Barnegat Bay National Estuary Program

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Barnegat Bay National Estuary Program

Assessment of a Shallow Ground-Water-Quality Indicator

Prepared by Christine M. Wieben of the U.S. Geological Survey,
in cooperation with the Barnegat Bay National Estuary Program

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Barnegat Bay Estuary Program

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The Barnegat Bay National Estuary Program adopted a number of environmental indicators to be monitored and periodically evaluated in order to assess progress toward achievement of CCMP goals. A description of these indicators is presented in the BBNEP Monitoring Program Plan (MPP), which was approved by the U.S. Environmental Protection Agency in 2003. The BBNEP 2005 State of the Bay Technical Report includes an assessment of six of these indicators.

Other MPP indicators can be assessed as resources become available to facilitate the assessments. One of these other indicators is the quality of ground water, which provides most of the drinking water used in the Barnegat Bay watershed, as well as most of the fresh water input to the estuary. Subsurface flow represents a significant contaminant transport pathway from the land surface to the estuary. Therefore, tracking the status of ground-water quality is an important means for tracking success in meeting CCMP water-quality goals. This report describes an assessment of this particular water-quality indicator by the U.S. Geological Survey.

Central Question

Is the quality of shallow ground water in the Barnegat Bay-Little Egg Harbor estuary changing with respect to established drinking-water standards?

Explanation of the Indicator

The shallow, unconfined Kirkwood-Cohansey aquifer system underlies most of the Barnegat Bay-Little Egg Harbor watershed and is a major source of water supply for communities within the watershed. Some ground water enters the estuary as direct seepage through estuarine sediments. More importantly, however, ground water discharges from this aquifer system to major streams in the watershed, including the Toms River and the Metedeconk River, and to other smaller streams and tributaries, with eventual release into the estuary. This ground-water discharge from the Kirkwood-Cohansey aquifer system accounts for a high percentage (71-93 percent) of surface-water flow in the watershed and is the largest source of freshwater input to Barnegat Bay (Watt and others, 1994; Gordon, 2003; Nicholson and Watt, 1997). For this reason, the quality of water in the Kirkwood-Cohansey aquifer system is a reasonable indicator of the quality of freshwater inflow into the estuary.

The Kirkwood-Cohansey aquifer system is highly susceptible to contamination from human activity because it is unconfined—that is, it generally lacks an overlying confining layer that would impede the downward movement of contaminants originating at the land surface (Watt, 2000). In addition, the aquifer system is made up of highly permeable unconsolidated sands and gravels that facilitate the migration of contaminants from the land surface into the system (Stackelberg and others, 1997). Most households with privately owned wells in the Barnegat Bay-Little Egg Harbor watershed rely on this aquifer system for domestic water supply (Nicholson and others, 2003).

Both natural processes and human activities contribute contaminants to ground water. For example, iron and manganese, both naturally occurring elements in rocks and sediment, can reach high concentrations in ground water through natural dissolution processes (Watt, 2000). On the other hand, ground-water contaminants also derive from anthropogenic sources including industrial discharge, waste disposal, leaky underground storage tanks, septic systems, and fertilizer application. Anthropogenic contaminants frequently co-occur in the environment such that the presence of one contaminant may indicate the presence of others (Stackelberg and others, 2001).

In this study, several contaminants that enter the environment through human inputs were examined. Some of the contaminants commonly detected in drinking-water supplies derived from the Kirkwood-Cohansey aquifer system are listed in Table 1.

Nitrate, a species of nitrogen, is a chemical constituent of water that is of particular concern in the estuary because of its role in eutrophication, or excess algal growth. Although nutrients such as nitrogen and phosphorous are essential for plant growth and production, excessively high inputs of nutrients can lead to increased algal and biomass production, toxic or nuisance algal blooms, shifts in species composition, and a decline in water quality (Kennish, 2001). Elevated turbidity in the water column resulting from increased biomass production can block sunlight and cause loss of habitat for submerged aquatic vegetation (Kennish, 2001). The decomposition of dead plant material consumes available oxygen and, in extreme cases, dissolved-oxygen levels may become too low to support fish and other aquatic organisms. Monitoring nutrient loads into Barnegat Bay, including inputs from the Kirkwood-Cohansey aquifer system, is critical to protecting the health of the bay's ecosystem. In addition, elevated levels of nitrate in drinking water can have serious health implications, primarily for infants and farm animals, whose immature digestive systems allow for the reduction of nitrate to nitrite (Stackelberg and others, 1997). The presence of nitrite reduces the oxygen-carrying capacity of blood, and can lead to methemoglobinemia, or "blue-baby" syndrome.

As a means of monitoring shallow-ground-water quality and protecting human health, the Ocean County Board of Health passed an ordinance in 1987 (Ocean County Board of Health Well and Individual Sewage Disposal System Ordinance 87-1, originally passed May 6, 1987, amended in 1990, and again in 1994; Robert Ingenito, Ocean County Health Department, written commun., 2002) that requires samples from privately owned wells in Ocean County to be analyzed upon well completion or in association with real-estate transactions (Nicholson and others, 2003). This well-testing program has resulted in an extensive database, which is maintained by the Ocean County Health Department (OCHD). The database contains results of analyses for a variety of water-quality constituents and characteristics, including physical properties, inorganic constituents, volatile organic compounds, microbial and radiological contaminants, pesticides, and trace elements.

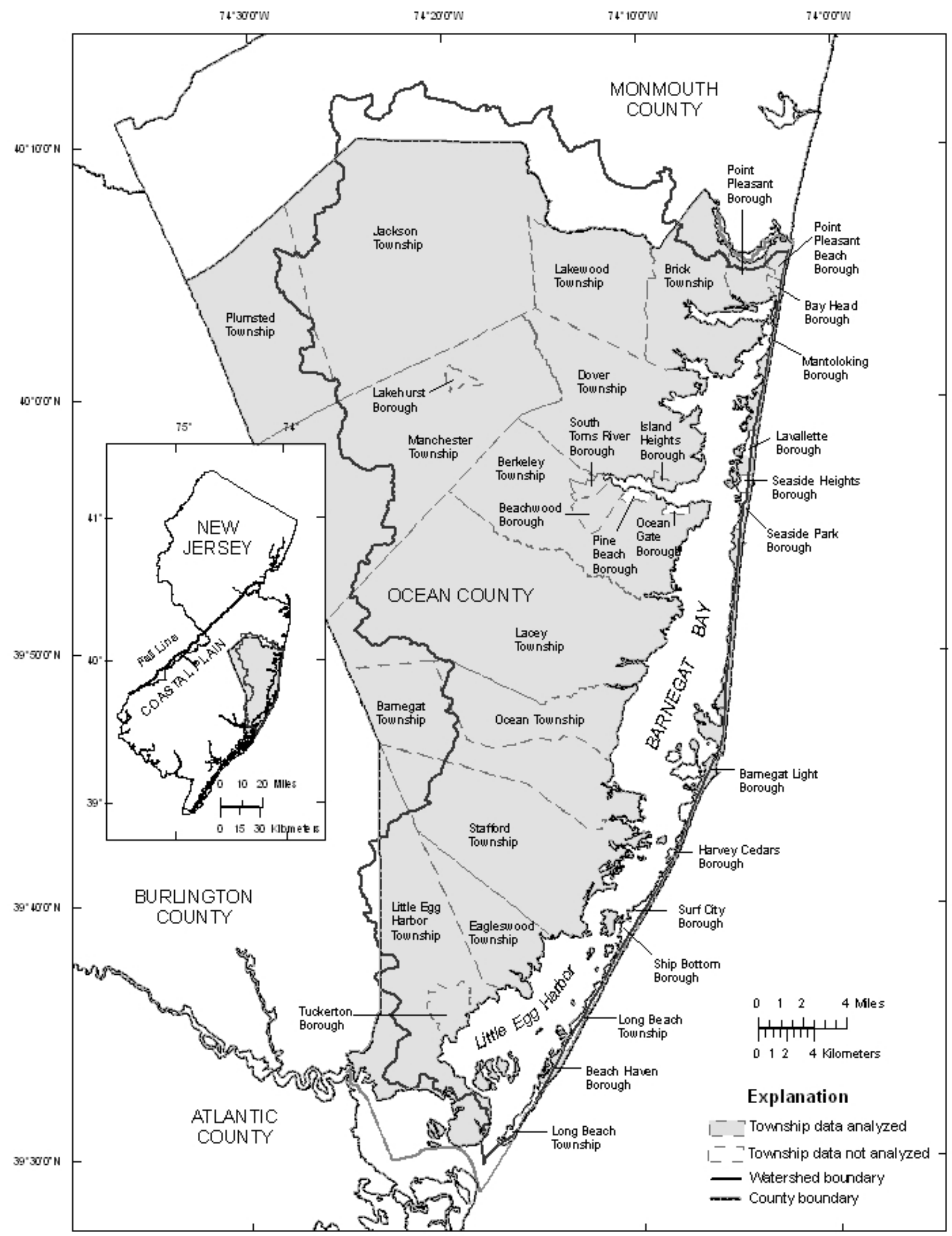
This report describes the status of and trends in regional ground-water quality in the Barnegat Bay-Little Egg Harbor watershed determined from analysis of the data stored in the OCHD water-quality database. The database currently contains results of laboratory analyses of more than 99,000 samples collected from more than 31,000 locations throughout Ocean County. Only raw water samples—that is, samples collected prior to any treatment—were analyzed. Also, samples that were collected as part of investigations of known or suspected areas of ground-water contamination were excluded from the analysis. Municipalities in Ocean County from which at least one sample met these criteria and were analyzed further are shown in Figure 1. Different wells were sampled each year and results from the earliest sample date per year for each well were analyzed. Additionally, because not all samples were analyzed for all constituents, the number of results for each constituent varies.

Table 1. Contaminants commonly detected in drinking water derived from the Kirkwood-Cohansey aquifer system.

[Modified from Watt, 2000]

Constituent	Sources to ground water
Inorganic constituent	
Arsenic	Enters environment from natural processes, industrial activities, pesticides, industrial waste, and smelting of copper, lead, and zinc ore.
Mercury	Occurs as an inorganic salt and as part of organic mercury compounds. Enters the environment from industrial waste, mining, pesticides, coal, electrical equipment (batteries, lamps, switches), smelting, and fossil-fuel combustion.
Nitrate (as nitrogen)	Occurs naturally in mineral deposits, soils, seawater, freshwater systems, the atmosphere, and biota. More stable form of combined nitrogen in oxygenated water. Found in the highest levels in ground water under extensively developed and agricultural areas. Enters the environment from fertilizer, feedlots, sewage, and atmospheric deposition.
Organic constituent	
Volatile organic compounds	Enter the environment from the manufacture of plastics, dyes, rubbers, polishes, solvents, crude oil, insecticides, inks, varnishes, paints, disinfectants, gasoline products, pharmaceuticals, preservatives, spot removers, paint removers, degreasers, and many other products.
Pesticides	Enter the environment as herbicides, insecticides, fungicides, rodenticides, and algicides.

Figure 1. Municipalities in the Ocean County Health Department water-quality database, Ocean County, New Jersey.



Status

The percentage of wells that contain water in which concentrations of a given constituent exceed the Federal and State primary drinking-water standard, known as the Maximum Contaminant Level (MCL), provides an indication of the amount of poor-quality ground water, (with respect to the MCL), that may be discharging to the estuary. The percentage of wells in which each constituent analyzed for exceeded the drinking-water standard in 2005 is shown in Figure 2. In cases in which analyses of raw well water indicated that a standard had been exceeded, water treatment, well replacement, and (or) retesting assured that applicable drinking-water standards were being met at the tap (Robert Ingenito, Ocean County Health Department, oral commun., 2007).

Inorganic constituents

As a result of its role in eutrophication, nitrate is of particular concern in water entering the estuary. A recent assessment conducted by the National Oceanic and Atmospheric Association (NOAA) on the effects of nutrient enrichment of the Nation's estuaries categorizes Barnegat Bay as highly eutrophic (Bricker and others, 1999). According to the assessment, Barnegat Bay exhibits high levels of chlorophyll *a*, macroalgae, and nuisance or toxic algal blooms. The distribution of nitrate concentrations in ground-water samples for municipalities with a total sample size, n, greater than 25 during 2000-05 is shown in Figure 3. In the Barnegat Bay watershed, median concentrations of nitrate tend to be higher in areas where nitrogen loads in surface water are high (Hunchak-Kariouk and Nicholson, 2001). The differences in median concentrations of nitrate among municipalities (Fig. 3) are statistically significant based on a Kruskal-Wallis statistical analysis. In cases where the median concentration of nitrate is equal to 0.01 mg/L (the value assigned to non-detects), nitrate was not detected in more than 50 percent of the samples. Approximately 0.5 percent of the nitrate concentrations in the OCHD water-quality database for 2005 (8 of 1,764 analyses) exceeded the 10-mg/L MCL. Although the MCL provides one benchmark that can be used to evaluate water quality, in the case of nitrates, much lower concentrations are considered to be environmentally problematic. The U.S. Environmental Protection Agency (USEPA) recommends a total nitrogen criterion level of 0.71 mg/L for rivers and streams in nutrient ecoregion XIV, which covers the Eastern Coastal Plain (U.S. Environmental Protection Agency, 2000). Values for 31.6 percent (557 of 1,764) of the nitrate concentrations in the OCHD water-quality database for 2005 were greater than the 0.71-mg/L nitrogen criterion for streams. No criterion has yet been developed for estuaries; however, regional studies indicate that the water-quality criteria that may be required for eelgrass bed (*Zostera marina*) maintenance in the polyhaline (18-30 ppt salinity) and mesohaline (5-18 ppt (parts per thousand) salinity) portions of the Chesapeake Bay is less than 0.15 mg/L dissolved inorganic nitrogen (Kemp and others, 2000). Of the 1,764 nitrate concentrations in the database for 2005, 855 (48.5 percent) exceeded this threshold value.

The presence of mercury in water is a major health concern for both human and aquatic life. Small concentrations of mercury occur naturally in the sediments of the Kirkwood-Cohansey aquifer system; mercury concentrations in the water from this aquifer system that exceed 10 ng/L, however, are likely the result of human inputs (Dooley, 1992). Approximately 0.6 percent of the wells (10 out of 1,815 analyses) in the OCHD database for 2005 were found to contain mercury at concentrations in excess of the 2-µg/L MCL. Like nitrate, the presence of mercury at concentrations lower than the MCL is considered to be environmentally important. On October 16, 2006, New Jersey adopted a surface-water standard of 0.94 µg/L for mercury in saltwater bodies (N.J. Department of Environmental Protection, 2006); values for 1.0 percent (18 of 1,815) of the analyses in the OCHD database for 2005 were found to exceed this new standard.

Growing concern about the health effects of long-term, chronic exposure to low levels of arsenic led the USEPA to lower the MCL for arsenic in public water supplies from 50 µg/L to 10 µg/L, effective January 23, 2006 (U.S. Environmental Protection Agency, 2001). New Jersey adopted a more stringent standard of 5 µg/L for public and non-public water systems, also effective January 23, 2006. Values for 0.6 percent (4 of 681) of the analyses in the OCHD water-quality database for 2005 exceeded the arsenic MCL of 5 µg/L.

Volatile Organic Compounds

Volatile organic compounds (VOCs) in ground water commonly originate from point sources such as leaking storage tanks, landfills, and industrial discharges, all of which typically are found in urban areas (Stackelberg and others, 2000). Consequently, VOCs have been detected more frequently in the Kirkwood-Cohansey aquifer system in urban areas than in agricultural and undeveloped areas (Stackelberg and others, 1997). Statistical analysis of the VOC concentrations in the OCHD database indicates that they exceeded drinking-water standards in 11 municipalities in Ocean County in 2005. Of the samples collected from the 1,822 wells in the study area and analyzed for VOCs in 2005, 71 (3.9 percent) contained at least one VOC at a concentration greater than its drinking-water standard. The compound most frequently detected at concentrations greater than its MCL was tetrachloroethylene, with concentrations in 0.9 percent of samples (17 of 1,811) in excess of the 1-µg/L MCL. The frequency of detection for trichloroethylene, carbon tetrachloride, 1,2-dichlorobenzene, methylene chloride, benzene, and 1,2-dichloroethane at concentrations greater than their respective MCLs ranged from 0.5 to 0.7 percent. Seven other VOCs (1,1,1-trichloroethane, *trans*-1,2-dichlorethylene, 1,4-dichlorobenzene, xylene, 1,1-dichloroethylene, vinyl chloride, and 1,3-dichlorobenzene) each had a frequency of exceedance less than 0.5 percent.

Pesticides

The OCHD water-quality database contains results for samples from 814 wells that were analyzed for chlordane in 2005. Chlordane is a persistent pesticide with potential health implications for humans and a tendency to accumulate in aquatic organisms; all commercial uses of chlordane were banned by the USEPA in 1988. Of the wells sampled, 3 (0.4 percent) contained chlordane at concentrations greater than the 0.5-µg/L MCL.

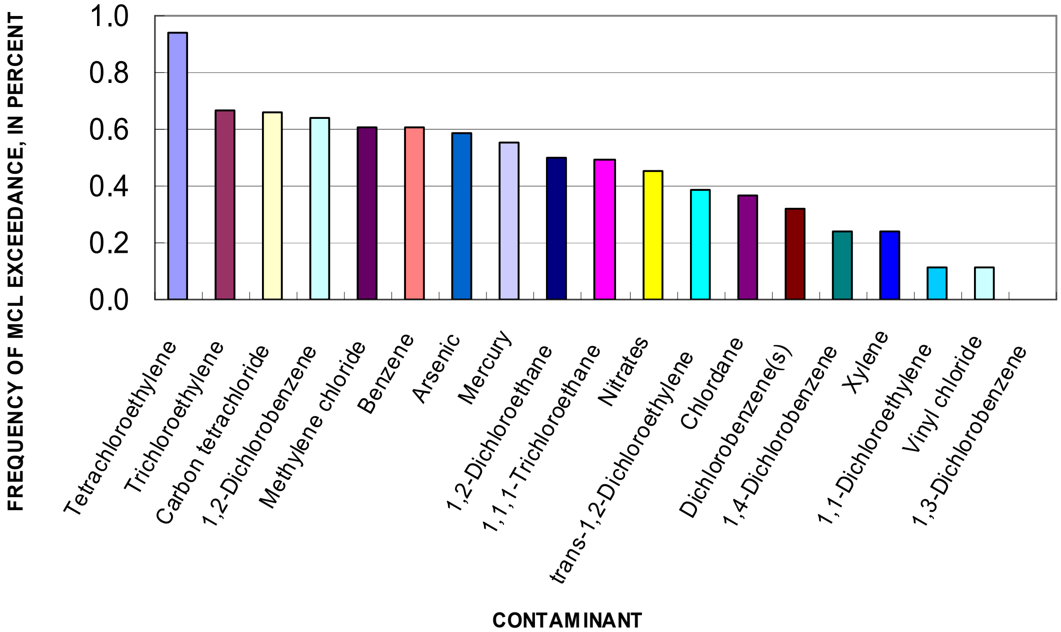


Figure 2. Percentage of privately owned wells in which concentrations of the contaminants analyzed for exceeded Federal and State MCLs in 2005 in the Ocean County Health Department, New Jersey, water-quality database. (MCL, Maximum Contaminant Level)

Figure 3. Distribution of nitrate concentrations in ground-water samples in the Ocean County Health Department, New Jersey, water-quality database, 2000-05.

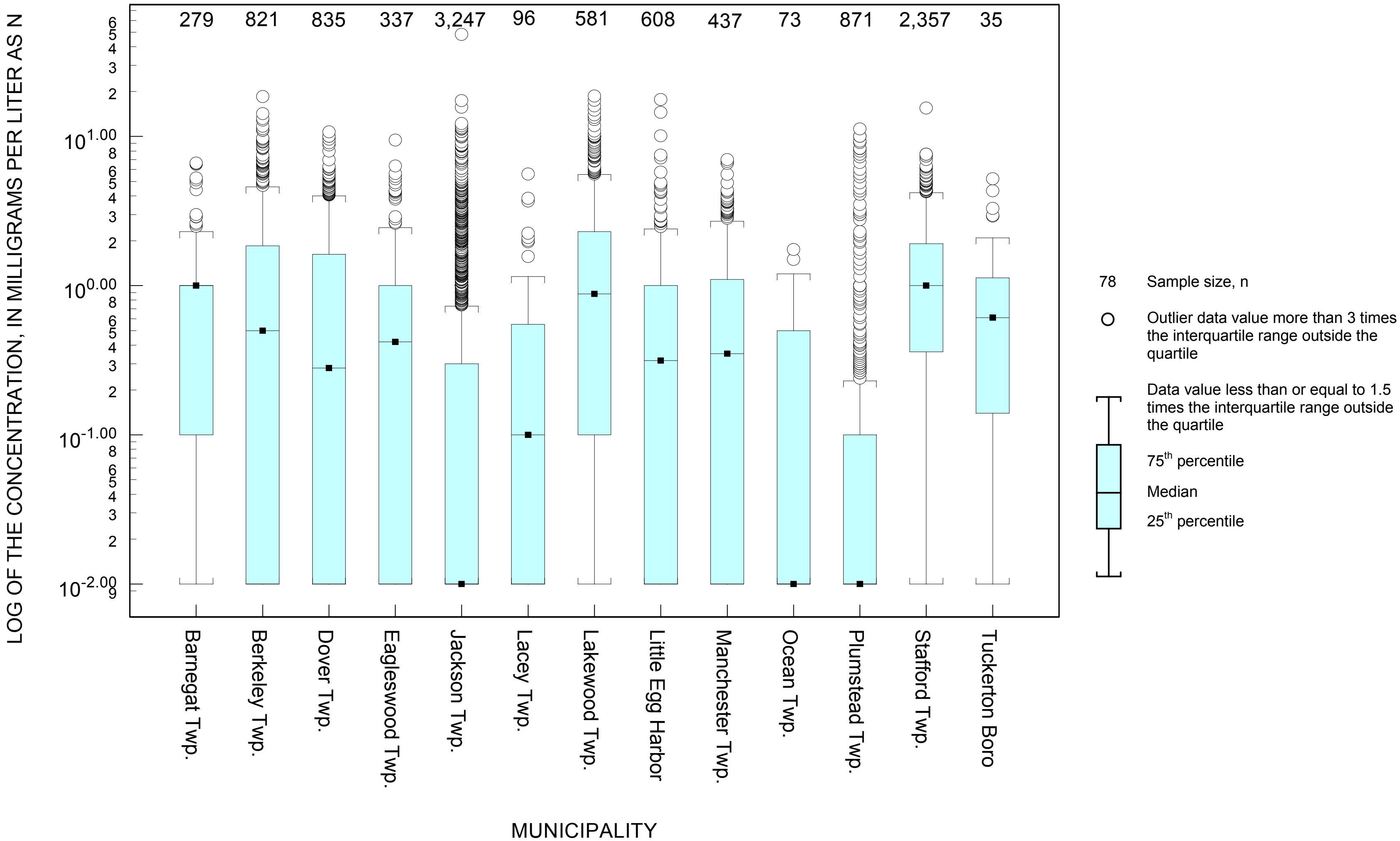


Figure 3. Distribution of nitrate concentrations in ground-water samples in the Ocean County Health Department, New Jersey, water-quality database, 2000-05.

Trends

Records of laboratory analyses of water samples collected from domestic wells in compliance with the Ocean County water-quality testing ordinance and maintained in the OCHD water-quality database date to 1987. This continuous period of record provides a valuable tool for assessing trends and fluctuations in the quality of ground water discharging to the Barnegat Bay-Little Egg Harbor estuary with respect to established drinking-water standards. In 1990, five constituents (arsenic, carbon tetrachloride, methylene chloride, tetrachloroethylene, and 1,1,1-trichloroethane) were found in excess of the MCL in more than 1 percent of the domestic wells sampled (Table 2). In 2005, the frequency of exceedance for each of the constituents measured was less than 1 percent. Because different wells were sampled each year, an accurate assessment of trends is not possible. Additional information is needed concerning local land-use change, well-construction characteristics, and changes in the geographic pattern of wells sampled, as each of these variables may factor into apparent trends. For example, a change in sampling locations from more developed to less developed areas, or from shallower wells to deeper wells, may affect the determination of the presence and levels of particular contaminants in the aquifer.

In general, without taking well depth, screened interval, and changes in land use into account, the percentage of concentrations of carbon tetrachloride, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene that exceeded the MCL decreased from 1987 to 2005 (Figure 4a). Exceedance frequencies for 1,1-dichloroethylene and vinyl chloride also decreased, but these decreases were smaller (Figure 4b). The exceedance value for mercury declined from 1.3 percent in 1987 to 0.1 percent in 1998, but this number has gradually increased in recent years (2002-05) to approximately 0.6 percent. Apparent trends for benzene have been variable as well, with alternating rises and declines; in 2005 the percentage of concentrations that exceeded the 1-µg/L MCL decreased to 0.6 percent from a high of 1.6 percent in 2002 (Figure 4b).

The percentage of concentration values that exceeded the MCL of 10 mg/L for nitrate has shown little variation over time; however, it appears that ecological thresholds are consistently exceeded in a high percentage of ground-water samples from the Barnegat Bay-Little Egg Harbor watershed. Additional statistical analysis of the relation of land-use change and sampling-location patterns to nitrate concentrations is necessary to determine and validate trends in median concentrations of nitrate over time.

Arsenic, *trans*-1,2-dichloroethylene, and the dichlorobenzene isomers (compounds that have the same molecular formula but different structures) were excluded from this broad trend analysis because the number of samples collected was insufficient (less than 100) for 5 or more consecutive years. Dichlorobenzene(s) was also excluded from this analysis because data stored in the OCHD database field "dichlorobenzene(s)" did not distinguish among dichlorobenzene isomers, which have different MCLs, until 2000. Methylene chloride also was excluded from this analysis because it is a common laboratory solvent and may be introduced to water samples accidentally during laboratory analysis.

Table 2. Water-quality standard and criteria exceedances for raw (untreated) ground-water analysis results contained in the Ocean County Health Department, New Jersey, water-quality database, 1990-2005.

[n, total number of samples; µg/L, micrograms per liter; --, sample size insufficient for analysis (n < 100)]

		1990		1995		2000		2005	
Water-quality constituent	Water-quality standard or criterion(µg/L)	Percent	n	Percent	n	Percent	n	Percent	n
Inorganic constituents									
Arsenic	[1]5	3.2	1,010	--	--	--	--	0.6	681
Arsenic	[2]36	0.6	1,010	--	--	--	--	0.3	681
Mercury	[3]2	0.5	1,888	0.2	1,922	0.1	2,044	0.6	1,815
Mercury	[2]0.94	1.8	1,888	3.9	1,922	0.4	2,044	1.0	1,815
Nitrate	[3]10,000	0.4	1,892	0.4	1,923	0.3	2,041	0.5	1,764
Nitrate	[4]710	25.5	1,892	33.9	1,923	25.4	2,041	31.6	1,764
Nitrate	[5]150	43.1	1,892	53.2	1,923	37.8	2,041	48.5	1,764
Volatile organic compounds									
Benzene	[1]1	0.5	1,895	0.2	1,924	0.6	2,023	0.6	1,820
Carbon tetrachloride	[1]2	1.8	1,896	0.2	1,924	0.1	2,034	0.7	1,814
Dichlorobenzene(s)	[6]75	0.9	1,893	0.1	1,924	0.0	1,302	0.3	944
1,2-Dichlorobenzene	[3]600	--	--	--	--	0.0	569	0.6	1,245
1,3-Dichlorobenzene	[1]600	--	--	--	--	0.0	536	0.0	932
1,4-Dichlorobenzene	[3]75	--	--	--	--	0.4	536	0.2	1,243
1,2-Dichloroethane	[1]2	0.7	1,895	0.1	1,924	0.5	1,981	0.5	1,794
1,1-Dichloroethylene	[1]2	0.6	1,896	0.0	1,924	0.2	1,990	0.1	1,809
Methylene chloride	[1]3	15.3	1,896	1.5	1,924	0.6	2,032	0.6	1,806
Tetrachloroethylene	[1]1	1.4	1,895	0.3	1,925	0.4	2,031	0.9	1,811
trans-1,2-Dichloroethylene	[3]100	0.2	1,896	0.1	1,924	--	--	0.4	512
1,1,1-Trichloroethane	[1]30	3.0	1,896	0.4	1,924	0.3	2,015	0.5	1,814
Trichloroethylene	[1]1	0.6	1,895	0.2	1,924	0.6	1,984	0.7	1,793
Vinyl chloride	[1]2	0.3	1,892	0.2	1,924	0.0	199	0.1	1,815
Xylene	[1]1,000	0.4	1,892	0.6	1,924	0.1	2,030	0.2	1,666
Pesticides									
Chlordane	[1]0.5	0.3	1,369	0.1	994	0.4	1,099	0.4	814

[1]NJDEP MCL as of February 2005 (NJ Department of Environmental Protection, 2007)

[2]NJDEP surface-water-quality standard as of October 2006 (NJ Department of Environmental Protection, 2006)

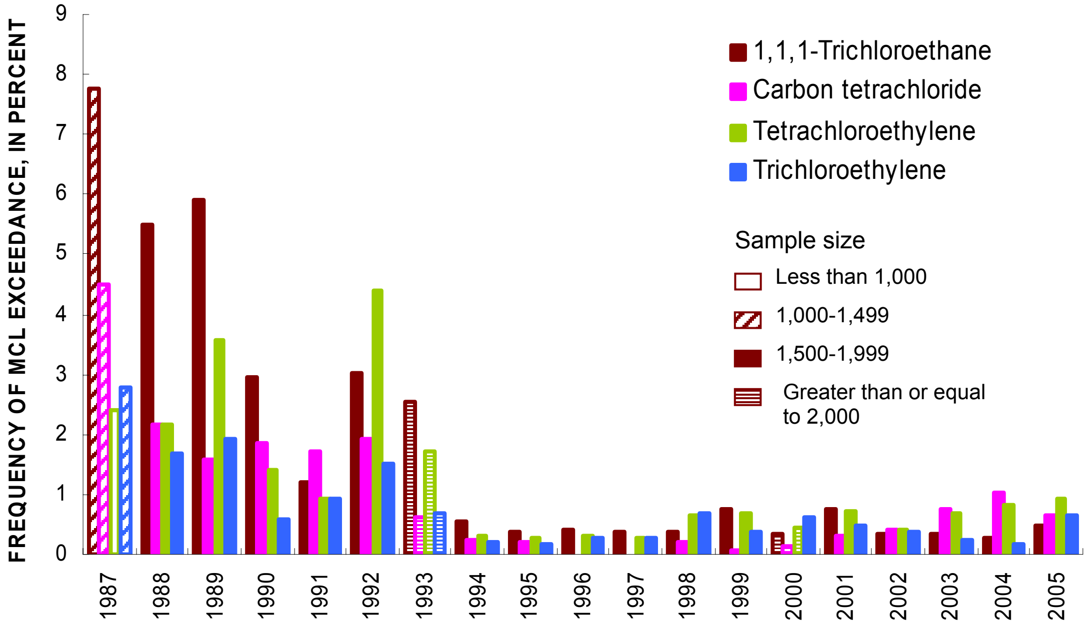
[3]USEPA MCL as of February 2005 (NJ Department of Environmental Protection, 2007)

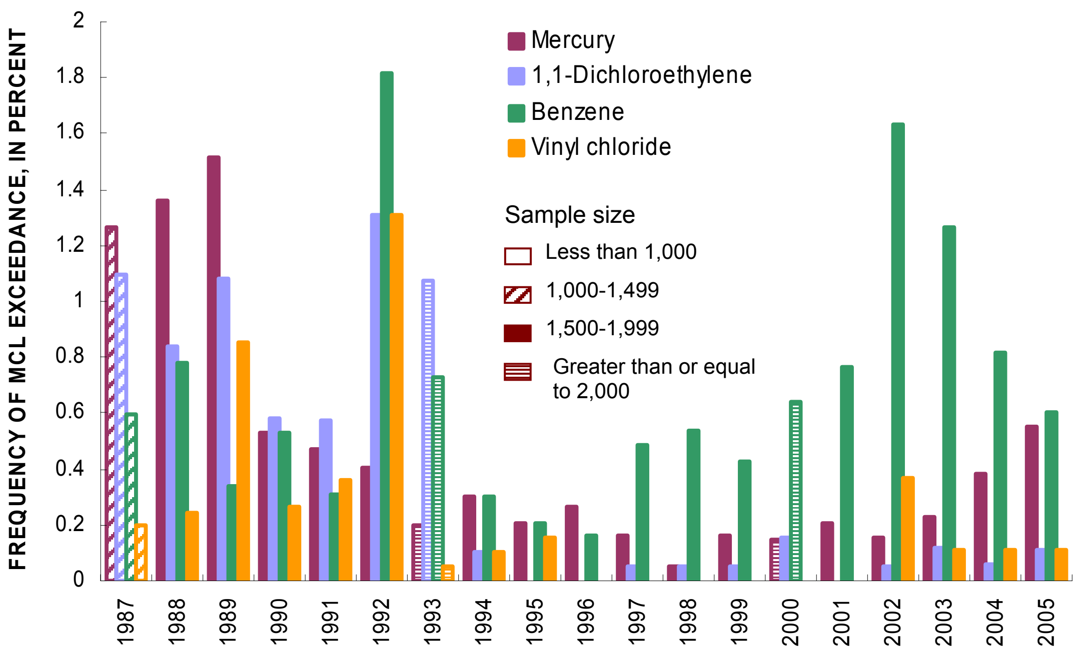
[4]USEPA nitrogen criterion for streams in Nutrient Ecoregion XIV (Eastern Coastal Plain) (U.S. Environmental Protection Agency, 2000)

[5]Suggested criterion for dissolved inorganic nitrogen for eelgrass beds in portions of Chesapeake Bay (Kemp and others, 2000)

[6]Data stored in the Ocean County Health Department database field "dichlorobenzene(s)" did not distinguish among dichlorobenzene isomers until 2000. For this analysis, the MCL for the dichlorobenzene isomer with the lowest MCL (75 *u*g/L for 1,4-dichlorobenzene) was used for comparison with analytical results.

Figure 4a-b. Frequencies of exceedance for selected constituents in the Ocean County Health Department, New Jersey, water-quality database, 1987-2005: (a) 1,1,1-trichloroethane, carbon tetrachloride, tetrachloroethylene, and trichloroethylene; and (b) mercury, 1,1-dichloroethylene, benzene, and vinyl chloride.





Major Information Gaps

Additional well-location information is needed for detailed spatial analysis of water-quality trends. Until recently (2006), the OCHD water-quality database relied on municipality, block, and lot codes to identify the locations of the wells in its database. Inconsistent and erroneous coding of block and lot codes, as well as the variability of spatial resolution based on plot size, limit the ability to conduct a spatial analysis of the data. Plans to incorporate Global Positioning System coordinates into the database in accordance with New Jersey's Private Well Testing Act (Public Law 2001, chapter 40 (C. 58:12A-26), approved on March 23, 2001) were instituted in 2006. Additional well-construction information is also needed to determine the depth of a well and its screened interval, and to verify the aquifer that is being tapped by a given well.

Links to Other Information Sources

The U.S. Geological Survey (USGS) collects and analyzes water-quality data at ground-water and surface-water sites throughout the country. These data are available to the public online through the USGS's National Water Information Service web interface (NWISWeb) at http://waterdata.usgs.gov/nwis/qw.

The New Jersey Department of Environmental Protection maintains a website with information about New Jersey's Private Well Testing Act—a recently enacted (2001) State law concerning the sampling and analysis of private well water and reporting of the results. A statewide report of initial results obtained after the law went into effect is available at http://www.state.nj.us/dep/pwta.

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