 ft^2/day) and 0.32 m/day (1 ft/day) for hydraulic conductivity as representative of fractured bedrock for this part of Rhode Island. Other estimated values for transmissivity range from 3.7 to 186 m^2/day (40 to 2000 ft^2/day), with a median transmissivity of 28 m^2/day (300 ft^2/day) (Veeger et al., 1997). These values indicate the low overall water-transmitting ability of the fractured bedrock underlying the island.

All fresh water on the island is derived from precipitation. Ultimately, about half is returned to the atmosphere via evapotranspiration (Veeger and Johnston, 1996). The remainder recharges the surface-water and ground-water systems. On Conanicut Island, the surface-water system consists of several small, seasonally intermittent streams the largest of which is Jamestown Brook. There are also several ponds including the Jamestown Reservoir, South Reservoir, the "Quarry," and ponds in the West Reach Estates and East Passage Estates (Figure 1). The surface-water bodies lose water in the summer months due to evaporation and lack of precipitation and small ponds in Jamestown Shores dry up in periods of prolonged drought.

Land Use and Water Use

Jamestown was first settled in the beginning of the 18th century. Land use was predominantly small-scale farming of corn. By 1783, most farms were in pasture and only 10% had cultivated land, still mainly in corn (RI Historical Society, 1995). Sparse settlement persisted in the northern end throughout the 19th century (D. G. Beer's & Co., 1870; Everts & Richards, 1895). When the Jamestown Bridge was constructed in 1940, access was much easier and many of the remaining farms began to subdivide into small lots, about ¼ acre, beginning in Jamestown Shores. The East Passage Estates and West Reach Estates were constructed beginning in the late 1970's and these newest developments are generally constructed on lots greater than 1 acre.

Present day land use in Northern Conanicut Island is predominantly residential (approximately 5.0 square kilometers), with some small farms, and minor amounts of commercial and grazing land. Cropland consists of approximately 0.6 square kilometers of agricultural farms. Pasture land accounts for 1.6 square kilometers. Pasture and cropland are often rotated, so these parcels of land can be treated together. Most of the small agricultural lots are not actively in use (O'Neil, Natural Resources Conservation

Service, personal communication). There are also two recent cemeteries and an historic cemetery.

Homeowners account for most water use. Approximately 15-19% of the residential population is seasonal (URI Community Planning and Development, 1985) and the greatest water use occurs in the summer months. The estimated seasonal occupancy is based upon the entire island and may be much higher for the northern end of the island, away from the center of town. Jamestown Reservoir is located in the northern part of the island. This surface-water reservoir serves as the main water supply for the residents of the southern part of the island.

3. APPROACH AND METHODS

This project involves the use of spatial water-quality data as well as existing land-use data. A sampling design incorporating existing domestic wells and surface water bodies was created for collection of water-quality data throughout the study area.

A survey was sent to homeowners in the study area asking permission to sample their well. The survey requested property information including well depth and location, year well was installed, and distance between septic tank, leach field and well. An effort was made to survey all residential areas, and a good spatial distribution of sampling locations was obtained (Figure 4). Areas showing preliminary evidence of contamination were extensively sampled in an attempt to further delineate those zones. Samples were collected over a period of several months. A total of 122 well sites and one surface-water body were sampled in the 1996 field season and an additional 50 well sites and eight surface-water bodies were sampled in the 1997 field season. Two of the well sites had two wells each, both of which were sampled, for a total of 174 individual wells sampled. Thirty-four wells from the 1996 group were resampled in the 1997 field season because of suspected contamination of the ground water. The 1996 field season lasted from May through September and the 1997 field season lasted from June through December.

Water samples were collected following standard sampling techniques (Standard Methods, Clecceri et al., eds., 1989). In addition to the collection of water samples, field measurements including temperature, pH, electrical conductivity, and dissolved oxygen were also completed. Water samples were analyzed for major cations and anions by ion chromatography (Standard Method 4110B, using the AS4A anion separator column and the CS3 cation separator column). Alkalinity was determined by potentiometric titration and dissolved silica and iron were determined by using spectrophotometric techniques (Standard Methods 2330; 4500-Si D, and 3500-Fe D, respectively). Bacteria analyses were completed by using the membrane filter procedure (for samples collected in 1996) (Standard Method 9222B) and the multiple tube fermentation technique (for samples collected in 1997) (Standard method 9221 B and C).

A charge-balance error was calculated for each analysis to screen for the accuracy of the analytical procedures. Errors less than 5% are generally considered acceptable (Freeze and Cherry, 1979) and errors greater than 10% were excluded. For this study, 131 samples had charge-balance error under 5% and a total of 200 samples had charge-balance error under 10%. Errors between 5% and 10% were considered acceptable for dilute waters (<250 mg/L total dissolved solids).

4. RESULTS

Physical and chemical characteristics of surface water and ground water on Northern Conanicut Island are summarized in Tables 1 and 2, respectively. Complete analyses are tabulated in appendix A.

Surface Water Chemistry

Nine surface-water bodies were sampled for this study. These include the Jamestown Reservoir, South Reservoir, a quarry pond, and small ponds and streams in the West Reach Estates and East Passage Estates (Figure 1). The chemistry is generally uniformly dilute, however, there are a few noteworthy comments. The chloride concentrations range from 9.6 to 35 mg/L. The higher chloride concentrations are found in a pond in the West Reach Estates, just off of North Main Road; in the South Reservoir; and in a stream discharging from Jamestown Shores. Phosphate concentrations range from not detected to 1.1 mg/L, at the pond in the West Reach Estates near North Main Road. Nitrate concentrations range from not detected to 1.4 mg/L as nitrogen, at the stream discharging from Jamestown Shores. Surface water temperatures, as shown in Table 1, vary greatly since they were collected over a period of several months.

Table 1: Physical and Chemical Characteristics of Surface-Water Samples

in mg/L, unless otherwise specified

	n=	Minimum	Maximum	Mean	Median	Standard Deviation	Drinking Water Limit
Na	9	2.1	18	11	11	5.4	20[1]
K	9	0.81	2.1	1.4	1.3	0.52	
Ca	9	2.4	7.7	5.1	4.5	2.1	
Mg	9	1.1	4.5	2.6	2.7	0.96	
Cl	9	9.6	35	21	19	8.6	250[2]
NO_3-N	9	ND	1.4	0.22	ND	0.49	10[3]
SO_4	9	2.2	14	7.4	7.6	3.3	250[2]
F	9	ND	0.06	0.02	ND	0.03	2[2], 4[3]
Br	9	ND	0.21	0.06	0.05	0.07	
PO_4	9	ND	1.1	0.12	ND	0.36	
Fe	9	0.11	1.1	0.46	0.42	0.34	0.3[2]
Alkalinity as $CaCO_3$	9	5.3	24	12	10	5.6	
SiO_2	9	ND	14	3.7	1.6	4.6	
Dissolved Oxygen	8	2.9	11	6.8	7	2.7	
Conductivity µS/cm	8	67	260	140	140	61	
pH	8	6.3	9.0	7.3	6.9	1.0	6.5 - 8.5[2]
Temp °C	8	4.2	32	25	28	9.3	

ND = Not Detected above method quantitation limits.
[1] DWEL = US EPA Drinking Water Equivalent Level set at 20 mg/L for "a lifetime exposure concentration protective of adverse, non-cancer health effects, that assumes all of the exposure to a contaminant is from a drinking water source" (EPA, personal communication).
[2] SMCL = US EPA Secondary Maximum Contaminant Level
[3] MCL = US EPA Maximum Contaminant Level

Table 2: Physical and Chemical Characteristics of Ground-Water Samples

in mg/L, unless otherwise specified

	n=	Minimum	Maximum	Mean	Median	Standard Deviation	Drinking Water Limit
Na	207	5.6	150	17	14	13	20[1]
K	207	ND	4.4	1.1	1.1	0.81	
Ca	207	ND	56	11	9.7	7.0	
Mg	207	ND	10	3.3	3.0	1.5	
Cl	207	7.6	130	28	21	21	250[2]
NO_3-N	207	ND	16	2.6	1.7	2.8	10[3]
SO_4	207	6.3	70	16	14	7.1	250[2]
F	207	ND	1.1	0.07	ND	0.16	2[2], 4[3]
Br	207	ND	1.3	0.09	0.05	0.15	
PO_4	207	ND	0.56	0.04	ND	0.08	
Fe	207	ND	11	0.6	0.2	1.5	0.3[2]
Alkalinity as $CaCO_3$	207	1.1	150	23	15	21	
SiO_2	207	1.5	42	17	15	6.4	
Dissolved Oxygen	201	0.04	11	4.3	4.5	3.0	
Conductivity µS/cm	204	24	700	210	180	110	
pH	204	5.0	8.9	5.9	5.8	0.57	6.5 - 8.5[2]
Temp °C	203	10	14	12	12	0.77	

ND = Not Detected above method quantitation limits.
[1] DWEL = US EPA Drinking Water Equivalent Level
[2] SMCL = US EPA Secondary Maximum Contaminant Level
[3] MCL = US EPA Maximum Contaminant Level

Ground-Water Chemistry

Nitrate

Ground-water nitrate concentrations (expressed as mg/L N) range from not detected to 16 mg/L (Figure 5). The highly elevated nitrate (>5 mg/L) sites are all found in the Jamestown Shores area. Slightly elevated sites (1-5 mg/L) are found throughout the study area (Figure 6). The US EPA Maximum Contaminant Level for nitrate of 10 mg/L is used here as a guide to the degree of contamination. Nitrate concentrations of 1-5 mg/L indicate incipient contamination. Nitrate concentrations of 5-10 mg/L indicate more pronounced contamination. Three sites had water samples with nitrate greater than or equal to 10 mg/L.

Chloride

Chloride concentrations range from 7.6 to 129 mg/L (Figure 7), all less than the US EPA Secondary Maximum Contaminant Level (SMCL) of 250 mg/L. Low concentrations (< 30 mg/L) are found throughout the study area; the elevated concentrations (>30) are found within Jamestown Shores and along the coastline (Figure 8).

Sodium

Sodium concentrations range from 5.6 to 146 mg/L (Figure 9). Sodium has a US EPA Drinking Water Equivalent Level (DWEL) set at 20 mg/L for "a lifetime exposure concentration protective of adverse, non-cancer health effects, that assumes all of the exposure to a contaminant is from a drinking water source" (EPA Safe Drinking Water Hotline, personal communication). Elevated sodium concentrations are found along the coastline (Figure 10).

Sulfate

Sulfate concentrations range from 6.3 to 70 mg/L (Figure 11). Sulfate has a SMCL of 250 mg/L and all sites had concentrations well below this level. Low concentrations (<25 mg/L) were observed throughout the study area. Sites with elevated sulfate (>25 mg/L) were found primarily in Jamestown Shores and along the shoreline (Figure 12).

Coliform Bacteria

The US EPA MCL for coliform is one colony in a 100 mL water sample. Twenty-four sites tested positive for coliform (Figure 13). Of these, 1 well had been "shocked" with chlorine bleach and was subsequently negative for coliform when retested. Twelve of the sites that tested positive in 1996 were negative in 1997, with no information from homeowners indicating that the well had been shocked. An additional five sites were still positive for coliform even though one of these had shocked the well and another had had the line from the well to the house replaced. One site tested positive for *E. coli* bacteria, but no other contamination was observed at this location.

5. DISCUSSION

In order to determine the land-use impact on the ground-water quality in a fractured bedrock aquifer, a determination of the background chemistry is first necessary.

Background Chemistry

Nitrate is not considered naturally occurring at high concentrations (Hem, 1985), so background concentrations should fall below 1 mg/L, approximately the concentration that occurs in precipitation (NADP, 1996). Background ground-water chemistry was determined by eliminating the sites with high nitrate (>4.5 mg/L as nitrogen) and chloride (>30 mg/L – which is higher than background concentrations that would be expected from sea-spray) that indicated an apparent anthropogenic input. The background chemistry was obtained from the median concentration of these remaining data. A range of background values was obtained using the standard deviation for each compound. Chloride background concentration was determined to be in the range of 10-20 mg/L for this study. Sea-spray causes this to be higher than inland areas of Rhode Island where background chloride is around 10 mg/L (Holden, 1994).

The background concentrations identified for this project are listed in Table 3. Precipitation data are for Barnstable, MA, North Atlantic Coastal Lab for 1994 (NADP, 1996). These background levels are expected to vary as a function of residence time and water-rock interactions. This is important because this is a fractured bedrock aquifer, so the bedrock composition will affect the ground-water chemistry, although the degree of this interaction depends largely on the residence time.

Table 3: Background Chemistry of Northern Conanicut Island (mg/L)

	Ground Water	**Precipitation**
Na	5.6 – 16	1.3
K	0.78 – 1.8	0.05
Ca	2.4 – 6.6	0.10
Mg	1.7 – 3.7	0.15
Cl	10 – 28	2.3
NO_3-N	< 0.5	0.31
SO_4	4.3 - 11	1.6
pH	5.9 – 7.9	4.5

Identification of Contamination Sources

Of the 207 total well and surface-water samples, 111 show evidence of anthropogenic impact. Anthropogenic impact is evident from a significant difference in chemistry from the background and because the nitrate and/or chloride concentrations were higher than could be accounted for naturally. These impacted sites tend to fall predominantly within the Jamestown Shores area or along the coastline. It is important to try to identify the potential sources of these contaminants.

The potential sources of contamination on Northern Conanicut Island used in this study include septic systems, fertilizers, road deicing salts, and seawater. The inorganic chemical constituents associated with these land-uses and their approximate concentrations are identified in Table 4. The concentrations for septic effluent were determined through literature review (Robertson et al. 1991, Wilhelm et al. 1994, Harman et al. 1996), saltwater from Drever (1988), and lawn fertilizer from AGWAY (N-P-K ratio of 27-4-6) (Exeter, RI 1/24/98; and Barcelona and Naymik 1984).

Table 4: Potential sources of contamination.

Source	Constituents	Concentrations
Septic Effluent	Nitrate as N	27-110 mg/L
	Chloride	56-84 mg/L
	Sulfate	20-30 mg/L
Fertilizer	Nitrate as N	45 - 56 mg/L
	Chloride	20-30 mg/L
	Sulfate	80-100 mg/L
Saltwater	Sodium and Chloride	1:1 mole ratio
	Sulfate and Chloride	1:19 mole ratio

Using the concentrations in the table above, the source concentrations were step-wise mixed with the background concentrations to produce mixing curves. These curves are plotted on Figure 14. Various sources for septic data provided a range of values, so the septic signature appears as a range from low to high on the figure. The data from the samples were then added to this graph. Samples where the nitrate:chloride molar ratio fell on or close to a curve were determined to have a chemistry resulting from impact with that source (Figure 14). For example, a site with elevated nitrate and chloride that falls within the septic system effluent range of values was determined to have a septic system effluent source of impact.

Sites with a fertilizer impact were identified by elevated nitrate with a much lower associated chloride concentration, as is shown by the fertilizer mixing curve. These sites lie above the range of septic impact on the graph, indicating a very high nitrate:chloride ratio. Additionally, the presence of very little chloride, as shown in Figure 15, indicates fertilizer contamination rather than septic. A combination of sources was determined for sites exhibiting impact from multiple sources. These sites were found below the zone of septic impact on the graph indicating elevated nitrate and chloride, but not high enough to be considered purely a septic source. Sites found in this area have been impacted by a variety of sources such as an addition of chloride or denitrification in varying proportions. Using Figures 14 and 15, it seems apparent that an additional source of chloride is more likely, as additional nitrate would not bring these samples within the septic-impact range.

Saltwater impact was also treated in a similar manner. The septic effluent mixing curve was used, plotted versus chloride concentrations (Figure 15). Here, the elevated chloride that is not derived from septic effluent is clearly distinguishable by low nitrate:chloride ratio and high chloride. This is also apparent on a plot of sodium:chloride versus chloride (Figure 16). Saltwater intrusion is the process by which the freshwater-saltwater interface migrates upward in response to a pumping-induced decline in the water table. Although wells that are screened below sea-level and located along the shore are most easily affected, any well screened below sea-level is at risk. To differentiate between seawater-impacted sites and those affected by road salt, a comparison was made between the land-surface elevation and the well depth. If the well did not penetrate below sea level, then the impact was deemed to be from road salt. In cases where any ambiguity remained, the presence of other constituents such as bromide or sulfate was used to identify seawater impact, as road salt does not contain these constituents and seawater does.

Determination of Degree of Contamination

The concentrations of constituents used to determine the relative degree of contamination are summarized in Table 5.

Table 5. Concentration (mg/L) ranges used for water-quality impact assessment and degree of contamination, with number of samples in parentheses.

	Background	Low	Moderate	High
Nitrate (as N)	<1 (81)	1-5 (68)	5-10 (23)	>10 (2)
Chloride	<20 (84)	20-50 (72)	50-100 (14)	>100 (4)

Septic System Impact

Based on the results of figures 14 and 15, septic systems were found to have impacted thirty-seven sites (Figure 17). Most of these sites are found in the Jamestown Shores area (Figure 18). The degree of the impact was determined from the nitrate concentration. For nitrate (as N), a concentration <1 mg/L was considered background; waters with nitrate concentrations of 1-5 mg/L were considered to have low impact.

Nitrate concentrations of 5-10 mg/L were considered moderately elevated, and ≥ 10 mg/L, the USEPA Maximum Contaminant Level for safe drinking water, is considered unacceptable for consumption. The highest levels of septic impact are equivalent to approximately 10% septage based on chloride and nitrate molar concentrations. The elevated sulfate within Jamestown Shores is due to primarily to incipient saltwater intrusion, based on the sulfate:chloride mass ratio, although some sulfate is from an unknown source.

Septic-system impact is of particular concern in relatively densely populated parts of the island. The Rhode Island Department of Environmental Management requires a 100-ft separation between a domestic-supply well and a septic leach field (Otis et al. 1980). This setback distance is designed to ensure adequate dilution and attenuation of contaminants before the water enters a well. Unfortunately, this setback distance may not be sufficient in fractured bedrock aquifers.

The septic system contamination in Jamestown Shores is not necessarily due to failing septic systems, but may be caused primarily by housing density. The lot sizes are small (~ ¼ acre), resulting in a significant input, over a small area, of nitrogen to the ground-water system in the form of septic-system leachate. At some sites the system is short circuited by an ineffective seal around the well casing, allowing more direct infiltration of contaminated soil water.

Fertilizer Impact

Twenty-five sites were determined to have a fertilizer impact, as shown in Figure 17, based on the results of Figures 14 and 15. This type of ground-water contamination appears to be a localized phenomenon, predominantly within Jamestown Shores (Figures 17 and 18). Many homeowners have private gardens and/or heavily-fertilized lawns. Overwatering, overfertilization, and improper timing of fertilizer application can cause significant nitrate leaching (Morton et al. 1988).

Twenty-two sites show impact from unknown sources indicating elevated concentrations of chloride and nitrate, but not enough nitrate to fall within the septic leachate range. These points plot just outside the septic mixing zone on Figures 14 and 15. It is unclear what the possible source of the observed chemistry is. This chemistry may be due to a loss of nitrogen due to denitrification, or elevated chloride from an additional source. Some of these sites may also have had nitrate released if the area was recently plowed or otherwise disturbed, increasing the amount of nitrate detected in the ground water (Gold et al. 1990).

Saltwater Intrusion

Twenty-two sites were found to have a saltwater impact. No evidence of severe saltwater intrusion was found; however, elevated concentrations of sodium and chloride occur in a number of wells along the coast (Figure 17) indicating that some intrusion of saltwater has occurred. The mass of chloride was used to determine the degree of contamination. Up to 20 mg/L of chloride was considered background, 20-50 mg/L was low, 50-100 mg/L was moderate, and >100 mg/L was high impact. The saltwater intrusion observed here is equivalent to less than 1% seawater (Drever, 1988). Sodium concentrations at or below the DWEL were found throughout the study area. Elevated sodium concentrations were found primarily in the Jamestown Shores area and along the coastline, with a similar distribution to the chloride concentrations. The elevated sulfate along the coastline is due primarily to incipient saltwater intrusion. The mole ratio of sulfate to chloride indicates saltwater impact rather than septic or fertilizer, although some sulfate is from an unknown source.

The sites exhibiting seawater contamination are generally located near the coastline where the freshwater lens is thinnest (Figure 3). A few of the wells are located slightly inland (up to approximately 250 meters), but the well depths indicate that they penetrate below sea level and may be inducing saltwater upconing. It is also possible that much of the saltwater-intrusion contamination is a seasonal phenomenon because the demand on the water supply is greatly increased in the summer, and this effect is possibly decreased over the winter months. Road salt was also found to be the source of contamination in an additional five sites (Figure 17).

Coliform Bacteria

The distribution of coliform-contaminated sites was fairly uniform across the study area. Of the sites with coliform bacteria present, ten had nitrate >1 mg/L and nine had nitrate >5 mg/L. Six sites with coliform had nitrate at or below background, indicating that the bacteria source is not always directly linked to the overall ground-water quality but may sometimes be a more localized phenomenon. Much of the bacterial contamination was of a transitory nature. The contamination may have been the result of organic matter falling into the well bore or a faulty seal on the well casing. The site that tested positive for *E. coli* was a shallow dug well with a poor seal, and could easily have become contaminated from the surface. For sites with coliform contamination, 17 sites with coliform present in the 1996 field season were retested in the 1997 field season. Five of these sites retested yielded positive results for coliform bacteria. Most wells had not been "shocked" between sampling periods, so the transitory presence appears to be a natural phenomenon. Two sites were retested in the 1997 field season because of high non-coliform bacterial presence. Different bacterial analyses were performed in this field season in an attempt to minimize non-coliform growth to see if any coliform was present but previously masked. Both of these sites were negative for coliform bacteria. The bacterial analyses used were a membrane filtration procedure the first field season and a multiple tube fermentation technique was used the second field season, to be more discriminating against non-coliform growth.

Surface Water Contamination

Using the above guidelines, the surface-water contamination was generally very low impact. Most surface-water sites fell within the identified background chemistry. Surface water does not appear to be affected to the degree that groundwater has been impacted. Only one site, the seasonal stream off of Seaside Dr. had a signature of multiple sources. This was low-level contamination, possibly due to the fact that this stream drains from the Jamestown Shores area.

Temporal Variation

Thirty-two sites were resampled for the 1997 field season. In general, sites with nitrate-related contamination were evaluated to have the same contaminant signature and similar levels of contamination. In a few cases, the chemistry plotted very close to the mixing boundary between two signatures, so the previous signature was referenced to pinpoint the likelihood of the new determination. This ambiguity occurred in sites with low levels of nitrate (1-5 mg/L as N) where the signatures are very similar.

The temporal variation of these analyses was low as is shown in Figure 20. Analytical results from the first sampling season were plotted against analytical results from the second season to evaluate the consistency of the chemical results from one sampling event to the next. An analysis of variance was then performed on this data (Appendix H). This analysis produced values of $F=2.34$, and $F_{crit}=3.99$. The populations are not significantly different from each other since $F< F_{crit}$, indicating that the two sampling seasons were statistically similar. The results are therefore reproducible over time and are not likely to be a one season aberration. Several samples do show a difference from one year to the next, however, and this could be due to the time of year sampled (possibly coinciding with fertilizer application), or a significant precipitation event occurring prior to sampling.

By studying the nitrate-nitrogen distribution within Jamestown Shores, several small clusters of elevated concentrations can be identified. The first of these is just south of Route 138. Here, several elevated nitrate sites are clustered along one street. When taken in conjunction with their determined contaminant source, there are four sites tightly clustered with a septic effluent signature, indicating the existence of a small plume. A second observable cluster occurs just east of Beacon Avenue between Route 138 and Frigate Street. Here, the common contaminant source is fertilizer. Along Frigate Street there are several sites of elevated nitrate-nitrogen. There does not appear to be a pattern in the contaminant source. The elevated nitrate here is attributed to multiple sources, maybe indicating a zone of mixing in this area. Water use and the type of agricultural practice can also influence nitrate output concentrations. If a household uses low-flow toilets, less water is used for the same mass of waste, so nitrate concentrations are higher in the outflow because of less dilution.

Minimum Housing Lot Size for Ground Water Protection

A critical lot size for housing density was determined by grouping nitrate data with other factors such as lot size, age of well, and age of septic system. Statistical analyses were performed using ANOVA analysis (see Appendix H) to determine if there were any links and a strong link was identified between lot size and nitrate concentrations. Below this one-acre critical value, nitrate concentrations exceed background criteria, but above the critical value, nitrate concentrations were below background concentrations (Figure 21). This lot size criterion is significant because it contradicts the RIDEM 100-foot setback that is the state-required minimum. The one-acre minimum lot size determined here is for a fractured bedrock aquifer and not a sand-and-gravel aquifer, where the 100-foot setback may be more appropriate.

6. SUMMARY AND CONCLUSIONS

Impact of Development on Ground-Water Quality

Four sources of ground-water contamination were identified in this study: septic-system effluent, fertilizer runoff, saltwater intrusion, and road salt leachate. Once the type of contamination, if any, was determined for these sites, this information was plotted on a map of the island (Figure 19) to see if any spatial trends exist in terms of ground water contaminated zones. The majority of northern Conanicut Island has water of good quality (Figure 19); however, one area stands out as having been substantially impacted by development - Jamestown Shores (Figure 18). It is noteworthy that the areas that have been most recently developed, West Reach Estates and East Passage Estates, have little or no evidence of ground-water contamination. This low incidence of contamination is because they were largely constructed under more recent and stringent zoning regulations where the lot sizes are larger, averaging one to two acres, and allowing for ample spacing of septic systems and wells.

Coliform is not always associated with nitrate contamination and, in fact, was often detected without any other contaminants. This suggests that coliform can travel in the shallow subsurface and penetrate wells, perhaps through leaky well casings, independent of the regional ground-water flow.

The water quality of Jamestown Shores has been adversely affected by high housing density. This has been shown from high average nitrate concentrations from septic effluent and fertilizer sources. These high nitrate concentrations are primarily due to insufficient buffer space between neighboring lots. A minimum lot size of one acre should be used (Figure 21 and Appendix F). This conclusion matches what Persky (1986) determined for critical minimum lot size for ground-water quality in Cape Cod, MA. A minimum lot size of one acre may not resolve all the ground-water quality problems, however, due to the fractured bedrock aquifer. The fractures may provide conduits for contaminated water to travel farther, and remain undiluted longer, than in a sand-and-gravel aquifer.

This study shows that high housing density is associated with an adverse impact on ground-water quality in a fractured bedrock aquifer. This impact could be for several reasons: the heterogeneous flow within a fractured bedrock aquifer may cause some wells to be contaminated and others not to be. The RIDEM 100-foot setback is shown to be inappropriate in fractured-bedrock aquifers. Also, some contaminants may travel in the shallow subsurface rather than the deeper bedrock, producing a very localized zone of contamination, as is shown with the bacteria. Future work in this area could investigate the role of fractures in contaminant transport by further qualifying the heterogeneous flow that occurs in the fractures. Isotopic studies of nitrogen, hydrogen, and oxygen as well as organic analyses could also be used in this endeavor.

Northern Conanicut Island

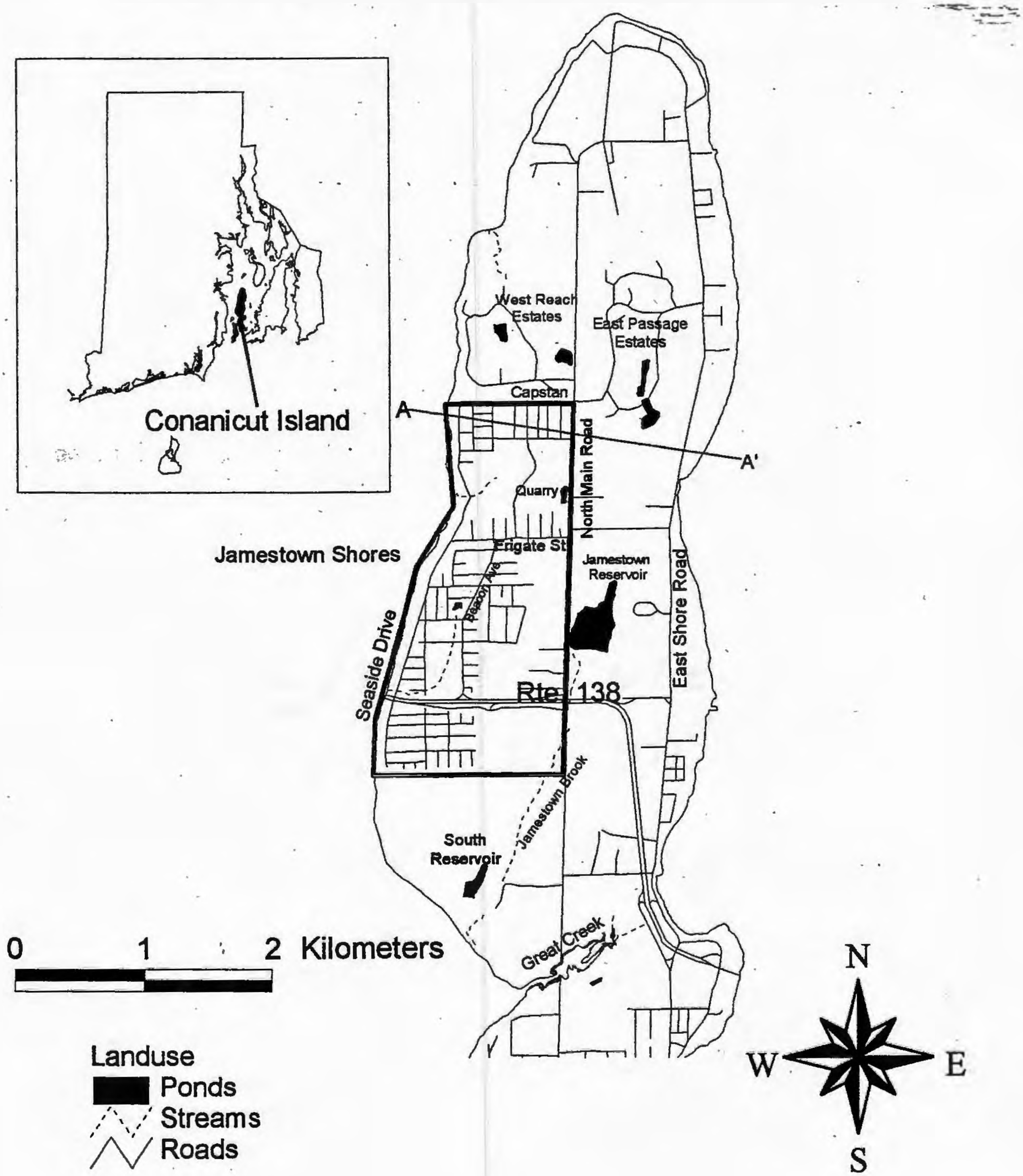

Figure 1: Study area - Northern Conanicut Island, showing location of cross-section A-A', Jamestown Shores, and surface water bodies.

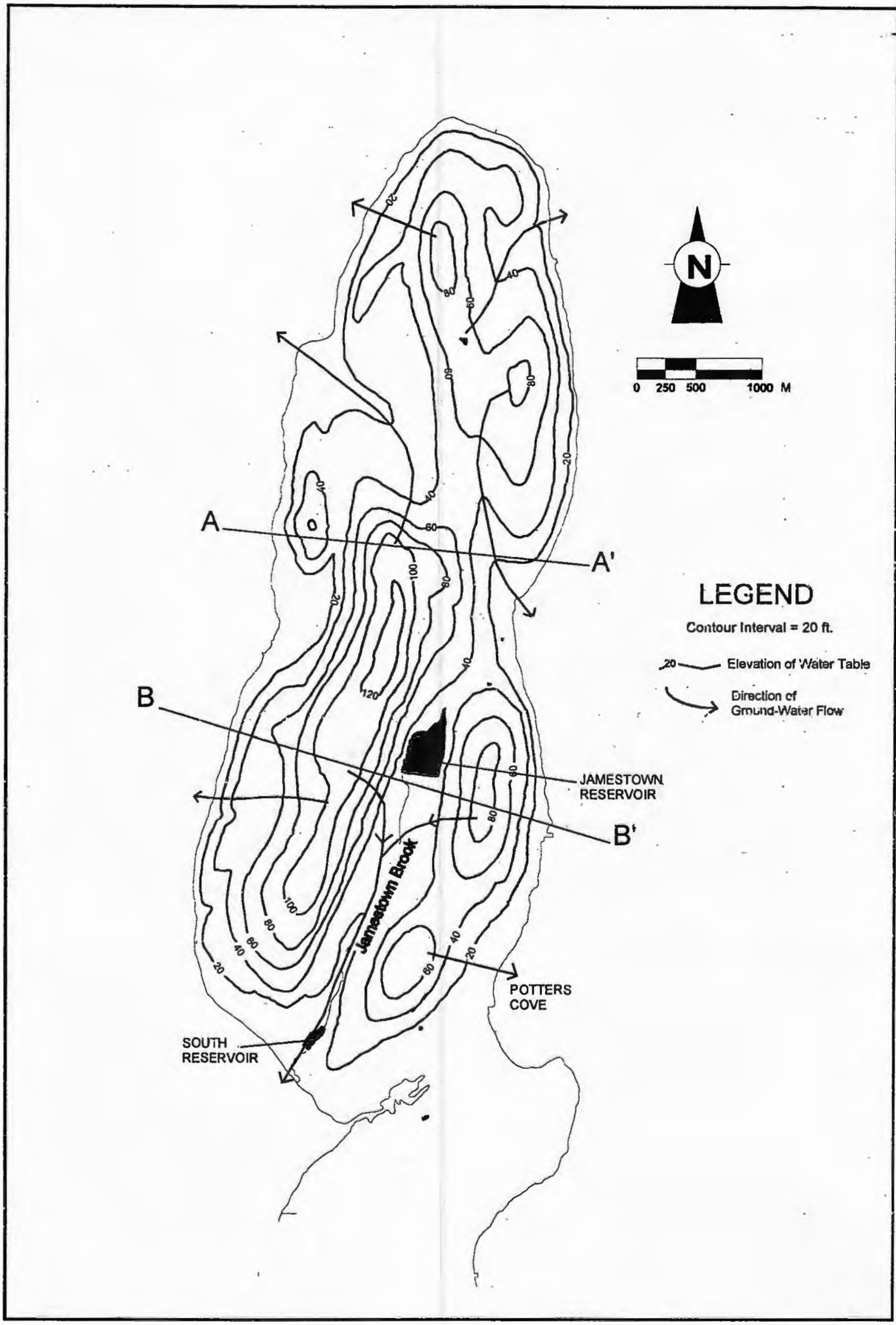

Figure 2: Water table map showing groundwater flow directions on Northern Conanicut Island, Rhode Island (from Veeger et al., 1997).

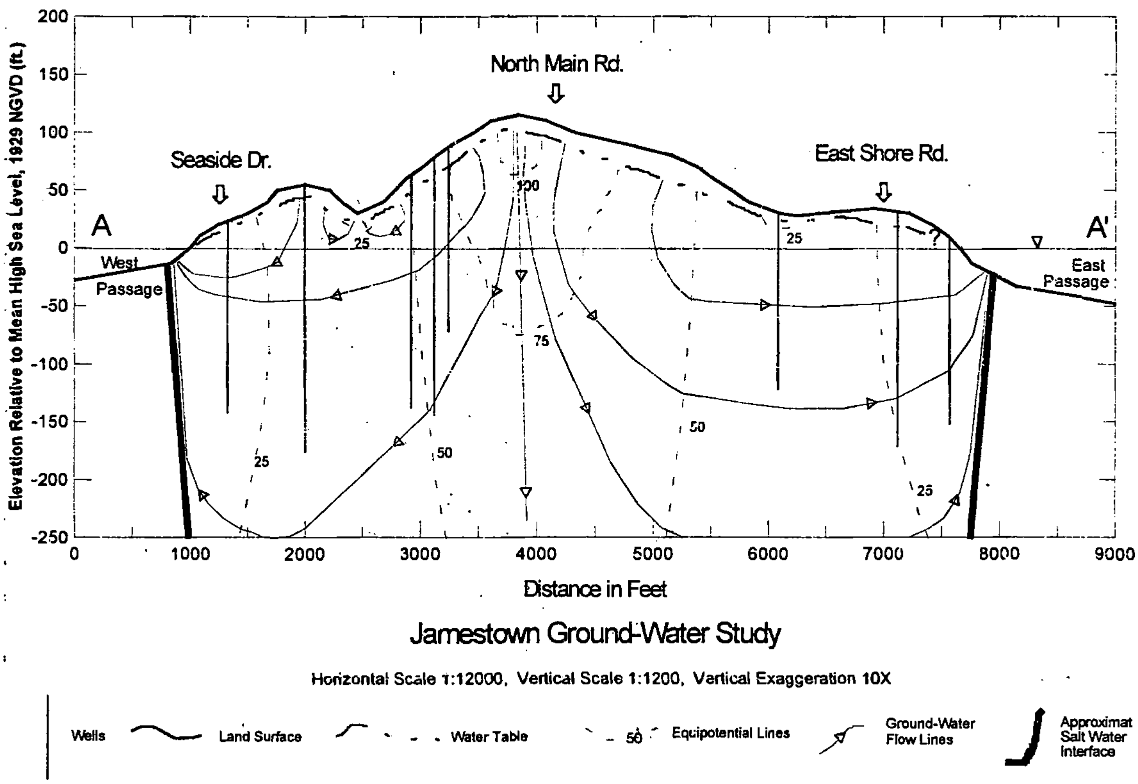

Figure 3: Cross-section A-A' showing water table, equipotential lines, and flow lines, Northern Conanicut Island, Rhode Island (modified from Veeger et al., 1997).

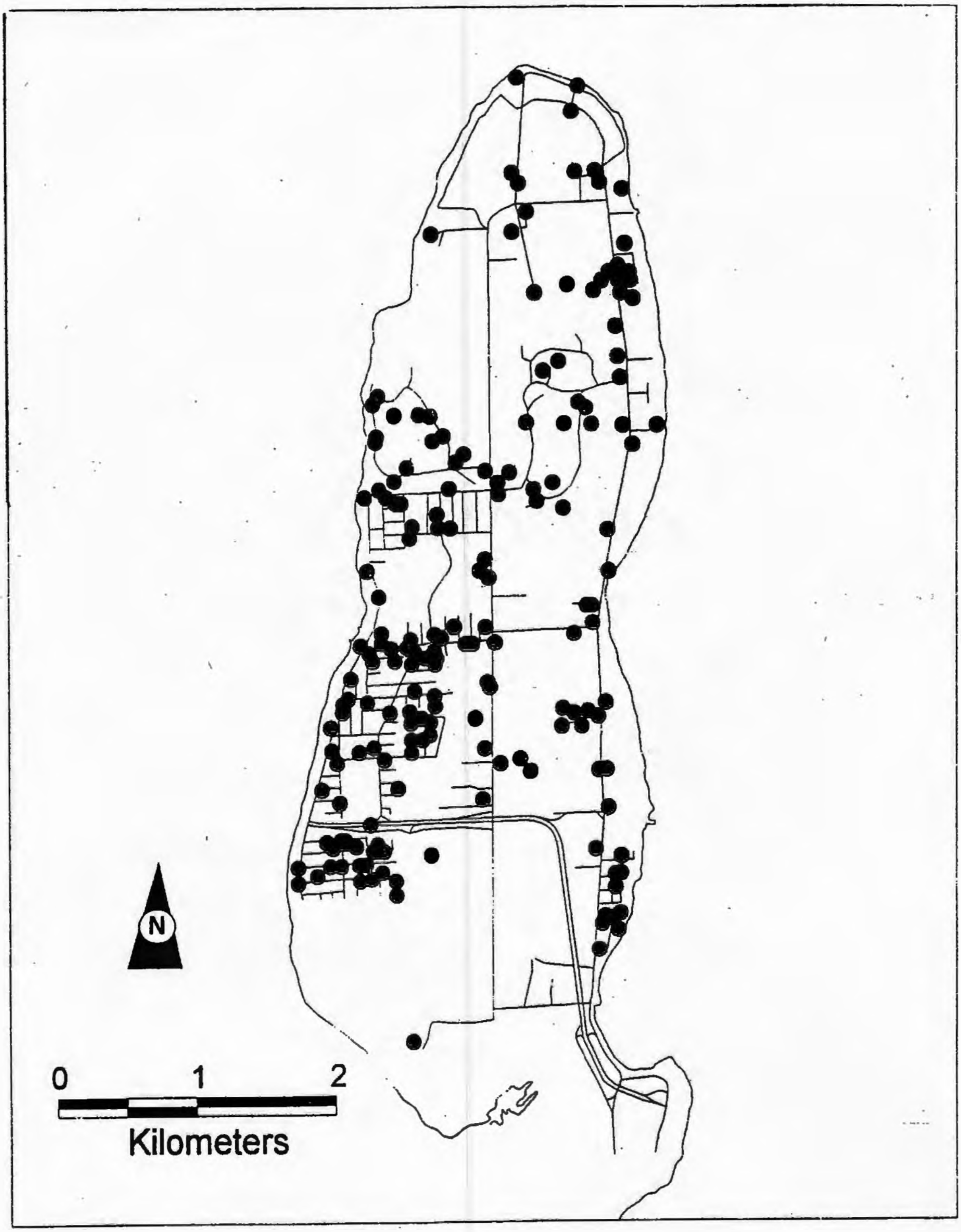

Figure 4: Study area showing all ground-water and surface water sampling locations on Northern Conanicut Island, Rhode Island.

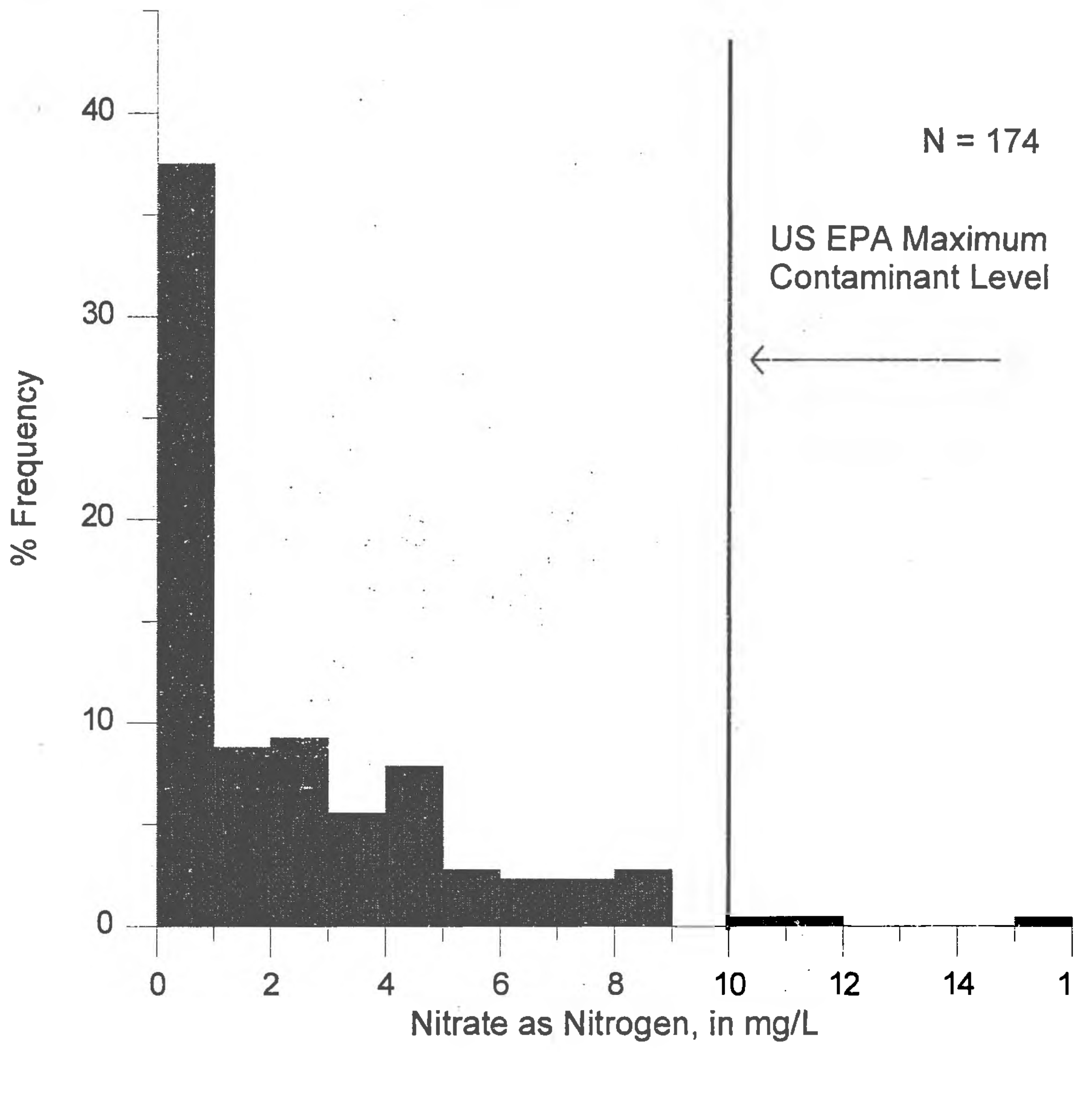

Figure 5: Frequency distribution of nitrate-nitrogen concentrations in groundwater, on Northern Conanicut Island, Rhode Island.

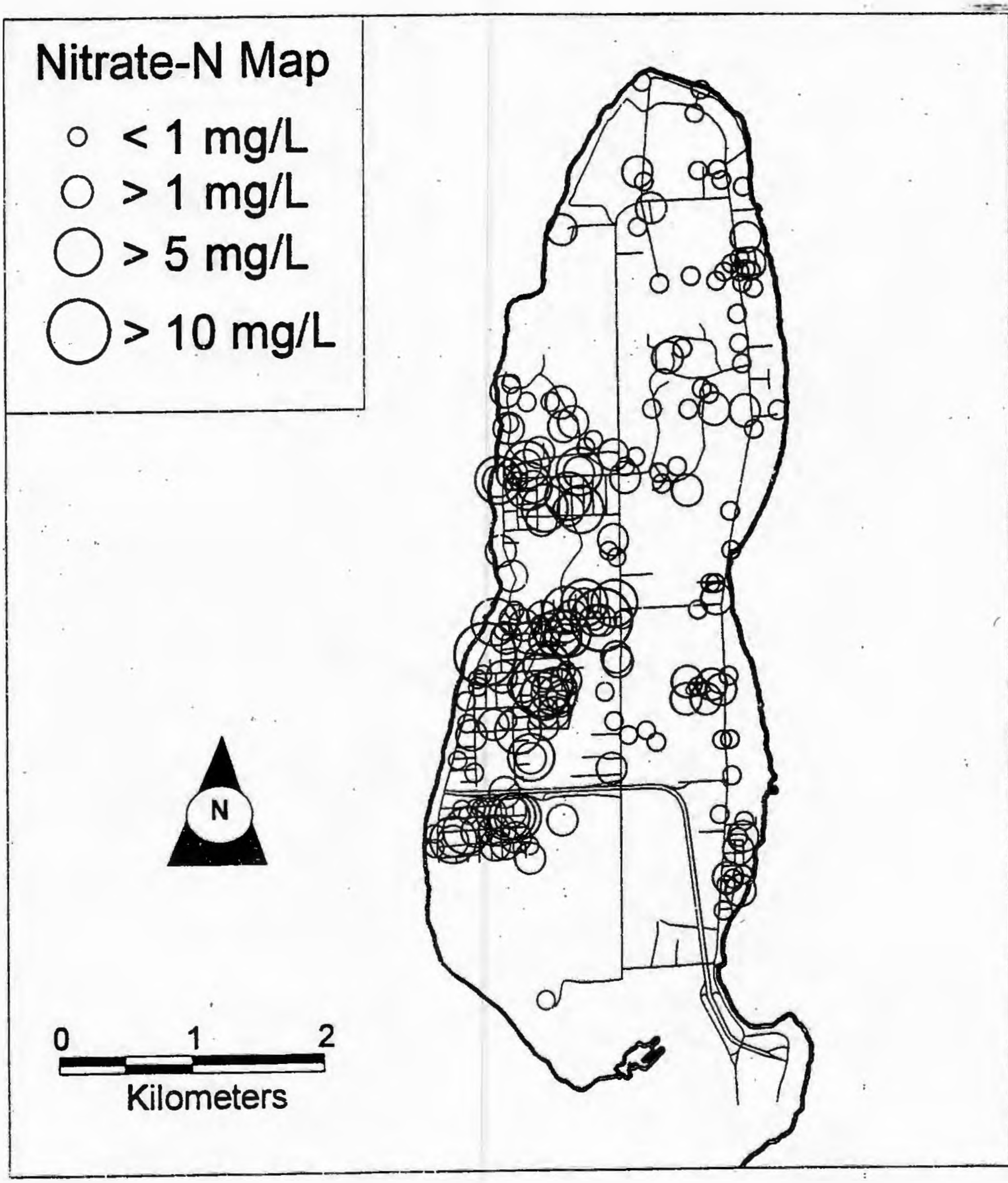

Figure 6: Spatial distribution of nitrate-nitrogen in groundwater and surface water, on Northern Conanicut Island, Rhode Island.

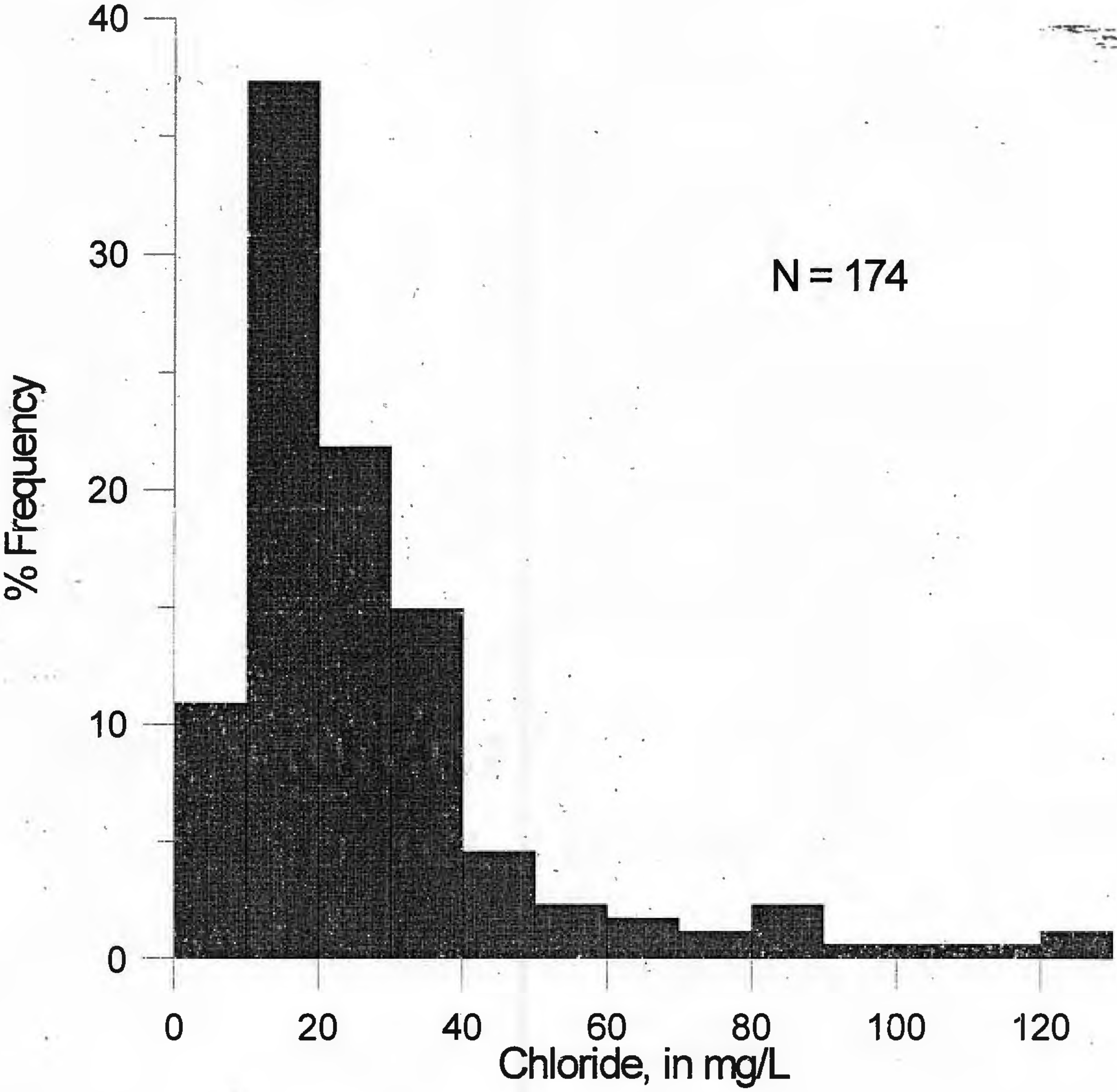

Figure 7: Frequency distribution of chloride concentrations in groundwater, on Northern Conanicut Island, Rhode Island.

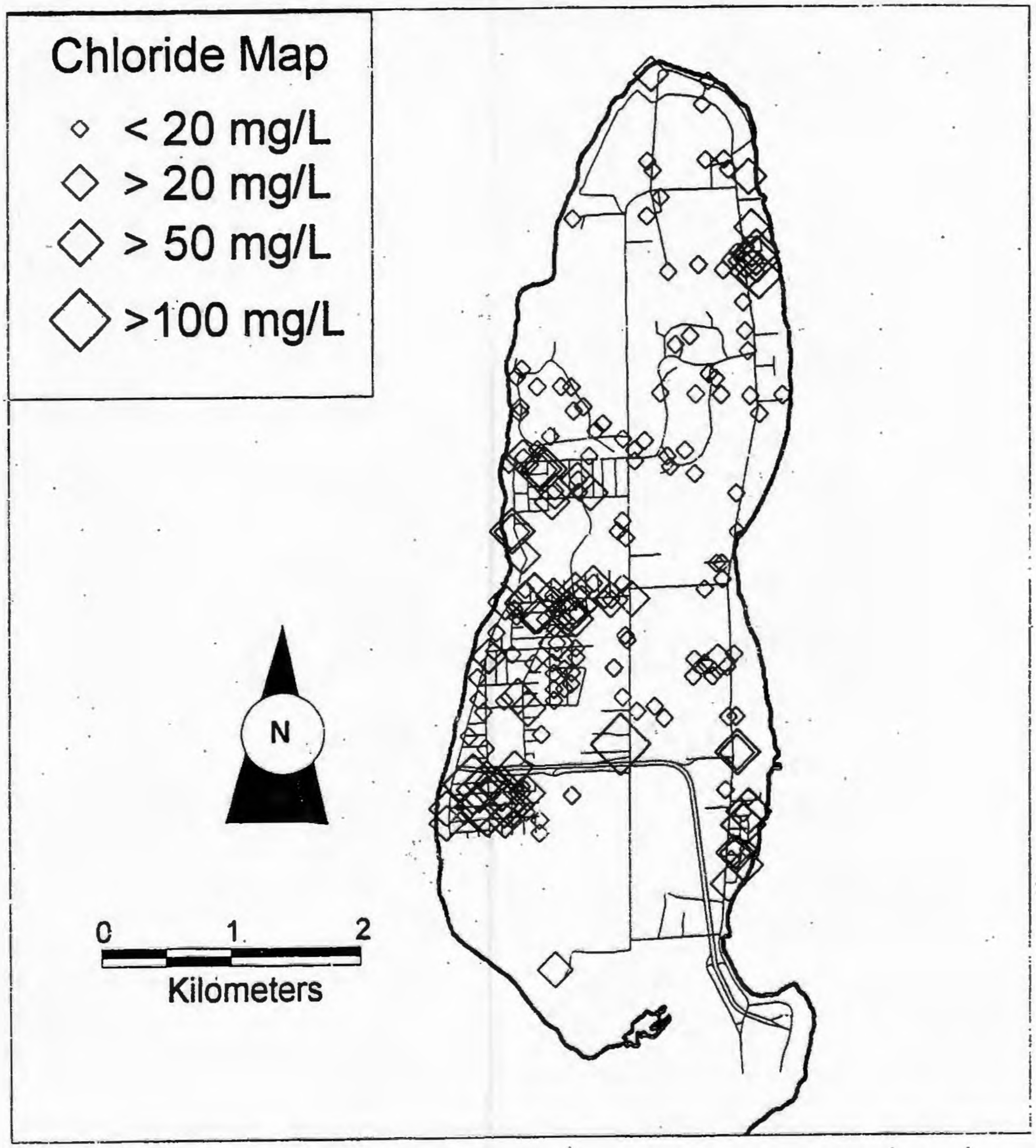

Figure 8: Spatial distribution of chloride concentrations in groundwater and surface water, on Northern Conanicut Island, Rhode Island.

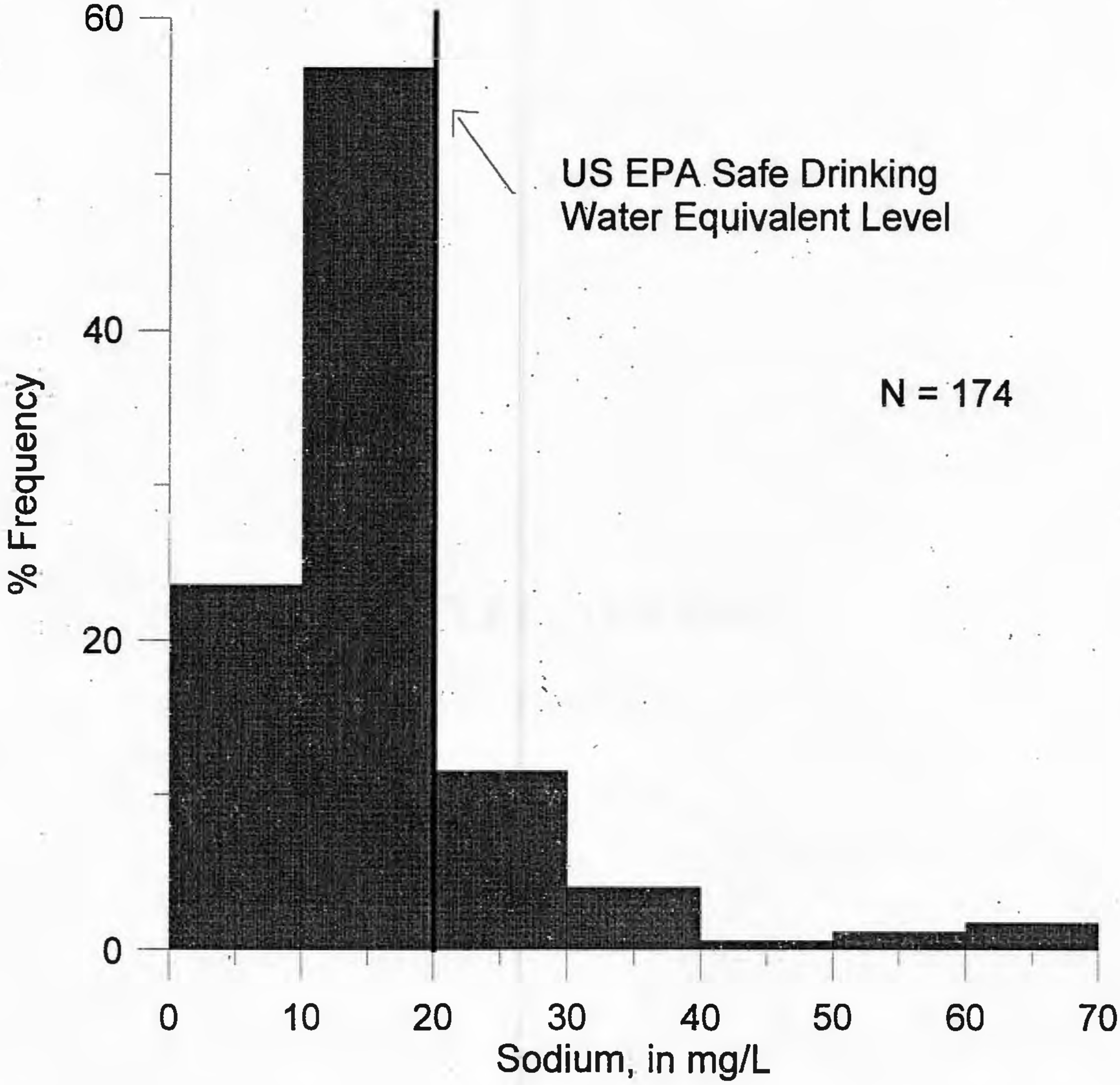

Figure 9: Frequency distribution of sodium concentrations in groundwater, on Northern Conanicut Island, Rhode Island.

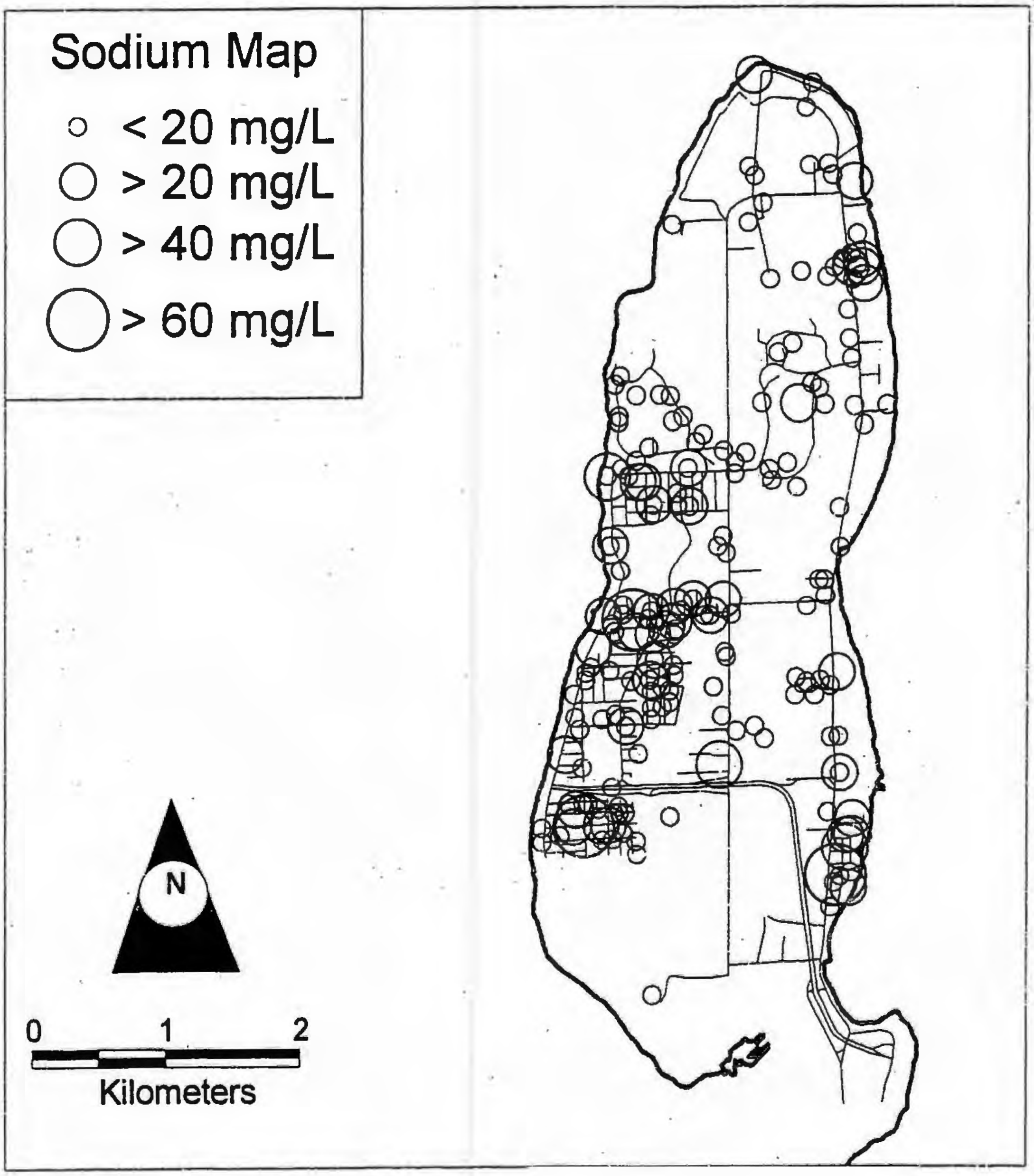

Figure 10: Spatial distribution of sodium concentrations in groundwater and surface water, on Northern Conanicut Island, Rhode Island.

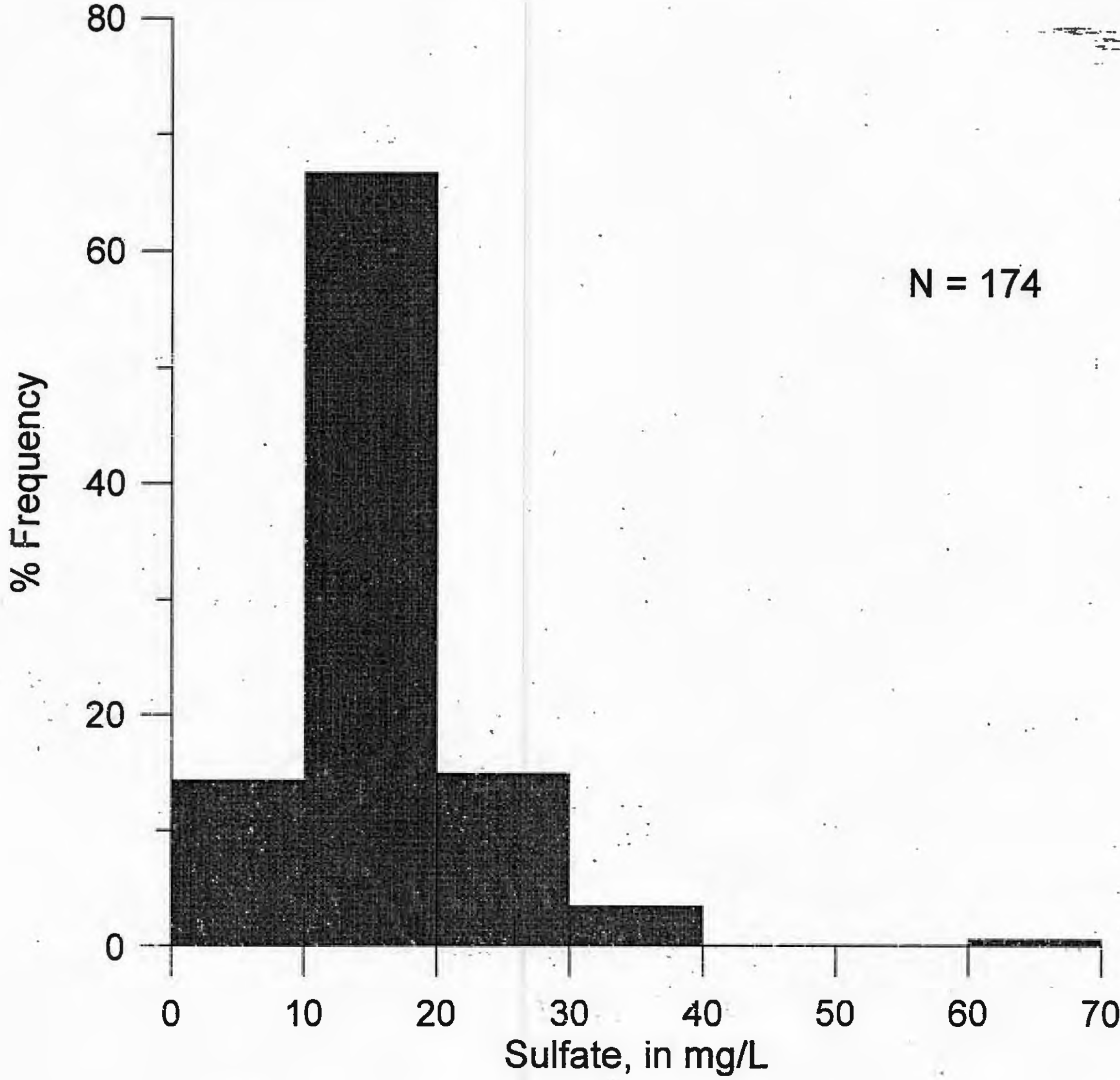

Figure 11: Frequency distribution of sulfate concentrations in groundwater, on Northern Conanicut Island, Rhode Island.

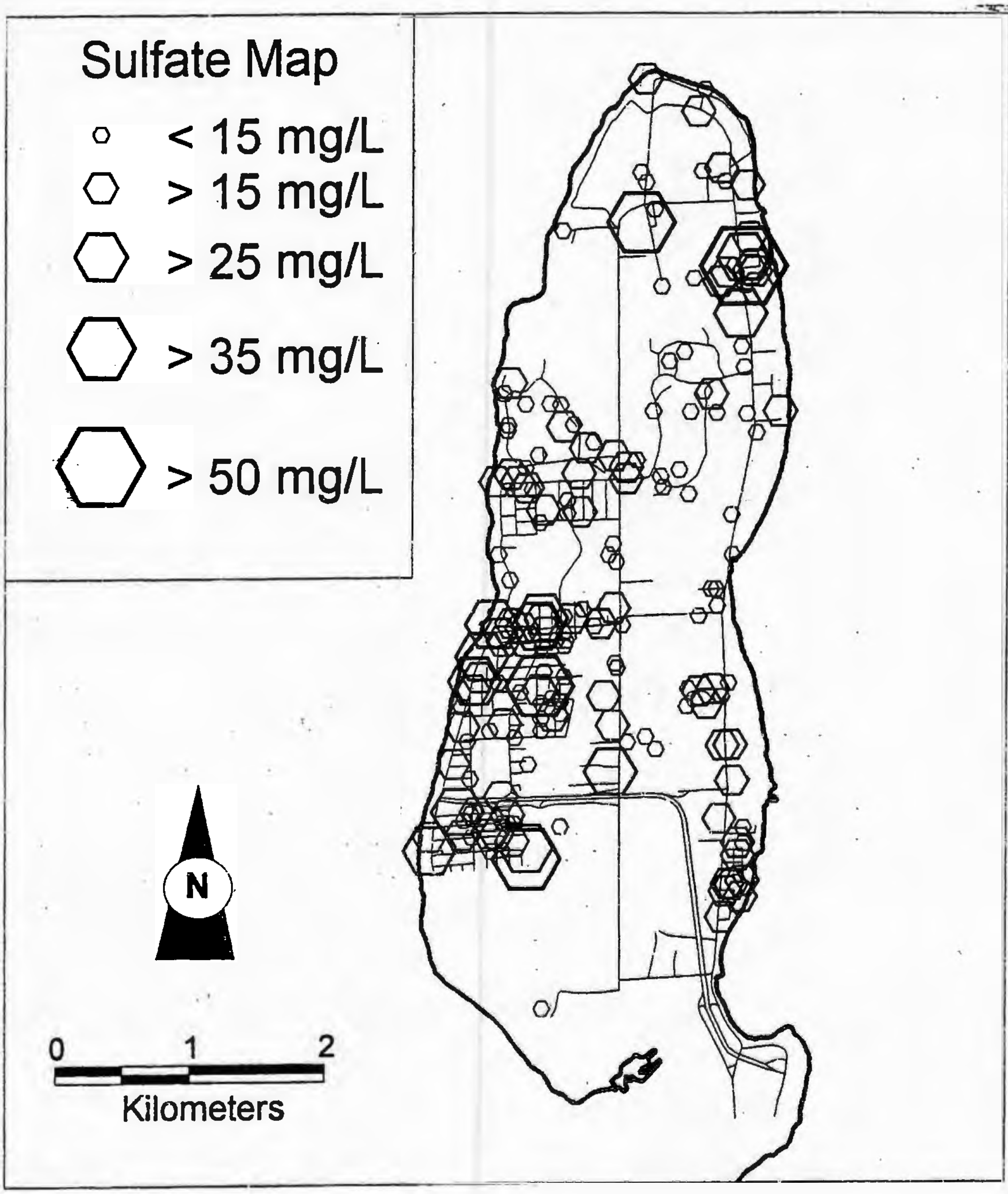

Figure 12: Spatial distribution of sulfate concentrations in groundwater and surface water, on Northern Conanicut Island, Rhode Island.

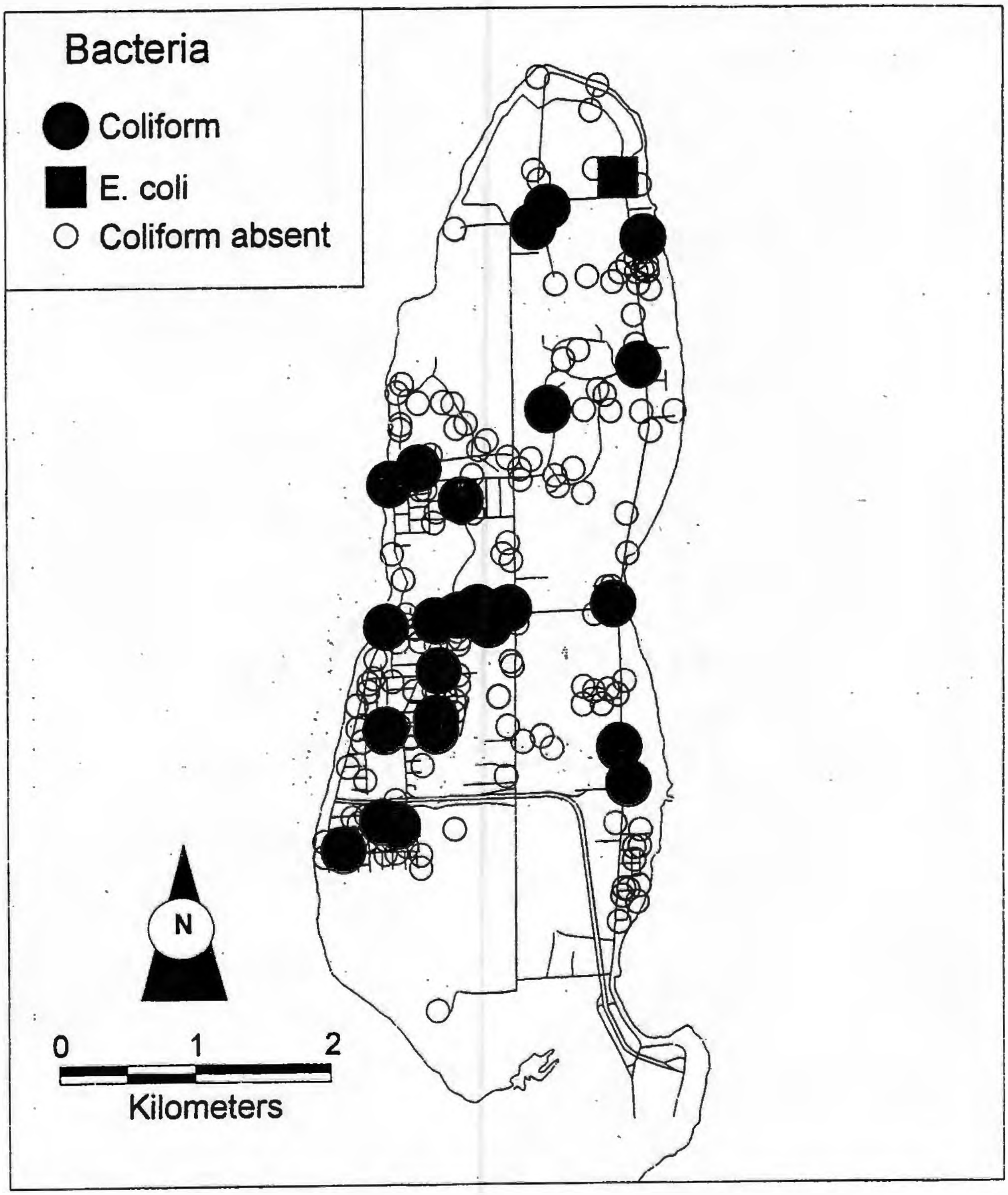

Figure 13: Spatial distribution of coliform bacteria in groundwater, on Northern Conanicut Island, Rhode Island.

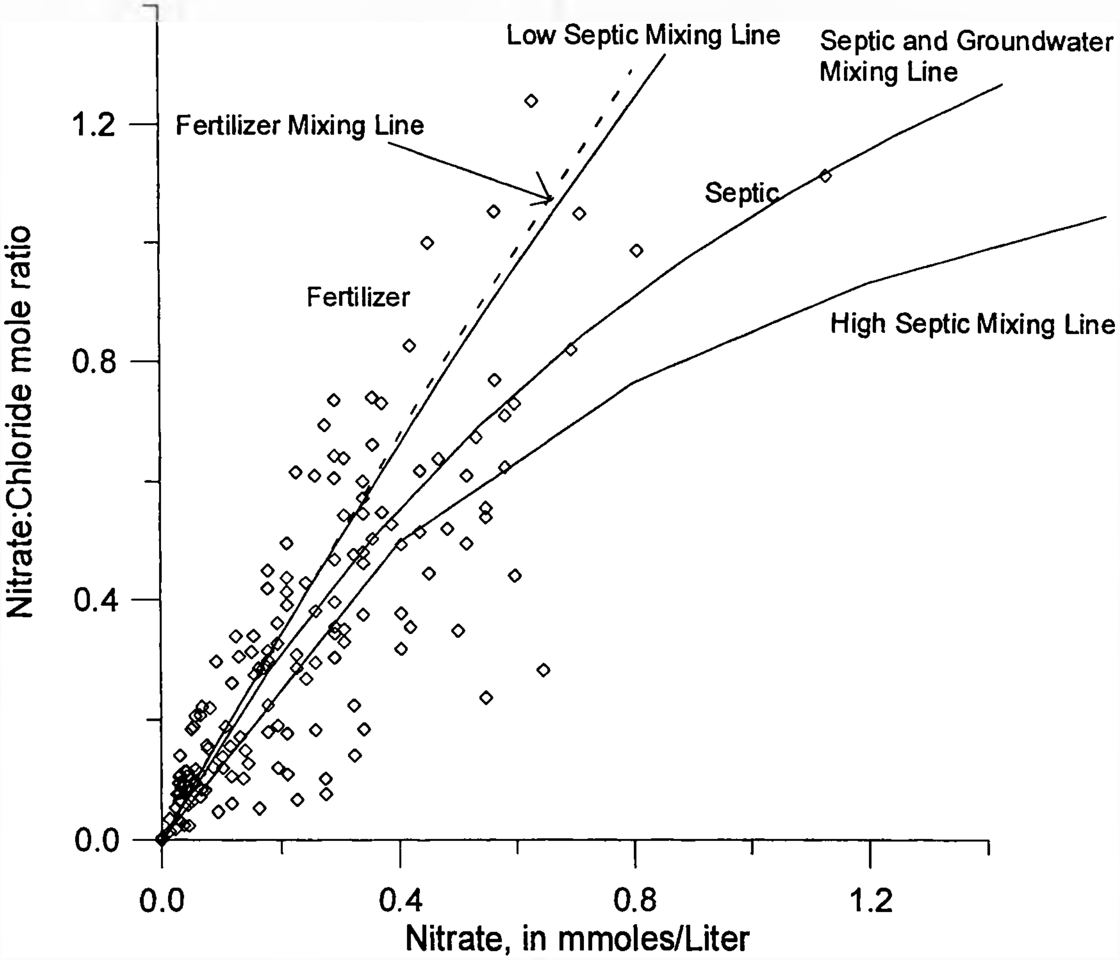

Figure 14: Mixing curve used for identification of septic effluent and fertilizer impacted sites. Sites assigned to a septic source fall between the septic mixing lines, acting as lower and upper boundaries. Sites falling on or above the fertilizer mixing line were assigned to a fertilizer source. Sites falling below the septic range were assigned to a multiple-source impact such as a combination of the above, soil or atmospheric nitrogen, or denitrification. The fertilizer mixing line is based on a fertilizer concentration of 52 mg/L NO_3 as N and 30 mg/L Cl; the septic mixing line is based on a septic concentration of 50 mg/L NO_3 as N and 70 mg/L Cl; the high limit septic line is 110 mg/L NO_3 as N and 190 mg/L Cl; and the lower limit septic mixing line is 27 mg/L NO_3 as N and 27 mg/L Cl. These concentrations were mixed with a background chemistry of 0 mg/L NO_3 as N and 20 mg/L Cl.

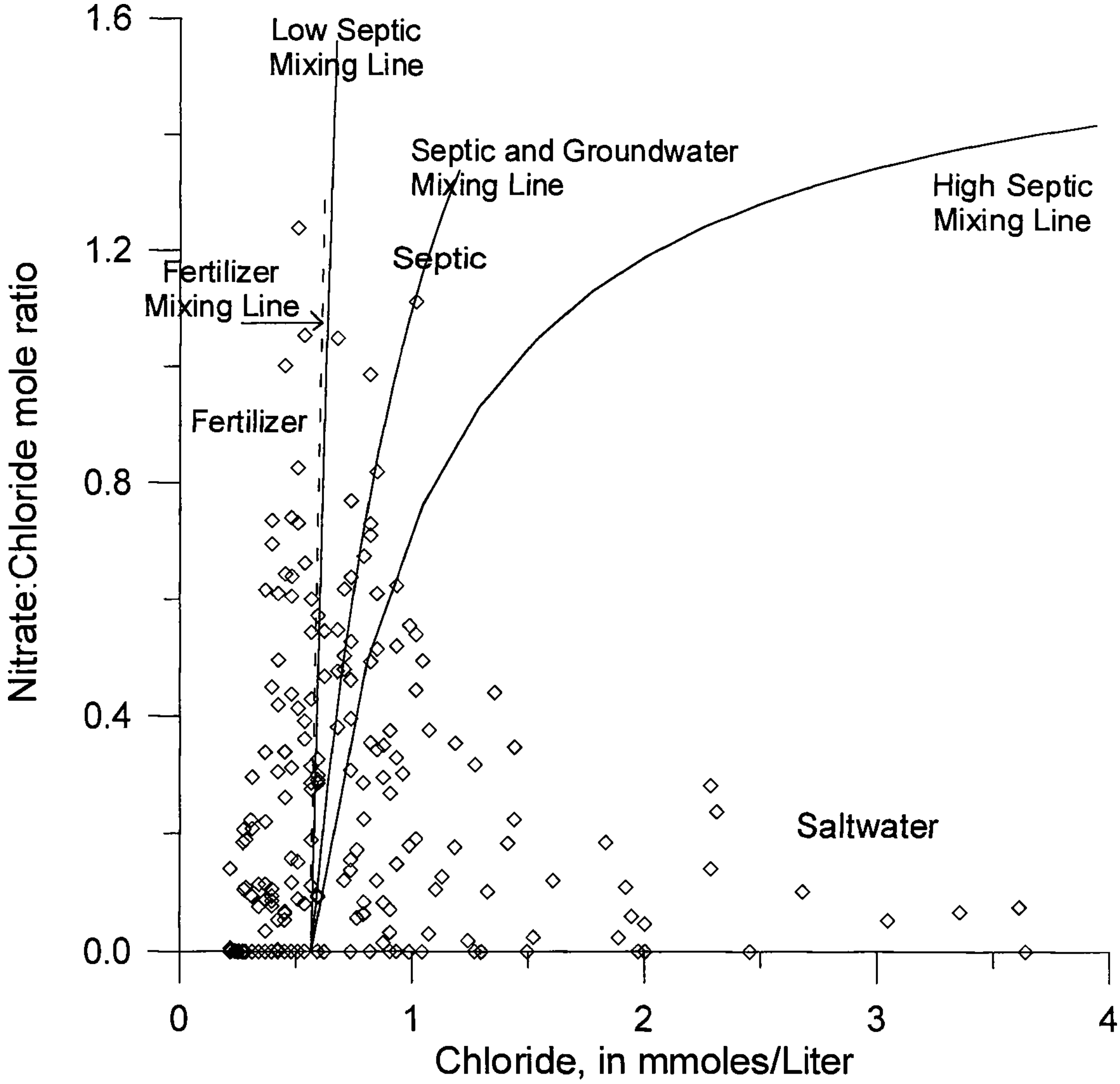

Figure 15: Mixing curve used for identification of saltwater-impacted sites for sites with elevated chloride but little to no nitrate. The fertilizer mixing line is based on a fertilizer concentration of 52 mg/L NO_3 as N and 30 mg/L Cl; the septic mixing line is based on a septic concentration of 50 mg/L NO_3 as N and 70 mg/L Cl; the high limit septic line is 110 mg/L NO_3 as N and 190 mg/L Cl; and the lower limit septic mixing line is 27 mg/L NO_3 as N and 27 mg/L Cl. These concentrations were mixed with a background chemistry of 0 mg/L NO_3 as N and 20 mg/L Cl.

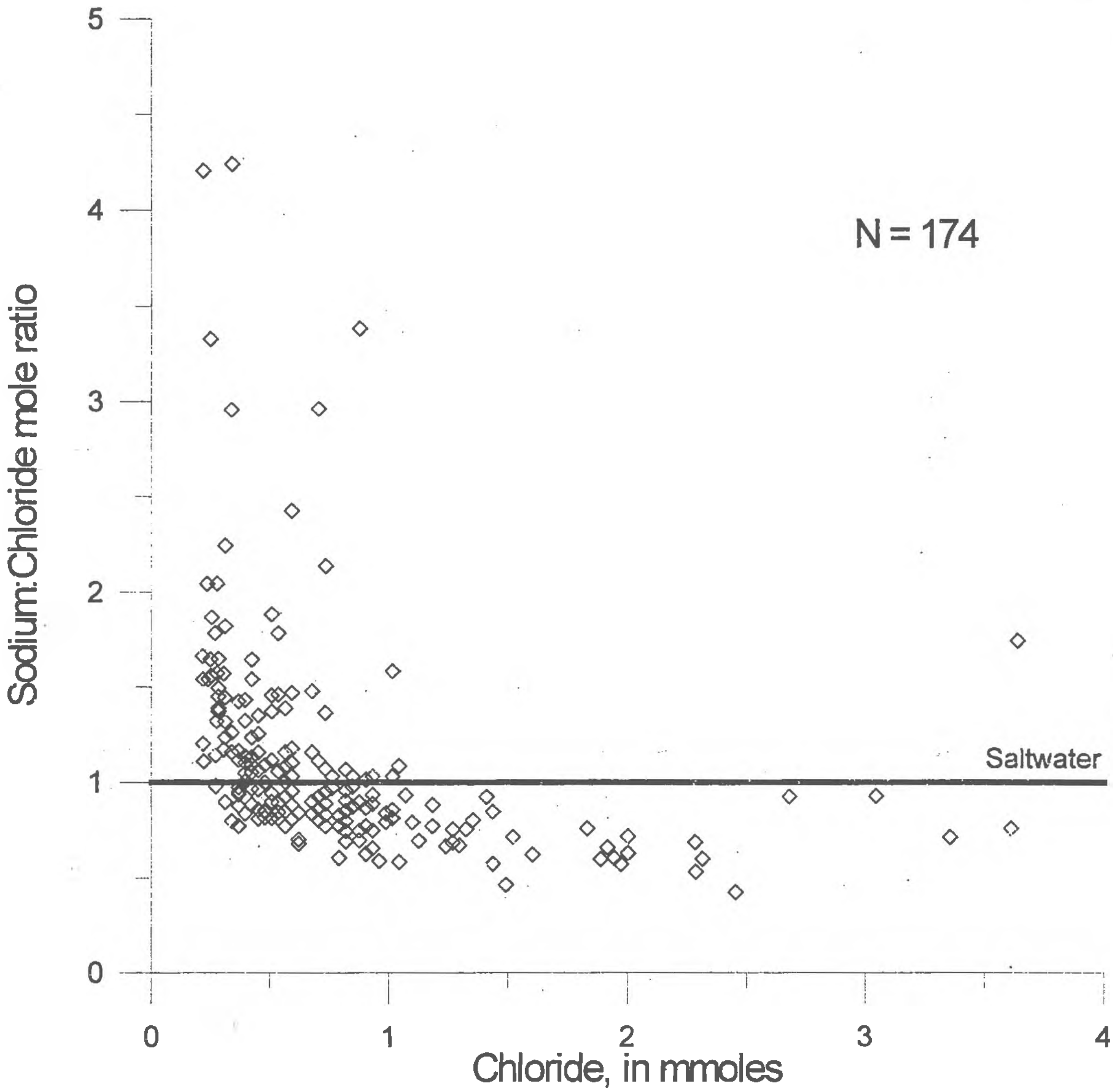

Figure 16: Mole-ratio plot used to determine saltwater contamination.

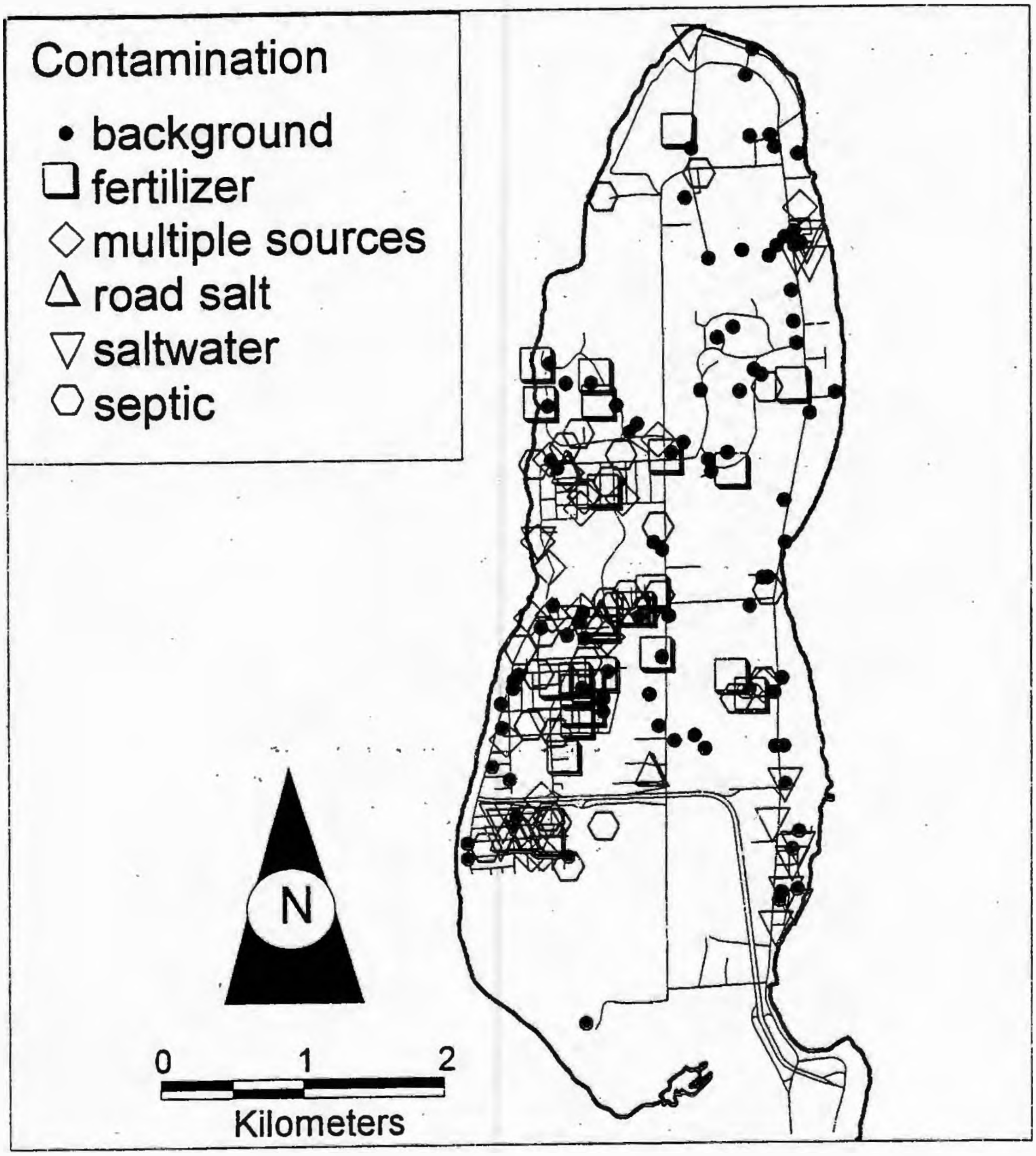

Figure 17: Spatial distribution of all contaminated sites on Northern Conanicut Island, Rhode Island.

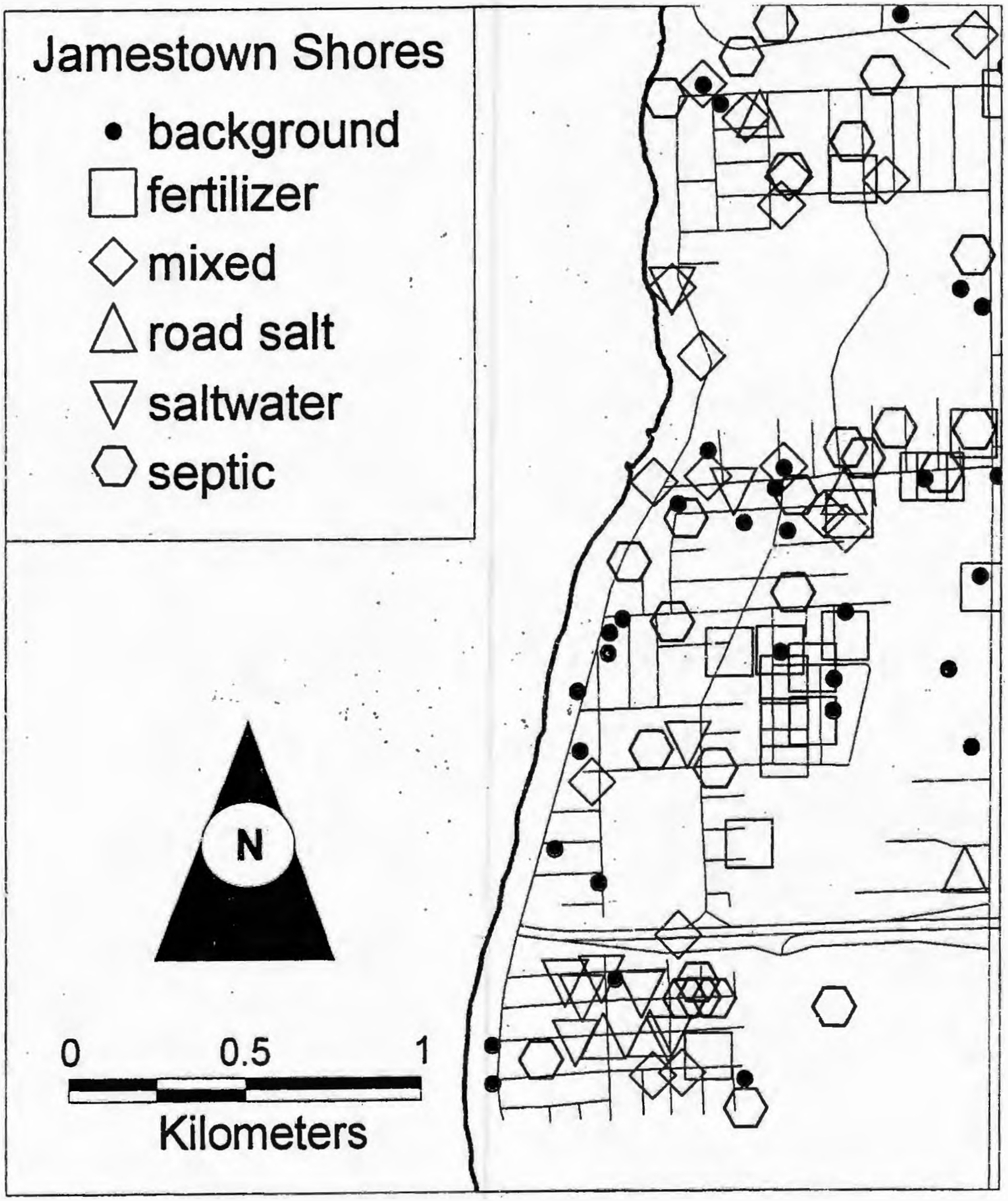

Figure 18: Detailed map showing the contaminated sites within the Jamestown Shores area. Areas exhibiting saltwater contamination occur mainly along the coastline.

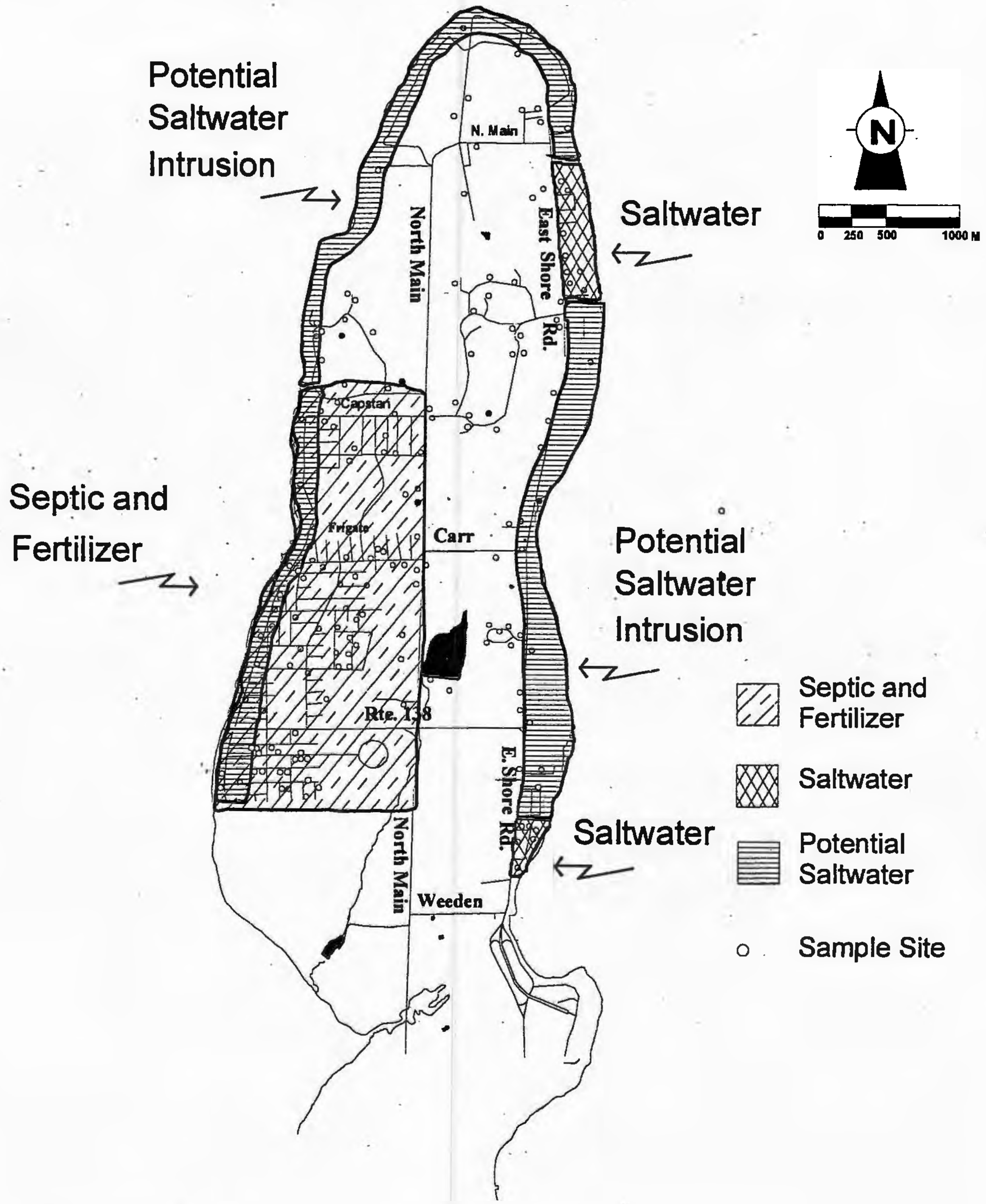

Figure 19: Summary map showing zones of ground water quality impacts.

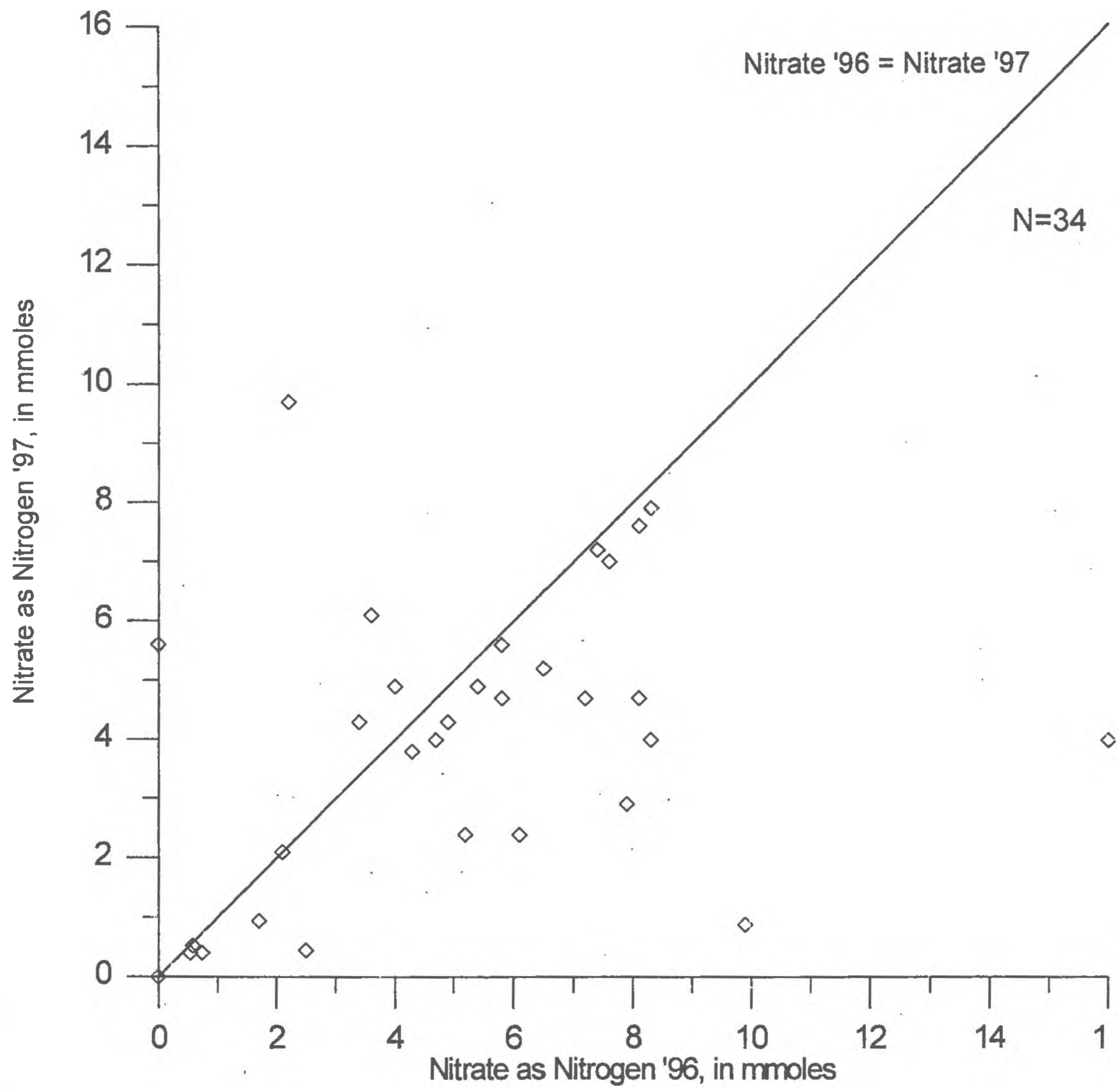

Figure 20: Temporal variation of resampled sites using nitrate-nitrogen concentrations in groundwater.

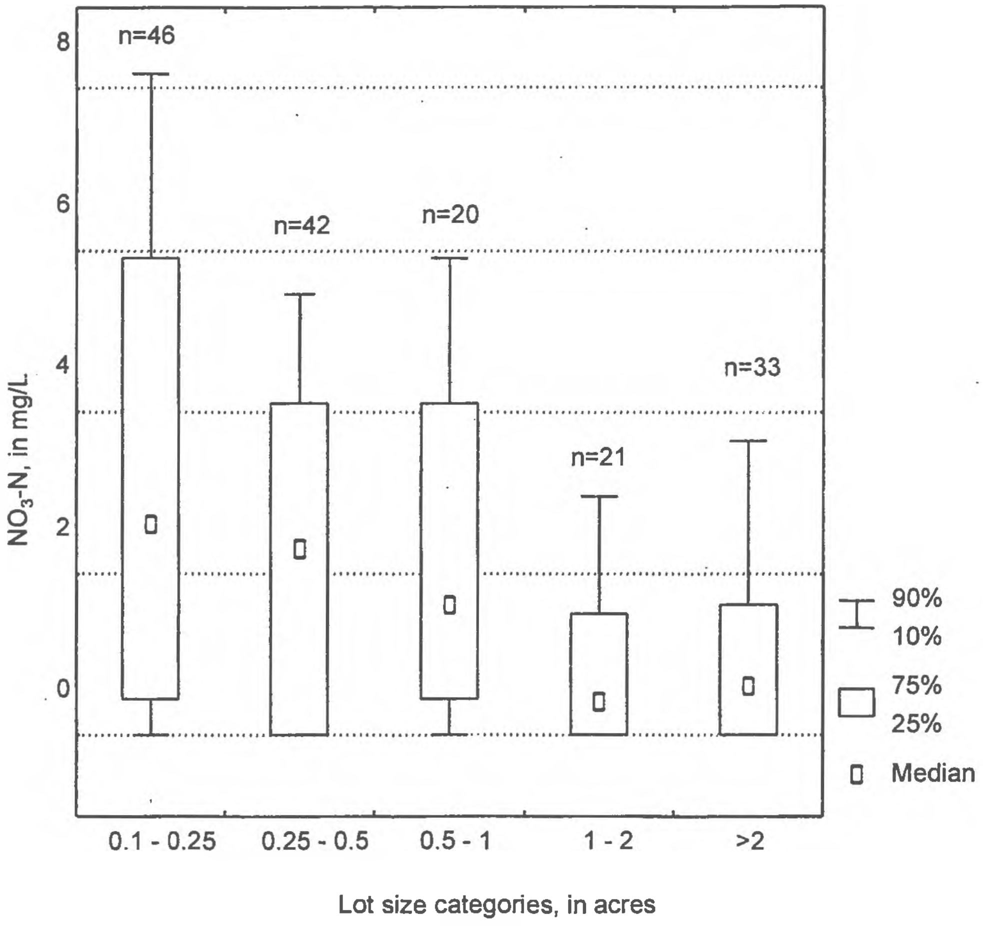

Figure 21: Nitrate-nitrogen concentrations by lot size category showing a large concentration decrease in lots greater than 1 acre, on Northern Conanicut Island, Rhode Island.

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APPENDICES

Appendix A: Data Table

Site No.	Well Depth (ft)	Well Installation Year	Well Yield (gpm)	Septic Installation Year	Lot Size (acres)	Date Sampled	sample year	Temperature °C	turbidity	odor	bacteria	Dissolved Oxygen (mg/L)	Electrical Conductivity (mS/cm)	pH	Alkalinity (as CaCO3)
2	150	70 or 80's	?	1975	0.17	7/31/96	96	11.6	none	none	absent	6.8	250	5.82	16
3	45 or 95	76	5	1994	0.42	7/9/96	96	12.8	brown	earthy	absent	3.8	136	5.8	9.9
4	145	84	-	1996	0.17	7/12/96	96	12	none	none	nc	3.5	173	6	21
5	-	81	-	1981	0.17	6/25/96	96	12.4	none	none	absent	2.7	134	5.85	21
6	250	95	4	1995	3.03	7/12/96	96	11.8	none	none	nc	0.25	140	8.4	39
7	250	83	3	1983	0.19	8/2/96	96	12.8	light brown	chlorine	nc	0.7	221	6.31	49
8	98	95	?	1995	0.48	7/2/96	96	12.4	slightly cloudy	none	nc	9.1	160	5.72	8
9	129	72	-	1972	0.19	8/8/96	96	13.2	orange brown	none	nc	3.3	496	5.61	22
10	300	72	?	1972	0.48	6/25/96	96	13	none	none	nc	6.9	182	5.73	11
12	100+	71	very good	1971	0.5	7/12/96	96	11.9	none	none	nc	8.8	135	5.9	14
13	120?	86	-	1986	0.33	8/9/96	96	12.8	none	none	absent	7.7	221	5.74	12
15	140	75	7	1975	0.43	7/12/96	96	12.5	none	none	nc	0.12	195	6.3	33
18	250	85	3.5	1985	0.19	8/12/96	96	12.9	present	none	absent	3.2	336	6.44	81
19	130	30?	-	1991	2.4	7/9/96	96	13.9	none	none	nc	6.3	510	5.7	12
20	300	85	1.5 to 2	1985	5.5	8/9/96	96	12.6	none	none	nc	1.1	189	7.29	51
23	-	75	-	1975	0.49	6/21/96	96	11.4	none	none	coliform	11	91	5.71	12
24	225	80	8?	1980	0.45	7/2/96	96	13	none	none	absent	0.35	152	6.22	26
25	90	~62	?	1984	0.33	7/12/96	96	12.8	none	none	nc	7.4	103	5.9	10
29	?	86	~2	1988	0.11	8/12/96	96	12.5	none	none	coliform	5	242	5.21	7
30	260	85	5	1985	0.17	7/12/96	96	13	present	chlorine	nc	1.3	110	5.7	8.4
32	150	80	8	1981	0.11	7/9/96	96	11.5	none	none	absent	6.9	116	5.3	4.7
33	220	89	9	1989	9.9	7/27/96	96	12.9	none	none	nc	0.75	295	7.87	109
34	85	74	7	1974	0.33	8/2/96	96	12.8	none	none	nc	7.5	148	5.6	16
35	75	?	5	1975	0.26	8/14/96	96	12.4	none	none	nc	8	197	5.7	15
36	125	87	?	1987	0.46	8/26/96	96	12.7	none	none	nc	5.9	243	5.66	10
38	?	78	?	1978	0.17	6/18/96	96	11.7	none	none	nc	3.6	272	5.9	32
39	85	<65	8.5	1965	0.17	7/15/96	96	11.7	grey/cloudy	none	coliform	6.7	96	5.77	10
45	260	87	6	1994	5.6	7/2/96	96	11.5	none	none	nc	4.9	115	5.9	24
46	-	87	-	1987	1.9	8/8/96	96	13.2	none	none	nc	2.9	169	5.69	11
47	200	84	7	1985	2.2	7/30/96	96	12	none	none	coliform	7.1	180	5.67	11
48	275	85	?	1985	0.19	8/9/96	96	12.4	light orange-br	earthy	nc	0.9	488	6.88	148
49	127	68	?	1976	0.34	7/15/96	96	11.8	none	none	nc	0.3	126	6.53	34
50	120 & 140	>1900	?	1993		7/30/96	96	12.8	none	none	nc	0.75	256	6.15	22
51	?	89	?	1989	0.46	7/31/96	96	11.9	brown to clear	none	nc	6.2	149	5.68	13
53	100	85	?	1985	0.57	8/24/96	96	13.9	none	none	nc	0.04	333	5.78	6.1
54	110	58	10 to 12	1958	5	7/31/96	96	12.6	none	none	nc	0.52	246	6.76	58
55	80 & 200	60 and 95	4+	1960	3	6/14/96	96	-	-	-	nc	7.4	-	6.05	15
56	110	77	20	1978	2.7	7/22/96	96	10.9	none	none	nc	6.2	122	6.25	26
57	200	80	-	1988	1.9	6/21/96	96	11.5	none	none	coliform	4.1	67	6.08	12
58	150	85	5 to 6	1987	2.3	6/28/96	96	12.2	none	none	absent	0.25	76	5.9	12
59	80	72	-	1993	0.23	8/29/96	96	11.5	none	none	nc	5	327	N/A**	4.4
60	135	32	> 5	1978	1.4	7/17/96	96	10.8	none	none	coliform	6.2	197	5.68	14
62	?	76	very good	1976	1.9	6/7/96	96	10.5	none	none	absent	7.3	85	5.35	8.8
63	150	87	8?	1987	1.8	8/12/96	96	12.5	none	none	absent	8	289	5.8	24

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65	195	87	?	1987	1.8	8/21/96	96	12.2	none	none	nc	1.3	119	6.4	23
66	300	37	-		5.7	7/30/96	96	12.5	none	none	absent	5.2	247	6.44	25
68	150	?	?		3	8/21/96	96	11.7	none	none	coliform	0.65	170	5.8	12
69	210	87	30	1970	0.46	6/7/96	96	12.2	none	none	absent	0.18	165	6.65	27
70	200	80 to 82	3	1984	2.3	8/14/96	96	11.5	none	none	nc	7.5	126	6.1	15
71	150	84	10	1985	0.46	6/7/96	96	11.5	none	none	nc	0.15	105	6.2	22
72	100	80	20	1980	1.9	6/28/96	96	12	none	none	absent	0.35	124	5.92	9.4
73	?	87	?	1987	2.3	7/17/96	96	12.1	none	none	nc	0.65	87	6.28	22
77	100	68	5	1968	22	8/9/96	96	13.3	none	none	absent	1.1	166	6.36	39
78	84	64	5	1964	0.65	7/17/96	96	12	grey/cloudy to	none	coliform	2.1	106	6.29	22
79	100±	60	?	1993	1	7/2/96	96	-	none	none	nc	5.6	128	5.65	9.5
80	-	65	-	1965	0.48	6/28/96	96	12	none	none	nc	8.3	124	5.7	16
81	150	?	?		3.7	8/2/96	96	12.8	black sedimen	none	absent	0.75	233	6.9	57
82	~170	~72	1 to 1.5	1972	3.5	8/2/96	96	11	none	none	coliform	4.6	328	5.97	14
83	75	~47	7 to 8	1947	0.3	6/14/96	96	-	clear to brown	none	nc	0.25	-	7.12	67
84	300	88	~2	1988	0.17	7/17/96	96	12.7	none	none	absent	0.75	129	6.15	22
85	128	89	24	1988	0.55	8/14/96	96	12	present	none	absent	1.5	409	8.88	75
90	129	82?	?	1990	0.46	7/31/96	96	11.8	none	none	coliform	-	172	5.82	29
92	51	87	30	1987	0.17	7/31/96	96	11.1	none	none	absent	8.5	217	5.77	13
93	?	82	-	1992	0.17	7/17/96	96	11.4	none	none	nc	7.5	175	5.74	12
94	~160	85	4 to 5	1985	0.17	7/15/96	96	11.8	none	none	coliform	5.5	189	5.98	29
95	95	110 & 140	50 & 85	1981	6.9	7/2/96	96	-	-	-	-	-	-	-	15
97	100 to 125	86	10	1986	0.54	8/12/96	96	12.2	none	none	absent	10	162	5.55	8.2
98	?	65	?	1965	0.21	7/12/96	96	11.8	none	none	nc	1.8	345	5.6	24
99	-	early 70's	-	1972	0.17	8/24/96	96	11.7	none	none	nc	0.45	244	6.83	65
100	?	?	?		0.49	6/21/96	96	12.4	none	none	coliform	9.6	103	5.8	8.6
102	~80	65?	> 8	1965	0.17	6/14/96	96	11.5	slight	none	coliform	10	290	6.36	42
104	60 & 240	72 & 80	? & 30	1972	0.1	8/26/96	96	13	none	none	nc	5.6	190	5.41	11
105	105	87	10	1987	0.25	8/22/96	96	13.6	none	none	absent	0.4	190	6.7	51
106	124	70	-	1970	0.1	8/26/96	96	11.9	none	none	nc	8.1	270	5.37	5.3
107	175	?	13	1983	1.9	7/30/96	96	12.4	-	-	absent	0.6	134	6.62	29
108	-	81	-	1981	0.1	8/21/96	96	11.3	none	none	nc	8.3	237	5.8	12
109	280	86	-	1986	5.9	8/26/96	96	11.5	none	none	nc	8.1	118	5.88	15
110	-	86	-	1986	2.2	7/15/96	96	11.7	none	none	nc	0.95	175	6.78	41
111	100+	?	?	1988	0.86	8/14/96	96	11.5	none	none	absent	6.4	83	6.1	8.4
112	75	62	?	1962	0.92	8/21/96	96	11.1	none	none	coliform	6.1	166	5.7	20
113	120 & 220	95	?	1987	4.6	6/7/96	96	12	none	none	absent	5.1	182	6.9	29
116	-	-	-	1972	0.59	8/12/96	96	12.3	none	none	nc	7.6	193	5.8	28
119	120?	48	-	1990	0.26	8/2/96	96	13.8	cloudy; orange	none	nc	1.6	192	7.17	67
122	175	73	4	1973	0.54	8/2/96	96	12.8	none	none	nc	4.1	357	6.49	47
123	33	47	8 to 10	1972	0.17	8/8/96	96	13.5	none	none	nc	0.75	230	6.15	26
124	?	68	?	1995	0.33	7/12/96	96	11.9	present	none	nc	3.9	145	5.65	13
125	?	90	5+	1990	0.35	8/22/96	96	11.2	none	none	absent	7.8	167	6	13
126	-	76	-	1976	0.5	8/26/96	96	13.3	none	none	nc	2.9	166	5.85	15

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127	?	82	?	1982	0.46	6/18/96	96	12.2	none	none	absent	8.5	63	5.76	8.1
128	125	83	12	1984	0.24	7/9/96	96	12.9	brown	none	nc	0.2	238	6	31
129	160	78?	35	1985	0.32	7/15/96	96	11.6	none	none	coliform	7	226	6.12	38
130	>100	66	3.5?	1994	0.17	8/14/96	96	12.2	none	none	absent	3.4	241	5.5	15
131	175	90	15 to 20?	1990	2	8/22/96	96	12.2	none	none	nc	7.6	165	5.6	9.5
132	68	73	?	1973	0.46	8/22/96	96	12	none	none	nc	7	143	6.2	25
134	215+	78+	?	1978	2.3	6/28/96	96	11.8	none	none	absent	7.2	112	5.77	10
135	95	76	10	1980	1.9	8/12/96	96	11.3	none	none	nc	6.5	148	5.77	19
136	104	90	12	1990	1.5	8/9/96	96	12.2	orange-brown	none	nc	4.2	118	6.04	19
137	150	?	?	1993	0.11	7/17/96	96	12.4	none	none	nc	1.2	159	5.38	1.1
139	145	79	?	1979	0.33	8/21/96	96	12.4	none	none	coliform	7.9	275	6.07	20
140	100	68 or 72?	-	1973	0.39	8/8/96	96	12.8	none	none	nc	6.7	226	5.59	14
141	130	75	?	1975	0.51	7/31/96	96	11.6	-	-	absent	1.1	24	6.18	24
142	100	76	-	1976	0.5	7/15/96	96	11.3	none	none	coliform	8.5	139	5.93	11
144	110	73	-	1973	0.69	8/21/96	96	12.7	none	none	nc	5.2	187	5.3	8
146	-	~85	-	1985	2	8/9/96	96	13.5	none	none	absent	5.7	156	6.11	22
149	?	79	?	1979	2.2	7/15/96	96	10.9	none	none	absent	6.5	106	5.56	9.5
150	350	78	?	1978	3.8	8/2/96	96	12.3	none	none	coliform	0.72	278	5.85	45
151	178	86	-	1987	2.1	8/12/96	96	12.3	none	none	absent	0.65	129	6.15	20
153	300	87	?	1987	0.46	7/27/96	96	13.2	none	none	nc	-	343	7.59	88
154	280	81	2	1981	0.33	8/9/96	96	13	none	sulfur	nc	0.65	311	6.5	45
155	125 to 130	71	6	1971	0.17	8/21/96	96	12.3	none	none	nc	7.2	323	5.5	9
156	330	79 - 80	-	1980	0.34	8/9/96	96	13.6	none	none	absent	7.8	142	5.92	14
159	9	86	30	1992	2.2	8/22/96	96	11.4	none	none	nc	0.3	127	6.3	17
160	?	>87	?	1987	2.3	8/16/96	96	11.9	none	none	nc	0.53	168	6.46	17
161	-	71	-	1971	0.41	8/16/96	96	12.4	none	none	nc	4.5	150	5.74	15
162	200+	96	5	1996	0.17	8/22/96	96	11.7	none	none	nc	0.4	158	7	33
163	115	72	12	1972	0.57	8/22/96	96	11.1	none	none	nc	7.7	378	6	24
164	270	95	4 or 5?	1995	0.11	8/16/96	96	12.4	none	none	nc	3.9	461	5.44	12
166	N/A	N/A	N/A		0.11	8/16/96	96	11.3	none	none	nc	7.8	114	5.6	13
167	N/A	N/A	N/A		0.17	8/22/96	96	12.2	none	none	nc	0.25	299	6.1	9.3
44G	N/A	N/A	N/A	1965	0.33	8/14/96	96	12.3	none	none	absent	0.9	141	5.7	9.3
44H	190	72	7	1965	0.33	8/14/96	96	12.6	present	none	nc	6.3	224	6	10
JR-1	-	-	-			8/1/96	96	11.2	-	-	nc	6.8	115	6.4	26
Res.	N/A	N/A	N/A	N/A		8/1/96	96	-	-	-	-	-	-	-	7.7
2	150	70 or 80's	?	1975	0.17	8/5/97	97	11.2	none	none	ABSENT	6.3	281	5.68	14
10	300	72	?	1972	0.48	8/14/97	97	12.4	none	none	ABSENT	1.6	184	5.55	7.5
23	?	75	?	1975	0.49	8/5/97	97	11.6	became cloud	none	ABSENT	6.8	134	5.5	12
29	?	86	~2	1988	0.11	8/8/97	97	12.3	none	none	Coliform	5.5	180	5.4	6.7
30	260	85	5	1985	0.17	8/2/97	97	13	none	none	ABSENT	3.9	138	5.61	9.4
33	220	89	9	1989	9.9	8/2/97	97	14.3	none	none	ABSENT	0.9	331	7.68	107
38	?	78	?	1978	0.17	8/8/97	97	12.1	high-lots of se	none	ABSENT	4.2, 5.8	279	5.22	7.3
39	85	<65	8.5	1965	0.17	8/8/97	97	11.8	none	none	ABSENT	?	108	5.7	13
47	200	84	7	1985	2.2	7/30/97	97	12.7	none	none	ABSENT	6.3	178	--	13

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57	200	80	?	1988	1.1	7/30/97	97	11.3	none	none	Coliform	3.8	99.2	5.96	12
68	150	?	?		3	7/30/97	97	12.3	none	none	ABSENT	3	153	5.67	12
78	84	64	5	1964	0.65	7/30/97	97	12.3	none	none	ABSENT	3.5	126	6.25	21
82 G	~170	~72	1 to 1.5	1972	3.5	8/5/97	97	11.3	none	none	ABSENT	1.8	351	5.66	13
82H				1972	3.5	8/5/97	97	12.1	none	none	ABSENT	3.8	257	6.07	21
90	129	82?	?	1990	0.46	8/5/97	97	11.8	none	none	ABSENT	7.4	174	5.9	31
94	~160	85	4 to 5	1985	0.17	8/14/97	97	12.1	none	none	ABSENT	4.3	249	5.92	32
97	100-125	86	10	1986	0.54	8/2/97	97	13.6	none	none	ABSENT	8.6	141	5.75	9.3
98	?	1966?	?	1965	0.21	10/29/97	97	11.1	none	none	ABSENT	5.5	263	5.95	30
100	?	?	?		0.49	8/14/97	97	12.4	none	none	ABSENT	7.8	140	5.74	11
102	~80	65?	>8	1965	0.17	8/5/97	97	11.9	none	none	Coliform	0.65	325	6.21	47
106	124	70	?	1970	0.1	8/2/97	97	11.9	none	none	ABSENT	7.7	289	5.22	3.8
108	?	81	?	1981	0.1	8/14/97	97	11.3	none	none	Coliform	6.4	285	5.5	12
112	75	62	?	1962	0.92	7/30/97	97	11.3	none	none	ABSENT	4.6	158	5.88	18
125	?	90	5+	1990	0.35	8/8/97	97	11.3	none	none	ABSENT	7.1	153	5.72	13
129	160	78?	35	1985	0.32	8/8/97	97	11.5	none	none	Coliform	5.7	190	5.55	15
130	>100	66	3.5?	1994	0.17	8/5/97	97	12.1	none	none	ABSENT	3.5	178	5.47	11
139	145	79	?	1979	0.33	8/2/97	97	14.4	none	none	ABSENT	7.9	262	5.91	19
140	100	68 or 72?	?	1973	0.39	8/19/97	97	12.9	none	none	ABSENT	6.8	254	5.54	15
142	100	76	?	1976	0.5	8/8/97	97	12	none	none	ABSENT	7.2	163	5.78	13
144	125	1973	15	1973	0.69	10/29/97	97	11.8	none	none	ABSENT	3.5	340	5.2	6.5
150	350	78	?	1978	3.8	8/14/97	97	12.5	none	none	ABSENT	0.35	374	5.66	60
155	125-130	71	6	1971	0.17	8/8/97	97	12.2	none	none	ABSENT	6.3	322	5.33	7.8
164	270	95	4 or 5?	1995	0.11	8/19/97	97	12.4	none	none	ABSENT	3.4	330	5.52	12
165	125	1981	9	1985	1.9	8/14/97	97	11.2	none	none	coliform	3.8	104	5.59	10
200S	N/A	N/A	N/A	N/A	N/A	7/17/97	97	31.2	v. slightly	none	N/A	7.8	178	8.91	24
201S	N/A	N/A	N/A	N/A	N/A	7/17/97	97	32	none	musty	N/A	3.6	85.8	7.22	5.3
202S	N/A	N/A	N/A	N/A	N/A	7/17/97	97	22	heavy organic	metallic	N/A	6.4	146	6.73	13
203S	N/A	N/A	N/A	N/A	N/A	7/14/97	97	27.3	low	none	N/A	7.6	105	6.72	10
204S	N/A	N/A	N/A	N/A	N/A	7/14/97	97	32.2	slight	none	N/A	2.9	67	6.6	10
205S	N/A	N/A	N/A	N/A	N/A	7/14/97	97	29.5	slight	none	N/A	6.2	166	7.1	14
206S	N/A	N/A	N/A	N/A	N/A	7/23/97	97	24.9	floatables	none	N/A	9	123	8.99	16
207	225	1983	?	1983	0.92	8/22/97	97	13.6	none	none	ABSENT	5.2	344	5.37	6.6
208	?	1985	?	1985	1.8	8/22/97	97	13.1	none	none	ABSENT	7.9	173	6.21	34
209	80	1989	?	1989	12	8/22/97	97	12.4	none	none	ABSENT	3.4	159	5.44	11
210	150	1972	8	1976	0.17	8/22/97	97	12.6	none	none	ABSENT	3.7	472	5.57	22
211	~140	~1989	?	1989	0.17	8/22/97	97	13.2	none	slight H2S	ABSENT	1.8	508	6.03	70
212	260	1983	6-7	1983	0.37	8/27/97	97	12.1	none	none	ABSENT	2.6	317	6.35	40
213	30	?1954	?	1971	0.17	8/27/97	97	11.9	none	none	ABSENT	6.1	285	5.4	10
214	120	1987	20	1991	3.3	8/27/97	97	11.7	light	none	ABSENT	1	113	5.45	12
215	>100	1986	?	1986	1.9	8/27/97	97	12.2	a little at 1st	none	ABSENT	5.5	159	5.8	31
216	?	1987	?	1987	1.8	8/27/97	97	12.2	?	?	ABSENT	--	135	5.82	13
217	?	?1972	?	1972	0.50	8/27/97	97	11	none	none	coliform	6.1	305	5.57	13
218	?	~1980	?	1980	0.33	8/27/97	97	11.4	none	none	coliform	7.1	188	5.35	8.4

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219	150	70s, early 80s	15	1975	1.9	9/10/97	97	10.3	none	none	ABSENT	6.3	98.5	5.2	6.6
220	?	1986	?	1986	2	9/26/97	97	11.4	none	none	ABSENT	0.4	100	5.65	20
221	225	?	?	1992	0.26	9/26/97	97	11.1	v. slightly	none	ABSENT	0.2	164	6.1	27
222	?	1989	?	1989	1.9	9/26/97	97	12	none	none	ABSENT	0.75	90	5.5	4.5
223	175	~1989	10	1997	1.9	9/26/97	97	11.7	v. slightly	none	ABSENT	0.8	98	5.9	11
224	100	1978	12	1978	1.9	9/26/97	97	11.2	none	none	ABSENT	7.6	80.5	5.25	3.4
225	90	~1970	?	1980	0.23	9/26/97	97	11.7	mod.	H2S slight	ABSENT	0.5	134	5.87	20
226	~200	~1977	?	1977	3.8	10/1/97	97	11.2	none	none	ABSENT	7	95	5.5	6.9
227	185?	1984	?	1984	0.165312	10/1/97	97	11.5	none	none	ABSENT	4.9	192	5.8	14
228	305	1989	1.5	1989	0.18	10/1/97	97	11.4	none	none	ABSENT	0.75	277	6.3	55
229	30	1957	?	1972	0.63	10/3/97	97	11	none	none	E. Coli	0.5	138	6.59	37
230	100	1969	?	1969	0.27	10/3/97	97	11.7	none	none	ABSENT	3.3	184	5.38	16
231	75	1950 or 60?	5-6	1983	0.33	10/3/97	97	11.8	none	none	ABSENT	2.7	567	5.3	10
232	175	1977-78	?	1978	1.8	10/8/97	97	10.9	slight yellow	H2S slight	ABSENT	0.35	127	6.84	26
233	100 +	1993	10	1993	0.52	10/8/97	97	10.6	mod.	none	ABSENT	0.4	99	5.15	2.1
234	103	1994	20	1994	0.23	10/8/97	97	12	little at 1st, cle	H2S slight	ABSENT	0.55	198	6.25	54
235	~100	1947?	?	1996	0.22	10/8/97	97	11.7	none	none	ABSENT	*	199/261	5.7	37
236	170?	1940?	10.5	1991	0.27	10/8/97	97	12	slight	none	ABSENT	1.2	200/270	5.6	9.2
237	~80	1977?	?	1962	0.41	10/8/97	97	12.4	none	none	ABSENT	3.7	336	5.4	11
238	300	1978	?	1978	0.17	10/14/97	97	11.6	none	none	ABSENT	5.4	254	5.88	19
239	400 +	1991	50 +/-	1991	0.17	10/14/97	97	11.6	v. slightly	none	ABSENT	4.8	335	5.9	22
240	108	1971	?	1993	0.35	10/14/97	97	12	none	none	Coliform	3.2	315	5.04	14
241	150	1973	12	1973	0.17	10/14/97	97	11	none	none	ABSENT	11	91.5	5.5	11
242	93	1972?	?	1972	0.17	10/16/97	97	12.3	none	none	ABSENT	7	164	5.93	12
243	185	1972	?	1972	0.17	10/24/97	97	10.9	none	none	Coliform	6.4	200	5.4	7
244	120	1981	?	1981	0.66	10/24/97	97	11.7	none	none	ABSENT	4.5	296	5.65	20
245	200	1995	?	1995	0.50	10/24/97	97	11.3	none	none	ABSENT	0.3	693	6.3	64
246	125	1976	7	1976	0.26	10/29/97	97	11.3	none	none	ABSENT	0.35	278	6.03	20
247	75	1963	2+	1997	0.18	11/5/97	97	12.2	none at 1st,clo	none	ABSENT	7.1	405	5.52	9.7
248	300	1982	9	1983	1.9	11/5/97	97	11.9	v. slightly	none	ABSENT	1.2	111	5.55	4.8
249	75-80	1993	10	1993	7.8	12/4/97	97	11	none	none	ABSENT	4.2	134	6.25	15
250	100	~1976	?	1976	0.48	12/4/97	97	12	none	none	ABSENT	6.3	462	5.36	5.1
251	?	1975	?	1975	0.49	12/4/97	97	11.5	none	none	ABSENT	9.6	154	5.63	7.5
252	?	1972	?	1987	0.33	12/4/97	97	10.3	none	none	ABSENT	6.4	185	5.45	12
253	~150	1972	?	1972	0.19	12/4/97	97	10.2	none	none	ABSENT	6.7	351	5.5	10
254	100+	1970+/-	?	1970	0.18	12/10/97	97	12.8	none	none	ABSENT	8.1	147	5.63	7.5
255					0.33	12/10/97	97	10.8	none	none	ABSENT	0.6	284	6.87	36
256S	N/A	N/A	N/A	N/A	N/A	12/10/97	97	4.2	none	none	ABSENT	11	260	6.32	8.7
257	400	~1985	?	1985	0.58	12/10/97	97	11.9	none	none	ABSENT	0.4	361	7.94	127
258	150	1989	?		0.53	12/19/97	97	10.2	none	none	ABSENT	0.5	323	5.74	38

ND = Not Detected BD = Below Detection Limit "<" = Below Given Detection Limit

Site No.	Ca2+	Mg2+	Na+	K+	SO42-	Cl-	F-	Br-	SiO2	NO3-	NO3-N	PO43-	Fe2+
2	13	3.4	19	1.6	10	33	ND	0.06	16	36	8.1	<.05	0.24
3	6.7	4.3	14	1.1	14	28	0.11	0.06	15	3.1	0.7	ND	0.36
4	13	2.3	14	1.7	17	28	<.05	<.05	16	11	2.5	<.05	0.22
5	11	3.1	15	0.91	11	26	0.06	0.06	12	14	3.1	0.07	0.25
6	17	2.2	6.4	1.7	18	11	1.1	<.05	16	<1.0	0	ND	0.29
7	18	3.5	12	0.79	22	17	0.12	0.06	18	<1.0	0	<.05	1.7
8	9.6	3.1	21	1.8	13	42	ND	<.05	13	13	2.9	<.05	0.2
9	13	4.1	65	1.7	23	108	0.19	0.09	17	10	2.2	ND	0.9
10	11	3.6	23	1.5	24	24	0.14	<.05	15	44	9.9	<.05	0.03
12	9.5	2.6	9.7	1.2	6.3	22	ND	0.14	15	18	4	0.07	0.21
13	9.3	2.5	18	1.3	12	32	ND	<.05	10	21	4.7	<.05	0.26
15	14	3	15	1.8	21	26	0.09	0.07	31	<1.0	0	ND	6
18	20	3.2	20	< 0.5	23	21	0.23	0.05	21	3.4	0.76	<.05	0.27
19	23	7.2	55	1.5	32	119	0.05	0.07	14	14	3.1	0.09	0.14
20	18	2.8	11	1.3	24	9.5	0.39	<.05	22	<1.0	0	ND	0.06
23	6.5	1.8	12	1.2	13	17	0.05	<.05	14	9.3	2.1	0.05	0.27
24	12	3	13	1.8	18	29	0.1	0.07	30	<.05	0	ND	3.3
25	6.8	1.7	9.8	1.4	11	13	<.05	<.05	15	14	3.1	<.05	0.11
29	9.8	2.8	20	2	12	30	<.05	0.05	12	32	7.2	<.05	0.22
30	5.5	1.8	12	1.4	23	13	0.09	<.05	28	2.6	0.58	ND	0.47
32	6.7	2	12	1.6	12	21	0.07	<.05	12	12	2.7	ND	0.29
33	32	3.1	16	0.86	17	11	0.12	<.05	18	<1.0	0	<.05	0.27
34	7.3	2.8	11	1.1	12	20	ND	<.05	13	15	3.4	0.11	0.26
35	8	2.6	19	< 0.5	17	33	ND	0.05	14	8.6	1.9	<.05	0.22
36	11	3.4	13	ND	14	34	<.05	0.05	16	18	4	ND	0.26
38	18	3.8	24	2.5	16	42	0.05	<.05	12	26	5.8	<.05	0.27
39	5.8	1.5	9.4	1.2	11	13	0.06	<.05	12	7.7	1.7	<.05	0.03
45	10	2.6	16	0.51	14	15	0.05	0.07	15	11	2.5	0.05	0.16
46	10	2.6	15	1.9	22	15	0.08	0.05	16	13	2.9	<.05	0.08
47	9.1	3.6	14	0.96	9.6	26	0.06	0.05	13	24	5.4	0.15	0.2
48	56	3.9	16	1.9	20	32	0.05	0.15	35	<1.0	0	ND	11
49	13	1.8	8.2	0.59	17	13	0.09	<.05	23	<1.0	0	ND	0.25
50	13	3.7	20	2	17	46	0.26	0.08	29	<1.0	0	ND	0.66
51	6.9	2.9	13	0.87	13	16	0.07	<.05	14	18	4	0.17	0.25
53	15	5.5	21	< 0.5	70	32	0.24	0.1	28	<1.0	0	ND	1.6
54	20	1.8	18	1.1	15	26	0.34	0.06	31	<1.0	0	0.16	0.31
55	8.6	1.8	13	0.67	13	21	<.05	<.05	15	3.5	0.79	ND	0.22
56	9.5	1.9	12	0.83	13	16	0.06	0.06	22	1.8	0.4	<.05	0.13
57	3.8	1.4	9.4	< 0.5	13	8.8	0.11	<.05	27	<.05	0	ND	0.41
58	< 1.5	ND	19	ND	13	8.8	0.1	<.05	14	<.05	0	0.17	0.27
59	7.6	4.1	27	0.66	15	69	0.24	0.05	10	7.2	1.6	0.17	0.25
60	10.7	4	19	1.2	16	36	<.05	0.08	14	12	2.7	0.07	0.22
62	3.1	2	6.5	0.75	10	13	<.05	<.05	8.2	0.8	0.18	0.1	0.27
63	12	3.6	25	1.1	15	54	ND	0.06	15	2.3	0.52	0.08	0.08

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Site No.	Ca2+	Mg2+	Na+	K+	SO42-	Cl-	F-	Br-	SiO2	NO3-	NO3-N	PO43-	Fe2+
65	5.1	1.6	8.5	1.1	13	8.5	0.07	<.05	27	<1.0	0	<.05	0.27
66	16	3.5	19	1.6	12	44	0.06	0.07	25	1.4	0.31	ND	0.02
68	6.7	4.2	9.8	0.54	37	12	0.22	0.05	14	2.4	0.54	ND	0.24
69	13	1.5	11	0.68	23	16	0.08	<.05	26	<.05	0	ND	0.55
70	6.6	2	10	0.78	17	14	0.06	<.05	22	2.6	0.58	0.14	0.03
71	4.8	1.4	11	0.98	13	9	0.3	<.05	34	<.05	0	0.4	0.26
72	8.8	1.8	11	< 0.5	31	15	0.23	0.06	30	0.08	0.02	ND	2.3
73	ND	ND	21	ND	11	7.7	0.09	<.05	19	0.07	0.02	0.36	0.27
77	6.8	3.6	16	2.1	8.2	18	0.24	0.1	27	4.8	1.1	0.2	0.37
78	6.5	2	11	0.58	15	10	0.08	<.05	29	3.3	0.74	<.05	0.49
79	7.3	3.8	13	0.55	7.4	32	0.05	<.05	9.5	4	0.9	0.06	0.04
80	8.8	2.7	13	< 0.5	11	24	<.05	0.05	14	16	3.6	0.08	0.26
81	16	1.4	22	< 0.5	14	18	0.36	0.07	36	<1.0	0	<.05	3.2
82	12	5.3	29	< 0.5	16	71	0.07	0.07	8.4	<1.0	0	<.05	0.14
83	31	3.3	14	0.61	20	33	0.07	0.06	25	<.05	0	ND	1.1
84	ND	ND	33	ND	12	21	0.09	0.05	16	<1.0	0	<.05	0.1
85	7.8	3.5	68	ND	18	31	0.15	<.05	15	4.5	1	ND	0.25
90	10	2.7	13	0.88	11	20	0.05	<.05	14	11	2.5	0.09	0.27
92	11	3	18	1.8	11	31	ND	<.05	14	19	4.3	<.05	0.1
93	11	2.8	16	2	12	29	ND	<.05	13	18	4	<.05	0.17
94	14	4.2	14	1.9	9.4	25	0.05	0.08	18	27	6.1	ND	0.17
95	6.9	1.6	9	0.91	9.9	17	ND	<.05	11	4.7	1.1	ND	0.28
97	6.9	2	13	0.85	12	18	ND	<.05	14	26	5.8	ND	0.23
98	16	4.4	37	4.2	17	36	0.23	0.06	14	70	16	<.05	0.26
99	21	2.7	10	< 0.5	12	19	0.07	<.05	22	<1.0	0	<.05	0.28
100	6.9	1.8	12	0.73	11	17	ND	<.05	13	18	4	0.05	0.07
102	19	3	22	2.6	24	33	0.05	<.05	15	19	4.3	ND	0.27
104	8.2	2	14	2.1	16	28	<.05	<.05	12	14	3.1	<.05	0.25
105	15	2.9	8.6	< 0.5	11	15	0.08	0.06	32	<1.0	0	ND	5.6
106	7.8	3	17	ND	19	29	<.05	0.05	11	37	8.3	0.08	0.25
107	8.2	1.7	10	0.58	11	9.8	0.34	<.05	25	<1.0	0	ND	5.1
108	11	3.8	15	0.78	11	28	ND	<.05	15	33	7.4	0.1	0.1
109	6	1.6	7.6	< 0.5	9.6	14	<.05	<.05	15	2.1	0.47	0.12	0.03
110	21	2.1	12	0.76	21	15	0.09	<.05	24	1.4	0.31	ND	0.28
111	3.5	2	6	< 0.5	11	7.7	0.12	<.05	11	1.9	0.43	0.32	0.21
112	8	2.8	11	1.4	11	20	ND	0.08	14	9.6	2.2	<.05	0.1
113	14	3.2	11	1.1	16	28	0.08	0.05	20	4.1	0.92	0.06	0.11
116	9.2	3.4	16	0.76	15	21	<.05	0.07	21	21	4.7	0.09	0.26
119	23	2.6	9.8	0.51	18	12	0.06	<.05	19	<1.0	0	ND	1.3
122	27	4.7	23	0.87	21	47	0.14	0.07	13	8.4	1.9	<.05	0.12
123	13	2.7	18	1.8	21	32	0.07	0.7	22	1.8	0.4	ND	0.9
124	8.1	3.1	13	1.4	13	26	0.06	<.05	15	6.3	1.4	ND	1.1
125	9	2.7	9.5	ND	10	18	ND	<.05	15	23	5.2	0.05	0.05
126	8.2	2.5	13	< 0.5	16	19	0.06	<.05	17	13	2.9	<.05	0.23

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Site No.	Ca2+	Mg2+	Na+	K+	SO42-	Cl-	F-	Br-	SiO2	NO3-	NO3-N	PO43-	Fe2+
127	3.8	1.2	7.4	0.77	7.7	13	ND	<.05	11	2.6	0.58	ND	0.02
128	11	5.5	15	2	25	31	0.09	0.09	24	0.79	0.18	ND	3.2
129	<1.5	ND	48	ND	15	25	ND	0.09	13	22	4.9	<.05	0.18
130	11	4.2	23	1.5	17	26	ND	0.06	15	29	6.5	<.05	0.24
131	7.3	3.1	12	< 0.5	9.5	22	ND	<.05	11	21	4.7	0.07	0.05
132	10	2.7	8.4	< 0.5	12	16	<.05	<.05	13	1.5	0.34	0.07	0.26
134	8	2.5	10	1.2	18	14	<.05	0.11	17	11	2.5	0.06	0.25
135	7.1	3.6	11	1.3	9.9	18	ND	<.05	12	13	2.9	0.18	0.03
136	7.5	1.6	10	0.78	14	11	0.07	<.05	24	1.8	0.4	<.05	0.46
137	8.2	3	14	1.3	27	29	0.28	0.05	13	<1.0	0	ND	0.38
139	15	3.9	18	0.99	12	29	ND	<.05	17	36	8.1	ND	0.3
140	11	4.3	14	1.1	17	31	<.05	0.07	15	16	3.6	0.15	0.21
141	9.7	2	14	0.64	23	16	0.1	0.06	31	1.9	0.43	0.07	0.02
142	9	2.7	12	1.3	11	20	ND	<.05	15	21	4.7	<.05	0.27
144	7.4	3	13	ND	12	32	<.05	0.07	12	15	3.4	ND	0.25
146	10	2.4	10	1.3	11	15	ND	<.05	15	16	3.6	<.05	0.2
149	5.3	2.1	8.9	0.97	12	16	ND	<.05	11	7.3	4.6	ND	0.25
150	9.8	2.6	22	1.8	16	19	0.06	0.11	13	35	7.9	<.05	0.23
151	6.2	1.9	9.1	1.8	11	14	0.23	0.08	22	<1.0	0	ND	4.6
153	39	3.7	13	0.51	24	32	0.14	0.06	22	<1.0	0	0.12	0.67
154	23	4.3	16	1.3	10	53	0.07	0.07	21	<1.0	0	ND	0.47
155	11	3.6	25	ND	10	48	ND	<.05	15	37	8.3	0.19	0.32
156	7.3	2	11	1.3	13	15	<.05	<.05	15	11	2.5	<.05	0.32
159	6.4	1.5	9	0.54	14	10	0.24	0.05	29	<1.0	0	ND	4
160	8.1	2	10	1.9	15	16	0.09	0.06	26	<1.0	0	ND	11
161	7.5	2.7	10	0.52	10	19	ND	0.06	16	12	2.7	0.12	0.05
162	15	1.2	8.9	ND	22	10	0.23	<.05	32	ND	0	ND	0.45
163	19	5.5	26	0.84	18	67	0.22	0.07	20	2.8	0.63	<.05	0.19
164	19	6.3	32	0.75	17	82	0.07	0.12	15	34	7.6	<.05	0.47
166	3.1	2.8	9.4	0.98	7.3	17	ND	0.05	8.6	3.5	0.79	<.05	0.24
167	19	4.7	17	1.9	39	27	<.05	<.05	17	8.1	1.8	ND	1.9
44G	4.9	2.3	11	0.89	19	18	<.05	<.05	25	2.8	0.63	<.05	0.22
44H	8.8	3.6	19	2.4	15	35	<.05	<.05	42	11	2.5	<.05	0.59
JR-1	6.3	2.4	9.7	0.51	9.5	10	0.09	0.05	17	1.9	0.43	0.12	0.16
Res.	4.5	2.1	11	1.5	9	15	0.05	<.05	1.6	<1.0	0	<.05	0.42
2	13	4.1	20	1.6	10	36.0	ND	0.3	16	34	7.6	0.07	0.02
10	11	3.5	14	1.1	38	20.0	0	BD	21	3.9	0.88	ND	0.04
23	6.4	2.5	11	1.2	13	16.0	ND	BD	16	9.5	2.1	BD	0.15
29	7.7	2.7	18	1.7	14	25.0	ND	0.3	12	21	4.7	ND	0.02
30	5.5	2.2	13	1.4	23	14.0	BD	BD	28	2.3	0.52	ND	1.3
33	32	3.9	23	0.69	18	12.0	0	BD	18	BD	0	ND	0.07
38	9.8	4.6	23	2.2	19	38.0	ND	0.3	12	25	5.6	BD	0
39	5.5	1.6	8.2	0.78	11	10.8	ND	BD	13	4.2	0.94	ND	0.02
47	9.6	4.2	15	1	11	25.0	ND	ND	14	22	4.9	0.08	0

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Site No.	Ca2+	Mg2+	Na+	K+	SO42-	Cl-	F-	Br-	SiO2	NO3-	NO3-N	PO43-	Fe2+
57	3.5	2.1	9	0.69	12	8.9	0	BD	24	BD	0	ND	0.36
68	7.1	5	11	0.89	35	10.8	0	BD	15	1.8	0.4	ND	0.09
78	6.6	2.4	13	0.44	17	9.8	0	BD	30	1.8	0.4	ND	0.46
82 G	16	7.5	26	0.64	18	70.0	0	0.3	12	BD	0	ND	0.12
82H	11	4.1	23	ND	19	38.0	0	0.3	15	2	0.44	ND	0.03
90	11	3.8	15	1.5	12	21.0	ND	ND	16	10.5	2.4	0.1	0.01
94	13	4.4	15	1.9	10	26.0	BD	0.2	20	21	4.7	ND	0.02
97	6.3	2.4	12	1.3	13	14.0	ND	BD	17	18	4	BD	0.03
98	12	3.9	18	3.3	22	19.0	nd	0.1	14	22	4.9	nd	0
100	6.9	2.5	12	1.2	13	14.0	ND	BD	15	17	3.8	BD	0.01
102	21	4.1	18	1.8	30	26.0	ND	0.3	19	18	4	ND	0.04
106	8	4	26	1.8	19	37.0	ND	0.3	12	32	7.2	0.06	0
108	14	5.1	19	1.5	11	30.0	0	0.4	15	43	9.7	0.12	0.02
112	8.4	3.6	11	2	11	21.0	ND	0.2	14	10.7	2.4	0.07	0.06
125	8.6	3.3	12	0.96	11	17.0	ND	BD	14	19	4.3	0.11	0.03
129	8.5	4.3	18	1.4	15	24.0	ND	0.3	13	23	5.2	BD	0.03
130	7.6	3.5	18	1.7	17	20.0	ND	ND	16	21	4.7	ND	0
139	14	4.3	20	1.3	12	30.0	ND	0.4	20	27	6.1	ND	0.02
140	12	5	17	1.1	17	30.0	ND	0.3	16	18	4	0.18	0
142	8.6	3.3	12	1.2	12	20.0	ND	ND	15	19	4.3	0.07	0
144	12	5.6	29	BD	14	68.0	nd	0.4	12	13	2.9	nd	0.6
150	13	3.7	36	4.4	18	26.0	0	0.3	12	35	7.9	ND	0.02
155	12	4.5	28	1.4	11	51.0	ND	0.3	16	31	7	0.08	0
164	16	5.4	22	1	20	45.0	ND	0.3	16	25	5.6	ND	0
165	3.8	3	8.2	0.64	11	13.0	ND	BD	12	2	0.45	0.17	0.01
200S	7.7	2.9	17	2.1	9	29.0	ND	BD	1	BD	0	1.08	0.21
201S	2.8	1.6	7.9	0.81	6	13.0	ND	BD	0	BD	0	ND	0.11
202S	4.5	2.6	11	1.1	8	19.0	0	0.2	7.6	2.7	0.61	ND	0.57
203S	3.6	2	9.3	2	8	17.0	ND	0.1	0.7	BD	0	ND	0.63
204S	2.4	1.1	6.1	2.1	2	9.6	ND	BD	0.3	BD	0	ND	0.68
205S	6.4	2.8	18	1.3	5	35.0	0	0.1	4.3	BD	0	ND	1.1
206S	4.2	2.7	11	0.87	6	19.0	ND	0.1	3.9	BD	0	ND	0.23
207	8.3	5.6	33	1	14	71.0	0	0.3	9.4	5.8	1.3	nd	0.08
208	15	3.3	11	0.73	11	17.0	ND	0.3	12	13	2.9	0.1	0
209	6	2.9	16	0.96	12	26.0	ND	0.2	12	7.1	1.6	BD	0
210	22	8.6	36	2.5	15	81.0	ND	0.6	17	40	9	BD	0.05
211	35	10	24	3.3	11	87.0	ND	0.3	24	BD	0	ND	5.9
212	11	5.4	18	1.6	18	40.0	BD	0.2	20	8.9	2	ND	0
213	9.9	3.7	30	2.5	19	50.0	ND	0.3	15	16	3.6	ND	0.01
214	4.4	2.3	8.8	0.84	11	11.0	0	0.1	1.5	5.7	1.3	BD	0.13
215	10	4.7	10	0.84	7	20.0	BD	0.1	8.9	6.6	1.5	0.1	0
216	7.6	3	9.4	0.69	13	15.0	0	BD	16	8	1.8	BD	0
217	16	4.9	19	2.5	15	51.0	ND	0.2	17	20	4.5	BD	0
218	9	3.1	15	1.8	11	26.0	ND	ND	14	24	5.4	BD	0

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Site No.	Ca2+	Mg2+	Na+	K+	SO42-	Cl-	F-	Br-	SiO2	NO3-	NO3-N	PO43-	Fe2+
219	2.8	2.2	8	0.62	8	13.0	ND	bd	8.3	5	1.1	0.1	0
220	2.1	1.9	11	0.7	7	8.3	0	0.1	18	BD	0	0.36	1.4
221	14	2.1	10	nd	17	22.0	ND	ND	14	BD	0	ND	1.3
222	3.5	2.2	5.6	0.55	16	7.8	0	ND	13	BD	0	ND	0.38
223	3.4	2	7.7	0.59	11	7.7	0	ND	17	BD	0	ND	1.7
224	6.3	2.1	9	0.64	8	12.0	ND	0.2	8.4	1.6	0.36	0.08	0
225	6.1	3.6	9.5	0.57	14	14.0	0	bd	14	1.9	0.43	ND	1.3
226	3.7	1.5	8.3	0.5	12	9.7	ND	BD	12	3.5	0.79	ND	0
227	12	3.4	14	2	17	24.0	ND	0.2	16	20	4.5	ND	0
228	22	4	13	2.5	25	11.0	ND	0.2	20	4	0.9	ND	0
229	6.7	4.9	9.4	0.7	13	10.0	1	BD	18	BD	0	0.58	0.09
230	8.1	5	16	0.96	20	33.0	BD	0.2	20	BD	0	ND	0
231	20	6.9	63	2.8	13	128.0	ND	1.3	19	17	3.8	BD	0
232	7.4	2.3	8.2	0.9	14	7.6	0	bd	33	BD	0	nd	4.4
233	3.2	2.5	6.2	bd	17	12.0	0	bd	9.2	BD	0	nd	0.25
234	18	3.9	11	1.1	17	17.0	BD	0.1	31	ND	0	ND	4.4
235	13	6.1	15	1.6	24	20.0	ND	0.2	20	10	2.2	ND	0.16
236	14	4.3	14	0.8	27	37.0	0	0.1	25	BD	0	ND	1.3
237	16	7	20	3.4	27	29.0	nd	0.1	15	50	11	ND	0.06
238	13	4.3	15	1.7	12	29.0	nd	0.3	17	25	5.6	ND	0
239	16	6.1	23	2	15	57.0	ND	0.2	17	12	2.7	ND	0
240	13	5.7	24	2.7	25	36.0	ND	0.3	11	28	6.3	ND	0
241	4.1	1.4	7.1	0.81	8	9.6	ND	bd	15	3.1	0.7	ND	0
242	10	2.6	12	2.3	17	17.0	ND	0.1	13	22	4.9	nd	0
243	9	3.4	20	1.7	11	33.0	ND	bd	13	30	6.7	ND	0
244	16	4.9	18	2.8	11	35.0	ND	0.4	17	34	7.6	ND	0
245	6	1.3	146	BD	33	129.0	ND	0.2	30	BD	0	nd	0
246	16	4	20	ND	23	45.0	ND	0.1	19	BD	0	nd	1.5
247	19	9.3	28	1.8	13	81.0	ND	0.4	12	20	4.5	ND	0.06
248	3.7	1.5	9.4	0.64	19	11.0	0	bd	32	ND	0	ND	3.5
249	7.5	3	13	0.64	10	25.0	bd	0.2	20	5.3	1.2	nd	0.05
250	11	4	57	2.5	21	95.0	nd	0.4	8.4	17	3.8	nd	0.12
251	8.6	2.9	14	1.3	13	16.0	nd	0.2	15	28	6.3	bd	0
252	11	3.8	17	1.4	13	18.0	nd	0.2	17	39	8.8	nd	0
253	14	4.6	32	1.4	10	65.0	nd	0.2	17	21	4.7	bd	0.02
254	5.8	2.3	14	1.5	16	21.0	nd	bd	14	11	2.5	nd	0.09
255	20	1.8	18	1.1	33	27.0	0	bd	18	2.7	0.61	nd	0
256S	6.9	2.8	17	1.1	14	30.0	bd	0.1	14	6.3	1.4	nd	0.12
257	28	3	33	1.4	20	12.0	0	bd	13	bd	0	nd	0
258	17	5	20	1.3	24	39.0	0	0.0	20	7.2	1.6	0	0.1

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Site No.	observations/comments
2	
3	
4	brown flakes; light iron stained filter
5	dark flakes
6	dark flakes; light iron stained filter
7	owner's hose
8	
9	high level iron-stained sediment
10	brown flakes
12	sediment
13	dark flakes
15	brown flakes; light iron stained filter
18	dark flakes; iron color
19	
20	sediment
23	dark flakes
24	
25	dark flakes
29	owner's hose; dark flakes
30	dark flakes; light iron stained filter
32	brown sediment
33	yellow stained filter
34	
35	dark flakes
36	
38	sediment; yellow stained filter
39	sediment
45	light brown stained filter; dark flakes
46	sediment
47	heavy sediment; dark flakes
48	
49	iron flakes
50	old filter in place
51	iron stained filter
53	owner's hose
54	
55	older well; sediment
56	iron flakes
57	
58	
59	sediment
60	light iron stained filter
62	dark flakes
63	

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Site No.	observations/comments
65	
66	light orange-tan sediment
68	light tan stained filter
69	iron stained flakes
70	
71	
72	
73	
77	
78	iron sediment and stain
79	sediment
80	filtered?
81	dark gray sediment
82	sediment
83	
84	
85	
90	
92	
93	dark flakes
94	iron stained flakes
95	well dry
97	
98	red-brown flakes
99	
100	iron flakes
102	sediment
104	
105	iron stained flakes and lightly stained filter
106	
107	
108	filter on line
109	owner's hose
110	
111	
112	
113	
116	iron flakes
119	hose on pavement
122	
123	iron stained flakes
124	iron stained flakes
125	filtered
126	

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Site No.	observations/comments
127	sediment
128	iron stain on filter
129	
130	
131	
132	
134	very fine brown sediment
135	owner's hose; iron and dark flakes
136	sediment
137	light iron stained filter
139	
140	
141	light iron stained filter
142	sediment
144	dark flakes
146	
149	some sediment
150	
151	iron flakes
153	sediment; sample for bacteria from hose
154	
155	owner's hose
156	
159	some sediment
160	
161	
162	
163	
164	sample for bacteria from hose
166	
167	owner's hose; dark flakes; light tan stained filter
44G	iron stained flakes
44H	sediment
JR-1	from outlet to reservoir
Res.	
2	none
10	Mn flakes, sm. quan. dissolved gas, Fe stain on filter, large veggie garden & swimming pool, Does use lawn weed & feed
23	clear, then became very cloudy ~50% with brown-gray sediment
29	sampled off owner's new hose off of pressure tank, some Mn flakes in bucket, had shocked well and put in new seal
30	sand in bucket, iron staining on filter & sand
33	orig. survey done for rental prop. - sent in new survey with info for this prop.
38	water became very cloudy w/sediment, mod. amt. dissolved gas, vfs brownish-gray, some Mn flakes
39	very few gas bubbles
47	iron flakes in bucket, pH probe broke in field

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Site No.	observations/comments
57	much dissolved gas bubbles
68	little dissolved gas bubbles
78	some medium to coarse sand grains in bucket
82 G	garden well, Mn (?) flakes in bucket, iron stain on filter
82H	house well, Mn flakes, light iron stain on filter
90	zone changed from 5 to 6, lots of dissolved gas, very light iron stain on filter
94	has had well shocked since last year, Mn flakes
97	none
98	had 70 mg/L NO3 last year and sent us new survey this year, faucet broken, gushed water
100	replaced line from well to house, med-size sand and bid Mn flakes
102	bacteria bottle sterilized in field, Mn & Fe flakes in bucket, slow filtering-lots of dissolved stuff
106	rust stained mica flakes in bucket
108	Mn flakes and green flakes (Cu?) - filter not bypassed this or last time
112	5 gpm max pump
125	a little fine sand, had bacteria but shocked well then not anymore
129	Mn flakes
130	bacteria bottle sterilized in field
139	none
140	initially significant degassing, then subsided
142	none
144	chemistry ok last year but wanted retest, neightbor's house 2 yrs old drains towards this one
150	Fe & Mn flakes
155	a few black flakes
164	f-vf sand in bucket, iron staining on filter
165	1st time sampled, not done last year, Mn flakes in bucket, heavy rain day before sampling
200S	slow filtering, road culvert dry, pond level ~2" below culvert
201S	attempt to take water level of pond-see field sheet
202S	shallow stream
203S	no outflow at spillway, beige flecks on filter
204S	filter clogs quickly w/brown sed.
205S	none
206S	pH, oxygen, and elec. cond. measured in pond by shore; beaker samples taken away from shore
207	owner's hose used for samples except for bacteria & isotopes
208	unfiltered
209	presumed bypassed
210	bypassed filter
211	filter bypassed
212	Mn flakes
213	sm. quantity dissolved gas, a few Mn flakes, water became brownish after ~15 min and cond. went up to 295
214	iron in bucket, a little Mn
215	water a litle cloudy at first, not later, some dissolved gas
216	unfiltered
217	Mn & poss. Fe flakes, fine-med sand of qtz, mica
218	none

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Site No.	observations/comments
219	calcite and chloroset (?) in filtration for pH?
220	sm. amt. dissolved gas, a few Fe flakes
221	lots of dissolved gas, Fe on filter & bucket, reports H2s smell in Aug.
222	Mn & slatelike xl frags, no qtz
223	iron on filter
224	mod. dissolved gas, sl. blue-green color, big organic stuff in water
225	lots of iron on filter, f-m qtz & slate-like sediment
226	slight bluish color in water, may not have bypassed particulate filter
227	Mn flakes in bucket
228	Fe & Mn flakes in bucket
229	dug well is in well house
230	sm. amt. dissolved gas, a few Fe flakes
231	septic tank ~25 feet from well
232	lots Mn flakes, iron/Mn on filter
233	Fe and Mn flakes on filter & in bucket, slow filtering
234	odor may also be septage/low tide type smell - owner lives in Cranston, new house
235	conductivity jumps, DO reads 3.2 but ozone unit not bypassed
236	conductivity jumps think 200?
237	high DO given location?
238	had been told from previous water test to shock well, but did not
239	very slow filtering, some iron, changed filter half way thru
240	none
241	a little Mn in bucket, well is under a lot of dead brush, washer discharges to surface
242	sm. amt. dissolved gas, just had plumbing work done today, well started to go dry, so cut off water and finished meas.
243	floatables, lots of sand in bucket, slight blue-green color
244	some Mn flakes
245	check if bypassed UV filter for bacteria
246	used to get H2S smell from water heater doesn't w/ new filter, light v.f. sand on filter
247	started going dry, so shut off water and then continued
248	faucet (pump?) shut off - took DO in stagnant bucket
249	Fe on filter
250	f.sand in bucket, lots of Fe in bucket by end + some on filter, stopped using water ~6 mos ago
251	Mn or shaly flakes in bucket
252	none
253	a little Mn in bucket
254	Mn flakes in bucket, vf sediment on filter
255	a few Mn flakes in bucket, near house with fecal coliform present and high NO3
256S	bad smell (sewage) reported here past summer, but none detected now, vf sediment on filter + some organic
257	some dissolved gas
258	some iron on filter

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Appendix B: Well Survey

GROUNDWATER SURVEY

UNIVERSITY OF RHODE ISLAND/TOWN OF JAMESTOWN

Directions: We are continuing our ground-water quality study of 1996 and wish to add new sampling sites to our data network. Please review and respond, to the best of you knowledge, to each of the following questions. All responses will be confidential. Once completed, please fold and mail in the envelope provided. We will contact you to arrange a sampling date if you agree to participate in this study. If you have any questions, please call Jennifer Sandorf or Dr. Anne Veeger in the Department of Geology at 874-2265.

THANK YOU FOR YOUR RESPONSE.

WELLS

1. What is the size of your property? ____________ sq. ft.
2. When was your well installed? ____________ year
3. Who installed your well? ____________ Company
4. Are you using your original well? ____________ Yes/No
5. How deep is your well? ____________ feet
6. What is the Yield in Gallons per minute? ____________ GPM
7. Has your well ever gone dry? When? ______ Yes/No ______ Date
8. Do you have any water quality problems? ____ Iron ____ Bacteria ____ Other
9. Do you have a filtration device? ____________ Yes/No
10. If yes to No. 9, what type of system? (pH, iron, Culligan, etc.) ____________
11. Would you be willing for us to collect a water sample for testing? ____________ Yes/No
    If yes, please fill in name and address below.

SEPTIC SYSTEM

12. When was your septic system installed? ____________ Year +/-
13. Do you have the system pumped on a regular basis? ____________ Yes/No
14. If Yes to No. 13, what frequency? (i.e. Once every 2 yr., etc.) every ____________ years
15. Have you ever encountered problems with the system? ____________ Yes/No
16. Sketch the locations of your house, well, and septic with dimensions (if known) and street names in the space provided.

Optional: Name ____________________

Address ____________________

Telephone ____________________

Best time to reach ____________________

Lot Sketch example:

Appendix C: Sampling Techniques

Sampling sites were selected from positive responses of homeowners to a survey asking permission to sample their well. Water samples were collected from surface water bodies and existing wells, bypassing any secondary filtration or treatment. The samples were collected within a short time period lasting several months so that chemical analyses were relatively consistent for that time of year. In addition to the collection of water samples at each location, several field measurements including temperature, pH, electrical conductivity, and dissolved oxygen were taken.

Water samples were collected for the following analyses: chloride, nitrate, sulfate, phosphate, fluoride, bromide, calcium, sodium, potassium, magnesium, iron, silica, alkalinity, and total coliform bacteria. Those samples testing positive for coliform bacteria were tested for *E. coli* bacteria. The major constituent samples were stored in high density polypropylene bottles and kept cool (<4°C) until ready for analysis. The anion, silica, and alkalinity samples were filtered. The cation samples also were filtered and acidified: iron samples were acidified with hydrochloric acid and the other cations by nitric acid. The bacteria samples were untreated and placed in sterilized polypropylene bottles.

The chemical analyses were performed in the Department of Geology Hydrogeology Laboratory, University of Rhode Island, and were kept cool in a refrigerator until ready for analysis.

Appendix D: Field Sheet

FIELD DATA SHEET - JAMESTOWN GROUND WATER STUDY - 1996-1997

SITE & ZONE #____________ LOCATION:______________________________

____

DATE:________ TIME:_______AM/PM PERSONNEL:__________

SAMPLING METHOD (CIRCLE): BAILED SUBMERGED PUMP VACUUM PUMP

WATER TREATMENT METHOD:______________________________________

REMARKS:

____

ON-SITE MEASUREMENTS: WATER LEVEL:_________________________

TEMPERATURE:____________ CONDUCTIVITY:_________________________

pH: _______________________ DISSOLVED OXYGEN:____________________

TURBIDITY:________________ ODOR:______________________________

____

SAMPLES COLLECTED FOR LABORATORY ANALYSIS:

____ANIONS	SAMPLE VOLUME_________	CODE_________
____CATIONS	SAMPLE VOLUME_________	CODE_________
____BACTERIA	SAMPLE VOLUME_________	CODE_________
____ISOTOPES	SAMPLE VOLUME_________	CODE_________

____OTHER____

MAP OF FIELD SITE:

Appendix E: Analytical Techniques

Table E1: Summary of analytical techniques.

Constituent or Property	**Method**
pH (Field)	Combination electrode, Accumet model 1002 pH/mv/Ion meter
Dissolved Oxygen (Field)	YSI Model 57 Dissolved Oxygen meter
Specific Conductance (Field)	Oakton Model 35607-20 TDS/Conductivity Meter
Cl, SO_4, NO_3, PO_4, Br, F	Standard Method 4110B, determination of Anions by Ion Chromatography: Ion chromatography with chemical suppression of eluant conductivity Dionex Series 4500I Ion Chromatograph with AS4A anion separator column
Ca, Mg, Na, K	Ion chromatography, Dionex Series 4500I with CS3 cation separator column
Alkalinity	Standard Method 2320, using Accumet model 1002 pH/mv/Ion meter
Silica	Standard Method 4500-Si D, Molybdosilicate colorimetric method using Milton Roy Model 1201 Spectrophotometer
Iron	Standard Method 3500-Fe D, Phenanthroline colorimetric method using Milton Roy Model 1201 Spectrophotometer
Total Coliform bacteria	Standard Method 9222B, Standard total coliform membrane filter procedure
Escherichia coli bacteria	Standard Method 9221 B, Standard total coliform multiple tube (MPN) fermentation technique Standard Method 9221C, Fecal coliform MPN procedure

Using an EC medium with MUG for *E. coli* analysis modified the fecal coliform MPN procedure (EPA, personal communication, 1997).

Appendix F: Analytical Accuracy

Ion chromatography analysis consisted of two parts - one each for anions and cations. The ion chromatograph is calibrated using four levels of standards, or three for the cations. Samples with values greater than the standards were diluted. The standards used are included in Tables F1 and F2. To insure accuracy of the method, standards were run as samples. The ion chromatograph results for the standards were then used to calculate the percent error for each run. Average percent errors for anion and cation analyses are shown in Tables F3 and F4.

Table F1. Concentrations of anion standards used in this study.

Standard Name	Concentration		
Standard A	0.1 mg/L F, Br, PO_4	1 mg/L SO_4, NO_3	1.5 mg/L Cl
Standard B	0.5 mg/L F, Br, PO_4	5 mg/L SO_4, NO_3	7.5 mg/L Cl
Standard C	1 mg/L F, Br, PO_4	10 mg/L SO_4, NO_3	15 mg/L Cl
Standard D	2 mg/L F, Br, PO_4	20 mg/L SO_4, NO_3	30 mg/L Cl
Standard E	0.05 mg/L F, Br, PO_4	0.5 mg/L NO_3	1.5 mg/L SO_4,CL
Standard F	0.25 mg/L F, Br, PO_4	2.5 mg/L NO_3	7.5 mg/L SO_4, CL
Standard G	0. 5 mg/L F, Br, PO_4	5 mg/L NO_3	15 mg/L SO_4, CL
Standard H	1 mg/L F, Br, PO_4	10 mg/L NO_3	30 mg/L SO_4, CL
Standard I	0.05 mg/L F, Br, PO_4	1 mg/L NO_3	1.5 mg/L SO_4, CL
Standard J	0.25 mg/L F, Br, PO_4	5 mg/L NO_3	7.5 mg/L SO_4, CL
Standard K	0. 5 mg/L F, Br, PO_4	10 mg/L NO_3	15 mg/L SO_4, CL
Standard L	1 mg/L F, Br, PO_4	20 mg/L NO_3	30 mg/L SO_4, CL
Dionex	2 mg/L F	3mg/L Cl	10 mg/L NO_3 15 mg/L PO_4, SO_4

Table F2. Concentrations of cation standards used in this study.

Standard Name	Concentration			
Standard A	0.5 mg/L K	3.5 mg/L Mg, Ca	6 mg/L Na	
Standard B	1 mg/L K	7 mg/L Mg, Ca	12 mg/L Na	
Standard C	1.5 mg/L K	10.5 mg/L Mg, Ca	18 mg/L Na	
Standard D	2 mg/L K	14 mg/L Mg, Ca	24 mg/L Na	
Standard E	2.5 mg/L K	17.5 mg/L Mg, Ca	30 mg/L Na	
Standard F	3 mg/L K	21 mg/L Mg, Ca	36 mg/L Na	
Standard G	0.15 mg/L K	1 mg/L Mg	1.5 mg/L Ca	2 mg/L Na
Standard H	0.3 mg/L K	2 mg/L Mg	3 mg/L Ca	4 mg/L Na
Standard I	0.6 mg/L K	4 mg/L Mg	6 mg/L Ca	8 mg/L Na
Standard J	0.5 mg/L K	1 mg/L Mg	5 mg/L Ca	
Standard K	1 mg/L K	2 mg/L Mg	10 mg/L Ca	
Standard L	2 mg/L K	4 mg/L Mg	20 mg/L Ca	
Standard M	0.5 mg/L K	1 mg/L Mg	5 mg/L Ca	7 mg/L Na
Standard N	0.75 mg/L K	1.5 mg/L Mg	7.5 mg/L Ca	10.5 mg/L Na
Standard O	1.25 mg/L K	2.5 mg/L Mg	12.5 mg/L Ca	17.5 mg/L Na
Standard P	1.75 mg/L K	3.5 mg/L Mg	17.5 mg/L Ca	24.5 mg/L Na
Standard Q	2.5 mg/L K	5 mg/L Mg	25 mg/L Ca	35 mg/L Na
Standard R	0.4 mg/L K	1 mg/L Mg, Ca	2 mg/L Na	
Standard S	1 mg/L K	2.5 mg/L Mg, Ca	5 mg/L Na	
Standard T	2 mg/L K	5 mg/L Mg, Ca	10 mg/L Na	
Dionex	2 mg/L K, Mg, Na	10 mg/L Ca		

Table F3. Average percent errors in anion analyses.

Standard Name	Fluoride	Chloride	Bromide	Nitrate	Phosphate	Sulfate	number of samples
Standard A	N/A	5.4	3.0	1.1	5.0	9.9	1
Standard C	N/A	1.0	1.1	0.4	2.3	1.2	1
Standard E	10	9.1	4.0	2.8	N/A	6.0	2
Standard F	N/A	3.4	1.2	1.1	0.8	2.3	2
Standard G	1.2	1.2	0.4	0.5	2.2	0.6	1
Standard H	1.8	0.8	1.0	0.6	1.6	0.3	3
Standard I	2.0	5.1	4.0	4.3	N/A	4.0	7
Standard J	4.4	3.3	2.6	2.1	3.4	2.8	24
Standard K	3.2	1.2	2.9	1.2	4.5	0.9	28
Standard L	2.0	0.6	2.8	0.8	2.5	0.5	28
Dionex	4.7	5.0	N/A	2.0	N/A	1.7	11

Table F4. Average percent errors in cation analyses.

Standard Name	Sodium	Potassium	Magnesium	Calcium	Number of Samples
Standard A	6.4	5.6	6.1	6.0	10
Standard B	5.2	6.9	4.2	4.1	15
Standard C	5.1	4.5	3.9	3.6	14
Standard D	4.8	5.1	4.2	3.2	6
Standard E	2.9	3.5	2.6	1.2	4
Standard F	6.6	4.1	4.8	4.0	3
Standard G	8.2	N/A	10	8.2	5
Standard H	6.8	N/A	3.2	4.0	4
Standard I	9.3	N/A	3.1	3.8	4
Standard J	N/A	4.6	1.8	1.4	4
Standard K	N/A	5.7	5.2	2.4	4
Standard L	N/A	5.3	3.9	0.4	3
Standard M	3.3	7.8	6.9	4.4	7
Standard N	2.9	5.9	5.6	3.4	12
Standard O	4.7	6.1	5.5	4.5	16
Standard P	4.6	6.2	3.2	4.3	11
Standard Q	6.6	9.6	5.2	4.4	7
Standard R	4.1	3.5	3.2	5.1	3
Standard S	1.7	3.2	4.1	3.6	3
Standard T	6.9	7.7	4.2	5.6	1
Dionex	2.8	5.3	3.8	6.3	15

Silica analyses were performed with a premade stock silica solution that was diluted to standards of 2, 5, 10, 15, 20, and 25 mg/L. These standards were run for calibration and a linear plot was made of the absorbances to see if there was a predictable pattern. A linear regression was performed and sample absorbances were substituted in to get concentration values. Standards were run as samples to check the accuracy of the method as well as blanks.

Table F5. Average percent errors for silica analyses

Standard (mg/L)	Error %	# of samples
2	3.2	3
5	2.6	8
10	2.8	9
15	2.3	8
20	1.1	7
25	2.1	2

Iron analyses were also performed with a premade stock solution that was diluted to standards of 0.05, 0.1, 0.2, 0.5, 1.0, and 2.0 mg/L. These standards were also calibrated to a linear fit and regression was performed on the absorbances. Standards were run as samples as well as blanks to check the accuracy of the method. A less than 10% error was considered acceptable, since the concentrations generally were very low.

Table F6. Average percent errors for iron analyses.

Standard (mg/L)	**Error %**	**# of samples**
0.05	7.1	2
0.1	6.9	3
0.2	7.2	3
0.5	8.0	3
1	9.2	10
2	3.0	6

Coliform bacteria analyses were performed using two different methods. For the membrane filter procedure, blanks were run with the samples to check the accuracy of the method. Distilled water was filtered and processed along with the samples on every run to check the accuracy of the sterilization procedure. For the multiple tube fermentation technique, the tubes were sterilized 24 hours before use and incubated. If any growth was observed within that period, the tubes were not used for analysis.

Appendix G: Geographic Information System

The source of the GIS data for this study was the RIGIS database (Rhode Island Geographic Information System). Data was collected on landuse such as residential, agriculture, and vegetation, as well as roads, surface water such as ponds and streams, and geology. The metadata on these coverages indicate that the landuse data are digitized from 1988 aerial photos. Some of this has since changed, but this was primarily an expansion of residential development. The roads data were from 1994 and included the recent Jamestown Bridge construction.

The GIS data were used for comparing the water chemistry to the surrounding landuse. Most samples were taken from residential sections, but some surrounding agriculture could have had an influence on water chemistry.

Table F2. Concentrations of cation standards used in this study.

Standard Name	Concentration			
Standard A	0.5 mg/L K	3.5 mg/L Mg, Ca	6 mg/L Na	
Standard B	1 mg/L K	7 mg/L Mg, Ca	12 mg/L Na	
Standard C	1.5 mg/L K	10.5 mg/L Mg, Ca	18 mg/L Na	
Standard D	2 mg/L K	14 mg/L Mg, Ca	24 mg/L Na	
Standard E	2.5 mg/L K	17.5 mg/L Mg, Ca	30 mg/L Na	
Standard F	3 mg/L K	21 mg/L Mg, Ca	36 mg/L Na	
Standard G	0.15 mg/L K	1 mg/L Mg	1.5 mg/L Ca	2 mg/L Na
Standard H	0.3 mg/L K	2 mg/L Mg	3 mg/L Ca	4 mg/L Na
Standard I	0.6 mg/L K	4 mg/L Mg	6 mg/L Ca	8 mg/L Na
Standard J	0.5 mg/L K	1 mg/L Mg	5 mg/L Ca	
Standard K	1 mg/L K	2 mg/L Mg	10 mg/L Ca	
Standard L	2 mg/L K	4 mg/L Mg	20 mg/L Ca	
Standard M	0.5 mg/L K	1 mg/L Mg	5 mg/L Ca	7 mg/L Na
Standard N	0.75 mg/L K	1.5 mg/L Mg	7.5 mg/L Ca	10.5 mg/L Na
Standard O	1.25 mg/L K	2.5 mg/L Mg	12.5 mg/L Ca	17.5 mg/L Na
Standard P	1.75 mg/L K	3.5 mg/L Mg	17.5 mg/L Ca	24.5 mg/L Na
Standard Q	2.5 mg/L K	5 mg/L Mg	25 mg/L Ca	35 mg/L Na
Standard R	0.4 mg/L K	1 mg/L Mg, Ca	2 mg/L Na	
Standard S	1 mg/L K	2.5 mg/L Mg, Ca	5 mg/L Na	
Standard T	2 mg/L K	5 mg/L Mg, Ca	10 mg/L Na	
Dionex	2 mg/L K, Mg, Na	10 mg/L Ca		

Table F3. Average percent errors in anion analyses.

Standard Name	Fluoride	Chloride	Bromide	Nitrate	Phosphate	Sulfate	number of samples
Standard A	N/A	5.4	3.0	1.1	5.0	9.9	1
Standard C	N/A	1.0	1.1	0.4	2.3	1.2	1
Standard E	10	9.1	4.0	2.8	N/A	6.0	2
Standard F	N/A	3.4	1.2	1.1	0.8	2.3	2
Standard G	1.2	1.2	0.4	0.5	2.2	0.6	1
Standard H	1.8	0.8	1.0	0.6	1.6	0.3	3
Standard I	2.0	5.1	4.0	4.3	N/A	4.0	7
Standard J	4.4	3.3	2.6	2.1	3.4	2.8	24
Standard K	3.2	1.2	2.9	1.2	4.5	0.9	28
Standard L	2.0	0.6	2.8	0.8	2.5	0.5	28
Dionex	4.7	5.0	N/A	2.0	N/A	1.7	11

Table F4. Average percent errors in cation analyses.

Standard Name	Sodium	Potassium	Magnesium	Calcium	Number of Samples
Standard A	6.4	5.6	6.1	6.0	10
Standard B	5.2	6.9	4.2	4.1	15
Standard C	5.1	4.5	3.9	3.6	14
Standard D	4.8	5.1	4.2	3.2	6
Standard E	2.9	3.5	2.6	1.2	4
Standard F	6.6	4.1	4.8	4.0	3
Standard G	8.2	N/A	10	8.2	5
Standard H	6.8	N/A	3.2	4.0	4
Standard I	9.3	N/A	3.1	3.8	4
Standard J	N/A	4.6	1.8	1.4	4
Standard K	N/A	5.7	5.2	2.4	4
Standard L	N/A	5.3	3.9	0.4	3
Standard M	3.3	7.8	6.9	4.4	7
Standard N	2.9	5.9	5.6	3.4	12
Standard O	4.7	6.1	5.5	4.5	16
Standard P	4.6	6.2	3.2	4.3	11
Standard Q	6.6	9.6	5.2	4.4	7
Standard R	4.1	3.5	3.2	5.1	3
Standard S	1.7	3.2	4.1	3.6	3
Standard T	6.9	7.7	4.2	5.6	1
Dionex	2.8	5.3	3.8	6.3	15

Silica analyses were performed with a premade stock silica solution that was diluted to standards of 2, 5, 10, 15, 20, and 25 mg/L. These standards were run for calibration and a linear plot was made of the absorbances to see if there was a predictable pattern. A linear regression was performed and sample absorbances were substituted in to get concentration values. Standards were run as samples to check the accuracy of the method as well as blanks.

Table F5. Average percent errors for silica analyses

Standard (mg/L)	Error %	# of samples
2	3.2	3
5	2.6	8
10	2.8	9
15	2.3	8
20	1.1	7
25	2.1	2

Iron analyses were also performed with a premade stock solution that was diluted to standards of 0.05, 0.1, 0.2, 0.5, 1.0, and 2.0 mg/L. These standards were also calibrated to a linear fit and regression was performed on the absorbances. Standards were run as samples as well as blanks to check the accuracy of the method. A less than 10% error was considered acceptable, since the concentrations generally were very low.

Table F6. Average percent errors for iron analyses.

Standard (mg/L)	Error %	# of samples
0.05	7.1	2
0.1	6.9	3
0.2	7.2	3
0.5	8.0	3
1	9.2	10
2	3.0	6

Coliform bacteria analyses were performed using two different methods. For the membrane filter procedure, blanks were run with the samples to check the accuracy of the method. Distilled water was filtered and processed along with the samples on every run to check the accuracy of the sterilization procedure. For the multiple tube fermentation technique, the tubes were sterilized 24 hours before use and incubated. If any growth was observed within that period, the tubes were not used for analysis.

Appendix G: Geographic Information System

The source of the GIS data for this study was the RIGIS database (Rhode Island Geographic Information System). Data was collected on landuse such as residential, agriculture, and vegetation, as well as roads, surface water such as ponds and streams, and geology. The metadata on these coverages indicate that the landuse data are digitized from 1988 aerial photos. Some of this has since changed, but this was primarily an expansion of residential development. The roads data were from 1994 and included the recent Jamestown Bridge construction.

The GIS data were used for comparing the water chemistry to the surrounding landuse. Most samples were taken from residential sections, but some surrounding agriculture could have had an influence on water chemistry.

Appendix H: Statistical Results

Statistical analysis was done on the nitrate as nitrogen data to test whether two populations were significantly different. This test was grouped by lot size categories, to see if lot size had a significant impact on nitrate concentrations. First, the ANOVA (single factor) test was done to statistically analyze the data. Then, the F-test was used to test whether the populations were significantly different.

F-test The hypothesis that the populations are not significantly different is rejected if $F > F_{crit}$. Both the F and F_{crit} values are found in the ANOVA output.

0.1 - 0.25 acre lots compared to 0.25 - 0.5 acre lots

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0.1 - 0.25	46	157.9386	3.433449	11.95618
0.25 - 0.5	42	108.7136	2.58842	7.896057

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15.67716	1	15.67716	1.564503	0.214399	3.951882
Within Groups	861.7664	86	10.02054			
Total	877.4435	87				

$F=1.56$, $F_{crit}=3.96$, $F< F_{crit}$, therefore, the 0.1 - 0.25 acre lot size nitrate concentrations are not significantly different from the 0.25 - 0.5 acre lot size nitrate concentrations.

0.25 - 0.5 acre lots compared to 0.5 - 1.0 acre lots

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0.25 - 0.5	42	108.7136	2.58842	7.896057
0.5 - 1.0	20	46.86364	2.343182	5.297515

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.814823	1	0.814823	0.115199	0.735486	4.001194
Within Groups	424.3911	60	7.073186			
Total	425.206	61				

F=0.12, F_{crit}=4.00, F< F_{crit}, therefore, the 0.25 - 0.5 acre lot size nitrate concentrations are not significantly different from the 0.5 - 1.0 acre lot size nitrate concentrations.

0.1 - 0.25 acre lots compared to 0.5 - 1.0 acre lots

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0.5 - 1.0	20	46.86364	2.343182	5.297515
0.1 - 0.25	47	157.9386	3.360397	11.94708

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	14.51705	1	14.51705	1.451217	0.232701	3.988561
Within Groups	650.2186	65	10.00336			
Total	664.7356	66				

F=1.45, F_{crit}=3.99, F< F_{crit}, therefore, the 0.5 - 1.0 acre lot size nitrate concentrations are not significantly different from the 0.1 - 0.25 acre lot size nitrate concentrations.

The lot size groups 0.1 - 0.25 and 0.25 - 0.5 are pooled together for further analysis.

0.1 - 0.5 acre lots compared to 0.5 - 1.0 acre lots

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0.5 - 1.0	20	46.86364	2.343182	5.297515
0.1 - 0.5	88	266.6523	3.030139	10.08556

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7.690398	1	7.690398	0.833438	0.363352	3.930694
Within Groups	978.0963	106	9.227324			
Total	985.7867	107				

F=0.83, F_{crit}=3.93, F< F_{crit}, therefore the 0.1 - 0.5 acre lot size nitrate concentrations are not significantly different than the 0.5 - 1.0 acre lot size nitrate concentrations.

The lot size groups 0.1 - 0.5 and 0.5 - 1.0 are pooled together for further analysis.

0.1 - 1.0 acre lots compared to 1.0 - 2.0 acre lots

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0.1 - 1.0	108	313.5159	2.902925	9.21296
1.0 - 2.0	21	18.95	0.902381	1.252784

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	70.36385	1	70.36385	8.840359	0.003526	3.91573
Within Groups	1010.842	127	7.959389			
Total	1081.206	128				

F=8.84, F_{crit}=3.92, F> F_{crit}, therefore, the 0.1 - 1.0 acre lot size nitrate concentrations are significantly different than the 1 - 2 acre lot size nitrate concentrations.

1.0 - 2.0 acre lots compared to >2 acre lots

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
1.0 - 2.0	21	18.95	0.902381	1.252784
>2.0	33	41.97955	1.272107	3.470529

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.754287	1	1.754287	0.670202	0.416717	4.026631
Within Groups	136.1126	52	2.61755			
Total	137.8669	53				

F=0.67, F_{crit}=4.03, F< F_{crit}, therefore the 1.0 - 2.0 acre lot size nitrate concentrations are not significantly different than the >2 acre lot size nitrate concentrations.

These lot size groups are now pooled together for further analysis.

0.1 - 1.0 acre lots compared to 1.0 - >2 acre lots

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0.1 - 1.0	108	313.5159	2.902925	9.21296
1.0 - >2	54	60.92955	1.128325	2.601262

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	113.3714	1	113.3714	16.14325	9.02E-05	3.900226
Within Groups	1123.654	160	7.022835			
Total	1237.025	161				

F=16.14, F_{crit}=3.90, F> F_{crit}, therefore, the 0.1 - 1.0 acre lot size nitrate concentrations are significantly different than the 1 - >2 acre lot size nitrate concentrations.

This is the final ANOVA analysis and it shows that there is a significant break in nitrate concentrations at 1 acre lot sizes. Below this value, there is a higher nitrate concentration and above this value there is a lower nitrate concentration.

<u>1996 Nitrate data versus 1997 Nitrate data</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
NO3-97	34	123.58	3.634706	7.072274
NO3-96	33	158.86	4.813939	12.89541

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	23.28722	1	23.28722	2.343003	0.130699	3.988561
Within Groups	646.0382	65	9.93905			
Total	669.3255	66				

$F=2.34$, $F_{crit}=3.99$, $F< F_{crit}$, therefore the 1996 sample group is statistically similar to the 1997 sample group.

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