Chemistry of Surface Waters in the Barnes Aquifer Hampshire and Hampden Counties, Massachusetts

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Introduction

The Barnes Aquifer in Hampshire and Hampden counties Massachusetts covers portions of the towns of Easthampton, Southampton, Holyoke, and Westfield (Map 1) and is extensively used to supply municipal and domestic water systems. The portion of the aquifer supplying groundwater to Easthampton has been designated a sole-source aquifer by the EPA as it is the only viable water supply for the town. At present, there are 8 municipal wells in three towns pumping approximately 5 million gallons of water from the aquifer daily (Map 1).

Water quality in the aquifer has historically been excellent. However, within the past 10-15 years there have been increasing problems associated with the contamination of the aquifer with trichloroethylene (TCE). TCE has contaminated municipal wells in Easthampton and more recently domestic wells in the area of the Southampton-Holyoke town line. The Town of Easthampton has constructed a treatment plant to remove TCE at the Hendrick St well field (Map 1).

The purpose of this study was to examine the major ion chemistry of surface waters in the area of the aquifer to determine how development and changes in land-use may be affecting water quality in both surface water and groundwater. Surface waters are intimately associated with groundwaters in areas of water table aquifers. Much of the area of the Barnes Aquifer is under water table conditions. In these areas, both surface runoff and groundwater supply water to streams making them a good measure of overall water quality.

The ions that best reflect both point source and non-point source contamination are chloride (Cl), sulfate (SO_4) and nitrate (NO_3). In this area, there are no significant sources of these ions outside of atmospheric deposition. Although there are low concentrations of chloride in rain, higher concentrations must be derived from either road salt or septic tank effluent. The maximum contaminant level (MCL) for chloride is 250 mg/L. Nitrate also occurs in precipitation and is one of the two principal components in acid rain. Natural processes in soils can also generate nitrate, but high concentrations are usually the result of agricultural runoff or sewage and septic tank effluent. The MCL for nitrate is 25 mg/L as nitrogen (62 mg/L nitrate). Sulfate is the other principal component in acid rain. It can also be released from certain types of rocks, however, these types of rocks do not occur in the area of the Barnes Aquifer. High sulfate concentrations are a general indication of contamination although the sulfate is generally not harmful except at very high concentrations.

Geology of the Aquifer

The Barnes Aquifer is an unconsolidated sand and gravel aquifer deposited by meltwater streams associated with the retreat of the last glacier from New England approximately 14,000 years ago. At this time a large glacial lake (Lake Hitchcock) (Map 2) formed at the front of the retreating ice. Meltwater streams flowing off the ice into the lake deposited coarse sands and gravel. During times of rapid retreat of the ice front, these deposits were laid as an apron of sediment on the lake floor. As the ice front retreated northward out of this area, the sands and gravel were overlain by yearly couplets of fine silty sand deposited during the summer and clay deposited during the winter. These deposits are referred to as varved clays and may cap the aquifer in some areas causing confined (artesian) conditions. When the ice front paused during its retreat or where major tributaries entered the lake, the meltwater streams built deltas that emerged above the lake surface. These deposits could not be covered with varved clays and have become recharge areas for both the water table and confined aquifers. After the lake drained approximately 12,000 years ago, rivers and streams began to flow across the floor of the lake dissecting and redistributing some of the sediment as flood plain alluvium. Map 3 shows the distribution of unconsolidated glacial sediments. Note the close correlation of the distribution of sand and gravel with the extent of the Barnes Aquifer. Areas where varved clay is exposed at the surface are areas of potential confined aquifers.

Streams receive water both from surface runoff and from groundwater inflow. Surface runoff provides most of the water to the stream during rain and snowmelt periods while groundwater discharged into the stream supports stream flow during dry periods.

Sampling and Methods

Surface water samples were collected from 30 sites (Map 4) across the aquifer on 6 different dates from March of 1998 through February of 1999 (Appendix A). Not all sample sites were sampled on each date. A total of 68 samples were collected and analyzed. Samples were collected both during summer base flow conditions and during spring melt events. In addition, groundwater samples were collected from the four Easthampton municipal wells.

Samples were collected in acid washed 500 ml polyethylene bottles. Each bottle was rinsed three times with stream water before the sample was collected. Samples were stored in the field in a cooler and were immediately transferred to a refrigerator for storage on return to the lab.

All samples were analyzed for the 13 parameters listed in Table 1. Temperature and specific conductance were measured in the field using a YSI model 430 specific conductance meter. Laboratory pH was measured using an Accumet model 1003 pH meter within 48 hours of sample collection. The acid neutralizing capacity (ANC) was determined within 2 weeks of sample collection by the Gran titration using 0.100N HCl. The bicarbonate concentration was calculated from the ANC and pH.

Table 1. Measured water chemistry parameters.

Parameter	**Method**
Temperature	Temp Probe
Specific Conductance	YSI Conductivity Meter
pH	pH Meter
ANC	Gran Titration
Silica	Heteropoly Blue
Ca^{2+}, Mg^{2+}	Atomic Adsorption
Na^{+}, K^{+}	Atomic Emission
Cl^{-}, NO_3^{-}, SO_4^{2-}	Ion Chromatography
HCO_3^{-}	Calculated from ANC

The divalent base cations calcium (Ca) and magnesium (Mg) were determined by atomic adsorption spectrophotometry using a Perkin Elmer model 4040. Samples were diluted with lanthanum chloride to prevent the effects of silica absorption. The monovalent cations sodium (Na) and potassium (K) were measured on the same instrument in the atomic emission mode. The anions chloride (Cl), nitrate (NO_3,), sulfate (SO_4) were measured by a Dionex model 2000i ion chromatograph. Dissovled silica (SiO_2) was measured using the heteropoly blue method on a Bausch and Lomb spectrometer 30.

Laboratory accuracy was checked by three different methods; analysis of blind standards, analysis of sample splits, and by calculation of the cation/anion balances. Samples were flagged if the balance was not within 15 percent. Only one sample (BB-300 on 3/27/98) was flagged with an imbalance of 23% (anions exceeded cations).

Results

While a number of samples showed some influence from road salt and other non-point source contaminants, none had concentrations for any of the measured parameters above any MCL. Table 2 compares the mean concentration of samples from the main drainage systems. In general, the Manhan River had the lowest average concentration of chloride and sulfate, while Powdermill Brook in Westfield had the highest concentrations of chloride, nitrate, and sulfate. Broad Brook in Easthampton also had relatively high concentrations of chloride nitrate and sulfate.

Table 2. Average concentration by drainage.

Drainage	Chloride	Nitrate	Sulfate
Pond Brook (n=5)	21.03 (5.53)	1.40 (0.59)	9.15 (0.76)
Broad Brook (n=23)	28.58 (40.92)	1.81 (1.48)	10.65 (3.70)
Manhan River (n=16)	15.53 (11.84)	1.63 (0.57)	7.41 (1.01)
Powdermill Brook (n=2)	43.64 (12.61)	4.05 (2.52)	10.27 (0.38)

n = number of samples, (standard deviation)

All the streams in the area have a low chemical load. This is reflected in the low values of specific electrical conductance (Figure 1.). Specific conductance is a measure of the ability of water to conduct an electric current. Since this ability is a function of the total of dissolved ions in the water it is a good measure of chemical load. The values of specific conductance in this project were found to range from about 50 to 350 µsiemens/cm. These values are generally quite low and reflect the non-reactive nature of the minerals found in the local rocks and unconsolidated sediments. As a comparison, specific conductance values in streams from the western U.S. can range as high as 7,000 µsiemens/cm

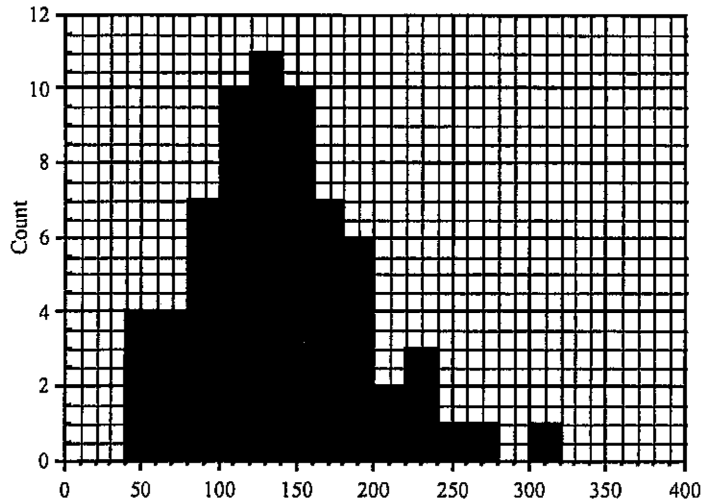


Figure 1. Distribution of specific conductance values from samples collected across the Barnes Aquifer.

where evaporite minerals containing salt are exposed. The distribution of specific conductance values in Figure 1 has a mode at 150 µsiemens/cm and the distribution tails toward the higher concentrations probably reflecting contamination by road salt or other contaminants.

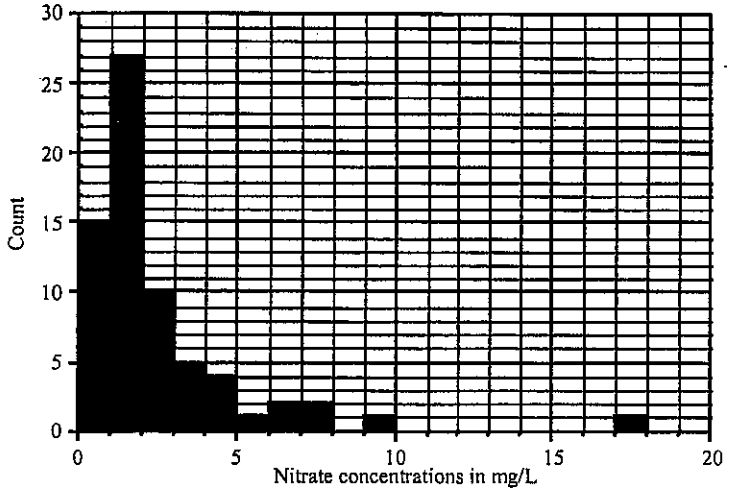


Figure 2. Distribution of nitrate concentrations in surface waters draining the Barnes Aquifer.

The distribution of nitrate concentrations (Figure 2) is also skewed to higher concentrations. The mode at 1.5 mg/L probably reflects the loading from atmospheric deposition while higher concentrations are likely due to contamination from agriculture or septic tanks.

Sulfate concentrations have a mode at 9 mg/L, again reflecting the loading from atmospheric deposition. This distribution is also skewed to higher concentrations again reflecting some local contamination.

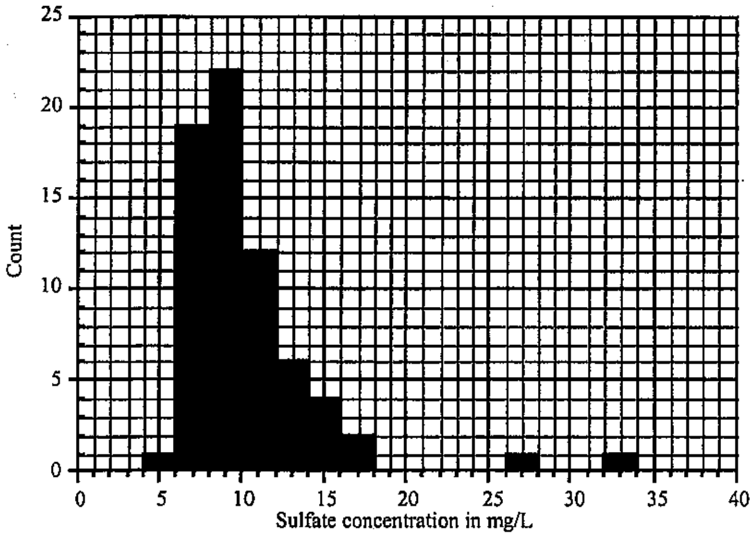


Figure 3. Distribution of sulfate concentrations in surface waters draining the Barnes Aquifer.

The concentration of chloride in municipal wells was not significantly different than that found in the adjacent surface waters. However, nitrate and sulfate were generally found to be higher in groundwater with the exception of the Lovefield St well where the lack of any nitrate suggests reducing conditions in the aquifer. The Barnes Aquifer at this site is confined by varved clay. The water in the aquifer here has moved a long distance from the recharge area and chemical reactions have consumed much of the dissolved oxygen.

Table 3. Average concentration in municipal wells.

Well	Chloride	Nitrate	Sulfate
Nonotuck Park	18.16	17.85	16.85
Hendrick St	23.05	6.92	15.67
Pines	14.71	3.94	15.19
Lovefield St	13.68	0.00	33.25

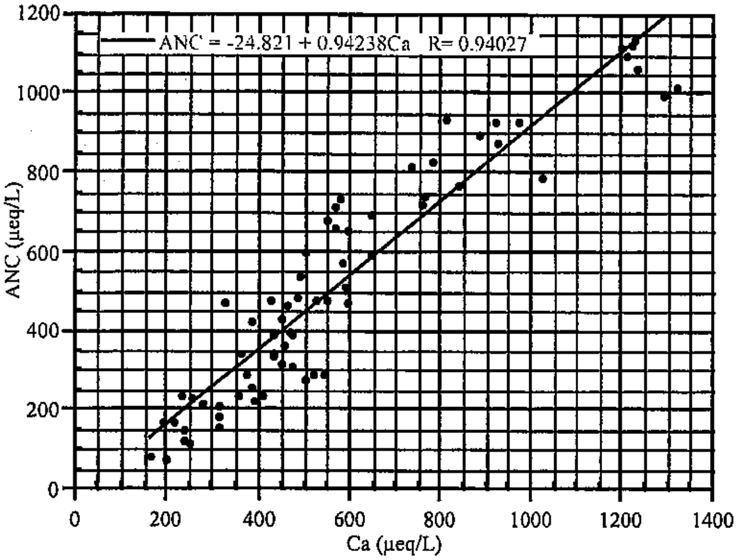


Figure 4. Plot showing the strong correlation between Ca and ANC.

Many surface waters in the northeastern U.S. have low pH due to the impact of acid rain. All the samples collected in this study had pH values greater than 6. ANC values ranged from a low of 73 μeq/L at site NB100 collected during a February 1999 snowmelt event to over 1,000 μeq/L for the municipal well samples. Neither surface water nor groundwater acidification is a problem in the Barnes Aquifer. There is a strong correlation between calcium concentrations and ANC (Figure 4). The slope of this relationship is 0.94 suggesting that the weathering of calcium bearing minerals like calcite accounts for most of the observed ANC. The high ANC of groundwater samples is due to the relatively long residence time of the groundwater in the aquifer. Time allows for more dissolution of the minerals and the production of more ANC.

There is also a strong correlation between sodium and chloride concentrations when plotted on a molar or equivalence basis (Figure 5). This is to be expected if the source of the chloride was from salt (NaCl).

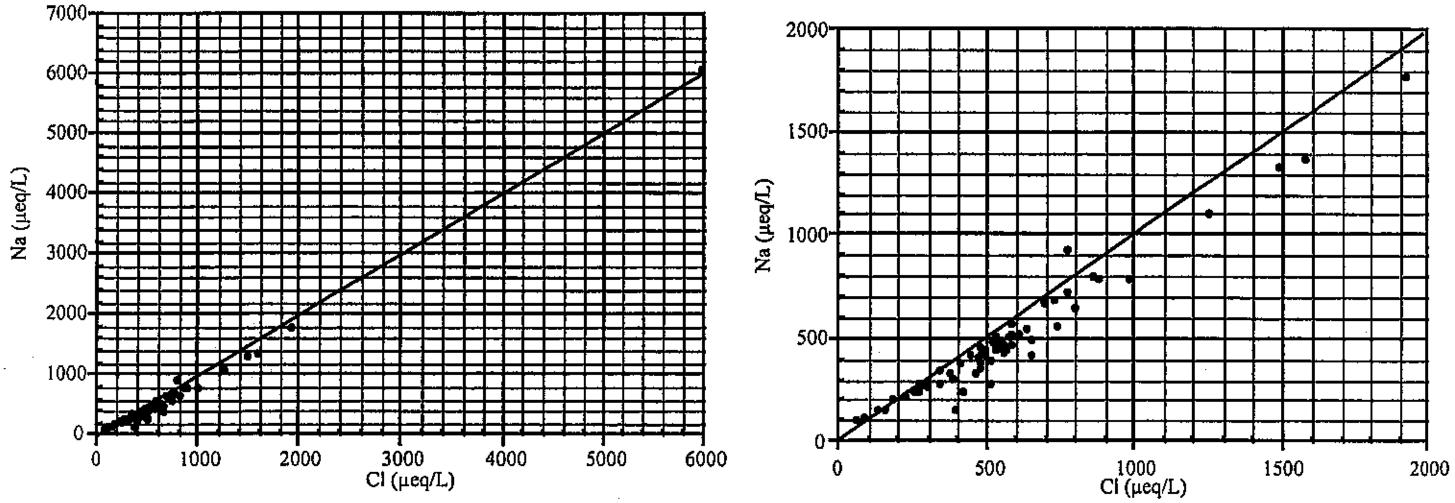


Figure 5. Plots of sodium verses chloride on an equivalence basis. The graph on the left represents all samples while the graph on the right is expanded at the lower concentrations. The line on each graph represents a perfect 1 to 1

Dissolving salt results in equal amounts of sodium and chloride according to the following reaction:

$$\mathrm{NaCl} \rightarrow \mathrm{Na}^{+} + \mathrm{Cl}^{-}$$

The nearly perfect correlation between sodium and chloride shown in figure 5 confirms that most of the chloride is from salt. Some of this comes naturally from atmospheric deposition but most is either from road salt or septic tank effluent. The figure on the right side of figure 5 shows that many of the points actually fall slightly below the 1:1 line. This means that there is less sodium than would be expected for the observed chloride concentration. This is likely due to the use of other deicing salts such as calcium chloride. Calcium chloride is often used as a deicing supplement at temperatures below 20 Fahrenheit.

A comparison of the distribution of concentrations across the aquifer in summer versus winter is useful in identifying the more contaminated areas. The concentration of chloride is generally much higher in the winter (Map 5) than they are in the summer (Map 6). The February 1999 sampling found relatively high chloride concentrations over much of the aquifer except in the lower part of the Manhan River. One sample was collected from a recently constructed channel that carries the runoff from County Road into Broad Brook near sample site 600. On this day, warm temperatures facilitated rapid melting of the snow along the sides of the road and producing runoff through this normally dry channel. The chloride concentration here was over 200 mg/L. This coupled with the generally high chloride concentrations found at all locations in the winter shows that road salting is impacting the aquifer although even here, chloride concentrations did not exceed the MCL.

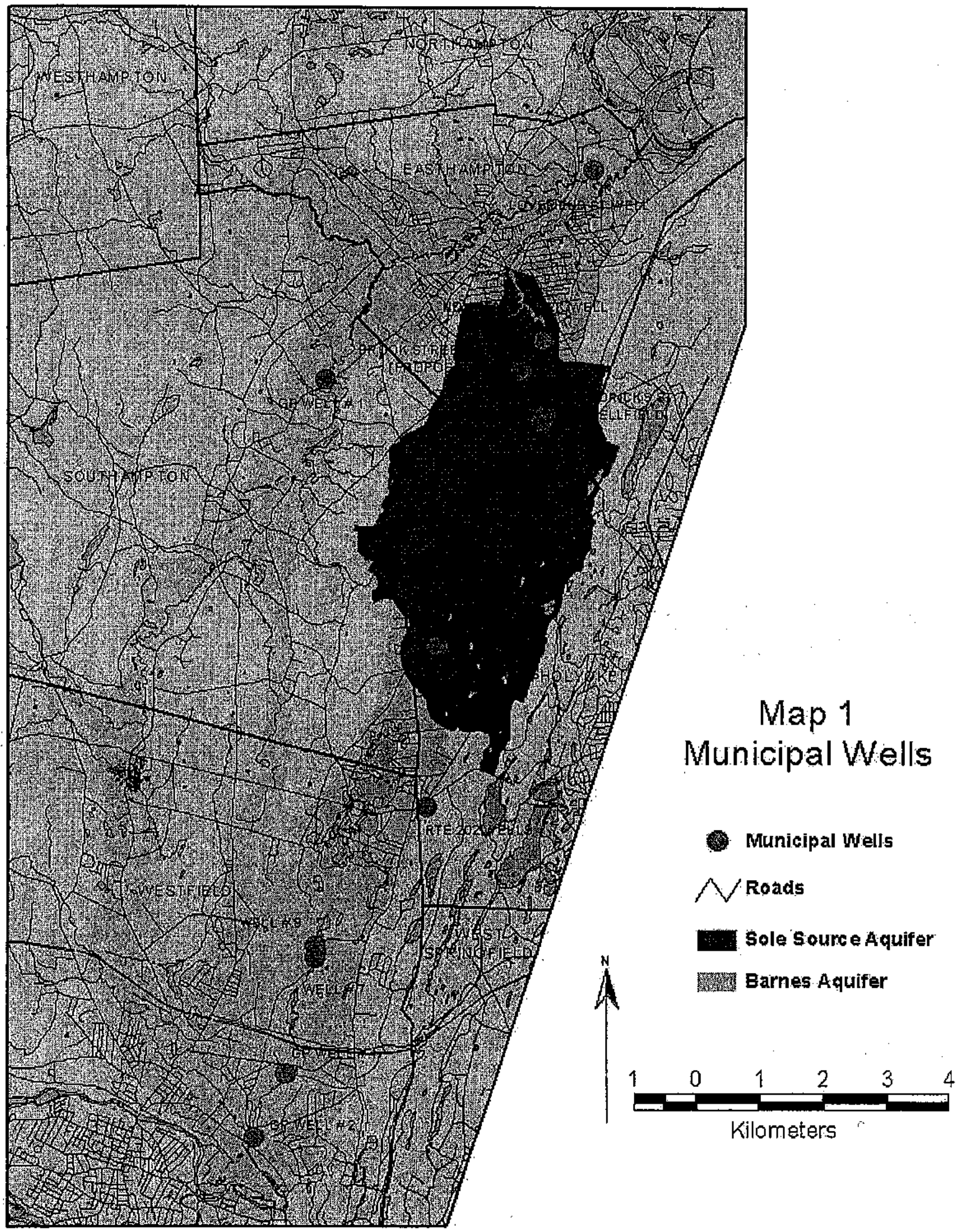
Nitrate concentrations show just the opposite trend from chloride. Nitrate concentrations are highest in summer (Map 7 and Map 8). The high nitrate concentrations are generally associated with agricultural activities. Site WB100 had the highest surface water nitrate. This sample was collected on the grounds of the White Brook Middle School from a brook that drains a large agricultural area. The nearby Nonotuck Park well also had the highest groundwater nitrate concentration. The Hendrick St well field is also located near this agricultural area and it also has a somewhat higher nitrate. It is clear that agricultural activities are impacting both surface and groundwater in the aquifer area but again no samples were collected that had nitrate concentrations above the MCL.

Sulfate concentrations were more uniform throughout the year (Map 9 and Map 10). During the summer the highest sulfate concentrations tended to be in the lower part of the Broad Brook watershed where there is a large Easthampton residential area ("The Plains") as well as the agricultural area associated with the high nitrate concentrations. In the winter these areas maintained their high concentrations and in addition high sulfate concentrations occurred in the upper part of the Manhan (south of the Westfield town line) and near the area where the PowderMill and Pond Brook enter the Westfield River.

Conclusions

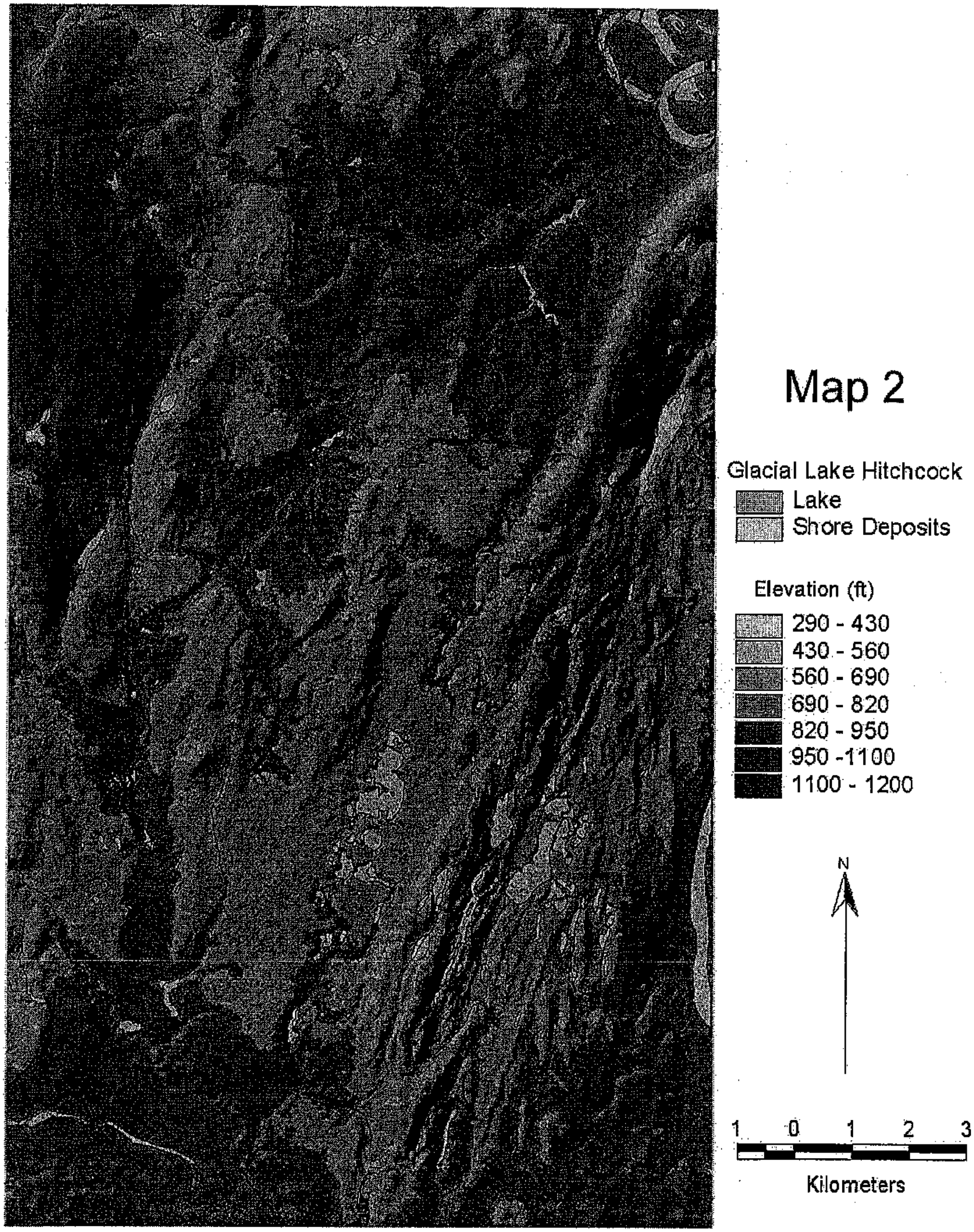
Analyses of major ions from both surface and groundwaters in the area of the Barnes Aquifer show that overall water quality is reasonably good. There is, however, clear evidence of impact from road salt, agriculture, and urban/suburban development. The land-use map (Map 11) shows that the lower Broad Brook area has both a large residential area and a large area of cropland. This area corresponds with the area of relatively high concentrations of chloride, nitrate and sulfate. Similarly, Powdermill Brook in Westfield and drainages near the rapidly developing Westfield Industrial Park have high concentrations. Meanwhile, the Manhan River basin has escaped significant development and consequently the concentrations of chloride, nitrate and sulfate are generally low.

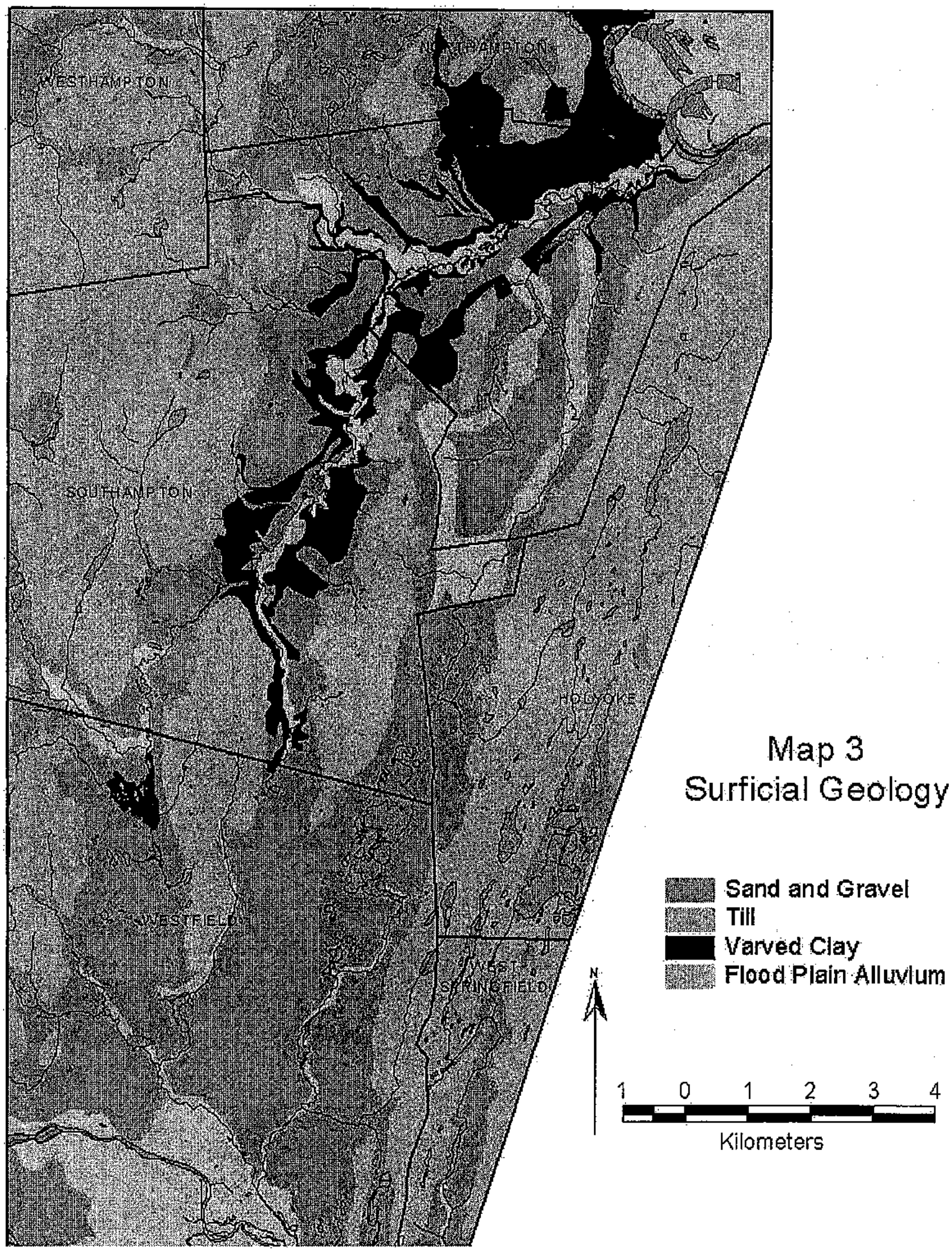
Any significant development within the recharge area of an aquifer will have some adverse impact on water quality. While any single project may have only a small impact, these impacts are cumulative. This fact must be considered in planning for future development within the Barnes Aquifer. As much of the recharge area as possible should be kept in its natural state.



Map 1
Municipal Wells

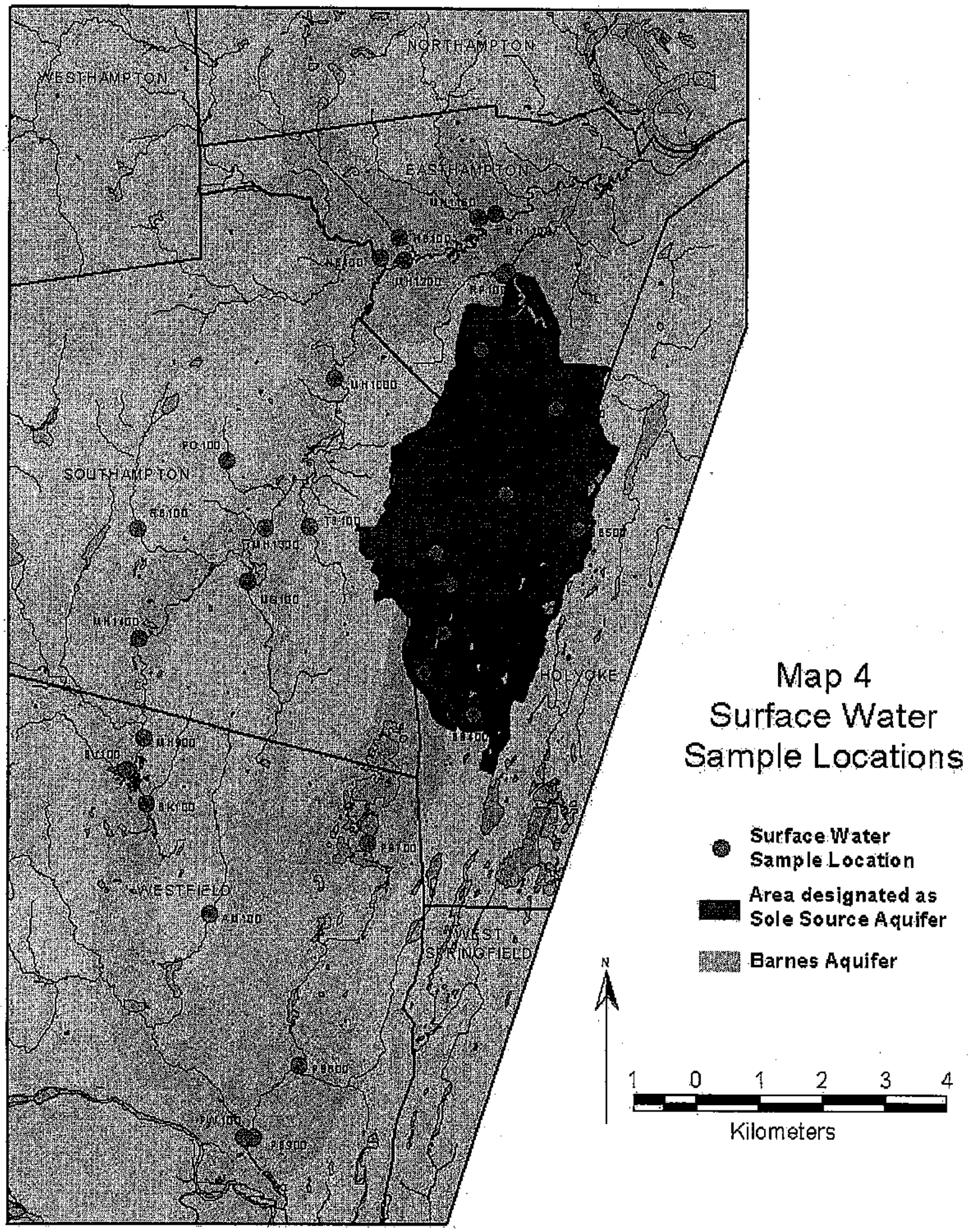
Map 2

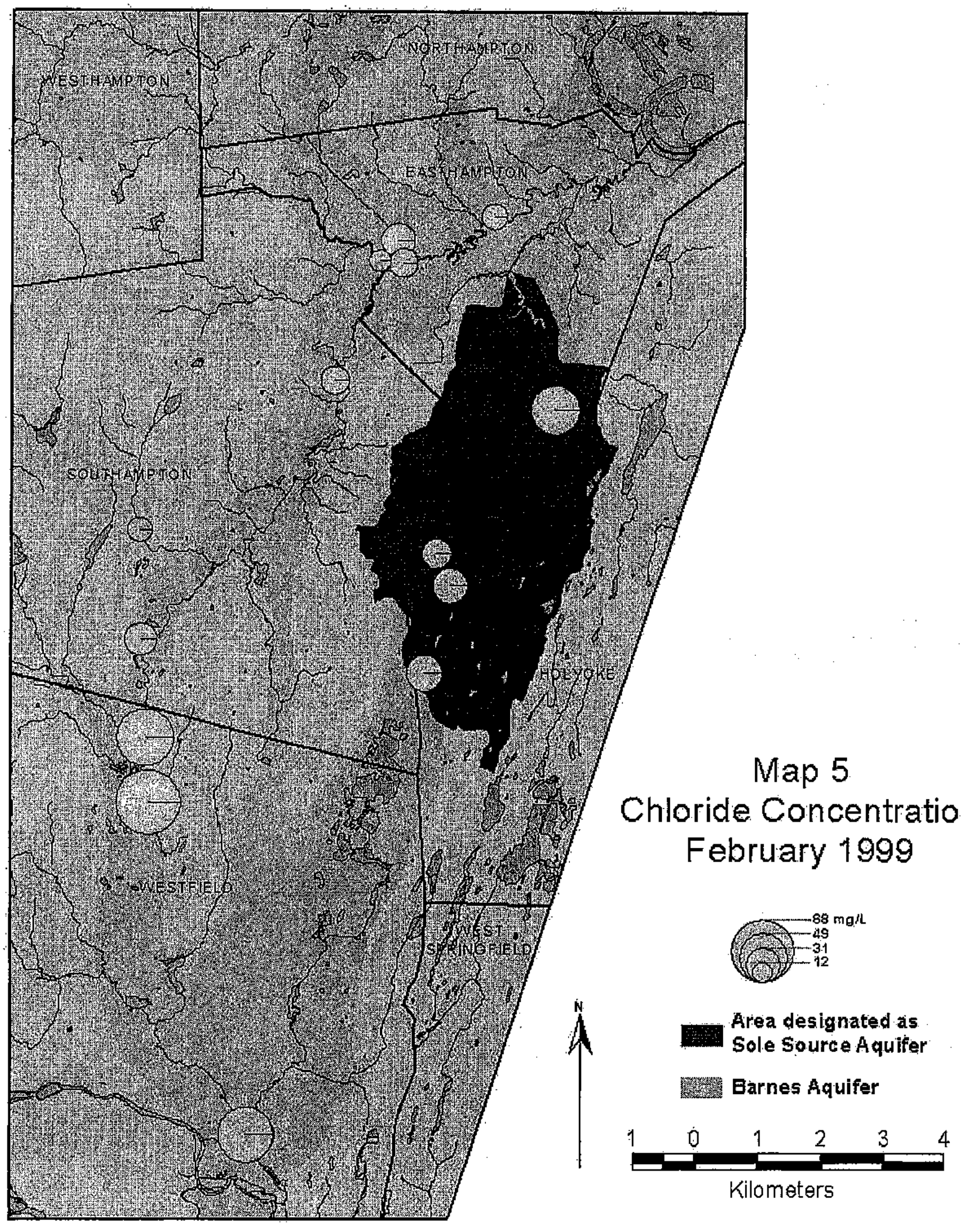

Glacial Lake Hitchcock
Lake
Shore Deposits
Elevation (ft)
290 - 430
430 - 560
560 - 690
690 - 820
820 - 950
950 -1100
1100 - 1200
N
1 0 1 2 3
Kilometers



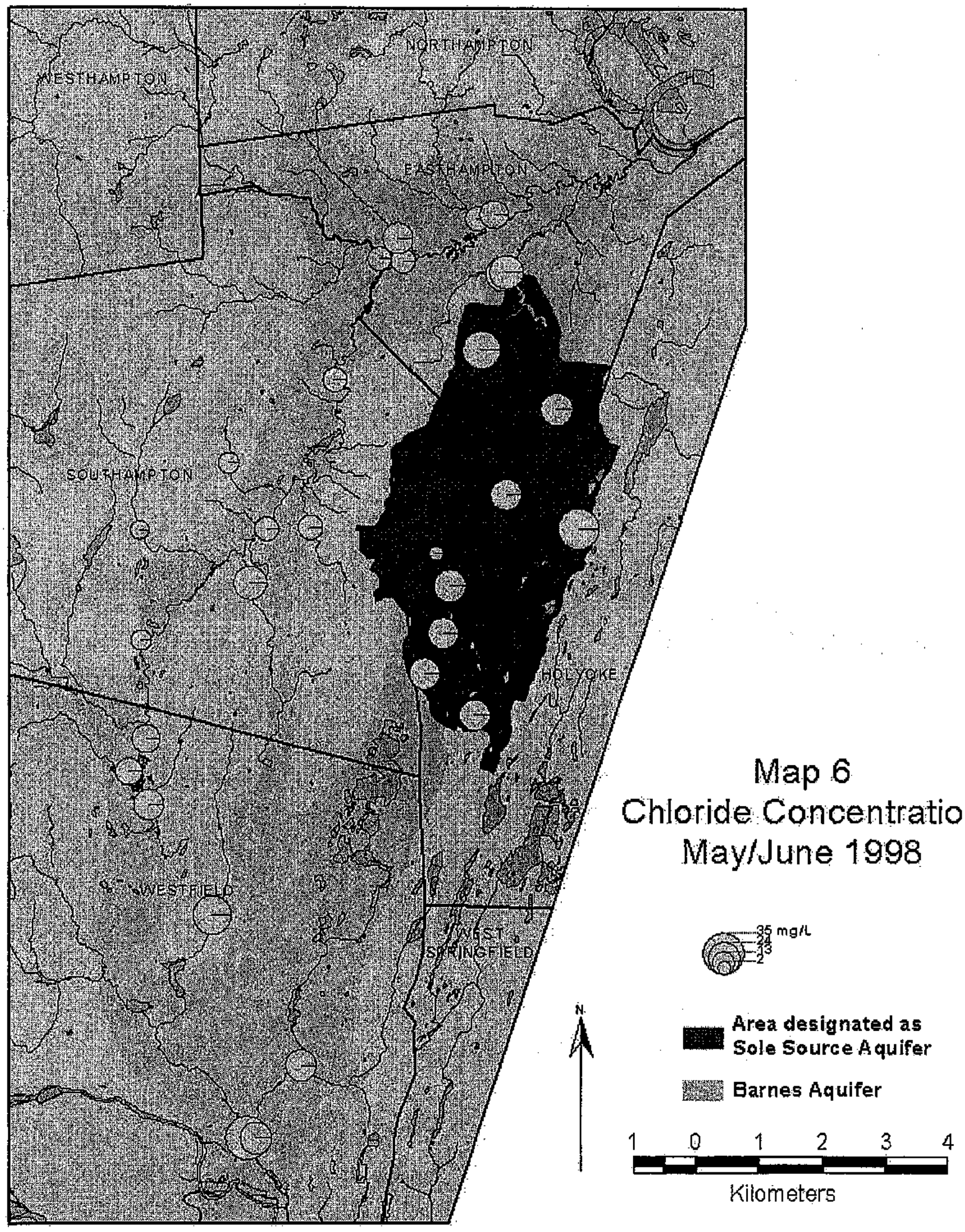
Map 3
Surficial Geology

Map 4
Surface Water Sample Locations

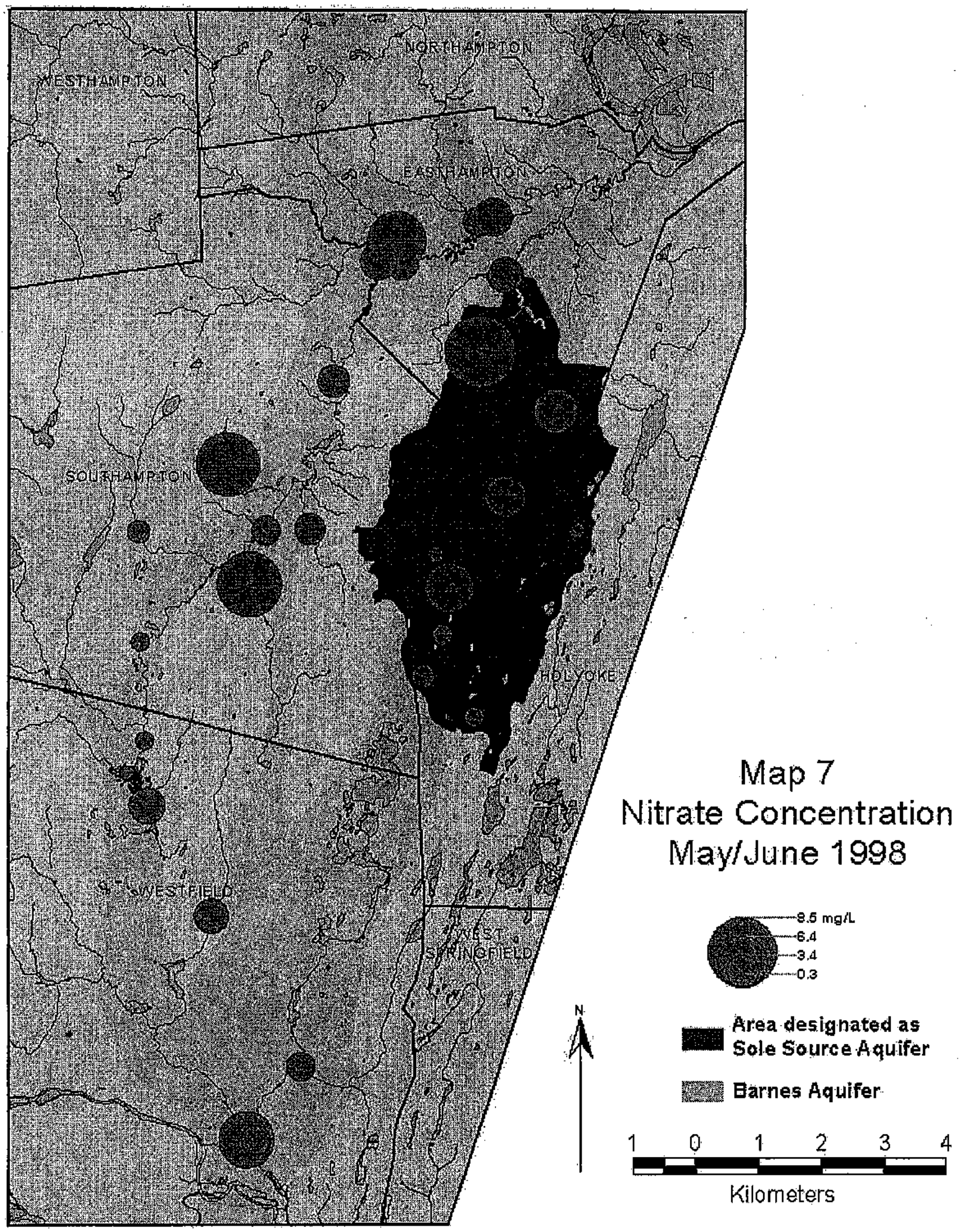




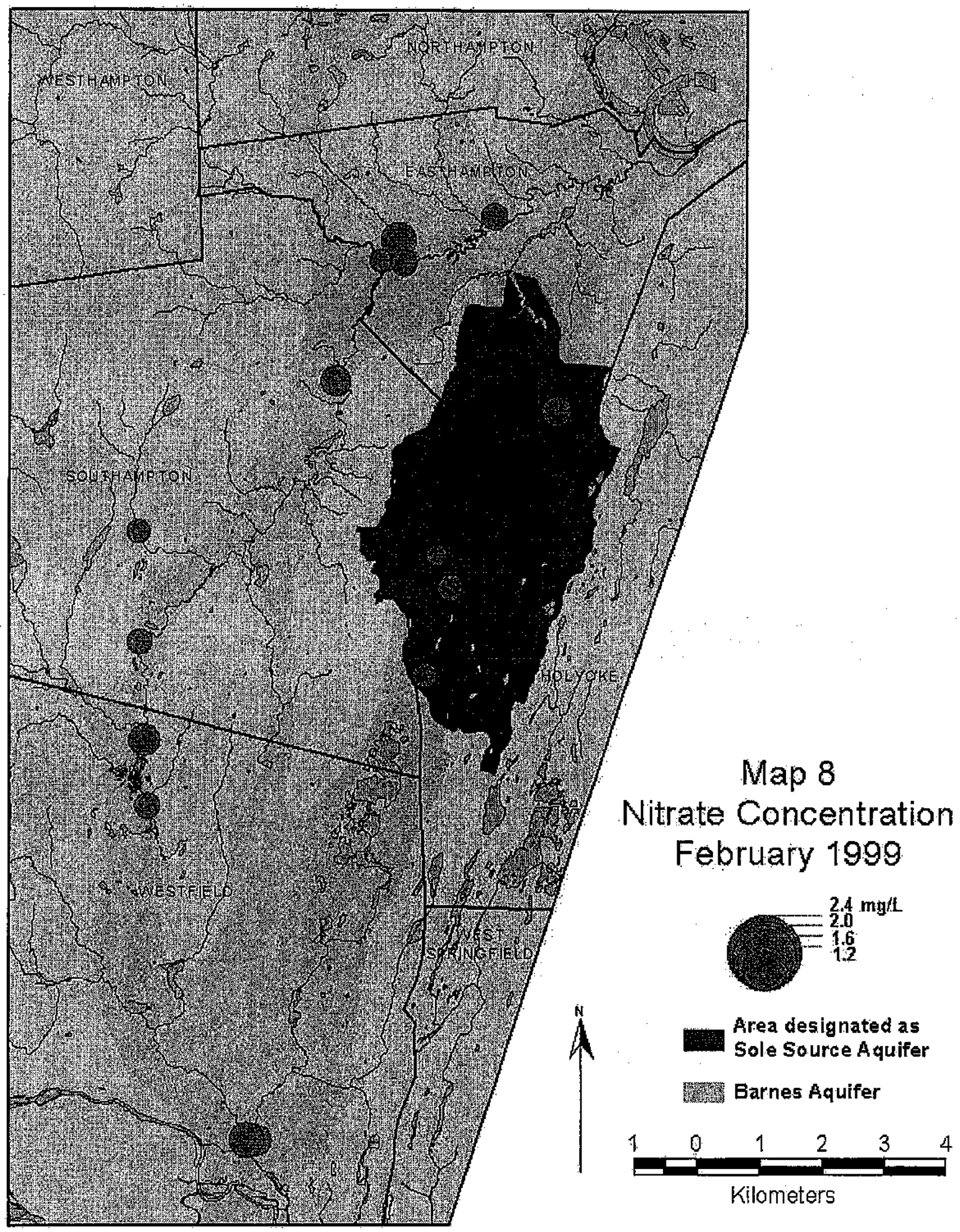
Map 5
Chloride Concentration
February 1999



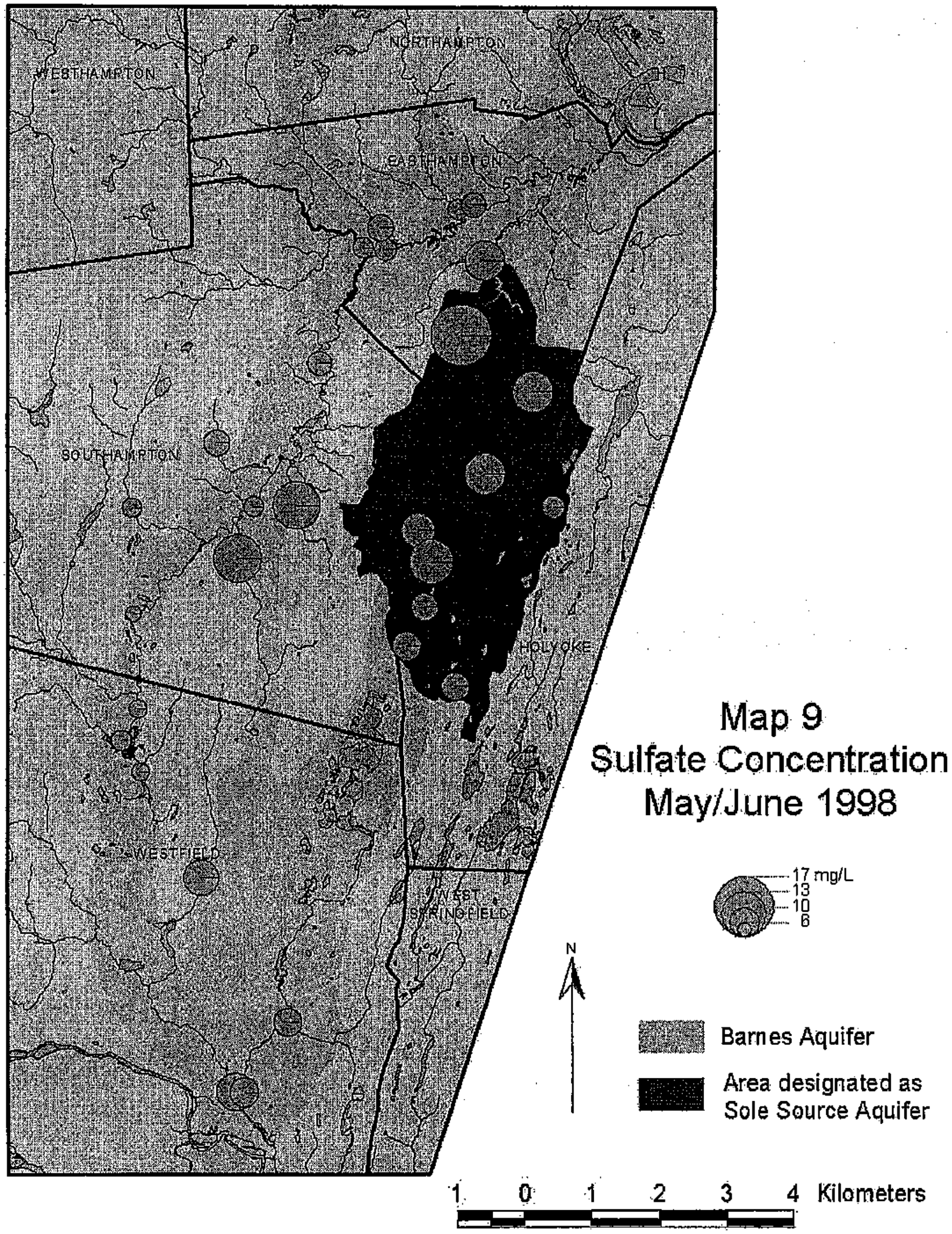
Map 6
Chloride Concentration
May/June 1998



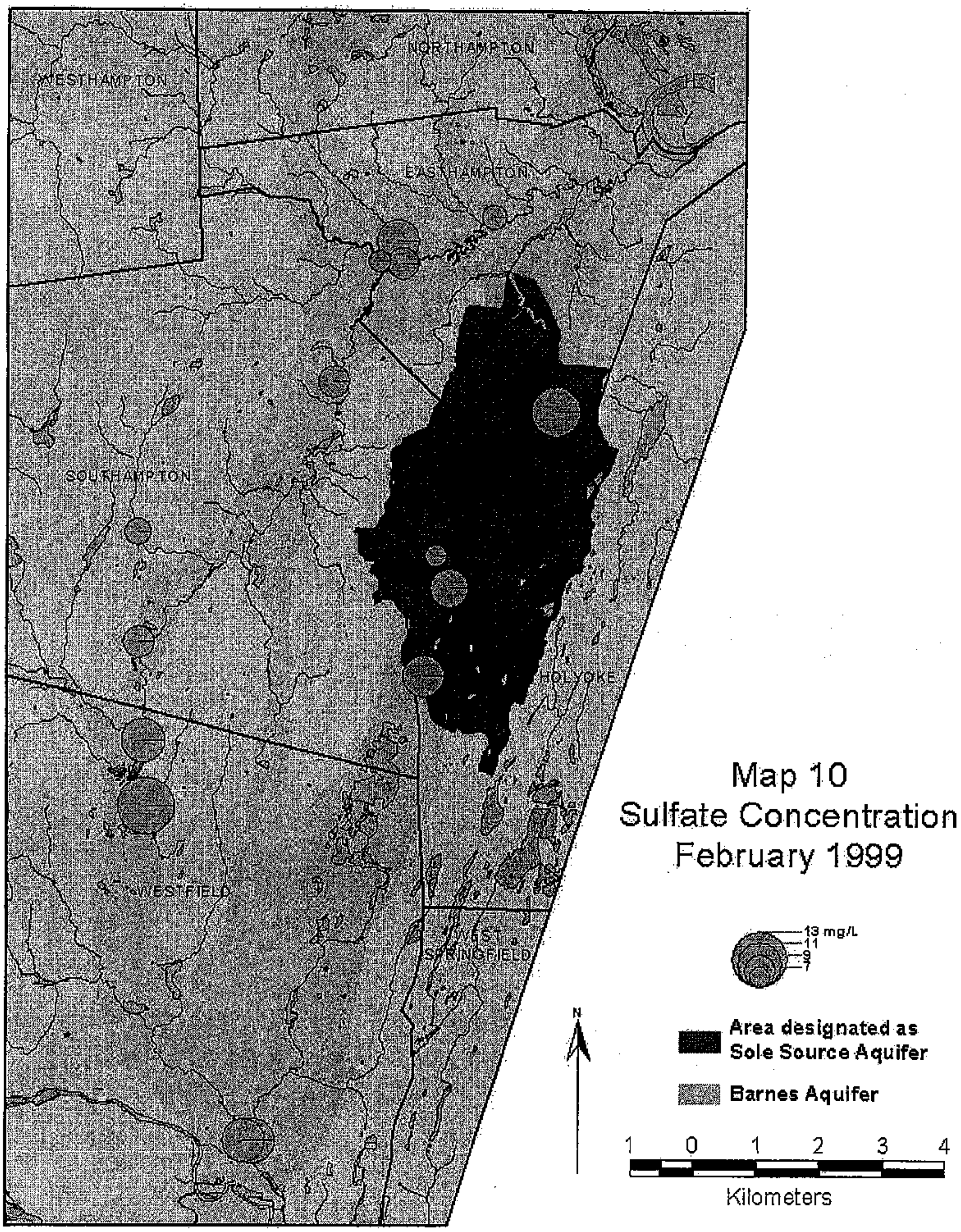
Map 7
Nitrate Concentration
May/June 1998



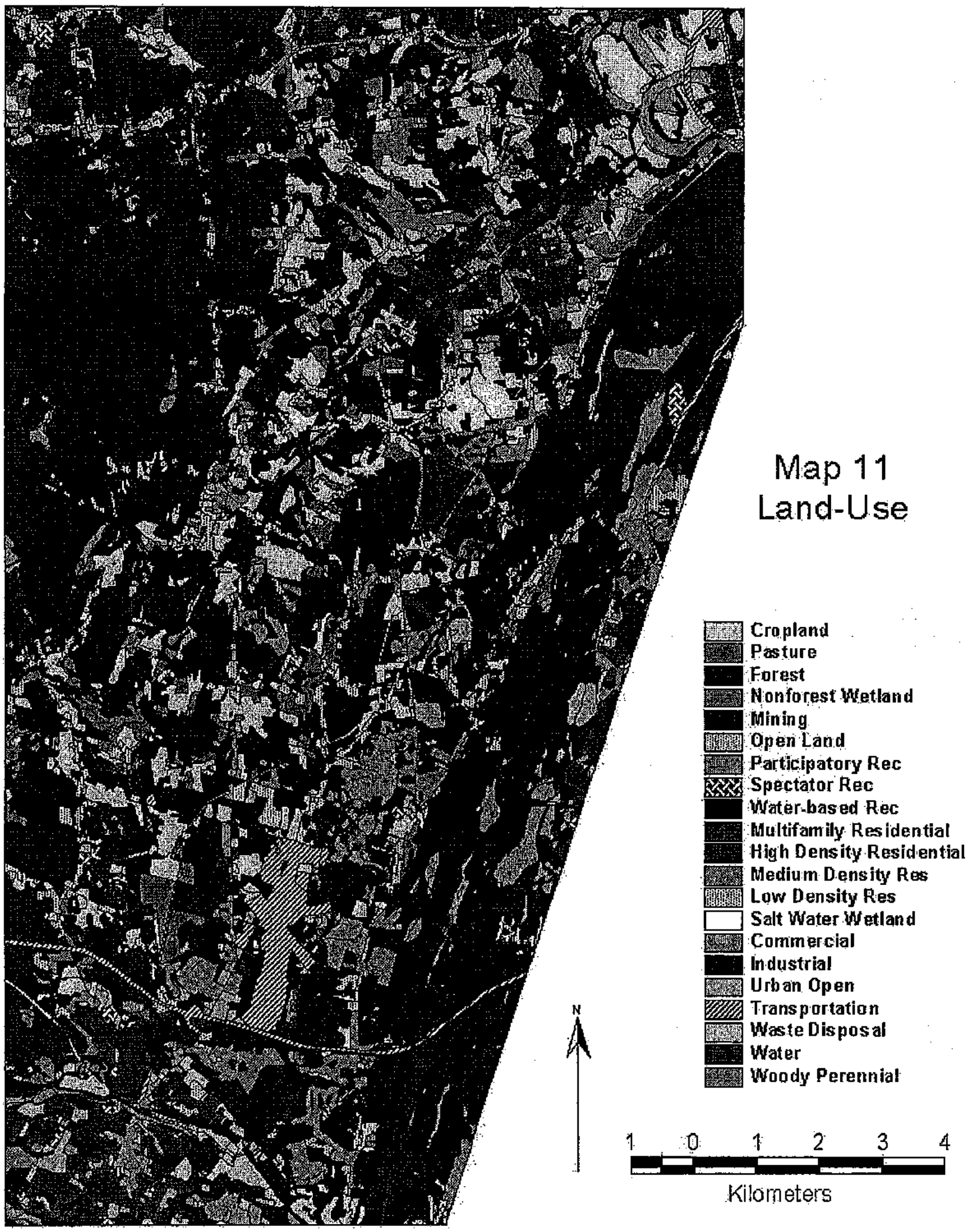
Map 8
Nitrate Concentration
February 1999



Map 9
Sulfate Concentration
May/June 1998



Map 10
Sulfate Concentration February 1999



Map 11
Land-Use

Sample #	Date	PH	ANC	HCO_3	Ca	Mg	Na	K	Cl	NO_3	SO_4	SiO_2	Cond
BB-100	3/27/98	7.42	570	34.77	11.65	2.85	11.55	0.54	23.16	1.85	10.57	11.55	156
BB-200	3/27/98	7.44	477	29.10	10.55	2.65	10.45	0.55	18.87	1.32	10.23	10.62	135
BB-250	3/27/98	6.67	166	10.10	4.29	1.43	2.76	0.26	2.98	0.53	9.20	11.30	46
BB-300	3/27/98	7.65	469	28.61	6.50	2.56	10.70	0.56	19.73	1.05	9.96	9.44	131
BB-400	3/27/98	7.38	486	29.63	9.65	2.80	10.10	0.49	19.67	0.62	9.37	10.12	117
BB-500	3/27/98	7.46	479	29.21	10.95	2.85	14.95	0.41	28.43	0.39	9.31	9.81	146
BB-600	3/27/98	7.26	432	26.35	8.95	2.75	10.80	0.54	19.59	0.74	9.54	10.22	129
PB-700	3/27/98	7.64	598	36.45	10.05	2.41	12.10	0.74	20.69	0.38	8.95	3.00	140
PB-800	3/27/98	7.62	515	31.40	11.80	2.33	10.20	0.68	18.85	1.63	9.49	8.08	137
MH-900	3/27/98	7.28	341	20.82	8.65	1.69	10.95	1.08	20.51	1.32	8.42	9.07	123
MH-1000	3/27/98	7.09	214	13.05	5.59	0.96	5.10	0.63	7.90	1.36	7.16	9.57	67
WB-100	5/22/98	7.52	785	47.89	20.55	4.25	12.95	1.61	26.21	9.49	17.28	12.09	205
RP-100	5/22/98	7.49	594	36.23	13.00	2.11	12.05	0.99	21.42	1.67	9.87	7.43	145
NP-100	5/22/98	7.76	744	45.38	15.30	3.00	11.75	0.65	20.25	2.27	11.10	8.89	172
BB-100	5/22/98	7.86	771	47.03	16.80	3.55	10.60	0.55	19.28	3.84	11.74	12.04	156
BB-200	5/22/98	7.90	720	43.92	15.20	3.40	9.45	0.50	16.60	3.40	11.59	11.35	149
BB-250	5/22/98	7.44	231	14.09	5.15	1.70	2.43	0.21	2.05	0.43	9.94	10.60	55
BB-300	5/22/98	7.79	827	50.45	15.65	3.25	9.70	0.47	17.51	3.11	10.83	11.25	150
BB-350	5/22/98	7.70	712	43.43	11.35	3.50	10.45	0.38	16.83	0.81	8.36	10.31	139
BB-400	5/22/98	7.77	734	44.77	11.60	3.55	8.20	0.31	16.80	0.73	8.43	10.41	133
BB-500	5/22/98	7.49	818	49.90	14.65	4.05	18.25	0.51	31.09	0.35	7.37	10.60	195
BB-600	5/22/98	7.87	662	40.38	11.30	3.50	10.40	0.42	17.50	0.99	8.65	10.63	132
MH-1100	5/22/98	7.31	259	15.80	7.75	1.48	5.65	0.91	9.52	1.98	7.04	9.61	81
MH-1100	6/5/98	6.85	397	24.22	9.35	1.20	6.05	0.95	10.39	2.10	6.95	9.95	89
MH-1150	6/5/98	6.77	390	23.79	8.70	1.46	6.40	0.74	9.38	1.42	6.67	8.64	84
MH-1200	6/5/98	6.81	315	19.22	9.00	1.45	5.85	0.86	9.63	2.12	7.04	10.32	85
HB-100	6/5/98	7.50	894	54.53	17.70	3.45	9.65	1.98	16.93	6.46	8.06	16.78	157
NB-100	6/5/98	7.08	343	20.92	7.20	1.36	5.65	1.04	9.04	2.63	6.80	11.70	81
MH-1000	6/5/98	6.96	393	23.95	9.50	1.28	5.60	0.74	9.01	1.97	7.54	9.84	84
PO-100	6/5/98	6.60	155	9.46	6.30	1.11	4.70	0.77	6.36	7.56	8.02	12.31	70
MH-1300	6/5/98	6.73	361	22.02	9.05	1.11	5.65	0.69	9.04	1.55	6.75	8.95	78
TB-100	6/5/98	7.31	469	28.61	11.85	2.06	6.50	0.83	9.81	1.85	13.21	11.03	103
MS-100	6/5/98	7.20	1094	66.73	24.20	1.78	10.30	0.93	19.85	7.94	13.44	13.35	197
RB-100	6/5/98	6.79	148	9.03	4.79	0.73	3.52	0.31	4.54	0.86	6.54	11.78	49
MH-1400	6/5/98	6.69	236	14.40	4.65	0.99	3.67	0.55	5.53	0.52	5.79	8.27	55
MH-1100	6/10/98	7.35	477	29.10	8.50	1.66	7.70	1.25	13.17	2.72	7.67	11.82	109
MH-900	6/10/98	7.23	539	32.88	9.75	1.85	6.95	1.03	13.38	0.52	6.23	6.43	107

Sample #	Date	PH	ANC	HCO_3	Ca	Mg	Na	K	Cl	NO_3	SO_4	SiO_2	Cond
BV-100	6/10/98	7.40	427	26.05	7.70	1.78	6.55	0.94	11.90	0.29	6.74	2.59	93
BK-100	6/10/98	7.15	467	28.49	9.20	2.04	7.75	1.40	16.39	2.47	6.22	16.29	115
AM-100	6/10/98	7.45	678	41.36	10.95	1.03	21.20	0.75	27.45	2.27	10.16	11.69	179
PW-100	6/10/98	7.68	931	56.79	19.45	3.05	18.25	1.54	34.72	5.83	10.54	12.48	233
PB-900	6/10/98	7.70	693	42.27	12.90	2.36	9.00	0.55	18.09	1.58	8.65	9.08	143
PB-800	6/10/98	7.67	652	39.77	11.90	2.34	8.85	0.47	16.91	1.49	8.38	8.73	130
BB-300A	6/10/98	7.68	876	53.44	18.55	3.40	11.15	0.59	18.91	4.68	12.50	13.05	177
BB-300B	6/10/98	7.69	933	56.91	16.15	3.45	10.70	0.57	18.90	4.72	12.43	13.02	177
BB-300C	6/10/98	7.76	931	56.79	18.40	3.15	11.00	0.56	19.19	4.72	12.10	13.11	175
Lovefield	7/23/98	7.97	995	60.70	25.90	5.70	3.50	1.53	13.68	0.00	33.25	11.75	187
Nonotuck Park*	7/23/98	8.13	1015	61.92	26.50	3.40	6.50	1.14	18.16	17.85	16.85	17.09	220
Hendrick St.*	7/23/98	8.01	1061	64.72	24.70	4.00	9.70	1.04	23.05	6.92	15.67	16.66	227
Pines A*	7/23/98	7.98	1137	69.36	24.60	3.45	5.70	0.87	14.71	3.94	15.19	16.99	199
Pines B*	7/23/98	8.03	1125	68.63	24.45	3.55	5.65	0.85	14.71	4.03	14.88	16.89	199
Pines C*	7/23/98	8.03	1118	68.20	24.00	3.45	5.60	0.86	14.66	3.98	14.86	16.96	199
BB-100	2/3/99	6.75	311	18.97	9.40	2.63	25.40	1.43	44.35	1.89	11.19	9.28	218
BB-250	2/3/99	6.23	80	4.88	3.28	0.80	13.20	1.45	20.46	1.20	6.66	5.46	104
BB-300	2/3/99	6.70	292	17.81	7.50	2.48	15.80	0.72	25.83	1.59	9.22	9.31	152
BB-600	2/3/99	6.78	334	20.37	8.60	2.75	16.80	0.82	27.35	1.45	9.75	9.74	171
BB-600a	2/3/99	6.77	225	13.73	7.80	0.41	139.50	1.10	212.30	1.17	26.11	2.54	830
BK-100	2/3/99	6.58	290	17.69	10.40	1.81	40.90	1.29	68.02	1.50	12.59	9.42	314
MH-900	2/3/99	6.52	291	17.75	10.80	2.15	31.40	1.53	55.85	2.01	10.09	9.85	276
HB-100	2/3/99	6.60	235	14.34	7.10	1.93	15.40	1.41	24.49	2.42	9.89	10.52	157
MH-1000	2/3/99	6.60	180	10.98	6.30	1.30	11.10	1.11	18.37	1.87	7.99	9.24	117
MH-1100	2/3/99	6.29	121	7.38	4.80	1.15	9.60	1.11	15.72	1.56	6.98	8.56	101
MH-1200	2/3/99	6.52	114	6.95	5.05	1.11	11.60	1.10	18.82	1.57	8.10	8.35	110
MH-1400	2/3/99	6.48	206	12.57	6.30	1.46	12.50	1.09	22.29	1.44	8.08	9.38	130
NB-100	2/3/99	6.33	73	4.45	3.94	1.01	8.00	0.91	12.10	1.29	6.58	8.78	79
PB-900	2/3/99	6.67	234	14.27	8.20	2.09	18.50	0.79	30.61	1.90	10.30	8.28	174
PW-100	2/3/99	6.69	277	16.90	10.00	1.83	30.70	1.33	52.56	2.27	10.00	8.67	252
RB-100	2/3/99	6.38	167	10.19	3.90	1.18	8.80	3.12	14.51	1.32	7.31	9.06	101

All concentrations are in mg/L except, ANC (μeq/L), SiO_2, (μmol/L) and specific conductance (μS/cm). * indicates samples from municipal wells.