WATER QUALITY AND OCCURRENCE OF METHYL TERT-BUTYL ETHER (MTBE) AND OTHER FUEL-RELATED COMPOUNDS IN LAKES AND GROUND WATER AT LAKESIDE COMMUNITIES IN SUSSEX AND MORRIS COUNTIES, NEW JERSEY, 1998-1999

Water-Resources Investigations Report 01-4149





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ABSTRACT

Densely populated communities surround many of the larger lakes in northwestern New Jersey. These communities derive most of their water supply from wells. The lakes can be navigated by gasoline-powered watercraft, can be in various stages of eutrophication, may contain pathogens associated with bathing and waterfowl, and are periodically subjected to chemical applications to control aquatic plant growth. Another feature that contributes to water-quality concerns in lakeside communities is the widespread use of septic tanks.

Concentrations of methyl tert-butyl ether (MTBE), a gasoline oxygenate, in samples from Cranberry Lake and Lake Lackawanna ranged from 20 to 30 μ g/L (micrograms per liter) and 5 to 14 µg/L during the summers of 1998 and 1999, respectively. These levels were persistent throughout the depth of the lakes when mixing conditions were present. MTBE concentrations in samples from the top 20 feet of Lake Hopatcong during summer 1999 were about 10 µg/L and about 2 to 3 μ g/L in samples below 20 feet. The source of the MTBE in the lakes was determined to be gasoline-powered watercraft. Other constituents of gasoline--tertiary amyl methyl ether (TAME) and benzene, toluene, ethylbenzene, and xylenes (BTEX)--were detected in the lakes but at much lower concentrations than MTBE.

Ambient ground-water quality at Cranberry Lake and Lake Lackawanna appears to be affected by the use of gasoline-powered watercraft. MTBE was detected in water samples from 13 of the 14 wells sampled at Cranberry Lake in fall 1998 and summer 1999. The wells were selected to monitor ambient ground-water quality and had no history of contamination. In groundwater samples collected during fall 1998, MTBE concentrations ranged from 0.12 to 19.8 µg/L, and the median concentration was 0.43 µg/L. In samples from summer 1999, MTBE concentrations ranged from 0.14 to 13.2 µg/L, and the median concentration was $0.38 \mu g/L$. MTBE was detected in samples from four of the five wells at Lake Lackawanna in summer 1999; concentrations ranged from 0.05 to 0.19 μ g/L. Lake/ground water interaction is a feasible explanation for the nearly ubiquitous presence of MTBE in ground water. The movement of water from lakes to wells is feasible because many static water levels and essentially all pumped water levels in the wells were below lake levels. Furthermore, diatom fragments were present in samples from the wells.

Ambient ground water at Cranberry Lake also may be affected by septic-tank effluent, as indicated by the relation among concentrations of nitrate, boron, and chloroform. This result indicates potential vulnerability of the water supply to contamination by other chemicals and pathogens.

Radon in ambient ground water is a concern throughout northern New Jersey. In particular, the median radon concentrations in ground-water samples collected from 14 wells at Cranberry Lake in 1998 and 1999 were 1,282 and 1,046 pCi/L, respectively. The median radon concentration in five ground-water samples collected at Lake Lackawanna in 1999 was 340 pCi/L. Although these values exceed regulatory levels, they are not high relative to radon concentrations measured in northwestern New Jersey.

Eight wells in a neighborhood of Cranberry Lake with known MTBE contamination were sampled by the U.S. Geological Survey in summer 1998. MTBE was detected at concentrations greater than or equal to 40 μ g/L in five of the wells. Concentrations of TAME, another gasoline oxygenate, were highly correlated with concentrations of MTBE; MTBE concentrations were about 10 times the TAME concentrations. In all samples, however, the concentrations of the BTEX compounds were less than 0.05 μ g/L, and the sample from the most highly contaminated well, where the MTBE concentration was 900 μ g/L, had no detectable BTEX.

INTRODUCTION

Lakes and reservoirs are located throughout the State of New Jersey; however, larger bodies of water generally are located in the three physiographic provinces underlain predominantly by consolidated rock (Valley and Ridge, New England, and Piedmont) in the northern part of the State (fig. 1). The density and size of the lakes generally increase north of the Wisconsinan terminal moraine because the erosion and deposition associated with the Wisconsinan glaciation combined with certain topographic features provide conditions favorable for impoundment with dams. The 25 largest lakes and reservoirs in New Jersey, ranked by estimated area, rather than volume, are listed in table 1; 19 of these lakes are located north of the Wisconsinan terminal moraine in what can be referred to as a "lakes region". Densely populated communities surround many of the larger lakes because of picturesque surroundings, beaches, and facilities for boating and water sports. Many of these communities derive their water supply from wells that tap either fractured crystalline-rock aquifers or unconsolidated glacial till. Much of that supply is provided by domestic wells for individual homes and the wells of small water companies. The withdrawal of water directly from lakes is a common practice in this area, although the extent to which such water is used for drinking and how it is treated is largely unknown (Stephen Stiansen, Sussex County Health Dept., oral commun., 1999).

Lakeside communities in this area have some unique characteristics. Wells potentially are

vulnerable to contamination because steeply dipping fractures that convey water are either exposed or submerged below thin soils. The combination of maintained lake-water levels and wells clustered near the shoreline makes it likely that the lakes feed some wells, in part. Lakes can be navigated by gasoline-powered watercraft, can be undergoing eutrophication, can contain pathogens associated with bathing and waterfowl, and periodically are subjected to herbicide applications to control aquatic plant growth. Another feature that contributes to water-quality concerns in lakeside communities is the widespread use of septic tanks. Septic tanks are prevalent because the hilly terrain and shallow overburden in the area are not amenable to the installation of municipal wastewater-treatment facilities. The effect of septic effluent on groundwater quality has been documented (Shadford and others; 1997, Lauerman and others, 1996; Eitan, 1994). It also has been shown to affect the water quality of lakes (Cherry and Rapaport, 1994; Fleming and Klosinski, 1990). The use of gasoline, oil, and other products associated with watercraft also increases the potential for groundwater contamination through small spills on the land surface. The effect of lakeside development in the region on the quality of drinking water is largely unknown because tests of domestic wells are not mandated and small water-company wells are more loosely regulated than larger systems. This study was conducted by the U.S. Geological Survey (USGS) as part of the Toxic Substances Hydrology Program to begin water-quality assessment at lakeside developments.

Purpose and Scope

This report presents results of an assessment of ambient ground-water and surfacewater quality at Cranberry Lake, Lake Lackawanna, and Lake Hopatcong in Sussex and Morris Counties, New Jersey. At Cranberry Lake, 14 wells were sampled during fall 1998 and again in summer 1999. At Lake Lackawanna, five wells were sampled in summer 1999. The wells selected had no known history of contamination. Samples were analyzed for a comprehensive list of inorganic and organic analytes and water levels

			Physiographic	
Lake name	Area (acres) ¹	County	province	
Lake Hopatcong	2,443	Sussex/Morris	New England	
Wanaque Reservoir	2,342	Passaic	New England	
Round Valley Reservoir	2,223	Hunterdon	Piedmont	
Spruce Run Reservoir	1,356	Hunterdon	Piedmont	
Union Lake	827	Cumberland	Coastal Plain	
Greenwood Lake	825	Passaic	New England	
Boonton Reservoir	789	Morris	Piedmont	
Lake Mohawk	754	Sussex	New England	
Manasquan Reservoir	751	Monmouth	Coastal Plain	
Lake Tappan	652	Bergen	Piedmont	
Merrill Creek Reservoir	648	Warren	New England	
Swimming River Reservoir	609	Monmouth	Coastal Plain	
Culvers Lake	562	Sussex	Valley and Ridge	
Splitrock Reservoir	561	Morris	New England	
Oradell Reservoir	527	Bergen	Piedmont	
Monksville Reservoir	522	Passaic	New England	
Swartswood Lake	521	Sussex	Valley and Ridge	
Green Pond	504	Morris	New England	
Clinton Reservoir	477	Passaic	New England	
Oak Ridge Reservoir	469	Passaic/Morris	New England	
Point View Reservoir	428	Passaic	Piedmont	
Upper Greenwood Lake	424	Passaic	New England	
Budd Lake	389	Morris	New England	
Charlottesburg Reservoir	330	Passaic/Morris	New England	
Highland Lake	324	Sussex	New England	

Table 1. The twenty-five largest lakes in New Jersey on the basis of area estimates

¹Area estimates based on land-use/land-cover data.



Figure 1. Location of study area, lakes and physiographic provinces in northwestern New Jersey.

were measured to provide data to assess the possibility of lake/ground water interaction and the effect of septic-system effluent on ground-water quality. The results of analyses of samples collected from eight additional wells in a neighborhood at Cranberry Lake affected by pointsource MTBE contamination are presented. Results also are presented for samples collected from Cranberry Lake and Lake Lackawanna. Lake Hopatcong, New Jersey's largest lake, was sampled twice during summer 1999 to assess the presence of MTBE and other VOCs. Ground water at Lake Hopatcong communities was not sampled. Frequent sampling was conducted at Lake Hopatcong and Cranberry Lake to document the seasonal and inter-week variability of MTBE concentrations in the lakes.

Previous Investigations

In April 1998, the USGS, in cooperation with the Sussex County Health Department, investigated contamination of several wells in a neighborhood of Cranberry Lake, Byram Township, Sussex County. MTBE concentrations in five of the wells sampled ranged from 40 to 900 µg/L, yet the source of MTBE was unknown because no gasoline storage tanks were present in the community and no spills had been reported. The USGS sampled Cranberry Lake and analyzed for volatile organic compounds (VOCs) in summer 1998 to determine the possible relation between lake-water quality and well contamination. Lake Lackawanna also was sampled. Concentrations of MTBE in Cranberry Lake were as high as 15.0 μ g/L on June 24 and as high as 29.0 μ g/L on September 8, 1998. Concentrations of MTBE in Lake Lackawanna were as high as 14.0 µg/L on September 9, 1998. The presence of MTBE in these lakes was attributed to gasoline-powered watercraft (Baehr and Zapecza, 1998).

Although these lake concentrations were among the highest observed for MTBE in ambient ground-water and surface-water samples nationwide by the USGS, another source of MTBE caused the well contamination at Cranberry Lake because concentrations in the lake were lower than those in the most contaminated wells. The most probable source of well contamination in this case was either spilled used motor oil (Baker and others, 2000) or small spills of gasoline from lawnmower or boat-engine refueling. Such small spills have been suggested as the cause of frequent low-level MTBE detection across the State of Maine (State of Maine, 1998).

MTBE and Oxygenated Fuel

MTBE has been added to gasoline since the late 1970s as an octane booster. MTBE use is now (2001) substantially greater because the compound is used as an oxygenate to increase fuel-burning efficiency and reduce atmospheric concentrations of carbon monoxide and ozone precursors in urban areas. The 1990 amendments to the Federal Clean Air Act mandating the use of oxygenated fuel do not specify the use of MTBE; however, it is the most widely used oxygenate across the country, particularly in the northeastern United States, including New Jersey. Other approved oxygenates include di-isopropyl ether (DIPE), tertiary amyl methyl ether (TAME), ethyl tertiary butyl ether (ETBE), methanol, ethanol, and tertiary butyl alcohol (TBA).

Gasoline sold during winter in carbon monoxide non-attainment areas must contain at least 2.7 percent oxygen. This oxygen content is achieved by blending 14.8 percent MTBE by volume to gasoline. In addition, oxygenated fuel, referred to as reformulated gasoline (RFG), is used to decrease ground-level ozone concentrations by reducing emissions of precursor VOCs and nitrogen oxides. RFG requires an oxygen content of 2.0 percent, which is achieved by blending 11.0 percent MTBE by volume to gasoline. During the time of data collection for this study, the State of New Jersey had in effect a program for which RFG was used statewide all year and winterformulated oxygenated fuel was used in northern New Jersey from November through February.

MTBE associated with lakeside communities adds another facet to the national debate on its usage. The major benefit derived from oxygenated gasoline is in its use in automobiles; however, oxygenated gasoline is used in watercraft across New Jersey and in other parts of the country. Contemporaneous studies document the presence of MTBE in lakes in California (Allen and others, 1998; Boughton and Lico, 1998; Reuter and others, 1998) and, as previously discussed, in New Jersey (Baehr and Zapecza, 1998).

MTBE is much more water-soluble than BTEX constituents in gasoline, and in oxygenated gasoline MTBE is present in larger amounts. Therefore, when oxygenated gasoline is spilled, MTBE is the principal contaminant in water on a mass basis. The use of MTBE in gasoline across the country is receiving considerable attention (Andrews, 1998; University of California, 1998) as scientists and regulators balance the benefits of improved air quality with the widespread presence of MTBE in ground and surface water. Although the USEPA recently (2000) announced its intention to reduce or eliminate the use of MTBE in domestic fuels over the next 3 years, its presence in the environment will remain an important water-resources issue. Following a ban on its use, MTBE in the lakes would be eliminated as a result of volatilization; however, the MTBE in the ground-water system could persist for many years. Identification of sources and transport mechanisms throughout the hydrologic cycle will be critical in developing an understanding of the long-term effect of historic MTBE releases.

Acknowledgments

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METHODS OF INVESTIGATION

Site Selection

Samples were collected at five locations on Cranberry Lake during 1999 (fig. 2). The sampling sites were selected to provide areal coverage and the ability to sample both deep and shallow parts of the lake. The site names, coordinates, and sampling depths are listed in table 2. Site 1306N just beneath the footbridge has been monitored more frequently than the other sites because samples could be obtained from the bridge without using a boat. It has been determined that concentrations in samples collected at site 1306N are similar in magnitude to those in samples collected from other sites in the lake north of Strawberry Point (fig. 2). The elevation of the lake surface measured at site 1306N (fig. 3) provided a measure of seasonal variation during the study period.

			Sampling depth (feet)			
Site name	Latitude	Longitude	9/8/98	8/3/99		
1306N	40 57' 14" N	74 44' 15" W	3.0	6.0		
306W	40 57' 00" N	74 44' 20" W	3.0, 6.0, 10.0	6.0		
2449SW	40 56' 45" N	74 44' 46" W	3.0, 6.0, 10.0	6.0		
1633W	40 57' 05" N	74 44' 38" W	3.0, 6.0, 10.0	6.0		
3061WSW	40 56' 55" N	74 45' 02" W	3.0	1.5		



Figure 2. Location of ambient ground-water network sites, neighborhood with Methyl tert-butyl ether contamination, and lake sampling sites, Cranberry Lake, Sussex County, New Jersey.



Figure 3. Depth of Cranberry Lake, Sussex County, New Jersey, June 24,1998, to November 22, 1999.

The red circle in figure 2 indicates the neighborhood affected by point-source MTBE contamination that was discussed in the Previous Investigations section in the Introduction. These wells were sampled initially by the New Jersey Department of Environmental Protection (Stephen Stiansen, Sussex County Health Dept., written commun., 1997) and resampled by the USGS in 1998 as part of this study because the report of MTBE detection in samples without BTEX cooccurrence was thought to be anomalous. Within this neighborhood, seven domestic wells (serving a single household) and one community well (serving multiple households) were sampled. The ambient ground-water sampling network consists of 14 wells, indicated by crosses in figure 2. Four community wells, including those of the two largest water suppliers, make up part of the ambient ground-water sampling network. The remaining 10 wells in the ambient network are domestic wells that were selected on the basis of availability of well-construction records, areal distribution around the lake, and owner permission. The 10 domestic wells in the ambient network had no history of contamination. All 14 wells in the ambient network draw water from fractured pre-Cambrian rock. All available information about the construction and location of the 14 wells that compose the ambient groundwater sampling network are summarized in table 3. The static water levels listed in table 2 were measured only when the wells were sampled in summer 1999.

Samples were collected at three locations on Lake Lackawanna and at five wells near the lake (fig. 4). The characteristics of the sampling sites are listed in table 4. Because no water companies serve the Lake Lackawanna community, all five wells sampled are domestic wells. The wells were selected on the basis of availability of well-construction records, distribution around the lake, and owner permission. Two wells were selected because they are relatively shallow wells driven into the Quaternary gravels, which overlie bedrock in parts of the study area. The other three wells were drilled through Quaternary gravels and draw water from fractures in the underlying bedrock. Characteristics of these five wells are listed in table 5.

Samples were collected at six locations on Lake Hopatcong (fig. 5). The characteristics of the sampling sites are listed in table 6. No wells were sampled at Lake Hopatcong. The sites were chosen to provide samples representative of different lake depths.

Collection and Analysis of Samples

Untreated (raw or source) ground water from a domestic well was sampled by tapping the supply line between the wellhead and treatment system. In most cases, the pressure tank drain was the most convenient access point. When available, an outdoor spigot supplied with untreated water was used. Clean plastic fittings were placed on the spigot, and the sample stream was split between a waste line and a sampling line where the sample flow could be controlled. The sampling line consisted of 3/8-in. inside-diameter by 1/2-in. outside-diameter Teflon-lined polyethylene tubing. Prior to sampling, the waste line was opened and the home's supply lines and storage system were purged by operating the well pump for 15 to 30 minutes. This operation typically resulted in the removal of 75 to 150 gal of water. Specific conductance, pH, and temperature were monitored while the system was purged to ensure stability of these field characteristics prior to sampling.

For sampling during summer 1999 at Cranberry Lake and Lake Lackawanna, groundwater levels were measured at the wellheads. Water levels were not measured during fall 1998 sampling at Cranberry Lake. The well owner was requested not to use water during the sampling period so that the pump would remain off initially to allow water in the well to rise to a static (unstressed) level and to allow for a measurement of total flow to the well at the sampling line. The water level was monitored at the wellhead with an electrical tape, and the initial (static) water level was recorded. After the sampling apparatus was installed and the water level stabilized, the sampling line was opened, and the time-drawdown data were recorded at the well head when the pump was turned on to determine hydraulic

Table 3. Description of wells sampled at Cranberry Lake, New Jersey

[--, no data; PCB, pre-Cambrian basement; PCSW, public-community supply well; DOM, domestic well]

Site Name	Latitude	Longitude	Elevation of land surface (feet above sea level)	Elevation of static water level (feet above sea level) (8/4-16/1999)	Distance from lake (feet)	Date installed	Total depth (feet below land surface)	Casing depth (feet below land surface)	Formation	Well diameter (inches)	Water use	Residences served (on/off season)
CR01	40 56' 52.22" N	74 44' 24.68" W	760		186.7				PCB		DOM	1
CR02	40 56' 59.37" N	74 44' 00.61" W	800		152.9	01/02/1992	225	91	PCB	6	DOM	1
CR03	40 57' 01.29" N	74 45' 01.65" W	820		348.4				PCB		DOM	1
CR04	40 57' 02.94" N	74 45' 03.69" W	820		580.4				PCB		DOM	1
CR05	40 57' 07.58" N	74 45' 04.78" W	810		857.6				PCB		PCSW	28/28
CR06	40 56' 57.70" N	74 45' 02.23" W	770		82.0				PCB		DOM	1
CR07	40 57' 00.20" N	74 45' 01.62" W	800		260.8				PCB		DOM	1
CR08	40 57' 01.29" N	74 45' 00.31" W	800		322.5				PCB		DOM	1
CR09	40 57' 15.30" N	74 44' 18.33" W	791.10	775.10	149.9	11/3/1962	305	50	PCB	6	PCSW	80/1
CR10	40 57' 15.18" N	74 44' 21.55" W	799.94	780.44	59.7				PCB		PCSW	80/1
CR11	40 57' 15.05" N	74 44' 25.91" W	783.73	756.13	62.7				PCB		PCSW	80/1
CR12	40 56' 52.63" N	74 44' 39.40" W	781.88	763.71	81.7				PCB		PCSW	37/33
CR13	40 56' 54.11" N	74 45' 26.00" W	840		1,477.7	9/21/1994	200	85	PCB	6	DOM	1
CR14	40 56' 54.66" N	74 44' 45.03" W	788.57	768.07	39.7	1/26/1989	175	52	PCB	6	DOM	1
CR15	40 56' 53.25" N	74 44' 39.02" W	791.50	769.65	226.4	9/4/1978	75	51	PCB	6	DOM	1
CR16	40 56' 53.93" N	74 44' 52.58" W	796.97	765.90	116.8	2/11/1998	175	50	PCB	6	DOM	1
CR17	40 56' 47.42" N	74 45' 34.18" W	855.95	801.85	2,209.3	9/28/1988	375	51	PCB	6	DOM	1
CR18	40 56' 48.85" N	74 45' 07.05" W	803.68	769.78	274.0	10/6/1970	99	50	PCB	6	DOM	1
CR19	40 57' 21.78" N	74 44' 20.91" W	779.84	770.03	26.6	3/17/1977	75	50	PCB	6	DOM	1
CR20	40 56' 47.89" N	74 45' 05.22" W	779.27	769.68	200.1	6/26/1990	198	85	PCB	6	DOM	1
CR21	40 56' 49.55" N	74 44' 24.93" W	804.22	760.72	265.4	8/13/1992	523	100	PCB	6	DOM	1
CR22	40 56' 45.90" N	74 45' 11.30" W	819.56	770.61	341.2	2/23/1989	148	50	PCB	6	DOM	1



Figure 4. Location of well sampling sites and lake sampling sites, Lake Lackawanna, Sussex County, New Jersey.

			Sampling depth
Site name	Latitude	Longitude	sea level)
1564NE	40 56' 59" N	74 42' 03" W	5
3237NE	40 57' 09" N	74 41' 38" W	3
751NE	40 56' 50" N	74 42' 05" W	5

Table 4. Description of surface-water-quality sampling sites,Lake Lackawanna, New Jersey

Table 5. Description of wells sampled at Lake Lackawana, New Jersey

 [--, no data; PCB, pre-Cambrian basement; QTG, quaternary glacial-fill deposits; DOM, domestic well]

Site name	Latitude	Longitude	Elevation of land surface (feet)	Elevation of static water level (feet) (8/12-8/26/1999)	Distance from lake (feet)	Date installed	Total depth (feet)	Casing depth (feet)	Formation	Well diameter (inches)	Water use	Residences served
1 4 0 1	40 571 12 00" N	74 411 47 00" 33	72(20	718.20	80.55	7/1//1022	146	50	DCD	(DOM	1
LA01	40 57° 12.99° N	/4 41 47.99 W	/36.29	/18.29	89.55	//16/1982	146	50	PCB	6	DOM	1
LA02	40 57' 03.68" N	74 41' 25.15" W	724.56	718.26	24.29	7/18/1978	50	50	QTG	6	DOM	1
LA03	40 56' 56.73" N	74 41' 40.95" W	725.75	714.01	23.45	8/15/1990	200	115	PCB	6	DOM	1
LA04	40 56' 56.37" N	74 41' 37.53" W	723.07		35.76	11/15/1982	95	35	PCB	6	DOM	1
LA05	40 57' 06.03" N	74 41' 47.34" W	726.74	718.64	129.31	6/30/1989	200	130	PCB	6	DOM	1





characteristics of the aquifer. The flow rate to the well was determined by measuring the outflow from the sampling and waste lines. The recovery of water levels at the well was recorded after the sampling and waste lines were closed in order to obtain data to evaluate the measured water level as an observation for the regional flow system. The elevation at the wellhead was surveyed so that the measured water levels could be compared to the water level of the lake.

Lake sites were accessed with a boat equipped with both electric and gasoline engines. The gasoline engine was used to travel between sites but, in all cases, the gasoline engine was cut off and lifted out of the water at least 150 ft from the sampling site. The electric motor was used to travel the final distance. A length of 0.25-in. outside-diameter high-density polyethylene (HDPE) tubing was strapped to a staff or weighted line and lowered to the desired depth. Back pressure was maintained while the sampling line was being lowered to prevent water above the desired sampling depth from entering the tubing before sampling. No sheens due to spilled oil or gas were observed at any time on any of the lakes. After the sampling line was purged, samples were withdrawn with a peristaltic pump and collected in the appropriate containers. A short length of flexible silicon tubing was fitted around the pump head and spliced into the plastic sampling line by pushing the line snugly into the flexible tubing. All tubing was replaced before sampling at another site or depth; therefore, no decontamination procedures were required. Equipment blanks were collected by sampling VOC-free water with the same apparatus and a 10-ft length of tubing. At each site, temperature was measured as a function of depth with a temperature probe.

The peristaltic pump imparts pressure that is less than atmospheric to the sample stream, a

condition that theoretically could result in VOC mass loss when the sample is transferred to the a vial. This effect is negligible when a boat is used to sample the lake because water is lifted only about 1 ft from the lake surface to the inside of the boat, where the vials are filled. This lift corresponds to a pressure differential of less than 3 percent of atmospheric pressure (1 standard atmosphere is equal to 406.38 in. of water). Samples also were collected using this same technique from the pedestrian bridge at Cranberry Lake (site 1306N) to document seasonal and shortterm variations in VOC concentrations. The pathway of the bridge is about 12 ft above the water surface; therefore, the sample stream is lifted by imparting a pressure differential with the peristaltic pump of about 35 percent of atmospheric pressure. To determine VOC loss (if any) incurred while filling 40-mL vials, duplicate samples were collected from the bridge and a boat on August 3, 1999. The concentrations of VOC compounds detected are listed in table 7. The MTBE and TAME concentrations compare favorably; the sample collected from the bridge contained slightly higher concentrations of MTBE and TAME. The samples collected from the bridge contained slightly lower concentrations of BTEX and chloroform. These compounds are considerably more volatile than MTBE and TAME; therefore, the potential for losses from the sample due to vacuum pumping are greater. The concentrations of these compounds are all low (less than 0.07 μ g/L), however. In a study in which the effect of the sampling technique on concentrations of VOCs was evaluated (Tai and others, 1991), the percent recovery using peristaltic pumps to sample highly volatile organic compounds was more than 97 percent for stock solutions with VOC concentrations of 10 to 30 µg/L.

Site number	Site name	Latitude	Longitude	Sampled depth (feet)
1	Point Pleasant	40 55' 18" N	74 39' 11" W	3, 8
2	Elba Point/Great Cove	40 56' 33" N	74 38' 06" W	5, 10, 20, 30, 40
3	River Styx	40 56' 32" N	74 39' 10" W	3, 6
3	River Styx Bridge	40 56' 32" N	74 39' 10" W	3, 6
4	Halsey Island	40 57' 23" N	74 38' 28" W	5, 10, 20, 30, 40
5	Henderson Bay	40 58' 00" N	74 38' 17" W	5, 15, 20
6	Liffy Island	40 58' 23" N	74 36' 43" W	3, 8

Table 6. Description of surface-water-quality sampling sites, Lake Hopatcong, New Jersey

Table 7. Concentration of selected volatile organic compounds in duplicate samples collected from and beneath the pedestrian bridge at Cranberry Lake, August 3, 1999

[ft, feet; µg/L, micrograms per liter; MTBE, methyl tert-butyl ether; TAME, tertiary-amyl methyl ether; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); E, estimated value]

											Chloroform,	
Site number	Site name	Latitude	Longitude	Sampling depth (ft) (00003)	Lift (ft)	MTBE (µg/L) (78032)	TAME (µg/L) (50005)	Benzene (µg/L) (34030)	Toluene (µg/L (34010)	M,P Xylene (µg/L) (85795)	total (µg/L) (32106)	Styrene (µg/L) (77128)
1	1306N (boat)	40 57' 14" N	74 44' 15" W	6	1	26.3	1.17	.046	.075	E.025	.0233	E.005
1	1306N (bridge)	40 57' 14" N	74 44' 15" W	6	12	27.2	1.29	.036	E.028	<.06	E.0169	<.042

LAKE-WATER QUALITY

Lake sampling consists of two types of data collection. One is synoptic sampling; multiple sites across the lake are sampled on the same day. This type of sampling provides data to assess the spatial variability of water quality. It is used in advance of ground-water sampling to provide a basis for comparing lake- and groundwater quality. Synoptic sampling was conducted at Cranberry Lake, Lake Lackawanna, and Lake Hopatcong. The second type of sampling is timeseries sampling; the lake is sampled frequently at a given location. At Cranberry Lake and Lake Hopatcong, sampling was conducted from a bridge because it provided easy access. These samples were used to assess seasonal and short-term changes in water quality. Samples collected during the Cranberry Lake and Lake Lackawanna synoptic samplings were analyzed at the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., for the VOCs listed in Appendix 1 (see table A1). Samples collected during the Lake Hopatcong synoptic study, as well as the timeseries sampling at Cranberry Lake and Lake Hopatcong, were analyzed at the New Jersey District laboratory (NJDL) in West Trenton, N.J. An evaluation of the VOC analysis results obtained at NJDL and those obtained at NWQL is presented in Appendix 1.

Cranberry Lake

Sampling was conducted at Cranberry Lake on June 24, 1998; September 8, 1998; and August 3, 1999. The 1998 data have been reported previously (Baehr and Zapecza, 1998) and are presented here to provide the total record and the context for the ground-water investigation. Timeseries samples were collected from the footbridge (site 1306N) during 1998 and 1999.

Results of analysis for VOCs in samples collected during the September 8, 1998, and August 3, 1999, synoptic studies are provided in table 8. On August 3, 1999, synoptic samples were collected only from one depth at each site because results of previous multilevel sampling and measurements of temperature-dependent stratification indicated that the water in Cranberry Lake was mixed. On both dates, therefore, the concentrations at the lake bottom where water could exchange between the lake and aquifer would be similar to those at the reported depths. Concentrations of fuel-related VOCs in samples collected on the two dates were similar. Concentrations of MTBE were the highest among the VOCs; concentrations in the 1999 samples from the northern part of the lake differ slightly $(23.4-27.1 \mu g/L)$. The lowest concentration of MTBE, 6.3 µg/L, was from site 2449 SW in the part of the lake south of Strawberry Point that, as a result of an obstructed channel, receives less boat traffic than the northern part of the lake (fig. 2). The spatial uniformity of concentrations in the northern part of the lake observed in 1998 also was observed in 1999. The concentrations of the other fuel-related VOCs (BTEX and TAME) were less than 2.2 μ g/L. With the exception of chloroform, the chlorinated VOCs detected in ground water-tetrachloroethylene (PCE), 1,1,1-trichloroethane (TCA), and trichloroethylene (TCE)--were not detected in Cranberry Lake. (See Ground-water quality section).

Estimates of VOC mass in Cranberry Lake (table 8) were calculated by numerically integrating concentration over volume. For this calculation, the lake is divided into northern and southern parts, with Strawberry Point as the dividing line. Lake volumes were calculated from available bathometric maps and adjusted for the elevation of the lake surface (Baehr and Zapecza, 1998). The volumes for the northern part of the lake were 289 and 271 and for the southern part of the lake were 102 and 95 Mgal on September 8, 1998, and August 3, 1999, respectively. Concentrations of VOCs in samples from the northern part of the lake were averaged for mass calculations. The concentrations at site 2449SW were assumed to represent the VOC concentrations in the southern part of the lake. The equivalent number of gallons of gasoline reported as estimated fuel volume in table 8 was obtained by assuming that the density of gasoline is 0.75 grams per cubic centimeter and that MTBE composes 10 percent of gasoline by volume. Under this assumption, a gallon of gasoline would contain 282 grams of MTBE. The purpose of the conversion of mass to equivalent gallons is to

Table 8. Concentrations of selected volatile organic compounds in samples and equivalent fuel volumes from Cranberry Lake, Sussex County, New Jersey, September 8, 1998 and August 3, 1999

[Concentrations are in micrograms per liter; differences in lake depths reported in 1998 and 1999 result from changes in overall lake level and slight differences in site location; ft, feet; <, less than, considered non-detect; kg, kilograms; gal, gallons; MTBE, methyl tert-butyl ether; TAME, tertiary amyl-methyl ether; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); E, estimated value]

			Dep bottor	oth to n from	San dep	npling th (ft)	МТ	BE	TA	ME	Ben	zene	Tol	uene	Ethyl	oenzene	M,P	Xylene	O x	ylene	Chlo	roform	St	yrene
17	Site number	Site name	surfa	ce (ft)	(00	0003)	(780)32)	(500	005)	(34	030)	(34	010)	(34	371)	(85	5795)	(77	(135)	(32	.106)	(7	7128)
			9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99	9/8/98	8/3/99
	1	C-1306 N	11.7	11.3	3.0	6.0	27.3	26.3	0.565	1.17	E.065	E.0461	E.18	E.0747	E.022	<.03	E.076	E.0249	E.037	<.06	E.022	E.0233	<.084	E.00458
	3	C-306 W	12.5	13.0	6.0	6.0	21.9	27	.701	1.59	E.075	.245	.198	1.93	E.027	.424	E.1	1.15	E.049	.463	E.025	E.0172	<.042	E.0507
	6	C-2449 SW	9.0	10.8	6.0	6.0	8.03	6.25	.202	.269	E.035	E.0350	E.053	E.0881	<.03	<.06	<.06	<.12	<.06	<.12	E.03	E.0755	<.042	<.084
	8	C-1633 W	11.8	11.2	6.0	6.0	20.6	26	.647	1.70	E.045	.357	E.056	2.23	<.03	.455	E.013	1.6	<.06	.694	E.019	E.0133	<.042	E.0687
	10	C-3061 WSW	4.0	1.5	3.0	1.5	18.3	23.4	.528	1.11	<.1	.146	E.024	.51	<.03	E.0870	<.06	.41	<.06	.197	E.013	E.0135	<.042	E.0179
	Total mass in la	ake (kg)					28.3	28.9	.736	1.65	0.053	.227	.098	1.36	.006	.28	.035	.916	.011	.393	.026	.021	0	0
	Estimated fuel	volume (gal)					101	102																

provide relevance to gasoline usage and not to suggest the timing of gasoline spillage. The presence of MTBE in the lake attributed to gasoline-powered watercraft results from the injection of exhaust fumes beneath the lake surface and subsequent equilibration in the water, as well as leakage of unburned gas.

Field-measured characteristics and results of analysis for major ions in samples collected during the August 3, 1999, synoptic study are provided in table 9. Results for two dates for samples collected at the bridge site 1306N also are provided. Boron was added to the standard NWQL major-ion analytical schedule (see Appendix 1, table A4) as a potential tracer of septic-tank effluent. Similarly, copper was added as a potential tracer of copper sulfate, a commonly used aquatic weed-control product. No primary drinking-water standards were exceeded with respect to the constituents; however, secondary drinking-water standards (which are based on aesthetics) for chloride, hardness, sodium and total dissolved solids (TDS) were exceeded.

The major-ion composition of samples collected at the five lake sites on August 3, 1999, is shown in a Piper Diagram (fig. 6). The tight clustering of data indicates insignificant spatial differences in the major chemistry of the lake. The relative abundance of major ions defines Cranberry Lake as mixed-type water. There is no dominant cation, and the anion composition of the water is dominated by equal amounts of carbonate and chloride with virtually no sulfate present. An average of the major ions in precipitation at the National Atmospheric Deposition Program (NADP) weather station at Washington Crossing, New Jersey, located approximately 40 mi. southwest of the study area, for 1998 also is plotted in figure 6 (National Atmospheric Deposition Program, 2000).

The results of analyses for nutrients in samples collected during the August 3, 1999, synoptic study are provided in table 10. Nitrogen and phosphorus concentrations are low. These values could be explained by the rapid reduction of available nitrogen and phosphorous through biologic pathways; the lake is eutrophic, as indicated by occasional algal blooms. The eventual sink for nutrients within Cranberry Lake could be biomass fixing and subsequent burial in the lake-bottom sediments. Sedimentation rates in the lake are high enough to necessitate frequent dredging of the lake; therefore, sedimentation could be a major factor in the nutrient cycle for the lake system. To improve the understanding of the nutrient cycle within this system, a thorough study of inputs (stream and overland inflows, septicsystem effluents, and precipitation) and outputs (stream outflows and sedimentation) is required.

The absence of pesticides was determined by analyzing only one sample, which was collected at site 1306N on June 28, 1999. The sample was analyzed for the compounds listed in USGS schedules 2001 and 2050 (Appendix 1, table A2). Although the sampling date was selected to correspond to the time of year when pesticide and herbicide use generally is high, no compounds were detected.

The measurements of other constituents are summarized in table 11. The values for fecal coliform, fecal streptococcus, and methylene blue activated substances (MBAS) were determined to assess the effect of septic-system effluents and biological contamination on the lake. The concentration of MBAS is a measure of certain types of detergents that could enter the lake through septic tanks, MBAS does not represent all types of detergents, however. Fecal coliform and fecal streptococcus are common bacteriological contaminants associated with feces from both animals and man. MBAS concentrations measured throughout the lake were low, but similar to MBAS concentrations measured in ground-water samples. Frequent low-level detections of MBAS throughout the lake indicate the presence of detergents, likely from septic-tank effluent. Fecal coliform and streptococcus values are low when compared to the New Jersey Surface Water Quality Standards of 200 counts per 100 mL; the highest values for Cranberry Lake were 40 counts per 100 mL.

Concentrations of total suspended solids (TSS) and chlorophyll-a and -b were measured to assess water clarity and productivity (table 11).

Table 9. Field characteristics and concentrations of major ions in samples from Cranberry Lake, Sussex County, New Jersey, 1999
[Env, environmental sample; NA, not applicable; ^o C, degrees celsius; DO, dissolved oxygen; SC, specific conductance in microsiemens per millimeter;
mg/L, milligrams per liter; µg/L, micrograms per liter; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the
U.S. Geological Survey water-quality data base (NWIS); <, less than; E, estimated value]

			Sam-		Water				Alka-												
			pling		temper-		DO		linity		Magne-		Potas-							Man-	Cop-
		Sam-	depth		ature		(winkler)		(mg/L as	Calcium	sium	Sodium	sium	Chloride	Sulfate	Fluoride	Silca	Boron	Iron	ganese	per
Cite analysis	Cite manual	pling	(feet)	Sample	(°C)	pH	(mg/L)	SC (00005)	(20086)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Site number	Site name	date	(00003)	type	(00010)	(00400)	(00300)	(90093)	(39080)	(00913)	(00923)	(00930)	(00933)	(00940)	(00943)	(00930)	(00933)	(01020)	(01046)	(01056)	(01040)
Synoptic study																					
1	C-1306 N	8/3/1999	6	Env	26.9	7.3	5.7	218	44	13.6	5.84	19.8	0.7	31.8	5.3	<.1	2.2	29	50	<3	<10
1	C-1306 N	8/3/1999	6	Replicate	26.9	7.4	5.7	216	44	13.3	5.66	18.3	<.1	33.5	8.2	<.1	2.3	22	40	<3	<10
1	C-1306 N	8/3/1999	NA	Blank	NA	NA	NA	NA	NA	<.02	<.004	M0.4	.5	<.1	<.1	<.1	.2	E8	<10	<3	<10
3	C-306 W	8/3/1999	6	Env	27.5	7.9	7.9	213	50	13.7	5.82	19.2	.6	32.5	7	<.1	2.1	24	30	<3	<10
6	C-2449 SW	8/3/1999	6	Env	25.3	6.8	2.5	189	50	13.6	5.63	17.7	.5	29.5	6.9	<.1	6.6	24	70	33	<10
8	C-1633 W	8/3/1999	6	Env	27.1	8.3	7.2	218	50	13.6	5.76	19	.7	33	5.3	<.1	2.2	26	60	<3	<10
10	C-3061 WSW	8/3/1999	1.5	Env	28.2	9.2	9.6	217	42	13.5	5.74	18.9	5.3	32.8	6.8	<.1	1.7	24	140	4	<10
Other studies					13.4	7.6	11.5	167	38	12.2	4.93	17.8	.6	31.1	12.1	<.1	1.2	20	30	E3	<10
1	C-1306 N	4/7/1999	3	Env	13.4	7.3	8.4	165	28	12.2	5	17.6	.6	31	12.1	<.1	1.1	19	20	E3	<10
1	C-1306 N	4/7/1999	10	Env	24.7	7.5	8	204	41	12.5	5.17	17.1	.6	30.6	10.8	<.1	.4	23	60	E2	<10
1	C-1306 N	6/1/1999	3	Env	21.7	7.1	6.2	154	36	12.5	5.24	17.9	.6	32.1	10.6	<.1	.4	21	70	<3	<10
1	C-1306 N	6/1/1999	10	Env	26.9	7.3	5.7	218	44	13.6	5.84	19.8	.7	31.8	5.3	<.1	2.2	29	50	<3	<10



Figure 6. Major-ion composition of samples collected from Cranberry Lake, Sussex County, New Jersey, during synoptic sampling, August 3, 1999, and of precipitation.

Table 10. Concentrations of nutrients in samples from Cranberry Lake, Sussex County, New Jersey [NA, not applicable; Env, environmental sample; mg/L, milligrams per liter; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); <, less than; --, not analyzed; E, estimated value]

Site number	Site name	Sampling date	Sampling depth (feet) (00003)	Sample type	Nitrogen, ammonia dissolved (mg/L as N) (00608)	Nitrogen, ammonia and organic dissolved (mg/L as N) (00623)	Nitrogen, ammonia and organic total (mg/L as N) (00625)	NO ₂ and NO ₃ dissolved (mg/L as N) (00631)	Phosphorus, total (mg/L as P) (00665)	Phosphorus, dissolved (mg/L as P) (00666)
Synoptic study										
1	C-1306 N	8/3/1999	6	Env	<.02	0.41	0.6	<.050	E.03	<.05
1	C-1306 N	8/3/1999	6	Replicate	<.02	.33	.5	<.050	<.05	<.05
1	C-1306 N	8/3/1999	NA	Blank	<.02	<.01	<.01	<.050	<.05	<.05
3	C-306 W	8/3/1999	6	Env	<.02	.42	.5	<.050	E.04	<.05
6	C-2449 SW	8/3/1999	6	Env	<.02	.42	.6	<.050	E.04	<.05
8	C-1633 W	8/3/1999	6	Env	<.02	.38	.4	<.050	E.03	<.05
10	C-3061 WSW	8/3/1999	1.5	Env	<.02	.41	.5	<.050	<.05	<.05
Other studies					0.04	.27		<.050		<.05
1	C-1306 N	4/7/1999	3	Env	0.04	.26		.081		<.05
1	C-1306 N	4/7/1999	10	Env	<.02	.27	.5	.063	E.04	<.05
1	C-1306 N	6/1/1999	3	Env	<.02	.27	.5	<.050	E.03	<.05
1	C-1306 N	6/1/1999	10	Env	<.02	.41	.6	<.050	E.03	<.05

Table 11. Concentration of constituents in samples from Cranberry Lake, Sussex County, New Jersey [Env, environmental sample; NA, not applicable; <, less than; --, not analyzed; col/100ml, colonies per 100 milliliters of sample; Chl-A, chlorophyll-A; Chl-B, chlorophyll-B; Phy, phytoplankton; Fl, filtered; TSS, total suspended solids; PE, precession estimate; pCi/L, picocuries per liter; TOC, total organic carbon; DOC, dissolved organic carbon; SOC, suspended organic carbon; MBAS, methylene blue activated substance; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); E, estimated value]

Site number	Site name	Sampling date	Sampling depth (feet) (00003)	Sample type	Fecal coliform (col/100ml)	Fecal strepto- coccus (col/100ml)	Chl-A Phy Fl (µg/L) (70953)	Chl-B Phy Fl (µg/L) (70954)	Residue, suspended, total (mg/L) (00530)	TOC (mg/L as C) (00680)	DOC (mg/L as C) (00681)	SOC (mg/L as C)	DOC:SOC Ratio	MBAS (mg/L) (38260)	Radon- 222 PE (pci/L) (76002)	Radon- 222, total (pci/L) (82303)
Synoptic S	Study															
1	C-1306 N	8/3/1999	6	Env	13	10	3.4	0.4	3	8.3	5.9	2.4	2.5	0.06		
1	C-1306 N	8/3/1999	6	Replicate					<1	7.6	6.5	1.1	5.9	.03		
1	C-1306 N	8/3/1999	NA	Blank					1	0.1	.1	0	NA	<.02		
3	C-306 W	8/3/1999	6	Env	5	2	3.6	.6	4	7.2	6.1	1.1	5.5	.07		
6	C-2449 SW	8/3/1999	6	Env	8	4	3.2	.6	4	9	7.6	1.4	5.4	.08		
8	C-1633 W	8/3/1999	6	Env	40	<1	6	1.1	5	7.6	5.7	1.9	3.0	.07		
10	C-3061 WSW	8/3/1999	1.5	Env	11	7	2.8	E.3	2	7.1	5.7	1.4	4.1	.04		
Other Stud	lies														14	40
															14	40
1	C-1306 N	4/7/1999	3	Env						14	5.2	8.8	.6	.03	14	30
1	C-1306 N	4/7/1999	10	Env						13	5	8	.6	.02	14	50
1	C-1306 N	6/1/1999	3	Env	13	10	3.4	.4	3	8.3	5.9	2.4	2.5	.06		
1	C-1306 N	6/1/1999	10	Env					<1	7.6	6.5	1.1	5.9	.03		

Chlorophyll concentrations are a direct measure of the phytoplankton biomass (Wetzel, 1983). Concentrations of TSS and chlorophyll were low, indicating high water clarity and relatively low productivity. The organic-carbon content and state were quantified by the measurements of total organic carbon (TOC) and dissolved organic carbon (DOC). Suspended organic carbon (SOC) content was calculated as the difference between TOC and DOC. Most of the organic carbon in Cranberry Lake is present as DOC. During the August 3, 1999, synoptic study, DOC:SOC ratios ranged from 2.5:1 to 5.9:1 and were as low as 0.6:1 on June 1, 1999. Typically, DOC:SOC ratios in lake water range from 6:1 to 10:1 (Wetzel, 1983). Chlorophyll concentrations measured during the August 3, 1999, synoptic study were low; therefore, the relatively high SOC concentrations could result from the presence of humic substances.

Time-series sampling was conducted at Cranberry Lake beneath the footbridge (site 1306N) to determine seasonal VOC trends. Lake water at the site was sampled 4 times in 1998 from June 24 to December 16 and 12 times in 1999 from April 7 to November 22. In 1999, the sampling typically was conducted on Mondays in an attempt to provide a consistent measure of seasonal trends. The VOC time-series concentration data for site 1306N are provided in table 12. As was the case for synoptic sampling, only fuel-related VOCs and chloroform were detected. MTBE concentrations always are higher than those of other VOCs; concentrations greater than 20 μ g/L are typical for the summer months with watercraft usage. TAME concentrations typically were the next highest among VOCs; TAME concentrations were highly correlated with MTBE concentrations (correlation coefficients of 0.85 and 0.96 for the 3-ft and 10-ft data sets, respectively). Both compounds are ether-type fuel oxygenates. The MTBE concentrations were approximately 20 times greater than the TAME concentrations. Toluene and benzene typically were detected in samples at low concentrations, and (excluding the sample collected at 3 ft on June 1, 1999) concentrations of toluene and benzene were less than 0.6 and 0.2 μ g/L, respectively. Concentrations of the other BTEX compounds,

when detected, were even lower. Chloroform was the only other VOC commonly detected. VOCs with isolated detections were 1,3-dichlorobenzene, which was detected on May 17 and June 1, 1999, in samples from both depths at concentrations less than 0.08 μ g/L, and styrene, which was detected in a low concentration (0.15 μ g/L) on June 1, 1999, in a sample from 3 ft.

MTBE time-series data are plotted in figure 7 (November 5, 1998-November 22, 1999). During this period, samples were collected regularly from the 3-ft and 10-ft sampling depths. The MTBE time series at 10 ft varies more smoothly than that at 3 ft because water 10 ft below the lake surface is less affected by shortterm variation in boat traffic. Water adjacent to the lake bottom is available for lake/aquifer exchange; therefore, the 10-ft time series is the most relevant for assessment of the lake as a potential source of VOCs to wells. Outside the recreational season (approximately mid-May through mid-October), the lake is not a significant source of MTBE or any other VOC. MTBE concentrations at 10 ft peaked about July 29, indicating that time the lake water was mixed. Early in the recreational season, concentrations can be substantially higher in the shallow part of the lake than in the deep part because the bridge from which samples were collected is over a deep part of the lake where, in early summer, density stratification occurs. Temperature profiles from measurements made at the bridge from April to November 1999 are shown in figure 8. Sometime between July 29 and August 26 (probably closer to July 29), the vertical temperature gradient and, thus, density stratification, dissipated in Cranberry Lake. This is consistent with the MTBE concentration data (fig. 7) because MTBE concentrations at the 3-ft and 10-ft depths became essentially equal during that time.

The seasonal variability of VOC mass in Cranberry Lake can be estimated from the timeseries data collected at the bridge (site 1306N). Results of synoptic sampling demonstrated that concentrations measured at the bridge were representative of VOC concentrations throughout the northern part of the lake. The concentrations of VOCs in the southern part of the lake are **Table 12.** Concentrations of fuel-related volatile organic compounds in Cranberry Lake as sampled from the Cranberry Lake footbridge,Cranberry Lake, Sussex County, New Jersey, June 24, 1998 - November 22, 1999

[Variations in depth to bottom are solely due to changes in lake depth. Concentrations are in micrograms per liter. 1,3-dichlorobenzene was detected on 5/17/1999 and 6/1/1999 in samples from both depths at concentrations less than 0.08 µg/L. Styrene was detected in a low concentration (0.1518 µg/L) on 6/1/1999 in a sample from 3 ft; MTBE, methyl tert-butyl ether; TAME, tertiary amyl-methyl ether; >, less than; --, not analyzed; *, windy--depth measure may have been affected; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); E, estimated value]

Sampling	Depth to	M (78	ГВЕ 3032)	TA (50	ME 005)	Ber (34	12ene 1030)	Tol: (34	uene 1010)	Ethyl-b	enzene 371)	M,P 2 (85	Kylene (795)	O x (77	ylene (135)	Chlor (32	roform 2106)
date	bottom (ft)	3 ft	10 ft	3 ft	10 ft	3 ft	10 ft	3 ft	10 ft	3 ft	10 ft	3 ft	10 ft	3 ft	10 ft	3 ft	10 ft
6/24/1998	12.7	13.6		0.384		0.122		0.648		0.119		0.451		0.196		<.052	
9/8/1998	11.7	27.3		.565		E.065		E.18		E.022		E.076		E.037		E.022	
11/5/1998	11.5	1.13	1.04	<.22	<.22	<.20	<.20	E.065	<.10	<.060	<.060	<.12	<.12	<.12	<.12	<.104	<.104
12/16/1998	11.0	.384	.373	<.11	<.11	<.1	<.1	<.05	<.05	<.03	<.03	<.06	<.06	<.06	<.06	<.052	<.052
4/7/1999	12.5	.726	.712	E.0285	E.0355	E.0461	E.0473	.252	.247	E.0591	E.0586	E.194	.201	E.0991	E.0962	E.0115	E.0111
5/17/1999	12.3	7.57	2.86	.402	E.0832	.132	<.1	E.0464	E.00759	E.00671	<.03	E.168	<.06	.119	<.06	E.0146	E.0192
6/1/1999	12.0	28.8	4.42	2.26	.302	1.75	<.1	2.63	E.0828	.388	<.03	2.31	<.06	2.45	<.06	<.052	E.0193
6/14/1999	12.0	15.9	10.8	.935	.677	E.0469	E.0115	E.0270	E.0291	<.03	<.03	<.06	<.06	<.06	<.06	E.0150	E.0174
6/28/1999	12.3	22	16.2	.98	.708	.133	E.0544	.137	E.0170	E.0248	<.03	E.0931	<.06	E.0529	<.06	<.052	<.052
7/13/1999	11.6	23.5	20.5	1.22	.972	E.0384	E.0230	<.05	<.05	<.03	<.03	<.06	<.06	<.06	<.06	<.052	<.052
7/26/1999	11.4	30.9	21.8	1.23	1.01	.228	E.0300	<.05	E.0488	<.03	<.03	<.06	<.06	<.06	<.06	E.0145	E.0150
8/26/1999	11.4	16.4	18	.739	.82	E.0237	<.1	E.0454	E.0209	<.03	<.03	<.06	<.06	<.06	<.06	<.052	<.052
9/20/1999	12.9	8.3	6.58	.595	.582	.167	E.0922	E.0784	E.0755	<.03	<.03	E.0915	E.0521	0.115	E.0545	E.0148	E.0254
10/18/1999	11.5*	2.54	2.35	.131	.132	E.0195	E.0170	E.0837	.127	<.03	<.03	<.06	<.06	<.038	<.038	<.052	E.0162
11/1/1999	12.2	2.8	2.21	.206	.137	E.0487	E.0284	.163	.191	E.00765	E.00933	E.0309	E.0249	E.0441	E.0275	E.0173	E.0151
11/22/1999	11.5	1.84	1.02	E.0778	E.0642	.103	E.0215	.555	.183	E.0863	E.0113	.303	E.0316	.182	E.0296	E.00975	E.00993



Figure 7. Concentrations of Methyl tert-butyl ether from shallow and deep sampling depths, at the footbridge over Cranberry Lake, Sussex County, New Jersey, November 5, 1998, through November 22, 1999.



Figure 8. Temperature profiles from measurements made at the footbridge over Cranberry Lake, Sussex County, New Jersey, April to November 1999.

assumed on the basis of results of the synoptic study to be one-third of those at site 1306N. South of Strawberry Point is the generally shallow, inlet part of the lake where boat traffic is greatly reduced and VOC concentrations are lower. The average volume of Cranberry Lake is approximately 1,709,387 cubic meters, of which 1,267,721 cubic meters, or 74 percent, constitutes the main part of the lake north of Strawberry Point. If the lake is mixed, then the mass estimate is obtained by multiplying concentrations by volumes for the northern and southern parts of the lake and adding the results. Estimates of VOC mass when the lake is stratified are obtained by assuming an exponential function to approximate the depth-dependence of concentrations fitted to the measured concentrations at 3 ft and 10 ft and numerically integrating over the lake volume by using the bathymetric map. The mass estimates for VOCs in Cranberry Lake during 1998-99 are summarized in table 13. If gasoline is assumed to consist of 10 percent MTBE by volume (282 grams per gallon), the equivalent of the MTBE mass in gallons of gasoline (fig. 9) provides an overall estimate of the seasonal contribution of MTBE from gasoline-powered watercraft. For example, for July 29, 1999, the amount of MTBE in Cranberry Lake was estimated to be the equivalent amount of MTBE in 129 gal of oxygenated gasoline.

To determine how concentrations can vary within a week during the peak boating season, water at site 1306N was sampled approximately every 2 days from August 26, 1999, to September 8, 1999, which included the Labor Day (September 6, 1999) holiday weekend. The results for MTBE are reported in table 14. Samples were analyzed for MTBE at the NJDL. A comparison of the results obtained by NJDL and NWQL for MTBE are provided in Appendix 1. The NJDL results agreed well (correlation coefficient 0.91) with those from NWQL for the concentration range tested (MTBE concentrations from 4.2 to $30.8 \mu g/L$). It previously was determined that analyses done by NJDL are appropriate for determining fuel-related VOC concentrations at levels greater than 1 μ g/L. The water in Cranberry Lake was mixed during this period; therefore, concentrations reported at different sampling

depths were similar and confirm one another. Within this period, MTBE concentrations did not vary significantly, which indicates that the seasonal sampling conducted every 2 weeks was adequate to estimate the mass of MTBE in Cranberry Lake.

Lake Lackawanna

Synoptic sampling was conducted on Lake Lackawanna on September 9, 1998, and August 19, 1999. The results of the September 9, 1998, synoptic study are reported in Baehr and Zapecza (1998). As was the case for Cranberry Lake, samples to be analyzed for a comprehensive suite of compounds were collected while the lake was well mixed to compare concentrations in lake water to those in ground water. Time-series samples were not collected for Lake Lackawanna.

Concentrations of VOCs in samples collected on September 9, 1998, and August 19, 1999, are listed in table 15. In the August 19, 1999, synoptic study, samples were collected only from one depth per site. On both dates the water in Lake Lackawanna was mixed, and, therefore, the concentrations at the lake bottom where water would be exchanged between the lake and aquifer would be similar to those reported. Concentrations of MTBE were the highest among VOCs for both synoptic studies. MTBE concentrations were considerably lower in 1999 than in 1998 (highest values reported were 5.1 and 14.0 µg/L, respectively). Some concentrations of TAME and BTEX were slightly higher in 1999 than in 1998, but all 1999 concentrations of TAME and BTEX were less than 0.57 and 0.21 µg/L, respectively. The lower MTBE values are attributed to reduced boat traffic associated with the drought conditions during the summer of 1999. The level of Lake Lackawanna was about 18 in. lower on August 19, 1999, than on September 9, 1998. Although the level of Cranberry Lake declined similarly. Lake Lackawanna is smaller and shallower (average depth of 4 ft compared to an average depth of 7.4 ft for Cranberry Lake) and the decline in its water level rendered much of the lake unnavigable because tree stumps and debris were exposed over a large part of the lake. No chlorinated VOCs (for example, PCE, TCA, TCE,

Table 13. Seasonal estimates of fuel-related volatile organic compound masses in Cranberry Lake, New Jersey, 1998-99

[Mixing condition was either stratified (S) or mixed (M); fuel volumes were estimated only when the lake was mixed; kg, kilograms; gal, gallons; MTBE, methyl tert-butyl ether; TAME, tertiary amyl-methyl ether; >, less than; --, not analyzed]

		MTBE (kg) / estimated fuel							
Date	Mixing condition	volume (gal)	TAME (kg)	Benzene (kg)	Toluene (kg)	Ethylbenzene (kg)	m,p-Xylene (kg)	o-Xylene (kg)	Chloroform (kg)
6/24/1998	S	18	0.51	0.14	0.69	0.15	0.55	0.24	0
9/8/1998	Μ	26 / 92.2	.7	.08	.22	.03	.09	.05	.03
11/5/1998	М	1.35 / 4.81	0	0	.08	0	0	0	0
12/16/1998	М	0.42 / 1.5	0	0	0	0	0	0	0
4/7/1999	М	1.00 / 3.74	.04	.06	.35	.08	.14	.27	.02
5/17/1999	S	8.79	.21	.17	.05	.02	.18	.12	.02
6/1/1999	S	30.1	2.35	1.74	2.65	.39	2.30	2.44	.01
6/14/1999	S	19.6	1.16	.05	.04	0	0	0	.02
6/28/1999	М	29.8 / 106	1.33	.18	.19	.03	.13	.07	0
7/13/1999	М	28.6 / 101	1.49	.05	0	0	0	0	0
7/29/1999	М	36.4 / 129	1.45	.27	0	0	0	0	.02
8/3/1999	М	28.6 / 101	.86	.03	.05	0	0	0	0
8/26/1999	М	9.79 / 34.8	.7	.2	.09	0	.11	.14	.02
9/20/1999	М	3.73 / 13.2	.19	.03	.12	0	0	0	0
11/1/1999	М	3.73 / 13.3	.27	.06	.22	.01	.04	.06	.03
11/22/1999	М	2.20 / 7.83	.09	.12	.67	.1	.36	.22	.01


Figure 9. Estimated Methyl tert-butyl ether content in Cranberry Lake in equivalent gallons of gasoline, Sussex County, New Jersey, June 24, 1998, to November 22, 1999.

Table 14. Concentrations of methyl tert-butyl ether in samples collected at the Cranberry Lake footbridge, Cranberry Lake, Sussex County, New Jersey, August 26 to September 8, 1999

[--, not analyzed; /, replicate samples; µg/L, micrograms per liter]

		Meth	nyl tert-butyl ether (µg	/L)
Sampling date	Day of the week	3 feet	6 feet	10 feet
8/26/1999	Thursday	14.3/15.1	13.5	16.2/15.6
8/29/1999	Sunday	18.1		15.3
8/30/1999	Monday	16.2	16.7	
9/31/1999	Tuesday	13.9	12	
9/1/1999	Wednesday	13.9	14.2	
9/3/1999	Friday	15.8	15.8	
9/6/1999	Monday (Labor Day)	18.9		
9/7/1999	Tuesday		19.9	
9/8/1999	Wednesday		17	

or chloroform) were detected. The estimate of total mass reported in table 15 was obtained as previously described for Cranberry Lake. The MTBE content in Lake Lackawanna during the 1998 and 1999 synoptic studies is equivalent to 17.92 and 3.68 gal of gasoline, respectively. The Lubbers Run site (table 15) is in the inlet stream just before it enters Lake Lackawanna.

Values of field characteristics and concentrations of major ions in samples collected during the August 19, 1999, synoptic study are provided in table 16; nutrient concentrations are listed in table 17. Values for organic carbon, MBAS, and TSS are listed in table 18. The majorion composition of water from Lake Lackawanna is summarized in a Piper diagram (fig. 10). The tight clustering of data indicates that the lake water is mixed. The relative abundance of major ions defines Lake Lackawanna as a mixed-type water. There is no dominant cation, and the anion composition of the water is dominated by equal amounts of carbonate and chloride with virtually no sulfate present. The distribution of ions and the concentration of nutrients in Cranberry Lake (fig. 6; table 10) and Lake Lackawanna are nearly identical, as may be expected because they are only 2.5 mi. apart.

Lake Hopatcong

The study of Lake Hopatcong was initiated in 1999. The inclusion of Lake Hopatcong, New Jersey's largest lake and most populous lakeside community, was a necessary step in developing a regional study. Only fuelrelated VOCs--MTBE, TAME, and BTEX--were analyzed for in lake-water samples at the NJDL. Synoptic sampling was conducted on August 18, 1999, and September 13, 1999. Time-series sampling was conducted from a highway bridge (fig. 5).

The results of the synoptic sampling are summarized in table 19. On August 18, 1999, MTBE concentrations in samples collected from shallow parts of the lake (10 ft and less) ranged from 5.0 to 8.3 μ g/L. MTBE concentrations were lower in samples collected from deeper parts of the lake; however, all concentrations, even those from depths of 40 ft, were greater than $2.0 \mu g/L$. MTBE concentrations were lower than anticipated on the basis of concentrations observed throughout the summer at the highway bridge site. Because the dynamics of mixing and the relation of VOC concentrations to boat traffic in Lake Hopatcong were not well understood, the second synoptic study was conducted shortly after the first. MTBE concentrations in samples collected on September 13, 1999, from shallow parts of the lake (10 ft and

Table 15. Concentrations of selected fuel-related volatile organic compounds in samples from Lake Lackawanna and total fuel-related volatile organic compound mass estimates, Sussex County, New Jersey, September 9, 1998, and August 19, 1999 [The value reported for 1998 corresponds to the synoptic sampling of September 9, 1998, and the value reported for 1999 corresponds to the synoptic sampling of August 19, 1999. Concentrations are in micrograms per liter; depths in feet below surface; kg, kilograms; ft, feet; <, less than (considered non-detect); --, not analyzed; MTBE, methyl tert-butyl ether; TAME, tertiary amyl-methyl ether; Differences in lake depths reported in 1998 and 1999 are due to changes in overall lake level and slight differences in site location. Styrene was detected in a low concentration (0.0051 μ g/L) at Site 3 (1564NE) on August 19, 1999. For total mass calculation, the lake volume on September 9, 1998, and August 19, 1999, was approximately 509,706 and 306,174 cubic meters, respectively; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); E, estimated value]

Site		Sampling depth (ft) ^I	Depth to I	bottom (f	MT t) (78	BE 032)	TA (50	ME 0005)	Be: (34	nzene 4030)	Tolu (34(ene)10)	Ethyl	benzene 4371)	m,p- (8;	Xylene 5795)	o-:	Xylene 77135)
number	Site name	(00003)	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
1	Lubbers Run	1.5	2.0	0.0	<.17		<.11		<.1		E.045		<.03		<.06		<.06	
3	1564NE	5	7.1	6.1	E14	5.05	.287	0.565	<.1	E.0751	<.05	0.206	<.03	E.0505	E.011	0.204	<.06	0.115
5	3237NE	3	4.0	4.0	E3.7	1.36	.167	E.0681	<.1	<.1	<.05	<.05	<.03	<.03	<.06	<.06	<.06	<.06
6	751NE	5	6.3	5.9	E12	3.75	.251	.294	<.1	E.0281	<.05	E.0638	<.03	<.03	<.06	E.0336	<.06	<.06
Average	in-lake				9.9	3.39	.235	.309	<.1	.052	<.05	.135	<.03	.051	<.06	.119	<.06	.115
Total ma	ass in lake (kg)				5.05	1.04	.12	.095	0	.016	0	.041	0	.015	0	.036	0	.035
Estimate	ed fuel volume (ga	al)			17.92	3.68												

Table 16. Field characteristics and concentrations of major ions in samples from Lake Lackawanna, Sussex County, New Jersey, August 19, 1999 [$^{\circ}$ C, degrees Celsius; DO, dissolved oxygen; SC, specific conductance in microsiemens per millimeter at 25 $^{\circ}$ Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); <, less than; E, estimated value]

Site number	Site name	Station identification number	Sampling depth (feet below lake surface) (00003)	Water temper- ature (°C) (00010)	pH (standard units) (00403)	DO (Winkler) (mg/L) (00300)	SC (90095)	Alka- linity (mg/L as CaCO ₃) (39086)	Calcium (mg/L) (00915)	Magne- sium (mg/L) (00925)	Sodium (mg/L) (00930)	Potas- sium (mg/L) (00935)	Chloride (mg/L) (00940)	Sulfate (mg/L) (00945)	Fluoride (mg/L) (00950)	Silica (mg/L) (00955)	Boron (μg/l) (01020)	Iron (μg/l) (01046)	Manga- nese (µg/l) (01056)	Copper (µg/l) (01040)
3	L-1564 N	405700074420301	5	26.1	9.4	11.3	285	68	21	10	22	0.7	41	3.7	0.1	17	E13.3	35	8	<10
5	L-3237 NE	405710074414201	3	26.2	9.1	10.2	280	70	20	10	18	.5	41	5.2	.1	13	E14.1	62	8	<10
6	L-751 NE	405652074420501	5	25.5	9.2	9.1	292	71	22	10	18	.8	41	5.3	<.1	17	26.9	62	15	<10

Table 17. Concentration of nutrients in samples from Lake Lackawanna, Sussex County, New Jersey, August 19, 1999 [mg/L, milligrams per liter; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); <, less than; --, not analyzed; E, estimated value]

Site number	Site name	Station identification number	Sampling depth (feet below lake surface) (00003)	Nitrogen, ammonia dissolved (mg/L as N) (00608)	Nitrogen, ammonia and organic dissolved (mg/L as N) (00623)	Nitrogen, ammonia and organic total (mg/L as N) (00625)	NO ₂ and NO ₃ , dissolved (mg/L as N) (00631)	Phosphorus, total (mg/L as P) (00665)	Phosphorus, dissolved (mg/L as P) (00666)
3	L-1564 N	405700074420301	5	<.02	0.49	0.5	<.050	E.04	<.05
5	L-3237 NE	405710074414201	3						
6	L-751 NE	405652074420501	5	<.02	.35	.5	<.050	E.05	<.05

Table 18. Organic carbon, methyl blue activated substances and total suspended solid concentrations in samples from Lake Lackawanna,

 Sussex County, New Jersey, August 19, 1999

[mg/L, milligrams per liter; MBAS, methylene blue activated substance; TSS, total suspended solids; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); <, less than]

Site number	Site name	Station identification number	Sampling depth (feet below lake surface) (00003)	Carbon, organic total (mg/L as C) (00680)	Carbon, organic dissolved (mg/L as C) (00681)	MBAS (mg/L) (38260)	TSS (mg/L) (00530)
3	L-1564 N	405700074420301	5	6.7	5.3	.03	<1
5	L-3237 NE	405710074414201	3	6.4	5.5	.04	<1
6	L-751 NE	405652074420501	5	6.6	5.2	.03	1



Figure 10. Major-ion composition of samples collected from Lake Lackawanna, Sussex County, New Jersey, during synoptic sampling, August 19, 1999, and of precipitation.

Table 19. Concentrations of selected volatile organic compounds in samples and fuel-mass estimates for Lake Hopatcong, Sussex and Morris Counties, New Jersey, August 18, 1999, and September 13, 1999

[Depth to bottom and sampling depth both in feet below lake surface. All concentrations in micrograms per liter. <, less than; --, not analyzed. Variation in the difference between lake depths for the two synoptics between sites because of slight differences in site location; ft, feet; gal, gallons; MTBE, methyl tert-butyl ether; TAME, tertiary amyl-methyl ether]

Site	Site name	Sampling depth (feet <u>[</u> below lake surface)	Depth to bo 8/18/ 9/13/	<u>ottom (ft)</u> /99 /99	N 8/ 9/	ITBE 18/99 13/99	TAN 8/18/ 9/13/	<u>//E</u> /99 /99	Benz/ 8/18/ 9/13/	ene 99 99	<u>Tolue</u> 8/18/ 9/13/	ne 99 99	<u>Ethylb</u> 8/18 9/13	<u>enzene</u> /99 /99	<u> </u>	<u>ylene</u> /99 /99	<u> </u>	<u>ene</u> /99 /99
		,																
H-1	Point Pleasant	3	9.2	8.2	7.6	13.7	0.1	1.9	< 0.2	< 0.2	< 0.2	0.3	<0.2	< 0.2	< 0.2	< 0.2		< 0.2
H-1	Point Pleasant	8	9.2	8.2	8.3	14	.5	1.9	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2		<.2
H-2	Elba Point	5	46.2	46.8	7.3	8.9	.1	.1	<.2	.2	<.2	<.2	<.2	<.2	<.2	<.2		<.2
H-2	Elba Point	10	46.2	46.8	7.6	8.8	.6	1.1	<.2	.4	<.2	.2	<.2	<.2	<.2	<.2		<.2
H-2	Elba Point	20	46.2	46.8	5.5	2	<.1	<.1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2		<.2
H-2	Elba Point	30	46.2	46.8	2.4	3.9	<.1	<.1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2		<.2
H-2	Elba Point	40	46.2	46.8	2	3.4	<.1	<.1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2		<.2
H-3	River Styx	3	6.9	6.3	7.3	18.4	.8	1.6	<.2	<.2	<.2	.5	<.2	<.2	<.2	.8		.5
H-3	River Styx	6	6.9	6.3	5.4	20.5	.5	1.7	<.2	.4	<.2	1.0	<.2	.2	<.2	1.3		.7
H-4	Halsey Island	5	42	41.5	7.3	9.7	.2	.6	<.2	.4	<.2	.6	<.2	<.2	<.2	.8	<.2	.4
H-4	Halsey Island	10	42	41.5	6.8	9.8	.8	.9	<.2	.4	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
H-4	Halsey Island	20	42	41.5	3.4	4.3	<.1	.1	<.2	.6	<.2	.4	<.2	<.2	<.2	<.2	<.2	<.2
H-4	Halsey Island	30	42	41.5	3	3.7	<.1	<.1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
H-4	Halsey Island	40	42	41.5	2.3	3.6	<.1	.1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
H-5	Hendersen Bay	5	23	24.3	7.3	10	.2	.1	<.2	0.5	<.2	.6	<.2	<.2	<.2	<.2		<.2
H-5	Hendersen Bay	15	23	24.3	7	10	.3	1.0	<.2	.4	<.2	.3	<.2	<.2	<.2	<.2		<.2
H-5	Hendersen Bay	20	23	24.3	4.4	8.2	<.1	.5	<.2	.2	<.2	<.2	<.2	<.2	<.2	<.2		<.2
H-6	Liffy Island	3	9.5	7	5	10	.2	1.1	<.2	<.2	1.0	.4	<.2	<.2	.8	<.2	<.2	<.2
H-6	Liffy Island	8	9.5	7	6.1	8.5	.4	.1	<.2	<.2	<.2	.3	<.2	<.2	.9	<.2	.5	<.2

Estimated total mass (kg)/Estimated fuel volume (gal) 173.6 / 616.3 240.2 / 853.0

less) were higher, ranging from 8.5 to 20.5 μ g/L. Concentrations in samples from depths greater than 10 ft were somewhat higher than those measured in the samples collected during the synoptic of August 18, 1999. Mass estimates for MTBE were obtained by using numerical integration with a method of concentration extrapolation with depth similar to that previously described for Cranberry Lake. If the MTBE content of gasoline is assumed to be 10 percent by volume (282 g/gal), the mass of MTBE in Lake Hopatcong corresponds to the amount of MTBE in 616 and 853 gal of gasoline on August 18, 1999, and September 13, 1999, respectively. TAME was detected in nearly all samples at concentrations less than 2.0 µg/L. BTEX was detected less frequently because of the low sensitivity of the NJDL method (minimum detection level of 0.2 µg/L); consequently, mass-balance estimates were not made for other VOCs.

The main channels of Lake Hopatcong are deep and, unlike Cranberry Lake and Lake Lackawanna, parts of the lake remain stratified through late summer. The differences in water quality across the bottom of the lake that result from variation of mixing conditions could affect the transport of contaminants to nearby wells. Wells whose contributing areas intersect shallow parts of the lake could draw in surface-derived contaminants like MTBE over most of the recreational season, unlike wells whose contributing areas intersect deeper parts of the lake beneath the main channels. Temperature profiles determined during sampling are plotted for selected sites that represent shallow, intermediate, and deep parts of the lake (fig. 11). The data indicate the persistence of stratification in parts of the lake deeper than 20 ft through September 13, 1999, which is consistent with the MTBE concentration data that show lower concentrations in samples from depths greater than 20 ft.

Time-series sampling of Lake Hopatcong was conducted from a bridge at the site referred to as River Styx (fig. 5). The lake water at this site was sampled 10 times from June 1, 1999, to November 22, 1999, at depths 3 ft and 6 ft below the lake surface to determine the seasonal variation of VOCs in the lake. At this site, the lake is only about 6.5 ft deep. A deeper part of the lake would have yielded samples more representative of the effects of stratification; however, the bridge at the River Styx location was the only safe location from which to sample the lake without a boat. Typically, samples were collected on Mondays to obtain maximum concentrations after a weekend and to provide consistent seasonal measurements. Samples were analyzed at the NJDL for MTBE, TAME and BTEX; the results are listed in table 20. The MTBE concentrations in samples collected at 3-ft and 6-ft depths are similar throughout the period of record as a result of mixing within the shallow depth. MTBE concentrations were highly variable between June 1 and September 20, 1999, ranging from 5.7 to 26.6 µg/L with no discernable seasonal pattern. The variability observed is most likely caused by boat traffic focused in this narrow part of the lake for access to Crescent Cove. After October 18, 1999, MTBE concentrations declined. Total mass estimates based on this data could not be calculated because of the lack of MTBE data representative of deeper parts of the lake.

To determine how much concentrations can vary within a week, the River Styx site was sampled nine times from August 26, 1999, to September 20, 1999, which included Labor Day (September 6, 1999). Samples were analyzed at the NJDL. MTBE concentrations in samples from the 3-ft and 6-ft depths are similar because of mixed conditions (table 21). The highest concentrations of MTBE reported were in samples collected on Sunday, August 29, and Monday, September 13, and are presumed to result from increased weekend boat traffic.

POINT-SOURCE CONTAMINA-TION OF WELLS AT CRANBERRY LAKE

In response to the contamination of a well from a point source, the New Jersey Department of Environmental Protection (NJDEP) sampled wells in a neighborhood of Cranberry Lake (fig. 2) in the summer of 1998. The results of the NJDEP sampling indicated that MTBE was the only contaminant in several wells in the neighborhood;



Figure 11. Temperature as a function of depth at selected sites on Lake Hopatcong, Sussex and Morris Counties, New Jersey, August 18, 1999, and September 13, 1999.

measur	ed from th	e bridge over t	he River Styx, I	Borough of Ho	opatcong, Susse	ex County, Nev	w Jersey, June	l, 1999-Noven	nber 22, 1999
[<, less TAME,	than;, n tertiary ar	ot analyzed; ^o (nyl-methyl eth	C, degrees Celsi ler]	ius. All concer	ntrations in mic	rograms per li	ter. MTBE, me	thyl tert-butyl	ether;
Sampling	Depth to bottom	Temperature (°C)	MTBE	TAME	Benzene	Toluene	Ethylbenzene	m.p-Xylene	o-Xylene

3 ft

0.4

<.2

<.2

<.2

.4

<.2

6 ft

--

--

<.2

<.2

<.2

<.2

.4

.1

3 ft

--

--

1.1

<.2

<.2

.1

.9

.1

6 ft

--

--

<.2

.3

<.2

.1

.9

.2

3 ft

--

--

<.1

<.1

<.1

<.1

.1

<.1

6 ft

--

--

<.1

<.1

<.1

<.1

.1

.1

3 ft

--

1.0

<.1

<.1

<.1

.7

<.1

6 ft

--

<.1

<.1

<.1

<.1

.8

<.1

3 ft

--

--

0.5

<.1

<.1

<.1

.6

<.1

6 ft

--

<.1

<.1

<.1

<.1

.7

.1

Table 20. Concentrations of selected volatile organic compounds in samples from Lake Hopatcong, and lake depth and temperature as

Table 21. Concentrations of selected volatile of	organic compounds in samples from
Lake Hopatcong, bridge over the River Styx, H	Borough of Hopatcong, Sussex County,
New Jersey, August 29, 1999-September 15, 1	999

[All concentrations in micrograms per liter; --, not analyzed; <, less than; MTBE, methyl tert-butyl ether; TAME, tertiary amyl-methyl ether; BTEX, sum of the concentrations of benzene, toluene, ethylbenzene, and xylene]

Sampling	Day of the	M	ГВЕ	TA	ME	B7	ΈX
date	week	3 feet	6 feet	3 feet	6 feet	3 feet	6 feet
8/26/99	Thursday	5.7	6.5	0.7	0.9	<.2	0.3
8/29/99	Sunday	15.3	17.1	1.8	2.3	10.8	11.9
8/30/99	Monday	10	9	1.2	1	.8	<.2
9/01/99	Wednesday	8.3	8	.9	.9	2.1	1.8
9/03/99	Friday	10	7.3	1.5	.6	5.7	<.2
9/10/99	Friday	8	10.7	.2	.5	.3	3.9
9/13/99	Monday	18.4	20.5	.5	1.7	1.8	3.6
9/15/99	Wednesday	8.5		.7		.4	
9/20/99	Monday	10.4	9.4	1.1	.2	<.2	<.2

date

06/01/99

06/14/99

07/13/99

08/26/99

09/20/99

10/18/99

11/01/99

11/22/99

(feet)

7.6

7.7

7.0

6.5

7.8

7.5

8.0

6.3

3 ft

22.7

23.2

23.9

23.0

18.9

14.3

13.0

7.6

6 ft

20.3

22.9

23.5

22.9

18.3

14.3

12.2

7.4

3 ft

26.6

11.5

20.2

5.7

10.4

3.8

7.2

2.3

6 ft

21.9

11

13

6.5

9.4

3.8

7.3

2.1

3 ft

1.5

.7

1.1

.2

.6

.1

6 ft

--

--

0.9

.9

.2

<.1

.7

.1

essentially, no BTEX was present (Stephen Stiansen, Sussex County Health Dept, written commun., 1998). To verify that MTBE was the sole contaminant and to provide additional waterquality data to improve the understanding of the source and migration of contamination, the USGS sampled eight wells in the neighborhood from July 21 to July 29, 1998. Results of the analysis for VOCs are presented in table 22. Field characteristics and concentrations of major ions in the samples are listed in table 23; concentrations of nutrients, MBAS, and organic carbon are listed in table 24.

MTBE was detected at concentrations greater than or equal to 40 µg/L in five of the eight wells. Other VOCs were detected in samples from the wells, most notably TAME and some chlorinated VOCs. The observation, based on the NJDEP data, that BTEX generally does not cooccur with MTBE in these wells was re-affirmed. Benzene and toluene were detected in a few samples at extremely low concentrations, all less than 0.05 μ g/L (table 22). Furthermore, BTEX was not detected in the sample from CR-08, the most highly contaminated well, which had a MTBE concentration of 900 µg/L. MTBE and TAME concentrations are highly correlated (correlation coefficient 0.98), indicating that the ether oxygenates migrated to the wells from the same source. The slope of the regression line fitted to the MTBE and TAME concentration data for the five highly contaminated wells in which TAME was detected is 10.9. This value indicates that MTBE source concentrations were about 10.9 times those for TAME. Concentrations of the chlorinated compounds are unrelated to MTBE and TAME concentrations and, therefore, these compounds originate from a different source. Nitrate concentrations were not related to MTBE concentrations; therefore, septic-tank effluent is not suspected as a source of MTBE ground-water contamination. MBAS either was not detected in the MTBE-contaminated wells or was detected at low concentrations near the reporting limit of 0.02 mg/L and, therefore, did not provide an indication of septic-tank influence.

The observation that BTEX compounds do not co-occur with MTBE may seem anomalous

given that the source is likely a spilled petroleum product. The data, however, are consistent with the solubility and content of MTBE in spilled products relative to those of BTEX compounds. For example, if an oxygenated gasoline consists of 10 percent, 5 percent, and 2 percent (on a mole fraction basis) of MTBE, toluene, and benzene, respectively, then the ratios of concentrations in water equilibrated with the gasoline would be 270: 1.4: 1. These ratios are determined by multiplying the mole fractions by the solubilities listed in table 25. If spilled oxygenated gasoline was the source of the well contamination, then, on the basis of solubility considerations alone, the MTBE source concentrations would be about 200 times the concentrations of any of the BTEX compounds. In a recent study (Baker and others, 2000) of used motor oil taken from vehicles in New Jersey, MTBE concentrations in water equilibrated with the used motor oil were on the order of 25 to 50 times the BTEX concentrations; therefore, similar MTBE-dominant concentration ratios would be expected if used motor oil was the source. Furthermore, BTEX compounds are believed to be more degradable than MTBE in aquifers, a factor that would further increase the dominance of MTBE in contaminated wells.

GROUND-WATER QUALITY

Comparison to Lake-Water Quality at Cranberry Lake and Lake Lackawanna

The 14-well network selected for sampling of ambient ground water at Cranberry Lake (fig. 2) was sampled first during November and December 1998, and then again in August 1999. At Lake Lackawanna, five wells were sampled in August 1999. Samples were analyzed for VOCs, major ions, nutrients, organic carbon, and radon for both the 1998 and the 1999 synoptic studies. Pesticide concentrations were determined only for the 1999 synoptic study.

Ground-water sampling of domestic wells and small-production community wells was more difficult than lake sampling because of the time required to schedule well sampling. A comprehensive analysis of ground-water samples, **Table 22.** Concentrations of volatile organic compounds detected in samples from eight wells in the Cranberry Lake neighborhood affected by methyl tert-butyl ether point-source contamination, Sussex County, New Jersey

[MTBE, methyl tert-butyl ether; TAME, tertiary amyl-methyl ether; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); all concentrations are in micrograms per liter; <, less than, considered non-detect; analyses conducted at the National Water Quality Laboratory, laboratory schedule 2022 (in appendix A); E, estimated value]

											1,1-		1,1-	Tertiary-		1,4-			
									Trichloro-		Dichloro-	Tetra-	Dichloro-	buytl	Carbon	Dichloro-			1,3-
						Ethyl-	m,p-		ethane,	Chloro-	ethane,	chloro-	ethylene,	ethyl	tetra-	benzene	o-Dichloro-	Chloro-	Dichloro-
		MTBE	TAME	Benzene	Toluene	benzene	Xylene	o-Xylene	e total	form	total	ethylene	total	ether	chloride	(p)	Benzene	benzene	benzene
Well name	Sampling date	(78032)	(50005)	(34030)	(34010)	(34371)	(85795)	(77135)	(34506)	(32106)	(34496)	(34475)	(34501)	(50004)	(32102)	(34571)	(34536)	(34301)	(34566)
CR01	7/21/98	0.6	<.1	E.02	<.05	<.03	<.06	<.06	<.03	E.02	<.07	<.1	<.04	<.05	<.09	1.53	4.6	2.52	1.44
CR02	7/21/98	94	0.6	<.10	<.05	<.03	<.06	<.06	2.21	0.15	E.07	E.1	0.19	E.05	0.09	<.05	<.05	<.03	<.05
CR03	7/22/98	343	35	<.10	<.05	<.03	<.06	<.06	E.06	<.05	<.07	<.1	<.04	0.11	<.09	<.05	<.05	<.03	<.05
CR04	7/22/98	.4	<.1	<.10	E.03	<.03	<.06	<.06	.5	.11	E.07	E.1	E.05	<.05	<.09	<.05	<.05	<.03	<.05
CR05	7/23/98	40	.6	<.10	<.05	<.03	<.06	<.06	.91	.12	E.06	E.1	E.08	<.05	<.09	E.06	<.05	<.03	<.05
CR06	7/23/98	E.2	<.1	<.10	<.05	<.03	<.06	<.06	2.23	.11	E.08	E.1	0.26	<.05	E.03	<.05	<.05	<.03	<.05
CR07	7/29/98	190	5.9	<.10	E.05	<.03	<.06	<.06	.31	E.05	E.04	М	<.04	E.06	E.02	<.05	<.05	<.03	<.05
CR08	7/29/98	900	73	<.10	<.05	<.03	<.06	<.06	<.03	<.05	<.07	<.1	<.04	0.17	<.09	<.05	<.05	<.03	<.05

Table 23. Field characteristics and concentrations of major ions in samples from eight wells in the Cranberry Lake neighborhood affected by

 methyl tert-butyl ether point-source contamination, Sussex County, New Jersey

[DO, dissolved oxygen was measured using the Winkler method; alkalinity was measured by incremental field titration; SC, specific conductance in microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; μ g/L, micrograms per liter; major ions (schedule 1) and boron (labcode 2110) were analyzed for at the National Water Quality Laboratory in Denver, Colorado; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); <, less than; --, not analyzed]

	Sampling	Temperature (°C)	DO (mg/L)	pH (standard units)	Alkalinity (mg/L as CaCO ₃)	SC	Calcium (mg/L)	Magne- sium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Boron (µg/L)	Iron (µg/L)	Manganese (µg/L)
Well name	date	(00010)	(00300)	(00400)	(39086)	(00095)	(00915)	(00925)	(00930)	(00935)	(00940)	(00945)	(00950)	(00955)	(01020)	(01046)	(01056)
CR01	7/21/1998	11.7	11.4	6.5	178	1290	88.3	13.5	147	2	268	24	<.1	8.8	21	<10	64
CR02	7/21/1998	11.4	1.1	4.7		672	77.2	18.5	18.7	1.9	102	22.2	<.1	15.5	32	<10	<4
CR03	7/22/1998	11.1	7	6.2	69	583	51.8	13	32.8	1.2	106	20.7	<.1	13.6	27	<10	<4
CR04	7/22/1998	11.1	5.5	6.4	111	1000	105	27.2	31	2.7	191	28.9	<.1	17.4	67	<10	<4
CR05	7/23/1998	10.8	2.5	6	109	1350	83.4	38.8	109	1.9	309	29.1	<.1	17.7	60	<10	5
CR06	7/23/1998	12	1.5	7	95	563	67.7	15.4	12.4	1.5	73.5	22.7	<.1	14.9	32	<10	<4
CR07	7/29/1998	11.8	2.8	6.7	73	560	54.5	13.5	28	1.2	102	21.7	<.1	13.5	21	<10	6
CR08	7/29/1998	15.1	5.1	6.3	106	568	29	12.6	62.6	0.9	92.3	18.1	<.1	7.1	<16	116	10

Table 24. Concentrations of nutrients, methylene blue activated substances, and organic carbon in samples from eight wells in the Cranberry Lake neighborhood affected by methyl tert-butyl ether point-source contamination, Sussex County, New Jersey

[mg/L, milligrams per liter; MBAS, methylene blue activated substance; TOC, total organic

carbon; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); <, less than]

Well name	Sampling date	Nitrogen, ammonia dissolved (mg/L as N) (00608)	Nitrogen, ammonia and organic dissolved (mg/L as N) (00623)	Nitrogen, NO ₂ and NO ₃ , dissolved (mg/L as N) (00631)	Phosphorus, dissolved (mg/L as P) (00666)	MBAS (mg/L) (38260)	TOC (mg/L as C) (00680)
CP01	7/22/08	0.143	0.15	< 050	< 010	< 02	4.2
CR01	7/21/98	0.143	0.15	<.050	<.010	<.02	4.2
CR02	//21/98	<.020	<.10	<.050	<.010	<.02	0.6
CR03	7/22/98	<.020	<.10	0.144	<.010	<.02	1.4
CR04	7/22/98	<.020	<.10	2.92	<.010	<.02	1.2
CR05	7/23/98	<.020	<.10	2.78	<.010	0.02	1.7
CR06	7/23/98	<.020	<.10	1.29	<.010	<.02	13
CR07	7/29/98	<.020	<.10	0.888	<.010	<.02	1.5
CR08	7/29/98	<.020	<.10	0.648	<.010	0.03	3

Table 25. Solubilities of selected volatile organic compounds in water

[Solubilities are in millgrams per liter and are from Zogorski and others, 1996]

Compound	Solubility
Methyl tertiary-butyl ether	48,000
Tertiary amyl-methyl ether	12,000
Benzene	1,780
Toluene	515
Ethylbenzene	152
m-Xylene	160
p-Xylene	215
o-Xylene	220

therefore, was conducted to provide as much information as possible to take full advantage of the field effort.

Concentrations of VOCs in samples from wells at Cranberry Lake and Lake Lackawanna are listed in table 26. A total of 22 of the 37 VOCs analyzed for (see appendix 1) were detected in at least one sample. The detection frequencies are summarized in figure 12. The arrows point to fuel-related VOCs which, along with chloroform, also were detected in samples from the lakes. The presence of chloroform and MTBE in ambient ground water was nearly ubiquitous; these two compounds were detected in samples from 13 of 14 wells (91 percent) at Cranberry Lake in 1998 and 1999 and in samples from 4 of 5 wells (80 percent) at Lake Lackawanna in 1999. The chlorinated solvents PCE, TCA, TCE, and 1,1dichloroethane also were detected frequently, as each had a detection frequency of at least 50 percent in at least one of the synoptic studies. These compounds were not detected in lake samples, and, therefore, their occurrence in ground water can be attributed to land use. These compounds are used in a wide variety of industrial and commercial products including metal degreasers, industrial solvents, aerosols, adhesives, protective coatings, and dry-cleaning solvents. Concentrations of VOCs in samples from wells are summarized in figures 13a and 13b. MTBE was the dominant VOC when the total VOC concentration exceeded 2 µg/L. For the 1998 synoptic study, the total VOC concentration exceeded $2 \mu g/L$ in 4 of the 14 wells; in these samples, MTBE constituted from 79.3 to 96.5 percent of the VOC mass. Similarly, for the 1999 synoptic study, the total VOC concentration exceeded $2 \mu g/L$ in 3 of the 14 wells; in these samples, MTBE constituted from 80 to 90 percent of the VOC mass. MTBE constituted more than 50 percent of the total VOC mass in 10 of the 14 wells sampled at Cranberry Lake in 1998 and 1999, and in 2 of the 5 wells sampled at Lake Lackawanna in 1999.

Pesticide concentrations in ground-water samples from the Cranberry Lake and Lake Lackawanna synoptic study of 1999 are listed in table 27. Of the 49 pesticides analyzed for (see schedule 2001 description in Appendix 1), only prometon, simazine, desethyl atrazine, corbaryl, and metolachlor were detected in at least one sample. The detection frequencies are shown in figure 14. Prometon, the most frequently detected pesticide, was detected in 6 of 13 samples from wells at Cranberry Lake (46 percent) and 1 of 5 samples (20 percent) from wells at Lake Lackawanna. All prometon concentrations, however, were less than 0.06 µg/L. Prometon is a general-use, non-selective herbicide used in areas where total vegetation control is desired (for example, roadway and utility rights-of-way). Prometon also is mixed with or applied beneath asphalt to control the growth of weeds through asphalt surfaces. The highest pesticide concentration was reported for simazine $(0.17 \ \mu g/L)$ in a sample from a well at Cranberry Lake. Simazine, the second most frequently detected pesticide, was detected in 3 of the 13 ground-water samples (23 percent) at Cranberry Lake; simazine was not detected in samples from wells at Lake Lackawanna. Simazine is a generaluse herbicide used in New Jersey primarily for agricultural weed control, lawn maintenance, and the clearing of vegetation along rights-of-way. No pesticides or herbicides were detected in samples collected from Cranberry Lake at the bridge site prior to the summer 1999 ground-water sampling. The other pesticides detected in ground water (table 27) were present at extremely low concentrations (all less than 0.004 μ g/L). Concentrations of pesticides in ground water at Cranberry Lake and Lake Lackawanna are low compared to those of VOCs.

Field-measured characteristics and concentrations of major ions, nutrients, MBAS, organic carbon, and radon are presented in tables 28, 29, 30, and 31, respectively. A Piper diagram (fig. 15) shows the major inorganic constituents of ground water at Cranberry Lake and Lake Lackawanna in relation to those of lake water and local precipitation. The quality of water Cranberry Lake and Lake Lackawanna as determined from the synoptic studies of August 3 and August 19, 1999, is assumed to represent average conditions. Measurements of major-ion concentrations at Cranberry Lake (fig. 6; table 9) show little variation over the period of record. **Table 26.** Concentrations and detection frequencies of detected volatile organic compounds in samples from 14 wells at Cranberry Lake and 5 wells at Lake Lackawanna, Sussex County, New Jersey

[F, fall; S, summer; VOC, volatile organic compounds; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); all concentrations in micrograms per liter and all masses in micrograms; <, less than (considered non-detect); E, estimated value]

Cranberry Lake

Well	Samp	ling date	Methyl et (78	tert-butyl her 3032)	Chlo (32	oroform 106)	Tetrac ethy (344	hloro- lene 75)	1, Trichlor to (34	1,1- roethane, otal 4506)	Trichlor (39	oethylene	1,4-Di benz (34	chloro- ene(p) 571)	1 Dichlor tot <u>(344</u>	,1- oethane, al 96)	Toh (340	10)	1,3-Di benz (34	ichloro- ene (m) 566)	Car tetrac (32)	bon hloride 102)	Dichlor metha (346	odifloro- ane total 668)	Trichloro meth (344	ofluoro- nane 88)
	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999
CR09	11/05/98	8/16/99	2.2	3.3	0.21	E.07	<.1	<.1	<.03	E.01	E.02	E.03	E.09	0.17 E 01	0.18	0.21	<.05	<.05	E.04	E.04	<.09	<.09	<.1	<.1	<.09	<.09
CR11	11/05/98	8/16/99	E.1	.4	.1 E.04	E.08	<.1	E.0312	<.03	<.03	<.04	E.02	<.05	<.05	<.07	<.07	<.05	<.05	<.05	<.05	<.09	<.09	<.1	<.1	<.09	<.09
CR12	11/24/98	8/04/99	1.8	13.2	.3	E.08	<.1	E.0302	<.03	<.03	<.04	<.04	<.05	<.05	E.05	E.05	<.05	E.01	<.05	<.05	E.03	<.09	<.1	<.1	<.09	<.09
CR13	12/04/98	8/04/99	E.2	.2	E.14	0.16	E.038	E.0357	<.03	E.018	<.04	<.04	<.05	<.05	<.07	<.07	<.05	<.05	<.05	<.05	E.18	0.14	E.017	<.1	<.09	<.09
CR14	12/04/98	8/10/99	<.2	<.9	E.03	E.45	E.021	<.5	<.03	<.16	E.02	<.19	<.05	<.25	<.07	<.33	E.07	<.25	<.05	<.27	<.09	<.44	<.1	<.7	<.09	<.45
CR15	12/07/98	8/09/99	.3	.2	E.05	E.05	E.035	E.0368	E.04	E.03	<.04	<.04	<.05	<.05	<.07	<.07	<.05	<.05	<.05	<.05	<.09	E.03	<.1	<.1	E.08	E.09
CR16	12/07/98	8/05/99	.4	.3	E.06	E.04	<.1	E.0032	<.03	<.03	<.04	<.04	<.05	<.05	<.07	<.07	<.05	E.03	<.05	<.05	<.09	<.09	<.1	<.1	<.09	<.09
CR17	12/08/98	8/09/99	2.3	E.1	<.05	<.05	<.1	<.1	<.03	<.03	<.04	<.04	<.05	<.05	<.07	<.07	<.05	E.01	<.05	<.05	<.09	<.09	E.1	E.1	<.09	E.1
CR18	12/15/98	8/05/99	.7	.5	.32	E.08	.1	.1	E.01	E.01	E.01	E.02	E.02	E.02	<.07	<.07	<.05	E.04	E.01	E.01	<.09	<.09	<.1	<.1	<.09	<.09
CR19	12/15/98	8/09/99	.4	.4	E.01	E.01	<.1	<.1	<.03	<.03	<.04	<.04	<.05	<.05	<.07	<.07	<.05	<.05	<.05	<.05	<.09	<.09	<.1	<.1	<.09	E.01
CR20	12/16/98	8/05/99	.7	.3	E.07	E.07	E.1	.1	E.06	E.06	E.01	E.01	E.01	E.01	<.07	<.07	<.05	E.02	<.05	E.01	.1	.1	<.1	<.1	<.09	<.09
CR21	12/16/98	8/10/99	.4	.2	E.09	E.07	<.1	<.1	E.01	<.03	.56	0.49	E.01	E.01	E.02	E.01	<.05	<.05	<.05	<.05	<.09	<.09	E.032	<.1	0.58	0.65
CR22	12/17/98	8/10/99	19.8	3.6	.14	E.10	.2	.2	<.03	<.03	E.03	E.03	E.07	E.04	<.07	<.07	E.02	<.05	E.04	E.03	<.09	<.09	<.1	<.1	<.09	<.09
Detectio	on frequency	y (percent)	92.9	92.9	92.9	92.9	42.9	64.3	28.6	42.9	42.9	50.0	35.7	42.9	21.4	21.4	14.3	35.7	21.4	28.6	21.4	21.4	21.4	7.1	14.3	21.4

Lake Lackawanna

Well name	Sampling date	Methyl tert-butyl ether	Chloroform	Tetrachloro- ethylene	1,1,1- Trichloroethane, total	Trichloroethylene	1,4-Dichloro- benzene (p)	1,1- Dichloroethane, total	Toluene	1,3-Dichloro- benzene (m)	Carbon tetrachloride	Dichlorodifloro- methane tot	Trichlorofluoro- methane
LA-01	8/12/99	E.1	0.16	<.1	E.05	E.02	<.05	E.02	<.05	<.05	<.09	<.1	<.09
LA-02	8/12/99	E.1	E.02	E.0084	E.01	<.04	<.05	E.02	<.05	<.05	<.09	<.1	<.09
LA-03	8/17/99	0.2	<.05	<.1	<.03	<.04	<.05	<.07	<.05	<.05	<.09	<.1	<.09
LA-04	8/17/99	<.2	E.04	E.0122	E.06	<.04	<.05	E.04	E.02	<.05	<.09	E.7	<.09
LA-05	8/26/99	E.048	E.02	E.0177	.27	E.07	<.05	E.04	E.02	<.05	<.09	<.1	<.09
Detection	frequency (percent)	80	80	60	80	40	0	80	40	0	0	20	0

Table 26. Concentrations and detection frequencies of detected volatile organic compounds in samples from 14 wells at Cranberry Lake and 5 wells at Lake Lackawanna, Sussex County, N.J.--Continued

Cranberry Lake

Well name	Sampl	ing date	Tertia buty (50	ry amyl- l ether 0005)	Bro dichloro (32	omo- omethane 2101)	Chloro (34	-benzene 301)	1,1-D ethyle (34	ichloro- ne, total 501)	Dichlor	obenzene, O 536)	Be (34	nzene 030)	Brom (32	oform 104)	Chloro met (32	dibromo- hane 2105)	cis-1,2-1 ethen (77	Dichloro- e, total 093)	Sty (77	yrene 128)		Total	VOC mass
	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999		F 1998	S 1999
CR09	11/05/98	8/16/99	<.1	E.1	<.05	<.05	E.02	E.04	<.04	<.04	E.04	0.15	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		2.8	4.12
CR10	11/05/98	8/16/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		.2	.58
CR11	11/06/98	8/16/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	E.02	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		.16	.71
CR12	11/24/98	8/04/99	<.1	.9	<.05	0.16	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	.51	<.2	.4	<.04	<.04	<.04	<.04		2.18	15.34
CR13	12/04/98	8/04/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		.58	.55
CR14	12/04/98	8/10/99	<.1	<.6	<.05	<.24	<.03	<.14	<.04	<.22	<.05	<.24	<.10	<.50	<.10	<.50	<.2	<.9	<.04	<.19	<.04	<.21		.14	.45
CR15	12/07/98	8/09/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		.51	.44
CR16	12/07/98	8/05/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		.46	.37
CR17	12/08/98	8/09/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		2.4	.21
CR18	12/15/98	8/05/99	<.1	<.1	E.01	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		1.18	.79
CR19	12/15/98	8/09/99	<.1	E.0176	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		.41	.43
CR20	12/16/98	8/05/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		1.66	1.33
CR21	12/16/98	8/10/99	<.1	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	E.04	E.04	<.04	<.04		1.13	.82
CR22	12/17/98	8/10/99	0.2	<.1	<.05	<.05	<.03	<.03	<.04	<.04	<.05	<.05	<.10	<.10	<.10	<.10	<.2	<.2	<.04	<.04	<.04	<.04		20.5	4
Detectio	on frequency	(percent)	7.1	21.4	7.1	7.1	7.1	7.1	0	0	7.1	7.1	7.1	0	0	7.1	0	7.1	7.1	7.1	0	0	Total VOC mass per synoptic	34.31	26.14

Lake Lackawanna

Well		Tertiary	Bromo-		1,1-Dichloro-	Dichlorobenzene,			Chlorodibromo-	cis-1,2-Dichloro-			
name	Sampling date	amyl-butyl ether	dichloromethane	Chlorobenzene	ethylene, total	0	Benzene	Bromoform	methane	ethene, total	Styrene		Total VOC mass
LA-01	8/12/99	<.1	<.05	<.03	<.04	<.05	<.10	<.10	<.2	<.04	<.04		0.35
LA-02	8/12/99	<.1	<.05	<.03	<.04	<.05	<.10	<.10	<.2	<.04	<.04		.1584
LA-03	8/17/99	<.1	<.05	<.03	<.04	<.05	<.10	<.10	<.2	<.04	<.04		.2
LA-04	8/17/99	<.1	<.05	<.03	E.02	<.05	<.10	<.10	<.2	<.04	E.01		.9022
LA-05	8/26/99	<.1	<.05	<.03	E.08	<.05	<.10	<.10	<.2	<.04	<.04		.5657
												Total VOC mass	
Detection	frequency (percent)	0	0	0	40	0	0	0	0	0	20	per synoptic	2.1763



Figure 12. Detection frequencies of volatile organic compounds in ambient ground water, Cranberry Lake, fall 1998 and summer 1999 and Lake Lackawanna, summer 1999, in Sussex County, New Jersey.



Figure 13a. Concentrations of volatile organic compounds in samples of ambient ground water, vicinity of Cranberry Lake, Sussex County, New Jersey, fall 1998.



Figure 13b. Concentrations of volatile organic compounds in samples of ambient ground water, vicinity of Cranberry Lake and Lake Lackawanna, Sussex County, New Jersey, spring 1999.



Figure 14. Detection frequencies of pesticides in samples of ambient ground water, vicinity of Cranberry Lake and Lake Lackawanna, Sussex County, New Jersey, summer 1999.

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Table 27. Concentrations of pesticides detected in ground-water samples from 14 wells at Cranberry Lake and 5 wells at Lake Lackawanna, Sussex County, New Jersey

[Number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); all concentrations are in micrograms per liter; <, less than, considered non-detect; --, not analyzed; E, estimated value]

Well name	Sampling date	Prometon (04037)	Simazine (04035)	Desethyl Atrazine (04040)	Carbofuran (82680)	Metolachlor (39415)	Number of detections	Total concentration
CR09	8/16/1999	0.052	<.005	<.002	E.0035	E.0029	3	0.0584
CR10	8/16/1999	.0531	<.005	<.002	<.003	<.002	1	.0531
CR11	8/16/1999	E.0145	<.005	E.0013	<.003	<.002	2	.0158
CR12	8/4/1999	<.018	<.005	<.002	<.003	<.002	0	0
CR13	8/4/1999							
CR14	8/10/1999	<.018	<.005	<.002	<.003	<.002	0	0
CR15	8/9/1999	<.018	<.005	E.0018	<.003	<.002	1	.0018
CR16	8/5/1999	<.018	<.005	<.002	<.003	<.002	0	0
CR17	8/9/1999	<.018	<.005	<.002	<.003	<.002	0	0
CR18	8/5/1999	E.0039	.0851	<.002	<.003	<.002	2	.089
CR19	8/9/1999	<.018	<.005	<.002	<.003	<.002	0	0
CR20	8/5/1999	<.018	.0104	<.002	<.003	<.002	1	.0104
CR21	8/10/1999	0.0296	<.005	<.002	<.003	<.002	1	.0296
CR22	8/10/1999	E.0048	.167	<.002	<.003	<.002	2	.1718
LA-01	8/12/1999	<.018	<.005	<.002	<.003	<.002	0	0
LA-02	8/12/1999	<.018	<.005	<.002	<.003	<.002	0	0
LA-03	8/17/1999	E.0175	<.005	<.002	<.003	<.002	1	.0175
LA-04	8/17/1999	<.018	<.005	<.002	<.003	<.002	0	0
LA-05	8/26/1999	<.018	<.005	<.002	<.003	<.002	0	0

Table 28. Field parameters of samples from 14 wells at Cranberry Lake and 5 wells from Lake Lackawanna, Sussex County, New Jersey [^oC, degrees Celsius; mg/L, milligrams per liter; SC, specific conductance in microsiemens per centimeter at 25 ^oC; dissolved oxygen (DO) was measured using the Winker method; F, fall; S, spring; alkalinity was measured by incremental titration; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); --, not analyzed; -, not sampled]

Well Name	Sampl	ing Date	Tempera (00	ature (oC) 010)	pH (stan (004	dard units) 400)	DO (00	(mg/L) 0300)	(00	SC)095)	Alka (mg/L (39	linity as CaCO3) 086)
	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999
CR09	11/05/98	8/16/99	11.3	14.2	6.1	6.6	4.5		1140	1150	120	166
CR10	11/05/98	8/16/99	10.5	13.3	7.3	7.2	1.5	1.7	845	797	110	166
CR11	11/06/98	8/16/99	10.3		6.7	6.9	5.5	6.8	748	789	105	144
CR12	11/24/98	8/04/99	11.4		7.2	7	8.6	1.5	1100	1030	212	192
CR13	12/04/98	8/04/99	10.5	15.8	6.9	6.9	2.8	3.3	818	845	150	144
CR14	12/04/98	8/10/99	11.9	12.1	7	7	2.9	3	1250	1560	134	130
CR15	12/07/98	8/09/99	11.9	12	6.3	6.4	2.8	2.8	849	836	124	118
CR16	12/07/98	8/05/99	11	12.5	6.1	6.1	3	3.8	970	1000	70	72
CR17	12/08/98	8/09/99	10.1	11.2	7.6	7.4	6.8	7.2	247	299	68	88
CR18	12/15/98	8/05/99	10.9	11.1	6.7	6.7	1.4	.9	725	824	166	176
CR19	12/15/98	8/09/99	11.8	12.2	6.8	6.7	0.8	2.8	1020	1660	178	180
CR20	12/16/98	8/05/99	10.8	14.8	7.2	7.2	1.6	1.5	476	490	146	144
CR21	12/16/98	8/10/99	11.1	11.8	7.3	7.3	.2	1.9	1130	1220	170	170
CR22	12/17/98	8/10/99	10.5	11.5	6.9	7	.1	0.9	984	996	244	232
LA-01	-	8/12/99	-	12.2	-	7.1	-	3.6	-	187	-	64
LA-02	-	8/12/99	-	16.9	-	7.6	-	1.3	-	366	-	102
LA-03	-	8/17/99	-	14.8	-	8.2	-	4.5	-	200	-	95
LA-04	-	8/17/99	-	17.9	-	7.4	-	4.4	-	230	-	88
LA-05	-	8/26/99	-	12.7	-	8.2	-	.9	-	224	-	52

Table 29. Concentrations of major ions in samples from 14 wells at Cranberry Lake and 5 wells at Lake Lackawanna, Sussex County, New Jersey [F, fall; S, summer; mg/L, milligrams per liter; μ g/L, micrograms per liter; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); <, less than, considered non-detect; -, not sampled; E, estimated value]

Well			Calci (mg	ium g/L)	Magne (mg	sium /L)	Sodi (mg	ium g/L)	Potas (m	sium g/L)	Chlo (mg	ride g/L)	Sulfa (mg	ate /L)	Fluo (m	oride g/L)	Sili (ms	ica g/L)	Bo (µ	oron g/L)	Coj (µ	pper lg/L)	Ir (µ	on g/L)	Mang (µg	anese g/L)
name	Samp	ling date	(009	15)	(009	25)	(00)	930)	(00	935)	(009	940)	(009	45)	(009	950)	(009	955)	(01	020)	(01	040)	(010)46)	(010)56)
	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999
CR09	11/05/98	8/16/99	88.2	77.7	22.7	18.7	88.4	95	2.2	2.1	206	191	24.9	24.7	<.1	<.1	14.3	14.5	46	37	E6	<10	E10	E10	27	165
CR10	11/05/98	8/16/99	96.9	98.1	16.9	16.9	44.5	37.8	1.8	1.8	125	129	24.3	23.5	<.1	<.1	14.1	15.5	36	28	12	E5	<10	<10	<3	E2
CR11	11/06/98	8/16/99	70	75.9	15.5	16.5	46.6	50.2	1.8	1.8	131	136	16.5	19	<.1	<.1	14.7	15.6	39	24	<10	<10	10	<10	<3	<3
CR12	11/24/98	8/04/99	114	105	23.3	22.5	68.2	80.2	1.9	2	197	260	15.8	<.1	.2	.2	13.8	13.5	106	119	<10	<10	<10	<10	<3	39
CR13	12/04/98	8/04/99	67.4	69.1	15.9	16.6	64.6	70.7	1.9	1.8	141	156	17.3	18	<.1	<.1	15.1	14	39	57	<10	<10	20	430	E3	27
CR14	12/04/98	8/10/99	115	122	19.7	19.2	78.3	106	1.6	1.9	285	329	17.3	15.7	.4	.3	14	12.5	18	24	<10	<10	30	240	12	35
CR15	12/07/98	8/09/99	78.4	77.4	21.4	20.4	45.1	41.7	1.9	1.9	173	163	22.2	21.8	<.1	.1	20.9	19.9	40	44	<10	<10	60	20	8	<3
CR16	12/07/98	8/05/99	85.4	88.3	23.4	23.9	55.4	56.9	1.6	1.6	239	255	20.3	19.1	.1	.2	20.3	20	E11	19	E8	19	60	E10	43	18
CR17	12/08/98	8/09/99	35.2	34.5	4.66	4.61	8.5	9.1	1	1	16	16	11.7	10.3	.2	.2	17.8	16.7	E14	20	<10	E8	<10	<10	<3	<3
CR18	12/15/98	8/05/99	64.7	68	19.3	20.8	55.7	62.3	1.7	1.7	123	126	20.5	20.2	.5	.4	19.3	19	40	45	E6	<10	<10	<10	<3	<3
CR19	12/15/98	8/09/99	56.8	78	26.4	35.5	108	149	2.7	3.2	219	320	21	22.3	<.1	<.1	13.5	12.7	17	25	<10	<10	20	120	E2	E2
CR20	12/16/98	8/05/99	62.1	59.2	17.7	16.8	15.4	13.6	1.3	1.2	57.3	57.7	17.5	16.6	.8	.8	17.6	17.1	20	27	<10	<10	<10	<10	<3	<3
CR21	12/16/98	8/10/99	123	122	13.2	12.5	86.1	86.9	1.1	1	237	257	21.6	20.8	.4	.4	12.5	11	36	23	<10	E9	<10	<10	16	7
CR22	12/17/98	8/10/99	63.3	70.9	24.8	24.1	102	90.2	1.9	1.8	160	154	22.7	20.1	.3	.4	19.8	18.4	60	59	E6	E7	<10	<10	<3	<3
LA-01	-	8/12/99	23.2	-	4.68	-	5.3	-	.8	-	10.6	-	14.7	-	.9	-	13.1	-	<16	-	<10	-	<10	-	E2	-
LA-02	-	8/12/99	30.8	-	14.3	-	21.5	-	.8	-	36.5	-	17.9	-	<.1	-	18.4	-	E10	-	<10	-	10	-	<3	-
LA-03	-	8/17/99	24.7	-	6.64	-	3.7	-	.5	-	3.1	-	12.9	-	<.1	-	18.4	-	<16	-	<10	-	<10	-	<2	-
LA-04	-	8/17/99	30.1	-	4.98	-	7.8	-	.6	-	11.1	-	13.9	-	<.1	-	18.7	-	E9	-	<10	-	<10	-	<2	-
LA-05	-	8/26/99	21	-	4.22	-	14.7	-	.5	-	17.7	-	10.4	-	2.1	-	18.2	-	40	-	<10	-	<10	-	<2	-

Table 30. Nutrient concentrations in samples from 14 wells at Cranberry Lake and 5 wells at Lake Lackawanna, Sussex County, New Jersey
[F, fall; S, summer; mg/L, milligrams per liter; MBAS, methylene blue activated substance; TOC, total organic carbon; number in parentheses
is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS);
<, less than, considered non-detect;, not analyzed; -, not sampled; E, estimated value]

Wall nome	Samo	ling data	Nitrogen, disso (mg/l	ammonia olved L as N)	Nitrogen, and o disso (mg/I	ammonia rganic blved . as N)	Nitrogen, and or to (mg/I	ammonia rganic, tal L as N)	Nitro NO ₂ ar disso (mg/L	ogen, nd NO ₃ , olved 2 as N)	Phosp to (mg/l	horus, tal L as P)	Phosp disso (mg/L	bhorus, blved 2 as P)	MI (r	3AS ng/L)
wen name	Samp		(00	<u>()))</u>	<u>(00</u>	<u>025)</u>	(00	<u>(1000</u>	(00	<u>()</u>	(00	<u>(())</u>	(00	<u>(000)</u>	(30	<u>,200)</u>
	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999	F 1998	S 1999
CR09	11/5/1998	8/16/1999	<.020	0.223	0.14	0.26		0.41	3.99	3.46		<.050	<.050	<.050	<.02	0.03
CR10	11/5/1998	8/16/1999	<.020	<.020	.1	E.09		E.08	4.81	4.52		<.050	<.050	<.050	E.04	.03
CR11	11/6/1998	8/16/1999	<.020	<.020	<.10	<.10		E.07	2.83	3.85		<.050	<.050	<.050	E.02	.03
CR12	11/24/1998	8/4/1999	<.020	<.020	.56	.19		<.10	1.36	1.3		<.050	<.050	<.050	.03	.02
CR13	12/4/1998	8/4/1999	<.020	<.020	<.10	E.09		E.05	2.38	2.22		<.050	<.050	<.050	.03	<.02
CR14	12/4/1998	8/10/1999	<.020	<.020	<.10	<.10		.1	.246	0.187		<.050	<.050	<.050	.05	.11
CR15	12/7/1998	8/9/1999	<.020	<.020	<.10	<.10		E.09	2.19	2.58		<.050	<.050	<.050	.02	.03
CR16	12/7/1998	8/5/1999	<.020	<.020	<.10	E.09		E.08	.683	1.96		<.050	<.050	<.050	<.02	<.02
CR17	12/8/1998	8/9/1999	<.020	<.020	<.10	<.10		.12	.415	.507		<.050	<.050	<.050	<.02	<.02
CR18	12/15/1998	8/5/1999	<.020	<.020	<.10	E.09		E.07	3.11	3.6		<.050	<.050	<.050	.03	.03
CR19	12/15/1998	8/9/1999	<.020	<.020	<.10	E.05		.16	.165	.335		<.050	<.050	<.050	.03	.08
CR20	12/16/1998	8/5/1999	<.020	<.020	<.10	E.05		E.05	1.66	1.63		<.050	<.050	<.050	<.02	.03
CR21	12/16/1998	8/10/1999	<.020	<.020	<.10	<.10		.14	1.13	1.12		<.050	<.050	<.050	<.02	.05
CR22	12/17/1998	8/10/1999	<.020	<.020	<.10	E.09		E.08	5.02	3.94		<.050	<.050	<.050	<.02	.05
LA-01	-	8/12/1999	<.020	-	.16	-	E.08	-	.816	-	<.050	-	<.050	-	<.02	-
LA-02	-	8/12/1999	<.020	-	<.10	-	.13	-	2.59	-	<.050	-	<.050	-	<.02	-
LA-03	-	8/17/1999	<.020	-	<.10	-	E.06	-	.25	-	<.050	-	<.050	-	<.02	-
LA-04	-	8/17/1999	<.020	-	<.10	-	E.06	-	1.49	-	<.050	-	<.050	-	<.02	-
LA-05	-	8/26/1999	<.020	-	<.10	-	.16	-	.533	-	<.050	-	<.050	-	<.02	-

Table 31. Concentrations of radon-222 in ground-water samples at Cranberry Lake and Lake Lackawanna, Sussex County, New Jersey

[F, fall; S, summer; radon concentrations in picocuries per liter; number in parentheses is parameter code used to identify the constituent, property, or characteristic in the U.S. Geological Survey water-quality data base (NWIS); --, not analyzed; -, not sampled]

	F 199	98	S 19	999
Well name	Sampling date	Radon-222 concentration (82303)	Sampling date	Radon-222 concentration (82303)
CR09	11/05/98	261	8/16/99	391
CR10	11/05/98	510	8/16/99	660
CR11	11/06/98	282	8/16/99	463
CR12	11/24/98	634	8/04/99	953
CR13	12/04/98	574	8/04/99	546
CR14	12/04/98	1650	8/10/99	
CR15	12/07/98	3880	8/09/99	
CR16	12/07/98	10100	8/05/99	10800
CR17	12/08/98	771	8/09/99	
CR18	12/15/98	6460	8/05/99	5960
CR19	12/15/98	1460	8/09/99	
CR20	12/16/98	1100	8/05/99	1140
CR21	12/16/98	13900	8/10/99	14400
CR22	12/17/98	6530	8/10/99	7060
LA-01	-	-	8/12/99	5370
LA-02	-	-	8/12/99	399
LA-03	-	-	8/17/99	340
LA-04	-	-	8/17/99	264
LA-05	-	-	8/26/99	108



Figure 15. Major-ion composition of samples of lake water from, and ground water at, Cranberry Lake and Lake Lackawanna, Sussex County, New Jersey, during synoptic sampling, and of precipitation.

The major-ion composition of ground water at Cranberry Lake is different from that at Lake Lackawanna. Ground water at Cranberry Lake is classified as calcium chloride-nitrate type water, whereas ground water at Lake Lackawanna is a calcium-magnesium carbonate type. Ground water at Cranberry Lake tends to contain more sodium and potassium than that at Lake Lackawanna. Water from the lakes is more mixed (equal distribution of major cations and anions) than the associated ground water and has similar major-ion composition. All samples have low concentrations of sulfate relative to other anions. The average of the major-ion composition of precipitation from the NADP station at Washington Crossing, New Jersey, in 1998 also is shown in figure 15. Differences between the major-ion composition of ground water at Cranberry Lake and Lake Lackawanna result from differences in geology within the drainage areas of the lakes. Hardness and concentrations of chloride, iron, and sodium in several ground-water samples exceeded Federal and New Jersey secondary (primarily aesthetic) drinking-water standards. None of the major ions was detected at a level that exceeded primary drinking-water standards, according to Federal and New Jersey safe drinking-water acts.

Nitrate (nitrite plus nitrate is assumed to be all nitrate; table 30) was detected in all groundwater samples; median concentrations of nitrate were 2.0 and 2.1 mg/L for the 1998 and 1999 Cranberry Lake synoptic studies, respectively, and 0.8 mg/L for the 1999 Lake Lackawanna synoptic study. These median concentrations are higher than the average nitrate concentration in precipitation (1.62 mg/L measured at Washington Crossing, New Jersey, in 1998). Nitrate, however, was not detected in any of the lake-water samples, indicating that biological processes within the lake ecosystem quickly consume it. The possibility that septic tanks are sources of nitrate in ground water is discussed in the section Septic Tanks as a Source of Nitrate and Chloroform.

Radon (Rn-222) is a radionuclide produced by the decay of uranium-238 that frequently is detected in ground-water and residential-air samples throughout New Jersey (Muessig and others, 1992). It has a half-life of 3.8 days, is soluble in water, and also is present in the environment in a gas phase (Hem, 1992). Radon exposure may lead to increased risk of lung and stomach cancer (National Academy of Sciences, 1999). Because drinking water can be a source of gaseous radon as well as an ingestion hazard, the U.S. Environmental Protection Agency has proposed a Maximum Contaminant Level (MCL) of 300 pCi/L and an alternate MCL (AMCL) of 4,000 pCi/L for radon in drinking water (U.S. Federal Register, 1999). These standards apply only to public water providers serving more than 25 people (not private well owners). Purveyors comply with the AMCL if they are following an approved multimedia mitigation program designed to reduce both airborne and water exposure to radon; however, if the 4,000-pCi/L AMCL is exceeded, the water must be treated to reduce the radon concentration prior to distribution. The NJDEP produced a radon-potential map based on concentrations in residential-air samples. Most of Sussex County, including Byram Township, is classified as having a high radon-hazard potential (Muessig and others, 1992). On the basis of 15 measurements of radon in drinking water made by the NJDEP and USGS (DePaul and others, 2000), the average radon concentration in Byram Township was 8,676 pCi/L.

The median radon concentrations are 1,282 and 1,046 pCi/L for the 1998 and 1999 Cranberry Lake 14-well synoptic studies, respectively, and 340 pCi/L for the 1999 Lake Lackawanna 5-well synoptic study (table 31). Water from 12 of 14 wells sampled at Cranberry Lake in 1998 and all 10 wells sampled in 1999 exceeded the MCL of 300 pCi/L; concentrations in four samples in the 1998 study and four samples in the same wells in the 1999 study exceeded the AMCL of 4,000 pCi/L. Water from three of the five wells sampled at Lake Lackawanna in 1999 exceeded the MCL; the concentration in one sample exceeded the AMCL. No significant relations between distance from lake or geologic unit and concentration of radon were identified. Samples collected from Cranberry Lake (table 11) had a median radon concentration of 35.5 pCi/L. Radon was not measured in samples from Lake

Lackawanna. Concentrations of radon in lakewater samples are less than those in ground-water samples because of radioactive decay, volatilization, and dilution.

Lake/Ground Water Interaction and MTBE Occurrence

MTBE concentrations in samples collected from 14 wells at Cranberry Lake from November 5 to December 17, 1998, were less than 2.5 µg/L, except for the sample from well CR22, with a concentration of 19.8 μ g/L (table 26). These concentrations were considerably lower than those (20-30 μ g/L) measured in samples from Cranberry Lake during the summer season; therefore, re-sampling of the well network was scheduled for summer 1999 to determine groundwater quality when concentrations of MTBE at the lake bottom typically are highest. During this period (approximately July 4 through Labor Day) the potential for MTBE to move into the aquifer from the lake would be greatest. The actual relation between MTBE concentrations in wells and those in the lake also depends on other source water, the time required for water to flow from the lake to the well, and the attenuation processes in the aquifer. MTBE also was found to degrade in sediment collected from the bottom of Cranberry Lake (Bradley and others, 2000), and, therefore, can be attenuated before entering the aquifer.

Concentrations of MTBE in samples from wells CR09, CR10, CR11, and CR12 were higher (1.5, 3.2, 5.2, and 7.5 times, respectively) in summer 1999 than in fall 1998. Water companies own these four wells and, therefore, withdraw more water than a typical homeowner even though these wells are constructed similarly. This increases the likelihood for more extensive lake/ ground water interaction because of the larger well-contributing areas and ground-water velocities associated with larger withdrawals. The water levels in these four wells were below the lake level during summer 1999 sampling (see discussion farther on); therefore, some flow from the lake to the wells is likely. In contrast, the MTBE concentrations in samples from wells CR17 and CR22 were higher in fall 1998 than in summer 1999. In the case of well CR17, which is

2,209 ft from the lakeshore and is the farthest from the lake among the wells sampled, lake-well interaction is not possible because the water level in the well remained above the lake level during sampling. For well CR17, and possibly well CR22 (because of the high MTBE concentration), the MTBE source is likely a petroleum-product spill at land surface.

Water-level measurements made during the 1999 synoptic study support the hypothesis that the wells at Cranberry Lake and Lake Lackawanna can be fed, in part, by the lakes. Static water levels observed after a period of pump inactivity and stressed water levels observed at the end of the sampling period are reported relative to lake elevation in table 32. For many of the wells (9 of 13 at Cranberry Lake and 1 of 4 at Lake Lackawanna), even the static water levels were lower than the lake elevation, which likely resulted because of pumping of nearby wells. Stressed water levels were lower than the lake level with the exception of the level in well CR17. The movement of water from the lake to nearly all of the wells in the ambient network, therefore, as depicted in figure 16, is possible. The other source of water to wells is recharge that enters the flow system beneath the land surface. Without model simulation of the flow system, it is not possible to determine the fraction of water that enters a well that is derived from a lake, but the blending of water from different sources could, in part, explain the lower concentrations of MTBE in samples from wells compared with those in samples from the lakes.

Further evidence of lake/ground water interaction is provided by the presence of diatom fragments in samples from wells. During the summer 1999 sampling of surface water and wells at Cranberry Lake and Lake Lackawanna, samples were collected and analyzed for the presence of algae, diatom fragments, and other microbiological interactions that would indicate surface water. Water samples were concentrated and filtered, and the residue was examined and photographed under a microscope. A diverse population of algae and fragments of vascular plants was observed in the samples collected from Cranberry Lake, Lake Lackawanna, and Lake Hopatcong. **Table 32.** Summary of water levels measured at Cranberry Lake and Lake Lackawanna,Sussex County, New Jersey, summer 1999

[--, data not available; water-level values for wells at Cranberry Lake are relative to the lake surface elevation of 770.1 feet above sea level on 8/3/1999 and water-level values for Lake Lackawanna wells are relative to the lake surface elevation of 717.75 feet above sea level on 8/17/1999]

Well name	Sampling date	Static water level (feet)	Pumped water level (feet)	Flow rate (gallons per minute)
CR09	8/16/1999	5		
CR10	8/16/1999	10.34		
CR11	8/16/1999	-13.97	-59.37	15.3
CR12	8/4/1999	-6.39		
CR13	8/4/1999			
CR14	8/10/1999	-2.03	-79.5	8.8
CR15	8/9/1999	45	-9.9	4.4
CR16	8/5/1999	-4.20	-6.8	4.5
CR17	8/9/1999	31.75	23.85	3
CR18	8/5/1999	32	-5.65	7.8
CR19	8/9/1999	07	-18.89	8.8
CR20	8/5/1999	42	-2.13	5.3
CR21	8/10/1999	-9.38	-74.5	6.9
CR22	8/10/1999	.51	-3.14	6
LA-01	8/12/1999	.54	-8.26	8.4
LA-02	8/12/1999	.51	69	8.2
LA-03	8/17/1999	-3.74	-13.83	3.6
LA-04	8/17/1999			
LA-05	8/26/1999	.89		5.8



Figure 16. Schematic diagram of flow to a lakeside well.

A photograph (fig. 17a) of a sample collected at the footbridge at Cranberry Lake is representative of the density and diversity of the organisms. A higher magnification version of the photograph (fig. 17b) shows a diatom fragment similar to those found in many ground-water samples. For example, figure 17c is a photograph of a sample from well CR22 and shows a diatom fragment with an axis length of about 10 µm. For reference, particles from 2 to 50 µm in size are characterized as silt. It is feasible for particles of this size to migrate through fractures. Preliminary results indicate that most of the ground-water samples collected from Cranberry Lake and Lake Lackawanna (ground water was not sampled at Lake Hopatcong) contained diatom fragments derived from the lakes.

Additional study is needed to quantify the amount of lake water entering the wells and the effect of lakes on ground-water quality. Interaction potentially renders the ground-water supply vulnerable to chemicals added to the lake, such as those added to control aquatic plant growth and microbial organisms. The MTBE findings with respect to MTBE also indicate that investigations of point-source contamination of wells in lakeside communities could be complicated because efforts to define the extent of a plume could be complicated by the presence of MTBE in lake water. This situation was encountered with the investigation of MTBE contamination in a Cranberry Lake neighborhood. Septic-tank effluent does not appear to be a significant source of MTBE for the contaminated wells in the neighborhood because the MTBE concentrations are unrelated to nitrate or boron concentrations.

Septic Tanks as a Source of Nitrate and Chloroform

The average concentration of nitrate in rainfall measured at Washington Crossing, New Jersey, was 1.62 mg/L in samples collected in 1998, which is typical of northeast-region rainfall concentrations measured as part of the USGS National Atmospheric Deposition Program. Nitrate concentrations in ground water that exceed this background level were most likely caused by local sources, such as fertilizer applications and septic-tank effluent because nitrate sources in the host rock are assumed to be negligible. Nitrate also could be present in ground water at concentrations lower than those in precipitation as a result of vegetation and subsurface denitrifying reactions. For the following discussion, it is assumed that the combined concentrations of nitrate plus nitrite are essentially equal to concentrations of nitrate.

Boron has been used in previous studies as an indicator of the presence of wastewater (LeBlanc, 1984; Leenhouts and others, 1998; Lee and Bennett, 1998) because it is an ingredient in soaps and detergents. Its co-occurrence with nitrate indicates septic-tank effluent as the source of nitrate. Boron concentrations in relation to nitrate concentrations are shown in figure 18. Eight wells were sampled at Cranberry Lake in July 1998, and 14 wells were sampled at Cranberry Lake in fall 1998. The same 14 wells were sampled in summer 1999, and 5 wells were sampled at Lake Lackawanna in summer 1999. Concentrations of boron less than 20 µg/L may not be meaningful measurements because boron also was detected in blank samples in this and other recent (2000) USGS studies. Nitric acid, which is used to preserve samples, was determined to solubilize certain elements from glass (borosilicate) ampoules, specifically aluminum, barium, boron, silica, chromium, and zinc (Horowitz and others, 1994). In September 1998, nitric acid was made available in polypropylene vials. Therefore, where boron concentrations are less than 20 μ g/L, only the nitrate value was measured accurately, and the boron concentration can be characterized as low (fig. 18). The highest concentrations of boron were measured in the samples collected from well CR12, 106 µg/L in the fall 1998 synoptic study and 119 µg/L in the summer 1999 synoptic study. If these two data points and the data points that represent boron concentrations less than 20 µg/L are not included, then the linear correlation coefficients are 0.61 for the ambient ground-water network data in fall 1998, 0.41 for ambient network data in summer 1999, and 0.92 for the Cranberry Lake neighboorhood 1998 data. These coefficients



Figure 17a. Photograph showing diatoms in a water sample collected at the footbridge at Cranberry Lake (site 1306N), Sussex County, New Jersey, July 1999. The large cylindrical structure is a long chain centric diatom; the shorter structure probably is a broken chain. Other debris are unidentifiable but may include mineral deposits. Both diatoms are possibly of the Melosira genus. (740 micrometers by 522 micrometers)



Figure 17b. Photograph showing a diatom fragment (center) similar to those found in ground-water samples (figure 17c) in a water sample collected at Cranberry Lake (site 1306N), Sussex County, New Jersey, July 1999. Another diatom fragment (upper left) is also shown. (185 micrometers by 138 micrometers)



Figure 17c. Photograph showing a diatom fragment in a sample collected from well CR22 at Cranberry Lake, Sussex County, New Jersey, August 1999. (40 micrometers by 40 micrometers)



× Cranberry Lake neighborhood point-source wells with contamination sampled in 1998 (8 samples)

Figure 18. Relation of boron concentration to nitrate concentration in ground-water samples collected at Cranberry Lake and Lake Lackawanna, Sussex County, New Jersey.
indicate that septic-tank effluent is present and is likely the source of nitrate and boron in wells at Cranberry Lake. Available data for wells at Lake Lackawanna were insufficient to provide a meaningful inference.

Chloroform is used as an intermediate in the production of some synthetic compounds and as a solvent, a dry-cleaning agent, a component in fire extinguishers, and a fumigant. Unlike other VOCs discussed in this report, chloroform can form naturally in the environment (Hoekstra and others, 1998) at low levels and when organic matter in water reacts with chlorine used to disinfect water for public supply (Rook, 1974). Presumably, these same reactions also occur in wastewater. That presumption and the use of chlorine in laundry bleach indicate that septic tanks are a source of chloroform to the environment.

In this study, chloroform was detected in virtually all ground-water samples; however, this finding is not exceptional because chloroform is the most frequently detected VOC across the country in studies of shallow-ground-water quality conducted as part of the USGS National Water Quality Assessment (NAWQA) program (Squillace and others, 1996). Boron concentrations in relation to chloroform concentrations are shown in figure 19 for the four well synoptic studies. If points that represent boron concentrations less than 20 µg/L are disregarded (as discussed above), then the linear correlation coefficients are 0.21 for the Cranberry Lake fall 1998 data, 0.12 for the Cranberry Lake summer 1999 data, and 0.546 for the Cranberry Lake neighboorhood 1998 data. Available data for the wells at Lake Lackawanna were insufficient to provide a meaningful inference. These relations suggest that septic-tank effluent could be a source of chloroform to some of the wells. As discussed in the following section, chloroform concentrations in samples from the lakeside wells generally are higher than those from other surveys of ambient ground-water quality in fractured rock aquifers in New Jersey which supports the hypothesis that septic-tank efluent affects ambient ground-water quality, however, the negative correlation coefficient associated with the

Cranberry Lake summer 1999 boron-chloroform data suggests the possibility of another chloroform source.

Septic-tank effluent is another factor that contributes to the uniqueness of the lakeside setting. Unmonitored contaminants, pathogens, and other microorganisms associated with septictank effluent could be entering lakeside wells. MBAS is another indicator of the presence of septic-tank effluent and was included in the analysis of samples for this study; however, the MBAS concentrations were less than 0.1 mg/L. Concentrations of MBAS greater than the reporting limit of 0.1 mg/L indicate a higher level of contamination; consequently, the MBAS data were not useful in verifying the lower level effect from septic-tank effluent indicated by the nitrateboron-chloroform relation.

Comparison to Ground-Water Quality in the New England, Piedmont, and Coastal Plain Physiographic Provinces

As part of the USGS Long Island/New Jersey (LINJ) NAWQA study, surveys of ambient ground-water quality in New Jersey were conducted by sampling untreated water from domestic wells (fig. 20) in the New England (30 wells), Piedmont (22 wells), and Coastal Plain (30 wells) Physiographic Provinces (J.A. Hopple, U.S. Geological Survey, written commun., 2000; Ayers and others, 2000). Because these studies were contemporaneous with this study, similar sampling protocols and analytical schedules were used, allowing comparison of concentrations and detection frequencies. A comparison between concentrations of constituents in samples from wells at Cranberry Lake and Lake Lackawanna to those from wells in the LINJ survey for the New England Physiographic Province provides a focus on the uniqueness of lakeside communities because the two lakes are in this province. A comparison to the Piedmont survey also is of interest because of the commonality of fracturedrock aquifers. The Coastal Plain survey provided data from an aquifer system composed of unconsolidated sediments.



- ♦ Wells in ambient ground-water network at Cranberry Lake sampled in fall 1998 (12 samples)
- Wells in ambient ground-water network at Cranberry Lake sampled in summer 1999 (12 samples)
- ▲ Wells in ambient ground-water network at Lake Lackawanna sampled in summer 1999 (5 samples)
- × Cranberry Lake neighborhood point-source wells with contamination sampled in 1998 (8 samples)

Figure 19. Relation of boron concentration to chloroform concentration in ground-water samples collected at Cranberry Lake and Lake Lackawanna, Sussex County, New Jersey.



Figure 20. Location of domestic wells in the Long Island-New Jersey National Water-Quality Assessment study area and physiographic provinces in New Jersey.

Detection frequencies for VOCs detected during the various surveys are plotted in figure 21. Although MTBE is detected frequently in the fractured rock provinces (47 percent of samples from the New England and 36 percent of samples from the Piedmont), its nearly ubiquitous detection (93 percent) in samples from lakeside wells underscores the uniqueness of the lakeside setting with respect to MTBE. The detection frequency for chloroform was greater than 80 percent for the lakeside wells and greater than 75 percent for the Coastal Plain and New England wells but only 41 percent for the Piedmont wells. The detection frequencies for other chlorinated VOCs--PCE, TCE, 1,4-dichlorobenzene, and 1,1dichloroethane--were greater in samples from lakeside wells than from other wells. Because these VOCs were not detected in samples from the lakes, a process other than lake/ground water interaction is necessary to explain the uniqueness of the lakeside setting. The use of these compounds in a recreational setting may be higher and (or) the thin soils and steeply dipping fractures characteristic of the land surrounding Cranberry Lake may explain the increased detection frequency. Because their Henry's Law coefficients are high, chlorinated VOCs, if present, would dissipate quickly from the lake surface.

The sum of the concentrations of fuelrelated compounds (MTBE, TAME, and BTEX) are plotted in figure 22a, chloroform in figure 22b, and all other VOCs in figure 22c. The boxed part of the data sets (box plots) marks the extent of the 75th and 25th percentiles of the concentrations. For the purpose of computing these percentiles, a sample with no detectable concentration was assigned a concentration of zero. In addition to detection frequency, the median concentrations were significantly higher for fuel-related compounds in the lakeside setting than in other settings (fig. 22a). The lakeside setting was the only class of survey for which the boxed part of the data (middle 50 percent) exceeded detection limits. Typically, concentrations of chloroform in samples from wells at Cranberry Lake were higher than those from wells in the Piedmont and New England Physiographic Provinces but lower than those from wells in the Coastal Plain (fig. 22b). Other VOCs, mostly halogenated compounds, typically were present in lakeside ground water at higher concentrations, as indicated by median concentrations (fig. 22c).

Samples collected in summer 1999 at Cranberry Lake and Lake Lackawanna were analyzed for pesticides (except for well CR13). Detection frequencies for pesticides for the NAWQA and lakeside studies are shown in figure 23. Prometon and simazine were detected more frequently in samples from wells at Cranberry Lake and Lake Lackawanna than in samples from other studies. Other pesticides (for example, desethyl atrazine, atrazine, and metolachor) were not detected in ground water at Cranberry Lake and Lake Lackawanna, probably because of the absence of agricultural activity in the immediate area of the lakeside communities.

Concentrations of nitrate detected during the NAWQA and lakeside studies are shown in figure 24. The median nitrate concentrations of 1.9 and 2.1 mg/L measured in ground-water samples at Cranberry Lake in 1998 and 1999, respectively, are higher than those for the other studies and are the only median concentrations greater than the 1998 precipitation average of 1.62 mg/L measured at Washington Crossing, N.J. Higher nitrate concentrations were found in the other studies, however, and likely are the result of fertilizer application. Concentrations of boron were determined in only two of the NAWQA ground-water surveys (Coastal Plain and New England); no relation was apparent between nitrate and boron concentrations in either survey (fig. 25).



Figure 21. Detection frequencies of volatile organic compounds in samples from domestic wells in the lakeside and the U.S. Geological Survey National Water-Quality Assessment study areas, New Jersey.



Figure 22a. Distribution of total fuel-related volatile organic compunds in samples from domestic wells, in the lakeside study area, 1998-99, and the U.S. Geological Survey National Water-Quality Assessment study areas, New Jersey.



Figure 22b. Distribution of chloroform concentrations in samples from domestic wells, in the lakeside study area, 1998-99, and the U. S. Geological Survey National Water-Quality Assessment study areas, New Jersey.



Figure 22c. Distribution of volatile organic compounds other than fuel-related compounds in samples from domestic wells in the lakeside study area, 1998-99, and U.S. Geological Survey National Water-Quality Assessment study areas, New Jersey.



Figure 23. Detection frequency of pesticides and herbicides in ground-water samples, lakeside study area, summer 1999, and the U.S. Geological Survey National Water-Quality Assessment study area, New Jersey.



Figure 24. Distribution of nitrate plus nitrite concentrations in samples from domestic wells in the lakeside study area, 1998-99, and the U.S. Geological Survey National Water-Quality Assessment study area, New Jersey.



Figure 25. Relation of concentration of nitrite plus nitrate to concentration of boron in samples from domestic wells in the lakeside and U.S. Geological Survey National Water-Quality Assessment study areas, New Jersey.

SUMMARY AND CONCLUSIONS

The study was conducted by the USGS as part of the Toxic Substances Hydrology Program to begin water-quality assessment of lakeside development. Densely populated communities surround many of the larger lakes in northwestern New Jersey. These communities derive most of their water supply from wells. The lakes can be navigated by gasoline-powered watercraft, can be in various stages of eutrophication, may contain pathogens associated with bathing and waterfowl, and are periodically subjected to chemical applications to control aquatic plant growth. Another feature that contributes to water-quality concerns in lakeside communities is the widespread use of septic tanks.

MTBE Concentrations in Lakes are Significant

Water samples were collected from three lakes in northern New Jersey--Cranberry Lake, Lake Lackawanna, and Lake Hopatcong. Concentrations of methyl tert-butyl ether (MTBE) in the lakes during the summer season were significant. Typical concentrations in Cranberry Lake ranged from 20 to 30 μ g/L and in Lake Lackawanna from 5 to 14 μ g/L during the summers of 1998 and 1999. In Lake Hopatcong, in water less than 20 ft deep, the concentration of MTBE was about 10 μ g/L and in water more than 20 ft deep about 2 to 3 μ g/L during summer 1999.

The Source of MTBE in Lakes is Gasoline-Powered Watercraft

The source of the MTBE, a gasoline additive, in the lakes was determined to be gasoline-powered watercraft. MTBE concentrations in months when boat traffic is low were negligable. Furthermore, the total MTBE mass estimates in equivalent gallons of oxygenated gasoline, which ranged from 157 to 164 gal for Cranberry Lake, 4 to 18 gal for Lake Lackawanna, and 616 to 853 gal for Lake Hopatcong, are reasonable for that hypothesis. TAME and BTEX, also are constituents of gasoline and were detected in samples from the lakes but at much lower concentrations than MTBE.

MTBE in Ambient Ground Water

Ambient ground-water quality showed the effect of human activities. MTBE was detected in samples collected from 13 of the 14 wells at Cranberry Lake during fall 1998 and summer 1999. MTBE also was detected in samples collected from four of five wells at Lake Lackawanna in summer 1999. Lake/ground water interaction is a feasible explanation for the nearly ubiquitous presence of MTBE in ground water because the movement of water from lakes to wells was demonstrated by the presence of diatom fragments in ground-water samples. In the wells sampled, many static water levels and essentially all water levels during pumping were below the levels of the lakes. Unmonitored substances could be present in ground water as a result of lake/ ground water interaction.

Septic-Tank Effluent and Ambient Ground-Water Quality

Ambient ground-water quality also appears to be affected by septic-tank effluent. Nitrate was present in ground water at concentrations that exceeded the concentration in rainfall. Concentrations of boron, an element found in soap and detergents, correlated with nitrate concentrations, which indicates that septictank effluent can be a source of nitrate. Concentrations of chloroform also correlated with boron concentrations, which indicates that septictank effluent can be a source of chloroform. Pathogens and other chemicals that were not analyzed for could migrate to wells as a result of septic-tank effluent.

Radon in Ambient Ground Water

Radon in ambient ground water is a concern throughout northern New Jersey. In particular, the median radon concentrations in ground-water samples collected from 14 wells at Cranberry Lake in 1998 and 1999 were 1,282 and 1,046 pCi/L, respectively. In five ground-water

samples collected at Lake Lackawanna in 1999, the median radon concentration was 340 pCi/L.

The U.S. Environmental Protection Agency Maximum Contaminant Level and Alternate Maximum Contaminant Level for radon are 300 and 4,000 pCi/L, respectively. Although these values exceed the MCL of 300 pCi/L, they are not high relative to radon concentrations measured in the region.

Point Source of MTBE

Near a known point source of groundwater contamination, MTBE concentrations in samples from wells in a neighborhood of Cranberry Lake were on the order of hundreds of micrograms per liter with essentially no cooccurrence of BTEX. That BTEX compounds do not co-occur with MTBE may seem anomalous given that the source is likely spilled fuel or perhaps motor oil; however, the observation is consistent with the solubility and content of MTBE and BTEX in these products. TAME, another fuel oxygenate, was detected in the well samples and highly correlated with MTBE concentrations. The TAME concentrations were about 10 times less than MTBE concentrations.

Densely populated lakeside communities are a common setting in northern New Jersey and other parts of the country. A more comprehensive, regional water-quality assessment could identify the potential threats to the ground-water supply near lakes and identify contaminants introduced by lakeside communities that are currently not monitored.

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APPENDIX 1. LABORATORY SCHEDULES

APPENDIX 1. LABORATORY SCHEDULES

Volatile Organic Compounds (VOCs)

Concentrations of fuel-related compounds --MTBE, TAME, and BTEX--in samples of lake water collected in 1998 (Baehr and Zapecza, 1998) were determined using the National Water Quality Laboratory (NWQL) schedule 1378. The minimum reporting level (MRL) for each of the fuel-related compounds on schedule 1378 is 0.2 µg/L. Beginning in 1999, NWQL began providing lower concentration estimates for the VOCs on schedule 2022, which was used in the USGS National Water Quality Assessment (NAWQA) program. Chromatographs from 1998 samples were reprocessed by NWQL to provide concentrations of 37 VOCs that approximately correspond to NWQL schedule 1307. This schedule (table A1) was used for all subsequent analyses. It was designed for this investigation to provide the same capability to report lowconcentration data as that developed for the NAWQA program; however, the number of VOCs was reduced. Confirmed detections less than the MRL are reported as estimated (E) values. The lowest reported (E)-values are listed in table A1. The analyses for VOCs in water samples conducted by NWQL were done by purge-and-trap gas chromatography/mass spectrometry (GC/MS) methods (Connor and others, 1997).

VOC concentrations in samples collected from the bridge (site 1306N) at Cranberry Lake from June 1, 1999, to November 22, 1999, and those in samples from Lake Hopatcong were determined at the New Jersey District laboratory (NJDL). The NJDL analyzed for VOCs by using gas chromatography with flame ionization detection (GC/FID). The results have been proven to be accurate for concentrations that exceed 0.1 µg/L. The NJDL analyses were evaluated against the established NWQL schedule by collecting and analyzing 12 replicate samples from site 1306N from June 1 to November 22, 1999. The results are summarized in table A2. The results for MTBE were good (fig. A1); the correlation coefficient for the replicate data was 0.91. The high correlation coefficient was obtained as a result of high MTBE concentrations. Although the NJDL was able to approximate the NWQL results for concentrations of TAME, the correlation with NWQL concentrations at the 1-µg/L level was poor. The NJDL was not able to provide estimated concentrations below 0.1 µg/L for BTEX compounds.

Other Schedules

Schedules for pesticides, major and trace elements, nutrients, and other compounds are summarized in tables A3, A4, and A5, respectively. **Table A1**. Volatile organic compounds analyzed for under National WaterQuality Laboratory schedule 2022 for sampling sites, Sussex County, New Jersey

[µg/L, micrograms per liter; ND, not detected]

Compound	Method reporting limit	Lowest reported value in ground-water samples collected during 1998-99
1,1,1-Trichloroethane	0.032	ND
1,1,2-Trichlorotrifluoroethane	.06	ND
1,1-Dichloroethane	.066	0.0145
1,1-Dichloroethylene	.04	.0241
1,2-Dichlorobenzene	.048	.044
1,2-Dichloroethane	.13	ND
1,2-Dichloroethane-d4 (surrogate)	.1	ND
1,2-Dichloropropane	.068	ND
1,3-Dichlorobenzene	.054	.007913
1,4-Bromofluorobenzene (surrogate)	.1	ND
1,4-Dichlorobenzene	.05	.00721
Benzene	.035	.2
Bromodichloromethane	.048	.013
Bromoform	.06	.5055
Carbon tetrachloride	.09	.02596
Chlorobenzene	.028	.016
Chloroform	.052	.0069
Dibromochloromethane	.18	.3879
Dichlorodifluoromethane	.27	.017
Dichloromethane	.38	ND
Diethyl ether	.17	ND
Diisopropyl ether	.1	ND
Ethyl tert-butyl ether	.054	ND
Ethylbenzene	.03	ND
Styrene	.042	.006273
Tetrachloroethylene	.1	.003214
Toluene	.05	.009953
Toluene-d8 (surrogate)	.1	ND
Trichloroethane	.032	.00416
Trichloroethylene	.038	.008
Trichlorofluoromethane	.09	.01332
Vinyl chloride	.11	ND
cis-1,2-Dichloroethylene	.038	.03988
m- and p-Xylene	.06	ND
o-Xvlene	.038	ND
tert-Butyl methyl ether	.17	.04772
tert-Pentyl methyl ether	.11	.01763
trans-1.2-Dichloroethylene	.032	ND
1,1,1-Trichloroethane	.032	ND
1,1,2-Trichlorotrifluoroethane	.06	ND
1.1-Dichloroethane	.066	.0145
1,1-Dichloroethylene	.04	.0241



Figure A1. Concentrations of Methyl tert-butyl ether in replicate samples collected from June 1, 1999, to November 22, 1999 and analyzed at National Water Quality Laboratory and New Jersey District Laboratory.

Table A2. Concentrations of volatile organic compounds analyzed for at the National Water Quality Laboratory and the New Jersey District Laboratory, for sampling sites, Sussex County, New Jersey, June 1, 1999-August 3, 1999

[Sampled from bridge unless noted, all concentrations are in micrograms per liter; NJDL, New Jersey District Laboratory; NWQL, National Water Quality Laboratory; NA, not analyzed for; <, less than; µg/L, micrograms per liter; E, estimated value]

	Sampling	М	TBE	TA	AME	Be	nzene	Tol	uene	Ethyl	benzene	<u> </u>	Xylene	o-X	ylene
Sampling date	depth (feet)	NJDL	NWQL	NJDL	NWQL	NJDL	NWQL	NJDL	NWQL	NJDL	NWQL	NJDL	NWQL	NJDL	NWQL
6/1/1999	3	27.2	28 84	NA	2 262	NA	1 746	NA	2 632	NA	0 3876	NA	2 306	NA	2 446
6/1/1999	10	4.2	4.419	NA	.3024	NA	<.035	NA	E.08278	NA	<.03	NA	<.06	NA	<.06
6/14/1999	3	9.9	15.9	NA	.9353	NA	E.04689	NA	E.02702	NA	<.03	NA	<.06	NA	<.06
6/14/1999	10	6.6	10.76	NA	.6765	NA	E.01155	NA	E.0291	NA	<.03	NA	<.06	NA	<.06
6/28/1999	3	22.1	22.03	NA	.9802	NA	.1329	NA	.1372	NA	E.0248	NA	E.09314	NA	E.05294
6/28/1999	10	16.1	16.17	NA	.708	NA	E.05439	NA	E.01695	NA	<.03	NA	<.06	NA	<.06
7/13/1999	3	24.2	23.48	1.4	1.222	< 0.1	E.03835	< 0.1	<.05	<.1	<.03	< 0.1	<.06	< 0.1	<.06
7/13/1999	10	25.1	20.46	1.5	.9719	<.1	E.02302	< 0.1	<.05	<.1	<.03	<.1	<.06	<.1	<.06
7/29/1999	3	31.3	30.87	1.5	1.227	.3	.2276	<0.1	<.05	<.1	<.03	<.1	<.06	<.1	<.06
7/29/1999	10	22.5	21.77	1.3	1.007	<.1	E.03004	< 0.1	E.04885	<.1	<.03	<.1	<.06	<.1	<.06
8/3/1999	6 (boat)	25.8	27.24	1.3	1.292	<.1	E.03577	< 0.1	E.02809	<.1	<.03	<.1	<.06	<.1	<.06
8/3/1999	6.0	29.1	26.27	.6	1.173	<.1	.04613	<0.1	E.07471	<.1	<.03	<.1	.02494	<.1	<.06

Table A3. Pesticides analyzed for under National Water QualityLaboratory schedule 2001

-		Lowest reported value in ground water
Compound	Method reporting limit	samples collected during 1998-99
compound	method reporting mint	samples concered during 1990 99
2 6-Diethylaniline	0.003	ND
Acetochlor	002	ND
Alachlor	.002	ND
Atrazine	001	ND
A zinphos-methyl	.001	ND
Renfluralin	.001	ND
Butulata	.002	ND
Carbaryl	.002	0.004
Carbatyr	.003	0.004 ND
Chlomurifac	.003	ND
Children Street	.004	ND
Cyanazine	.004	ND
Dacthal	.002	ND
Desetnyi atrazine	.002	.001
Diazinon	.002	ND
Diazinon-d10 (surrogate)	.1	ND
Dieldrin	.001	ND
Disulfoton	.017	ND
EPIC	.002	ND
Ethalfluralin	.004	ND
Ethoprophos	.003	ND
Fonofos	.003	ND
Lindane	.004	ND
Linuron	.002	ND
Malathion	.005	ND
Metolachlor	.002	.0029
Metribuzin	.004	ND
Molinate	.004	ND
Napropamide	.003	ND
Parathion	.004	ND
Parathion-methyl	.006	ND
Pebulate	.004	ND
Pendimethalin	.004	ND
Phorate	.002	ND
Prometon	.018	.0039
Propachlor	.007	ND
Propanil	.004	ND
Propargite	.013	ND
Propyzamide	.003	ND
Simazine	.005	.030
Tebuthiuron	.01	ND
Terbacil	.007	ND
Terbufos	.013	ND
Terbuthylazine	.1	ND
Thiobencarb	.002	ND
Tri-allate	.001	ND
Trifluralin	.002	ND
alpha-HCH	.002	ND
alpha-HCH-d6 (surrogate)	.1 percent	ND
cis-Permethrin	.005	ND
p,p'-DDE	.006	ND

[All concentrations are in micrograms per liter, except as, where noted; ND, not detected]

Table A4. Major and trace ions analyzed for under National Water Quality Laboratory schedule 1 and lab code 657 and 2110

	Schedule or lab code	2	
Compound	number	Method reporting limit	Units
Calcium	1	0.02	mg/L
Silica	1	.1	mg/L
Manganese	1	2.2	μg/L
Chloride	1	.29	mg/L
Magnesium	1	.014	mg/L
Sodium	1	.09	mg/L
Sulfate	1	.31	mg/L
Iron	1	10	μg/L
Fluoride	1	.1	mg/L
Potassium	1	.24	mg/L
Copper	657	10	μg/L
Boron	2110	16	μg/L

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Table A5. Nutrients and organic compounds analyzed for under National Water QualityLaboratory schedule 931 and lab codes 96, 113, 114, 169, 586, 587

[mg/L, milligrams per liter; µg/L, micrograms per liter]

	Schedule or lab cod	e	
Compound	number	Method reporting limit	Units
Phosphorus	931	0.05	mg/L
Nitrogen, nitrite + nitrate	931	.037	mg/L
Nitrogen, ammonia + organic nitrogen	931	.1	mg/L
Nitrogen, ammonia	931	.029	mg/L
Methylene blue active substances	96	.02	mg/L
Dissolved organic carbon	113	.1	mg/L
Total organic carbon	114	.1	mg/L
Residue on evaporation	169	10	mg/l
Chlorophyll-a	586	.1	μg/L
Chlorophyll-b	587	.1	μg/L