U.S. Department of the Interior
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REVIEW OF SELECTED REFERENCES AND DATA SETS ON AMBIENT GROUND- AND SURFACE-WATER QUALITY IN THE METEDECONK RIVER, TOMS RIVER, AND KETTLE CREEK BASINS, NEW JERSEY, 1980-2001

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 03-4259

Prepared in cooperation with the

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2003

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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

Temperature Conversion

Degree Celsius (°C) can be converted to degree Fahrenheit (°F) by using the following equation:
°F = 9/5(°C) + 32

Water-quality abbreviations:

mg/L – milligrams per liter
µg/L – micrograms per liter
pCi/L – picocuries per liter
µS/cm – microsiemens per centimeter at 25 degrees Celsius
ng/g – nanograms per gram
ng/L – nanograms per liter
nm – nanometers

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ABSTRACT

Surface water and ground water from unconfined aquifers are the primary sources of drinking water for much of the population, about 391,000, in the Metedeconk River, Toms River, and Kettle Creek watersheds in the New Jersey Coastal Plain. The quality of these sources of drinking water is a concern because they are vulnerable to contamination. Indications of the occurrence, distribution, and likely sources and transport mechanisms of certain contaminants were obtained from 48 selected reports and 2 selected data sets on water quality in or near the watersheds (1980–2001). These indications are described and briefly summarized in this report.

The findings of studies on ground-water quality indicate that shallow ground water within the study area generally meets primary drinking-water standards, with notable exceptions. Volatile organic compounds, mercury, arsenic, radionuclides, nitrate, and coliform bacteria have been detected in shallow ground water in some areas at levels that exceed Federal and State drinking-water standards. For example, results of analyses of untreated samples collected from more than 13,000 private wells during 1983-99 indicated that concentrations of volatile organic compounds in samples from 7.3 percent of the wells exceeded at least 1 of 11 drinking-water standards, according to records maintained by the Ocean County Health Department. In cases of exceedances, however, water treatment, well replacement, and (or) retesting assured that applicable drinking-water standards were being met at the tap. Reported concentrations of the pesticide chlordane in some areas exceeded the drinking-water standard; few data are available on the occurrence of other pesticides. Studies of nearby areas, however, indicate that pesticide concentrations generally could be expected to be below drinking-water standards. The combination of low pH and low dissolved solids in many areas results in shallow ground water that is highly corrosive and, if untreated, able to leach trace elements and release asbestos fibers from plumbing materials.

Reported concentrations of nitrate, volatile organic compounds, trace elements, and pesticides in samples from the monitored mainstem and tributary streams within the study area generally are below maximum contaminant levels for drinking water or below detection limits. Results of studies in other areas indicate that pesticide concentrations in surface water could be considerably higher during high flows soon after the application of pesticides to crops than during low flows. Fecal coliform bacteria counts in streams vary considerably. Concentrations or counts of these classes of surface-water-quality constituents likely are functions of the intensity and type of upstream development. Results of limited monitoring for radionuclide concentrations reported by the Brick Township Municipal Utilities Authority of the Metedeconk River indicate that radionuclide concentrations or activities do not exceed maximum contaminant levels for drinking water. As a consequence of organic matter in surface water, the formation of disinfection by-products is an issue in the treatment of surface

waters in the study area. During 1997-2000, concentrations of dissolved organic carbon and calculated values of specific ultraviolet absorbance in samples from the Metedeconk River and the Toms River exceeded the alternative compliance criteria for source water (2.0 milligrams per liter for total organic carbon and 0.02 absorbance units-liters per milligram-centimeter for specific ultraviolet absorbance) with respect to treatment requirements for preventing elevated concentrations of disinfection by-products in treated water.

Water-quality and treatment issues associated with use of ground and surface water for potable supply in the study area are related to human activities and naturally occurring factors. Additional monitoring and analysis of ground and surface water would be needed to determine conclusively the occurrence and distribution of some contaminants and the relative importance of various potential contaminant sources, transport and attenuation mechanisms, and transport pathways.

INTRODUCTION

The Metedeconk River, Toms River, and Kettle Creek drain 330 mi^2 in the New Jersey Coastal Plain (fig. 1). Their drainage areas compose the northern two-thirds of the Barnegat Bay watershed. In recent years, instances of water-supply contamination have raised concerns about the quality of the sources of water used for the public and private supply that serves the resident population, which was estimated from information compiled by CH2M Hill and others (1994, table 6) to be approximately 391,000. In response to public health issues, concerned citizens, elected officials, and Federal, State, and local agencies initiated plans (New Jersey Department of Health and Senior Services and Agency for Toxic Substances and Disease Registry, 1996) that include focused evaluations of the public drinking-water supplies that serve most of Dover Township and Brick Township, New Jersey (New Jersey Department of Health and Senior Services, New Jersey Department of Environmental Protection, and Agency for Toxic Substances and Disease Registry, 2001; Agency for Toxic Substances and Disease Registry, 2001) (fig. 2). These plans also include public health assessments of selected hazardous sites (New Jersey Department of Health and Senior Services and Agency for Toxic Substances and Disease Registry, 2001a-c).

Legislation (New Jersey P.L. 1998, c.67) authorized a study to assess water quality throughout the watershed area. The study was conducted by the U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP), and was coordinated by the Barnegat Bay Estuary Program, which is part of a U.S. Environmental Protection Agency (USEPA) initiative to identify "nationally significant" estuaries and to oversee the development of plans to restore and protect their ecological health and biological integrity.

In addition to a general concern for the quality of water resources in the study area, there is a particular concern for the quality of ground water in the shallow, unconfined aquifers, which are known to be particularly susceptible to contamination resulting from human activities at the land surface and from naturally occurring sources. Many public and private supply wells tap water in this vulnerable source, and most of the flow in streams is derived from ground-water discharge. Although county ordinances and recently enacted State legislation require the testing of water from privately owned wells as part of real-estate transactions and new well completion, many privately owned wells that serve homes and businesses might not be tested on a regular basis. Public water supplies are tested as required by State and Federal statute.

Many known and potential sources of contamination are present in the region, and numerous instances of ground-water contamination have been documented (Robert Ingenito, Ocean County Health Department, written commun., 1997; New Jersey Department of Environmental

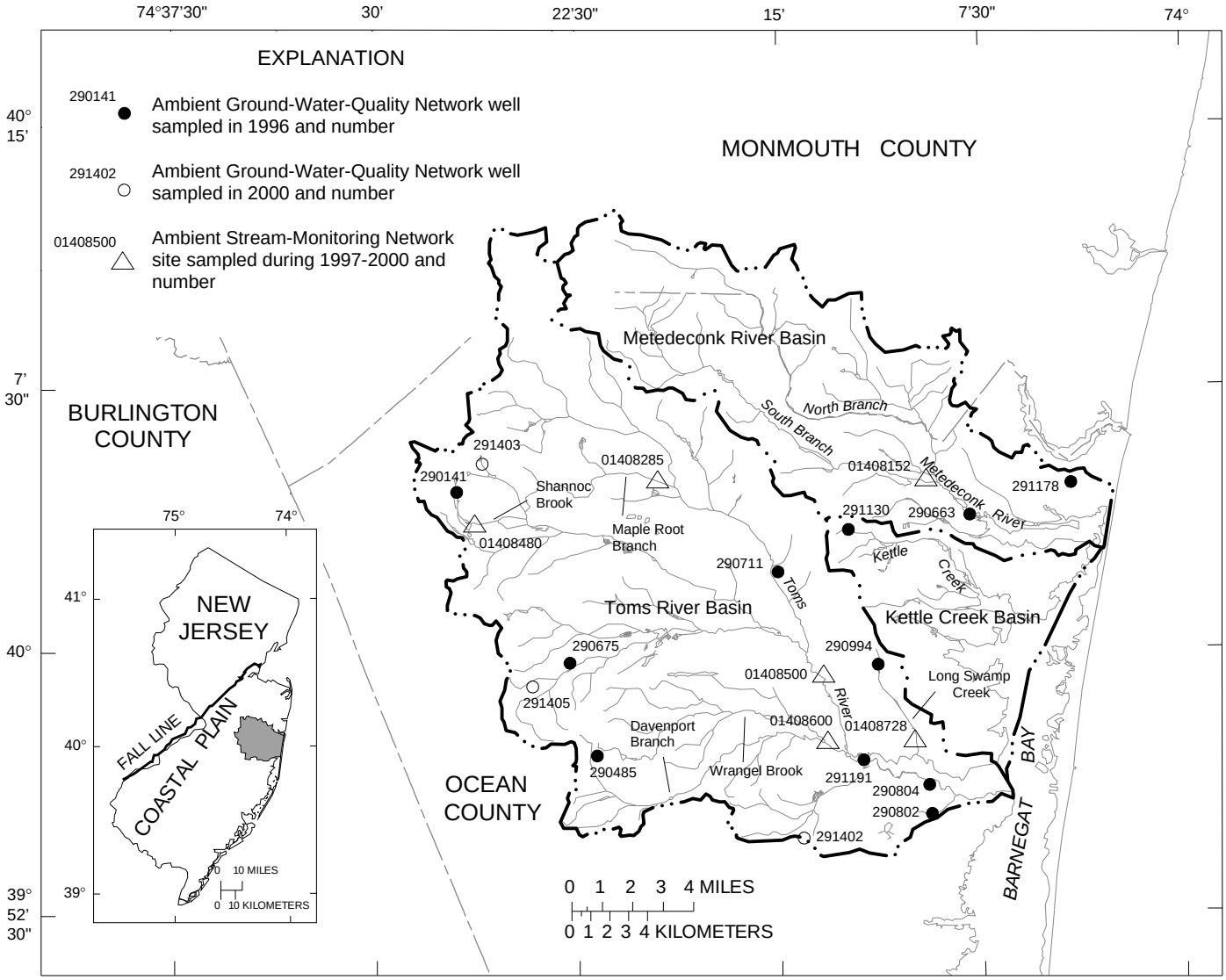

Figure 1. Location of water-quality sites sampled in the Metedeconk River, Toms River, and Kettle Creek Basins, New Jersey Coastal Plain, 1996-2000.

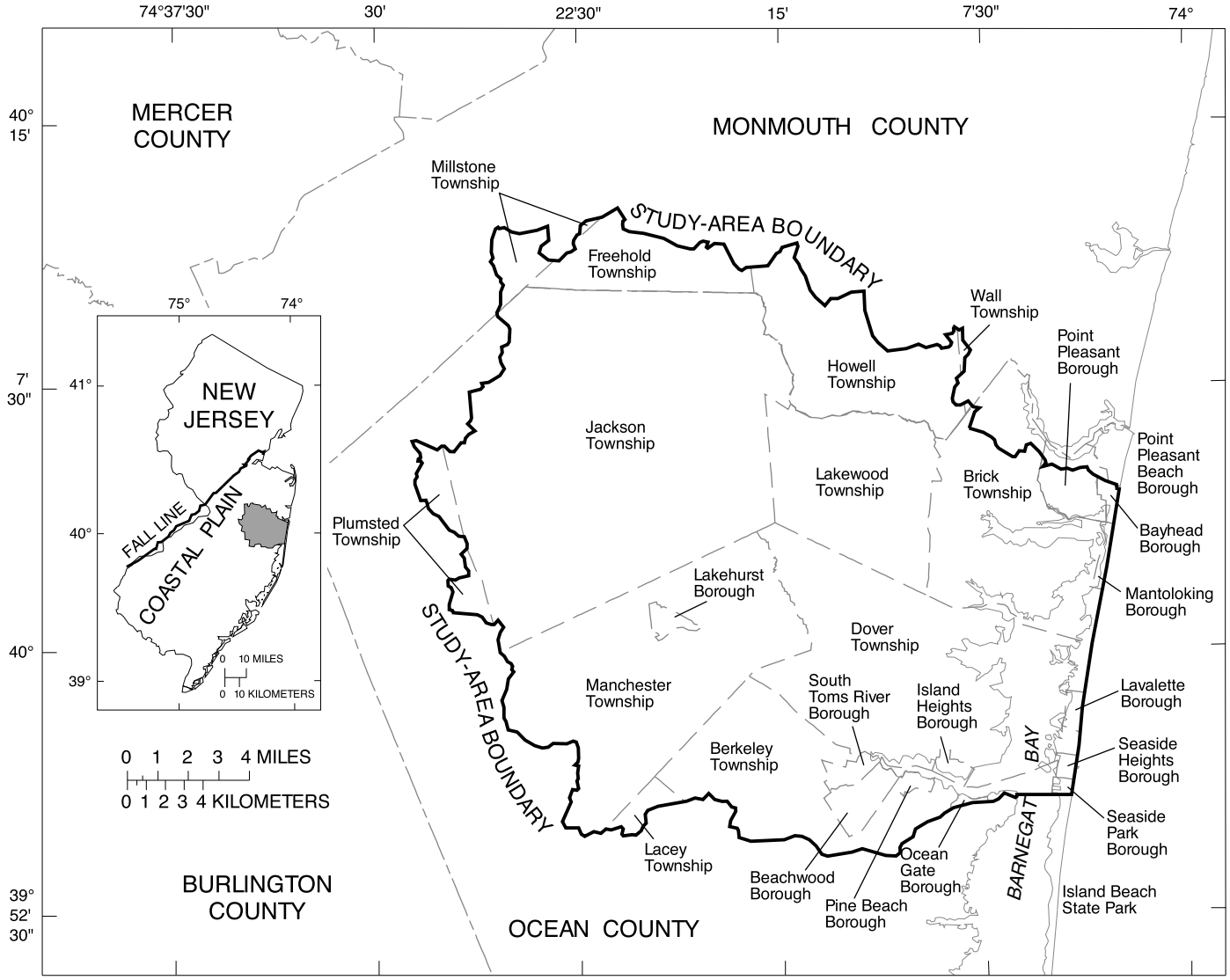

Figure 2. Municipalities in the Metedeconk River, Toms River, and Kettle Creek Basins, New Jersey Coastal Plain.

Protection, 2001a). During the past 20 years, in addition to evaluations of public water-supply systems and specific contaminated sites and sources, a number of studies and data-collection efforts have been conducted in the watersheds and nearby areas to characterize ambient water quality and evaluate general relations among water quality, human activities, and natural conditions. Synthesis of these efforts and their results can provide a basis for directing future studies and other actions to address water-quality concerns.

Purpose and Scope

This report describes and briefly summarizes the findings of interpretive studies that were released or published during 1980-2001 on ambient water quality of the unconfined ground water and freshwater parts of streams in the Toms River, Metedeconk River, and Kettle Creek Basins. Summaries of USGS data collected during 1996-2000 also are presented. This more recent period was selected because major sampling efforts were focused in the study area beginning in 1996; other reports cited herein describe water-quality conditions during earlier time periods. A general discussion on the possible sources of the contaminants that are present, or likely to be present, in ambient water also is provided. Reports and peer-reviewed journal articles by Federal, State, and local agencies; universities; and private consulting firms were examined for content and relevance. Most of the summary statistics cited in this report are those reported by the authors of the original reports. The calculation of additional or different summary statistics generally was considered outside the scope of this work and, therefore, not given here, with one exception. An updated statistical summary of analytical results contained in the Ocean County Health Department water-quality database for samples collected during 1983-99 was considered especially relevant and is presented here. The studies summarized in this report emphasize ambient water, as represented by samples from streams, monitoring wells, and private domestic wells (untreated). Results are related to relevant water-quality guidelines and standards where possible. The large body of reports on water quality relating to specific contaminant sites, contaminant sources, or public water-supply systems was considered outside the scope of this work, so reports on these topics were not examined.

Description of study area

The Toms River, Metedeconk River, and Kettle Creek Basins are entirely within the New Jersey Coastal Plain Physiographic Province. The study area lies mostly within Ocean County; parts of the Metedeconk River and Toms River Basins are in Monmouth County (fig. 1). The basins are characterized by gentle slopes and low topographic relief. Miocene and younger sediments, which include gravel, sand, silt and clay, compose the unconfined Kirkwood-Cohansey aquifer system, which underlies most of the study area (fig. 3). Like most hydrogeologic units of the New Jersey Coastal Plain, the Kirkwood-Cohansey aquifer system dips gently and thickens to the southeast. The major geohydrologic units that compose the aquifer system are the Kirkwood Formation, Cohansey Sand, and, depending on location, the Beacon Hill Gravel, Bridgeton Formation, and Cape May Formation. Other near-surface sedimentary deposits also are present in many areas. Near the coast, where the aquifer system is thickest, clay layers up to many tens of feet thick are present. Underlying the unconfined aquifer system is a series of confined aquifers and confining units.

The study area is composed of the drainage areas of three major tributaries to Barnegat Bay; these tributaries are, from north to south, the Metedeconk River, Kettle Creek, and the Toms River (fig. 1). Ground-water discharge from the Kirkwood-Cohansey aquifer system to streams constitutes most of the average annual flow in streams, which discharges to Barnegat Bay, a shallow backbarrier lagoon-type estuary. A barrier beach complex separates Barnegat Bay from the Atlantic Ocean.

Land cover in the study area primarily is forested (49 percent) and urban (24 percent), with

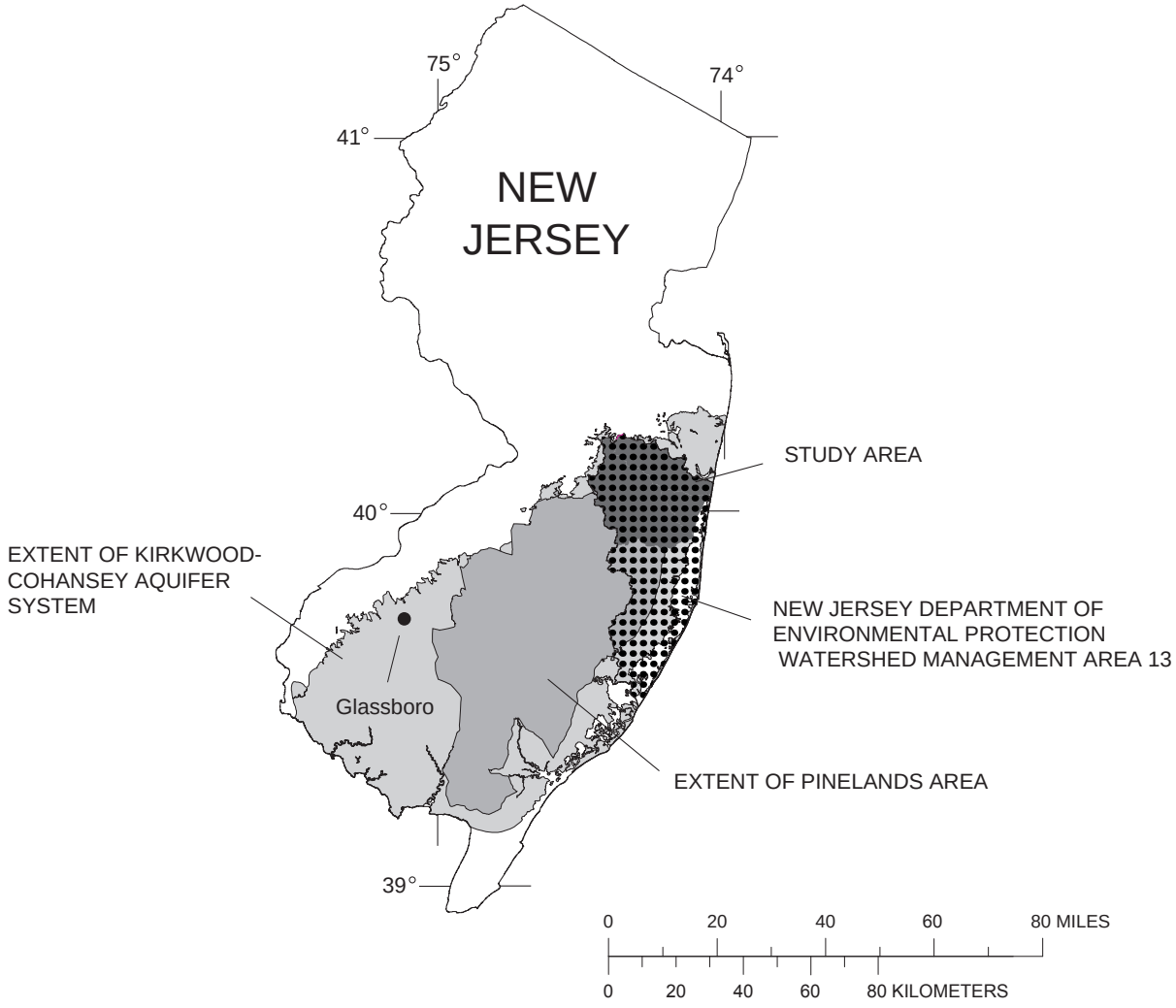

Figure 3. Location of the Metedeconk River, Toms River, and Kettle Creek Basins, and extent of the Pinelands Area and the Kirkwood-Cohansey aquifer system, New Jersey.

lesser amounts of wetlands, surface-water bodies, agricultural land, and barren land (Watt and others, 1994). Urban land is most concentrated in the eastern part of the study area. The resident population was projected to increase from 276,000 to about 391,000 (about 42 percent) during 1980-2000 (CH2M Hill, 1994, table 6). Much of the population in urban areas is served by public water suppliers and regional sewer service. Since about 1980, effluent from regional wastewater-treatment plants has been discharged by way of ocean outfall, and no major point discharges of wastewater to streams are present in the study area. In 1990, about 20,000 households in Ocean County municipalities that are wholly or partly in the study area were served by on-site sewage disposal systems (Ocean County Department of Planning, 1998). Many households now served by regional sewer service previously were served by on-site sewage disposal.

Acknowledgments

The authors gratefully acknowledge Dr. Robert Scro, Director of the Barnegat Bay Estuary Program, formerly of the New Jersey Department of Environmental Protection (NJDEP), for his support and assistance in planning and coordinating the work that contributed to this report. Members of the National Water-Quality Assessment team for the Long Island-New Jersey Coastal Drainages study unit and the Water Resources Workgroup of the Barnegat Bay Estuary Program recommended a number of the references reviewed in this report and provided valuable feedback on a number of technical points. Special thanks are extended to Robert Ingenito of the Ocean County Health Department and John Rissel of the Brick Township Municipal Utilities Authority for their cooperation and assistance in providing and interpreting data records of their respective agencies and for their helpful comments on this report. Thanks also are extended to Kathryn Hess and Ronald Baker of the USGS, and Jerald Fagliano of the New Jersey Department of Health and Senior Services, for their helpful comments. Steven Tessler of the USGS conducted the important work of migrating the water-quality database of the Ocean County Health Department to a new design that facilitated an efficient statistical analysis.

SELECTION OF REFERENCES AND DATA SETS

This report summarizes reports relating to the characterization of ambient freshwater quality in the Metedeconk River, Toms River, and Kettle Creek Basins, as represented by water samples collected from streams, monitoring wells, and private domestic wells. The emphasis of the report derives from a specific, recognized need to characterize the sources of water to private supplies and potential public supplies. A comprehensive suite of State and Federal programs and plans is in place to characterize the vulnerability to contamination of currently operated public water-supply systems and the threats posed by known contaminant sources. For example, the vulnerability of public water supplies to contamination from a wide variety of sources, including those within the study area, is evaluated statewide through the New Jersey Source Water Assessment Program (SWAP), as required by provisions of the 1996 Amendments to the Safe Drinking Water Act. One element of the SWAP is the development of a comprehensive contaminant source inventory that documents known sources of contamination statewide. Characterization of contaminated sites is addressed by programs such as the Site Remediation Program (SRP) of NJDEP and USEPA activities under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as the Superfund program. To avoid duplication of efforts, a decision was made by the authors, in cooperation with NJDEP, to select and summarize references and data that provide relevant information on ambient water quality, and to exclude information on specific contaminated sites, specific contaminant sources, and public water-supply systems. Most references pertain to studies or data-collection efforts that include the monitoring of ambient ground water or surface water within the study area, although some references from nearby areas in hydrologic settings

similar to and with important findings relevant to the study area also were selected. A number of reports on local and regional studies of water quality of the Kirkwood-Cohansey aquifer system are among these additional references.

Literature Search and Methods

Relevant documents were identified through computerized and manual literature searches. Each publication was screened for relevance by examination of title and abstract, or the full document. Electronic searches were made in the following six databases: New Jersey State Library[1] (which includes all of the NJDEP library holdings), New Jersey Environmental Digital Library[2], U.S. Geological Survey Selected Water Resources Abstracts[3], Aqualine[4], Water Resources Abstracts[5], and GeoRef[5]. Both geographic keyword qualifiers (Toms River, Metedeconk River, Kettle Creek, Ocean County, Monmouth County) and a topical keyword qualifier (water quality) were used together to narrow the search. A broader search was made in the electronic bibliography of the New Jersey District office of the USGS. These searches together yielded a total of 455 unique titles, which were screened manually. To supplement the results of the electronic search, manual searches of scientific literature were done in the library and the individual files of project members in the USGS District office in West Trenton, New Jersey. On-line listings of reports and documents of the New Jersey Geological Survey[5] and the NJDEP Division of Science and Research[6] also were searched. References were retained for further review if titles indicated relevance to water quality in the study area or in surrounding areas. Discussion with members of the USGS Long Island-New Jersey National Water-Quality Assessment (NAWQA) team and the Water Resources Workgroup of the Barnegat Bay Estuary Program also was useful in identifying publications cited in this report. The criteria for selecting references were inclusion of relevant information on ambient water quality (1) in the study area or (2) in similar hydrologic settings elsewhere in the New Jersey Coastal Plain.

Selected information on the 48 selected references on water quality are listed in table 1. Most of these reports document data-collection efforts within the study area, and many of these also include data collected from outside the study area. Although a few of the reports document studies conducted in other parts of New Jersey, the results of these studies were considered to have special relevance to likely conditions within the study area. Some additional general references and supporting references that relate to statewide studies and studies conducted outside New Jersey are cited in the text as appropriate, but these references are not listed in table 1. Full citations for all cited reports are listed in the section "References Cited."

Data Sets

Although the primary purpose of this report is to summarize reports on ambient water quality in the study area, analysis of selected data sets also is included because the data sets fill important information gaps not covered by the associated investigations. The selected data sets are from the Ocean County Health Department (OCHD) and Brick Township Municipal Utilities Authority (BTMUA) water-quality databases. The BTMUA monitoring program and resultant data sets provide

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[1]New Jersey State Library database accessed at URL http://www.njstatelib.org/

[2]New Jersey State Library database accessed at URL http://www.njstatelib.org/

[3]U.S. Geological Survey Selected Water Resources Abstracts database accessed at URL http://water.usgs.gov/swra/

[4]Aqualine, Water Resources Abstracts, and GeoRef databases accessed at URL http://www.csa.com/csa/index.html

[5]New Jersey Geological Survey Web site accessed at URL http://www.state.nj.us/dep/njgs/

[6]New Jersey Department of Environmental Protection, Division of Science and Research publications web site accessed at URL http://www.state.nj.us/dep/dsr/pub.htm

Table 1. Selected information on water-quality studies conducted in or near the Metedeconk River, Toms River, and Kettle Creek Basins, New Jersey

Report author and year of publication[1]	Years of data collection	Environmental media		Data collected within study area	Data collected outside study area	Reported water-quality constituents[2]					
						Inorganics			Organics		
		Ground water	Surface water			Major ions	Trace elements	Radio-nuclides	Volatile organic compounds	Pesticides	Pathogen indicators
Ayers and others, 2000	1996-98	X	X	X	X	X	X		X	X	
Barringer and others, 1997	1973-93	X		X	X		X				
Barringer, 1994	1985-88	X		X	X		X				
Barringer and MacLeod, 2001	1973-93	X		X	X	X	X		X		
Barringer and others, 1993	1951-87	X		X	X	X					
Camp Dresser & McKee, 1993	1986-91	X		X		X	X		X		X
Camp Dresser & McKee, 2000	Unspecified		X	X		X	X				X
Carter, 2001	1975-94		X	X		X					X
Clawges and others, 1999	Various[3]	X			X	X			X	X	
Deluca and others, 1999	1997-1998	X	X	X	X	X	X		X	X	X
Deluca and others, 2000a	1998-1999	X	X	X	X	X	X		X	X	X
Deluca and others, 2000b	1999-2000	X	X	X	X	X	X	X	X	X	X
Dooley, 1992	Various	X		X	X		X				
Fusillo and others, 1980	1965-78	X	X		X	X					X
Harriman and Voronin, 1984	1981-82	X		X	X	X	X		X		
Harriman and Sargent, 1985	1981-82	X		X	X	X	X				
Hay and Campbell, 1990	1975-86		X	X	X	X	X				X
Hickman and Barringer, 1999	1985-95		X	X	X	X					X
Hunchak-Kariouk, 1999	1994-95		X	X		X					X
Hunchak-Kariouk and Nicholson, 2001	1960-97	X	X	X	X	X	X	X	X	X	X
Hunchak-Kariouk and others, 1999	1975-93		X	X	X	X	X				X
Johnsson and Barringer, 1993	1984-88	X	X		X	X	X				
Jones and DeLuca, 1997	1995-96	X		X	X	X	X	X	X	X	X
Kish and others, 1987	1983-84	X		X	X		X				
Kish and others, 1989	Prior to 1989	X		X	X	X					
Kozinski and others, 1995	1983-89	X			X	X	X	X			
Moser, 1997	1990-92		X	X	X	X	X				
NJDEP, 2001	1995-97, Various	X	X	X	X	X	X				X
NJDEP, 1998	Various		X	X	X	X	X				X
NJDEP, 1996a	mid-1980s to mid- 1990s		X	X	X	X					X
O'Brien and others, 1997	1997		X		X				X		
Reed and others, 1998	1996-97	X	X	X	X	X	X		X	X	X
Reiser and O'Brien, 1999	1997		X		X					X	
Reiser and O'Brien, 1998	1996-97		X		X				X		
Robinson and others, 1996	1975-86		X	X	X	X					X
Rogers, Golden, and Halpern, Inc., 1990	Unspecified		X	X	X	X					X
Schaefer, F.L., 1983	1977-81	X		X	X	X					
Stackelberg and others, 1997	1996	X			X	X			X	X	
Szabo and DePaul, 1998	1988-96	X		X	X	X		X			
Szabo and others, 1997	1990-91	X		X	X	X	X	X		X	
Szabo and others, 1994	1991	X			X	X		X		X	
Terracciano and O'Brien, 1997	1996		X		X				X		
Vowinkel and others, 1996	Various	X	X	X	X					X	
Watt and others, 1994	1981-89	X	X	X		X	X			X	
Windisch and Zampella, 1989	1983-88		X	X	X	X	X				X
Windisch, 1990	1988-90		X	X	X	X	X				X
Windisch, 1991	1990-91		X	X	X	X	X				X
Zampella and others, 1994	1988-91		X	X	X	X					X
Zampella, 1994	1975-86		X	X	X	X					

[1]References listed are those cited in this report that relate to water quality in or near the Metedeconk River, Toms River, and Kettle Creek Basins. General references and those relating to studies conducted outside New Jersey are listed in "Selected References" but are not listed here.

[2]Constituents shaded are those reported in the subject report that are relevant to this summary; one or more constituents in the indicated category were reported for one or both environmental media (ground water and (or) surface water). Some references summarize or synthesize earlier data reported by others.

[3]"Various" indicates that data for different constituents or in different geographic areas were collected during different time periods.

information about water quality of the Metedeconk River, which otherwise has been monitored infrequently at few locations in recent years as part of the NJDEP/USGS Ambient Stream Monitoring Network.

In response to concerns about shallow ground-water quality, Ocean County passed an ordinance in 1987 (Ocean County Board of Health Well and Individual Sewage Disposal System Ordinance 94-1, originally passed May 6, 1987, amended in 1990, and again in 1994; Robert Ingenito, Ocean County Health Department, written commun., 2002) under which samples from wells are required to be tested in association with well completion or real estate transactions involving properties served by private wells. Laboratories that conduct the required analyses must be certified by the NJDEP. The ensuing well sampling and analysis program has resulted in the accumulation of an extensive database, which is maintained by the OCHD. The database contains results of analyses for selected water-quality constituents, including turbidity, total coliform bacteria, nitrate, sodium, pH, chlordane, selected trace elements, and selected VOCs. A limitation of this database is a paucity of information about well construction and location. Results of analyses of samples from more than 25,000 private (domestic) wells, conducted during 1986-91, were statistically analyzed by Camp Dresser & McKee (1993) and by the USGS (M.A. Ayers, U.S. Geological Survey, written commun., 1995). Results of a more recent statistical analysis of the data (from 1983 through 1999) are noted in this report. Statistical analyses provide an indication of the frequency of elevated levels (above drinking-water standards) of contaminants in shallow ground water in the watershed. Various quality-assurance issues associated with this county-level data set must be considered, however, in drawing conclusions. Data-quality objectives for this program revolve primarily around a need to obtain the best available assurance that water from a given well meets selected water-quality criteria at a particular point in time--the time of a real-estate transaction or well completion. Although a recent (2000) examination of the database by USGS revealed some data-quality issues (see appendix 1), there was no indication that the data-quality objectives were not being met.

Monmouth County requirements for private well water-quality testing are less stringent than those in Ocean County and vary across the county. Howell Township, the Monmouth County municipality with the largest area within the study area, requires testing for pH, iron, bacteria, lead, hardness, and manganese (Steven Prosser, Monmouth County Health Department, oral commun., 1998).

Some additional data on ambient shallow ground-water quality have been collected in recent years as part of the NJDEP/USGS cooperative Ambient Ground-Water-Quality Network. In 1996, 11 shallow wells within the study area were sampled (Jones and DeLuca, 1997). In 2000, three different shallow wells in the study area were sampled (DeLuca and others, 2000b).

The examination of the OCHD water-quality database provides insights into the utility and the limitations of the large amounts of structured information that can be acquired through programs that require the testing of water samples from private wells. Under recent State legislation known as the "Private Well Testing Act," (Public Law 2001, chapter 40 (C. 58:12A-26), approved on March 23, 2001) the testing of water from any private well in New Jersey that is used for potable supply is required when the well installation is completed or whenever property served by the well is sold or leased. The statistical analysis of information contained in the Ocean County water-quality database provides a useful illustration of how information obtained through this type of regulatory program can contribute to the assessment of regional ambient ground-water quality and examples of the complications, interpretive challenges, and other limitations of its use for this purpose.

REGIONAL WATER QUALITY

Recent findings of the NAWQA program (Ayers and others, 2000) especially are noteworthy

in that they provide a broad, regional context for results of water-quality studies in the study area. The NAWQA program of the USGS is a systematic, nationwide investigation of water quality in the Nation's major river basins and ground-water systems. One of 51 NAWQA water-quality assessments initiated since 1991 covers coastal watersheds in New Jersey and Long Island, New York, and the findings of this assessment provide an improved understanding of the occurrence of chemical constituents in ambient water and the natural and human factors that affect water quality. The NAWQA study in New Jersey and New York included sampling sites in the New Jersey Coastal Plain (primarily south and west of the study area of this report) and Long Island. These areas are similar to the subject area of this report in that they are characterized by gentle slopes, low topographic relief, and mixed land uses, and are underlain by sandy aquifers that are highly vulnerable to the contamination that can result from human activities. Although most of the assessment was focused in areas other than the Metedeconk River, Toms River, and Kettle Creek Basins, the findings of this assessment provide general indications of the frequency of occurrence, concentration ranges, and distribution of contaminants in similar land-use and hydrogeologic settings. These findings, therefore, are useful in understanding water-quality conditions in the study area and the factors that likely contribute to these conditions.

The NAWQA study in New Jersey and New York (Ayers and others, 2000) found that human activities associated with urban and agricultural land uses are the primary factors that affect the quality of surface and ground waters. Pesticide and VOC concentrations in samples from streams and shallow aquifers rarely exceeded water-quality guidelines or standards; however, such guidelines and standards have not been established for many of the pesticides and VOCs that were detected[7].

The assessment by NAWQA also addressed the effects of water-quality on aquatic community health. The findings indicate that urban and suburban development, especially when it replaces forest and wetlands, results in habitat degradation, reduction in biological diversity, and shifts toward species more tolerant of disturbance (Ayers and others, 2000).

Results of the other studies and data analysis presented in this report indicate water-quality conditions and the relations to human activities that generally are similar to findings of the NAWQA study. A notable difference is that some of the contaminants (tetrachloroethylene, 1,1-dichloroethylene, and trichloroethylene) present in shallow ground water in southern New Jersey outside the study area and detected as part of the NAWQA study at concentrations less than the drinking-water standards also were detected in shallow ground water in the some parts of the Metedeconk River, Toms River, and Kettle Creek Basins at concentrations greater than these standards.

GROUND-WATER QUALITY

The unconfined Kirkwood-Cohansey aquifer system underlies most of the study area. It is the

[7]A number of different water-quality guidelines and standards are referenced in this report. Maximum Contaminant Level (MCL) is the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. In the subject study area, selected MCLs apply to private water systems under certain circumstances through local ordinance. Action Level (AL) is a trigger concentration at which remedial action, source-water monitoring, and public education is required of public suppliers. Recommended Upper Limit (RUL) is a recommended maximum concentration of a secondary contaminant. RULs reflect aesthetic qualities such as odor, taste, staining, foaming, corrosivity, or appearance and generally are not based on direct adverse health effects. Human Health Advisory (HA) is guidance provided by U.S. Environmental Protection Agency, State agencies, or scientific organizations, in the absence of regulatory limits, to describe acceptable contaminant levels in drinking water or edible fish. Aquatic-life criteria (AQLs) are water-quality guidelines for protection of aquatic life in streams and lakes.

source of water supply for most households with private wells in the study area and for many households served by public supplies. An estimated average 5 Mgal/d was withdrawn from private domestic wells completed in the Kirkwood-Cohansey aquifer system in the study area in 1990 (New Jersey Department of Environmental Protection, 1996b). Some of this water is returned to the aquifer system as septic-system leachate, and some is transported out of the study area through sewers. The Kirkwood-Cohansey aquifer system is highly susceptible to contamination from human activities because it is unconfined and highly permeable; the ground water is weakly buffered (Means and others, 1981); and the overlying soils in upland areas are generally sandy and well-drained, and have low cation-exchange capacities (Tedrow, 1979). Various other studies on the occurrence of various contaminants in ground water in the Kirkwood-Cohansey aquifer system and in similar settings on Long Island, New York, are summarized in detail by Clawges and others (1999).

Inorganic Constituents

Water in the unconfined Kirkwood-Cohansey aquifer system is generally acidic with low ionic strength and alkalinity; the pH of ground water from the aquifer system in Ocean County typically ranges from 4.4 to 6.7 (Anderson and Appel, 1969), and total dissolved solids typically are less than 100 mg/L (Barringer and others, 1993). As a result of the widespread occurrence of these conditions, the water is moderately to highly corrosive and, if untreated, can leach trace elements and release asbestos fibers from plumbing materials (Buelow and others, 1980; Kish and others, 1987, 1989; Barringer and others, 1993; Murphy, 1993; Barringer, 1994).

Specific conductance ranges from less than 20 to more than 1,000 µS/cm. Watt and others (1994) describe the general inorganic chemistry of ground water in the Kirkwood-Cohansey aquifer system in the study area. The predominant cations in shallow ground water are sodium and potassium. The major anion is chloride. Sea salts from wind-blown marine aerosols or saltwater intrusion and the effects of human activities, such as roadway de-icing, waste disposal, and leachate from fertilized land, all contribute to the concentrations of predominant ions. The distribution of chloride concentrations in the Kirkwood-Cohansey aquifer system and the intrusion of saline water in the Seaside Heights and Point Pleasant Beach areas are described in a report by Schaefer (1983). Bicarbonate, a product of the oxidation of organic matter and the dissolution of carbonaceous shell material, is a predominant anion in some areas (Watt and others, 1994).

Results of more detailed studies of inorganic chemistry of ground water and geochemical processes in small (less than 8 mi^2) watersheds near the study area are described by Fusillo and others (1980) and Johnsson and Barringer (1993). These studies document the relations among the chemical compositions of precipitation, ground water, and surface water in relatively undeveloped Pinelands watersheds, such as those that encompass some of the headwater areas of the study area (fig. 3).

Concentrations of nitrogen and phosphorus in shallow ground water in most areas within the Barnegat Bay watershed generally are low, relative to concentrations observed in surface water, but there are exceptions. Harriman and Sargent (1985) reported median concentrations in the Kirkwood-Cohansey aquifer system of less than 0.05, less than 0.01, 0.14, and 0.08 mg/L for ammonia, nitrite, total ammonia plus organic nitrogen, and nitrate plus nitrite, respectively, and less than 0.01 mg/L as P for both dissolved phosphorus and orthophosphate (n=152, 156, 141, 154, 133, 183, respectively). The median concentration of organic carbon was 0.5 mg/L (n=162). Nitrate plus nitrite concentrations were as large as 10.5 mg/L, and ammonia concentrations were as large as 5.6 mg/L. Nitrate is a major constituent in ground water sampled in some residential areas (Watt and others, 1994). A small percentage (0.5) of the nitrate values stored in the OCHD water-quality database for wells in municipalities in the study area (69 out of 13,907 tests) were in excess of the 10-mg/L MCL (table 2). Sodium concentrations exceeded

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

[Analytical results are for non-incident well-water samples collected from wells in study-area municipalities during 1983-99. See appendix for listing of study area municipalities. For wells sampled more than once, the most recent sample results were retained for this summary; mg/L, milligrams per liter; <, less than; --, no data; mg/L, micrograms per liter; VOC, volatile organic compound; OCHD, Ocean County Health Department]

Water-quality constituent	Water-quality standard	Number of wells with sample results	Number of wells with water-quality standard exceedances	Percent of water-quality standard exceedances
		Inorganics		
Nitrate	10 mg/L	13,907	69	0.5
Arsenic	10 µg/L	4,190	99	2.4
Iron	0.3 mg/L	10,605	3,406	32
Lead[1]	15 µg/L	13,955	1,389	10
Manganese	0.05 mg/L	10,601	1,357	13
Mercury	2 µg/L	13,869	93	0.7
Cadmium	5 µg/L	4,300	34	0.8
Chromium	100 µg/L	4,357	2	<0.1
		Volatile organic compounds		
Methylene chloride[2]	3 µg/L	13,753	1,412	10
VOCs other than Methylene chloride	Various (see respective values listed below)	13,869	1,007	7.3
1,1,1 trichloroethane	30 µg/L	13,754	355	2.6
Tetrachloroethylene	1 µg/L	13,751	228	1.7
Trichloroethylene	1 µg/L	13,754	155	1.1
1,2 dichloroethane	2 µg/L	13,393	146	1.1
Carbon tetrachloride	2 µg/L	13,756	155	1.1
Benzene	1 µg/L	13,760	101	0.7
Dichlorobenzene(s)	[3]75µg/L	13,736	90	0.7
1,1-dichloroethylene	2 µg/L	13,750	79	0.6
Trans-1,2-dichloroethylene	100µg/L	13,699	48	0.4
Vinyl chloride	2 µg/L	13,749	54	0.4
Xylenes	100 µg/L	13,748	42	0.3
		Pesticides		
Chlordane	0.5 µg/L	9,315	129	1.4
		Pathogens		
Total coliform bacteria	None detected	Indeterminate	932	Indeterminate

1. A likely source of lead in samples is plumbing materials from which lead is leached by characteristically corrosive raw water.
2. Methylene chloride is a particularly common laboratory solvent that can be introduced accidentally to water samples prior to analysis.
3. Data stored in the OCHD database field "dichlorobenzene(s)" did not distinguish among dichlorobenzene isomers, which have different Maximum Contaminant Levels (MCLs). For this analysis, the MCL for the dichlorobenzene isomer with the lowest MCL (75 µg/L for 1,4-dichlorobenzene) was used for comparison with analytical results.

the 50-mg/L RUL in 1.5 percent of the 13,441 wells for which sodium was analyzed.

Harriman and Sargent (1985) present a statistical summary of concentrations of various trace elements in water from the Kirkwood-Cohansey aquifer system in the Barnegat Bay watershed. Maximum concentrations of barium, chromium, copper, lead, silver, and zinc were less than the applicable MCL, AL, or RUL (n=154, 155, 158, 160, 137, 148, respectively). Reported maximum concentrations of cadmium and beryllium slightly greater than the current, respective MCLs (5 µg/L and 4 µg/L, respectively) could be artifacts of outdated sampling procedures for trace elements (David Rickert, U.S. Geological Survey, written commun., 1991) or possibly analytical interferences with other constituents (Jacob Gibs, U.S. Geological Survey, oral commun., 2001). Concentrations of iron and manganese were greater than the respective RULs in some areas; however, median concentrations were less than these levels (n=166). Slightly elevated concentrations in some samples could be attributed to the leaching of metals from well-construction materials because shallow ground water in the area generally is corrosive (Barringer and others, 1993).

Of the samples collected from 11 wells in 1996 and 3 wells in 2000 as part of the Ambient Ground-Water Quality Network (Jones and DeLuca, 1997; DeLuca and others, 2000b), none contained concentrations of arsenic, barium, cadmium, chromium, copper, lead, mercury, or selenium that exceeded the respective MCLs. Aluminum concentrations in six wells exceeded the RUL of 200 µg/L; iron concentrations in five wells exceeded the RUL of 300 µg/L; and manganese concentrations in three of these wells exceeded the RUL of 50 µg/L. Likely sources of elevated concentrations of iron, manganese, and aluminum in ground water in the study area are minerals in the native soils and aquifer sediments (Means and others, 1981; Budd and others, 1981; Johnsson and Barringer, 1993). Silver and zinc concentrations in all 14 wells were less than the respective RULs.

The OCHD database contained arsenic, cadmium, and chromium values for 4,100 to 4,400 wells in study area communities for 1983 through 1990 and some additional values for 1991 through 1999. After 1990, arsenic, cadmium, and chromium were no longer required analytes under the amended Ocean County ordinance. Values for 99 of the wells, or 2.3 percent, exceeded the arsenic standard of 10 µg/L. As of January 2003, plans were being considered to amend the Ocean County water-quality testing ordinance to include arsenic as a required analyte (Robert Ingenito, Ocean County Health Department, written commun., 2003). The frequency of cadmium and chromium exceedances was less than 1 percent; reported detections of these particular trace elements could have been artifacts of sampling procedures or analytical interferences with other constituents (Jacob Gibs, U.S. Geological Survey, oral commun., 2001). Results of analyses for lead in samples from 13,955 private wells in the study area communities for 1983 through 1999 indicated that 1,389 samples, or 10 percent, exceeded the 15 µg/L Action Level. Likely sources of lead in these samples are plumbing materials from which lead is leached by corrosive untreated water (Kish and others, 1987 and Barringer 1994). Testing conducted in compliance with the Ocean County ordinance typically involves the collection of samples from plumbing fixtures, such as faucets. Many samples have been subject to the leaching of plumbing materials.

Mercury in water is a primary health concern for both human and aquatic life. Total mercury concentrations that exceed the MCL of 2 µg/L have been determined in ground-water samples from the Kirkwood-Cohansey aquifer system, including samples from the study area (Barringer and others, 1997; Barringer and MacLeod, 2001). A statistical analysis of values in the OCHD Water Quality database from 1983 through 1999 indicated that, of the 13,869 wells in study area communities analyzed for mercury, 93 (about 0.7 percent) were found to contain mercury in concentrations in excess of the 2-µg/L MCL. Of the 14 wells sampled in 1996 and 2000 as part of the Ambient Ground-Water Quality Network (fig. 1), mercury was detected in 3 wells at

concentrations of 0.1 to 0.4 µg/L (Jones and DeLuca, 1997; DeLuca and others, 2000b).

In the Kirkwood-Cohansey aquifer system, mercury concentrations approaching the 2-µg/L MCL or greater generally occur where there is an anthropogenic source and a chemical or physical process conducive to mercury mobilization and transport. Dooley (1992) concluded that mercury concentrations are small (approximately 10 ng/g) in the sediments of the Kirkwood-Cohansey aquifer system, and that concentrations in samples from the aquifer system that exceed 10 ng/L probably are contaminated by anthropogenic sources. In this report, in the same manner as that of Barringer and others (1997), mercury concentrations greater than or equal to 1 µg/L are referred to as "elevated" concentrations. Anthropogenic sources of mercury include landfills, industrial sites, military installations, and cemeteries; waste discharged from schools, hospitals, laboratories, and dental offices; agricultural and managed turf lands where mercurial compounds once had been used; and industrial emissions to the atmosphere. Municipal and domestic wastewaters also contain some mercury (Association of Metropolitan Sewerage Authorities, 2000). Mercury in the form of mercuric chloride (which is highly soluble in water) and phenyl mercuric acetate has been used historically as pesticides on agricultural crops in the New Jersey Coastal Plain. These pesticides also have been used on lawns, and mercurial fungicides have been used on golf courses. Studies of the Kirkwood-Cohansey aquifer system to date (2003) have not conclusively linked particular sources with elevated concentrations of mercury in ground water found at the 34 southern New Jersey sites investigated by Barringer and others (1997).

Elevated mercury concentrations in samples from the aquifer system appear to be spatially clustered, although this pattern could be related, at least in part, to the non-random manner in which incidences of mercury contamination typically are investigated (Barringer and others, 1997). Wells that yield water samples with detected concentrations of mercury predominantly were domestic wells drilled to depths from 50 to 200 ft in residential areas that were formerly agricultural areas (Barringer and MacLeod, 2001). Elevated concentrations of nitrate, chloride, other inorganic constituents, and (or) chloroform were detected in samples from some of the wells that yielded detectable concentrations of mercury. These co-occurring constituents may be attributable to historical agricultural activities and the effects of septic systems (Barringer and MacLeod, 2001). Further investigation is needed to better understand the sources, transport, and fate of mercury in the Kirkwood-Cohansey aquifer system.

Unstable radioactive elements are found in a wide range of concentrations in all rocks, soil, and water. In parts of the Kirkwood-Cohansey aquifer system, concentrations of total radium (the sum of radium-226 and radium-228) exceeded the USEPA MCL of 5 pCi/L (Kozinski and others, 1995). Concentrations of total radium in samples collected during 1988-96 from 2 of 19 wells in the study area exceeded the MCL (Szabo and DePaul, 1998). Application to croplands of nitrogen, calcium, and magnesium in agricultural chemicals may increase the mobility of radium in ground water (Szabo and others, 1997). Other studies are underway to evaluate the distribution of other radioisotopes in the Kirkwood-Cohansey aquifer system and their contribution to the gross alpha-particle activity in water supplies (Szabo and DePaul, 1998). These ongoing studies include investigations of the short-lived radionuclides radium-224 (half life = 3.64 days) and lead-210 (half life = 10.64 hours), which contribute to gross-alpha particle activity in acidic (pH less than 5.0) ground waters.

Volatile Organic Compounds

Shallow ground water in the study area is vulnerable to contamination by volatile organic compounds (VOCs). VOCs are found in common household products and are used in many industrial and agricultural applications. They also are present in fuels and in the exhaust from fuel combustion. Potential sources include industrial discharges, landfills, municipal-wastewater discharges, leaks and spills from storage tanks and pipes, domestic septic-system effluent, and the atmosphere.

Because VOCs are most often associated with urban land use, they have been detected more frequently in the Kirkwood-Cohansey aquifer system in urban areas than in non-urban areas (Stackelberg and others, 1997; Eric Vowinkel and William Battaglin, U.S. Geological Survey, written commun., 2003). In urban areas nationwide, atmospheric deposition generally is a less-important source of VOCs than urban land surfaces (Lopes and Bender, 1998). Baehr and others (1999) evaluated atmospheric deposition as a source of VOCs in shallow ground water in the Glassboro region of southern New Jersey approximately 40 mi southwest of the study area and found small concentrations of chloroform, methyl *tert*-butyl ether (MTBE), 1,1,1-trichloroethane, and tetrachloroethylene (PCE) (also carbon disulfide, which is not a VOC) in shallow ground water of the Kirkwood-Cohansey aquifer system. Collocated atmospheric data from the Glassboro study indicated that atmospheric concentrations of MTBE (but not the other compounds) were large enough to potentially explain the frequent detection of MTBE at low concentrations in shallow ground water. The sources of other VOCs in concentrations greater than drinking-water standards are likely other than the atmosphere.

Results of studies and ongoing monitoring network sampling provide an indication of the occurrence of VOCs in the study area. Harriman and Voronin (1984) found that 5 percent of the samples collected during 1981-82 (7 out of 142) from wells that tap the Kirkwood-Cohansey aquifer system in the Barnegat Bay watershed had detectable concentrations of compounds that were included in VOC scans for either 4 or 10 VOCs. The detected compounds included benzene, toluene, and xylenes.

Samples from 12 wells in the study area were collected as part of the Ambient Ground-Water-Quality Network in 1996 or 2000 and analyzed for 29 (in 1996) or 34 (in 2000) VOCs. VOCs were detected in samples from 8 of the 12 wells sampled for VOCs. One VOC was detected in six of these wells, and three VOCs were dectected in two of these wells (table 3). VOCs were detected in these samples at concentrations less than their respective MCLs. The VOCs detected were chloroform (0.3-1.72 µg/L, 7 wells), tetrachloroethylene (0.2 µg/L, 2 wells), MTBE (0.6-1.70 µg/L, 2 wells) and toluene (0.26 µg/L, 1 well) (Jones and others, 1997; DeLuca and others, 2000b).

Analytical data contained in the OCHD water-quality database provide a broad basis for evaluating the frequency of VOC occurrence. A statistical analysis of the OCHD database confirmed a widely scattered presence of VOCs at small concentrations in ground water in the study area. Of the samples collected from the 13,869 wells in study- area communities and analyzed for VOCs during 1983-99, samples from 1,007 wells (or 7.3 percent) contained at least one VOC other than methylene chloride, a particularly common laboratory contaminant at concentrations greater than the MCL for that VOC (table 3). This result indicates that in areas where the water quality has been evaluated, a fairly substantial percentage of shallow ground water is likely to contain VOCs at concentrations of concern for human health. 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. (Camp Dresser & McKee, 1993; Robert Ingenito, Ocean County Health Department, oral commun., 2002).

The frequency of individual VOC occurrence in well-water samples provides a rough indication of the prevalence of a particular compound in shallow ground water. The compound most frequently detected at concentrations greater than its MCL (10 percent of wells tested with values in the OCHD database) was methylene chloride, which commonly is used as a solvent and aerosol propellant; it also can be introduced accidentally to water samples through laboratory contamination because it is a common laboratory solvent. The quality-assurance information needed to evaluate the likelihood of laboratory contamination of these samples by methylene chloride is not readily available.

Table 3. Data on pesticides and volatile organic compounds in samples from the Ambient Ground-Water-Quality Network wells, New Jersey, 1996-2000

[VOC, volatile organic compound; MTBE, methyl tert-butyl ether; ND, none detected; --, pesticides not analyzed; WRD, Water Resources Division; Site locations shown on figure 1. Information listed compiled from Jones and DeLuca (1997) and DeLuca and others (2000b)]

New Jersey WRD well number	Local identifier	Date sampled	Number of VOCs analyzed	Number of VOCs detected	VOCs detected	Number of pesticides analyzed	Number of pesticides detected
29-141	Colliers Mills 4 Obs	09-20-96	29	0	ND	--	--
29-485	Crestwood Vil 4	09-04-96	29	1	Chloroform	--	--
29-675	1	09-09-96	29	1	Chloroform	--	--
29-711	Stuart Dr	09-10-96	29	3	Chloroform Tetrachloroethylene MTBE	--	--
29-802	OCUA 13 - 1	09-17-96	29	0	ND	--	--
29-804	OCUA 14 – 2e	09-17-96	29	0	ND	--	--
29-994	Bey Lea Golf Course 2	08-23-96	29	0	ND	--	--
29-1130	Oak St Treatment 14	09-23-96	29	3	Chloroform Tetrachloroethylene MTBE	--	--
29-1178	Memorial Sch Fld Irr	10-07-96	29	1	Chloroform	--	--
29-1402	Doubletrouble MW60	08-03-00	34	1	Toluene	48	0
29-1403	Colliersmills MW65	08-02-00	34	1	Chloroform	48	0
29-1405	Manchester MW62	07-31-00	34	1	Chloroform	48	0

The compound most frequently detected at concentrations greater than the MCL, besides methylene chloride, was 1,1,1 trichloroethane (355 out of 13,754 wells tested, or 2.6 percent; table 2), which also is used as an industrial solvent. The frequency of detection of tetrachloroethylene, trichloroethylene, 1,2 dichloroethane, and carbon tetrachloride at concentrations greater than the respective MCLs was from 1 to 2 percent for each of these VOCs in study-area communities. The frequency of detection of six other VOCs that are required analytes under Ocean County Ordinance 94-1 (benzene, dichlorobenzenes, 1,1-dichloroethylene, 1,2-dichloroethylenes, trichloroethylene, and xylenes) was less than 1 percent. Values for trichlorobenzenes were not readily available in the OCHD database. Plans are underway to amend the Ocean County water-quality testing ordinance to include additional VOCs as required analytes (Robert Ingenito, Ocean County Health Department, oral commun., 2002).

VOCs in shallow ground water are a primary water-quality concern in the study area. Evaluation of the spatial distributions of VOCs and the relations of these distributions to possible sources in the study area is constrained by the lack of information about well construction and well location in the OCHD water-quality database.

Pesticides and Non-Volatile Organic Compounds

Recent studies have evaluated the occurrence and transport of pesticides in the Kirkwood-Cohansey aquifer system (Szabo and others, 1994; Vowinkel and others, 1996; Stackelberg and others, 1997). Vowinkel and others (1996) examined relations between pesticide occurrence and various land use and hydrogeologic factors, and determined that some public supply wells in the study area were moderately to highly vulnerable to pesticide contamination. In a NAWQA study of shallow ground water in the Kirkwood-Cohansey aquifer system (Stackelberg and others, 1997), 19 pesticides were detected in 1996 in 2 or more samples from a network of 72 shallow wells in the Glassboro area approximately 40 mi southwest of the study area. The frequency of detection for individual pesticide compounds was as high as about 75 percent in agricultural areas, although concentrations generally were less than established drinking-water regulations and long-term health advisories.

The distribution of agricultural pesticides in ground water is related to the application of pesticides to the land surface, ground-water-flow patterns, and ground-water age distribution; shallow, younger ground water in agricultural areas is more likely to contain pesticides than deeper, older ground water. The non-detection of pesticides in deep (85 ft) wells in agricultural areas indicates that pesticides have degraded or have not yet penetrated the deeper parts of the aquifer system (Szabo and others, 1994). Although little agricultural land use is currently present (2003) in the study area, historical agricultural land use was more extensive. In addition, some pesticides commonly are applied in residential areas and along roadways.

The atmosphere is another potential source of pesticides in ground water. Pesticides can be transported into the atmosphere by volatilization, dispersed by air currents, and then re-deposited on land and water surfaces. More than 24 agricultural pesticides have been reported in fog and rainfall in the United States, Canada, and Europe (Goolsby and others, 1997). Although typical atrazine and alachlor concentrations of 0.2 to 0.4 µg/L were measured in precipitation sampled in Midwestern cornbelt States during 1990-91, concentrations of these compounds measured in precipitation across the northeastern United States during 1990-91 generally were less than 0.05 µg/L (Goolsby and others, 1997). In the Glassboro area of New Jersey, pesticide concentrations in precipitation were less than 0.05 µg/L during most of the year but were higher during the spring application period (Arthur Baehr, U.S. Geological Survey, written commun., 2000).

The OCHD water-quality database contained results for raw water from 9,315 private wells in study-area communities that were tested for

chlordane, a persistent pesticide. The USEPA banned all uses of chlordane in 1988. Of these results, 129 or 1.4 percent, were greater than the MCL for chlordane. Few data are available on the occurrence of other pesticides in shallow ground water in the study area. Samples from three shallow (less than 20 ft deep) wells (fig. 1) in the undeveloped headwaters were collected as part of the Ambient Ground-Water-Quality Network in 2000 and analyzed for 48 pesticide compounds, none of which were detected (DeLuca and others, 2000b).

Although few data are available on the occurrence of other pesticides in shallow ambient ground water, the results of studies in nearby areas described above indicate that, on the basis of the land-use history of the study area, pesticides might be present in shallow ground water, but that concentrations generally could be expected to be low.

Pathogen Indicators

Although soil and aquifer sediments filter and immobilize particulate matter, including bacteria and viruses, in ground water, subsurface microbial transport and survival can result under certain conditions in sandy aquifers (Bales and others, 1995), and can result in microbial contamination of wells and waterborne disease outbreaks (Craun, 1979; Abbaszadegan and others, 1999). An evaluation of the OCHD water-quality database indicated that coliform bacteria were present in samples from 932 wells in study-area communities (table 2); however, the frequency of occurrence of coliform bacteria cannot be determined because the total number of wells tested for coliform bacteria cannot be determined from the information contained in the OCHD database. Common sources of pathogens in ground water include septic systems, cesspools, infiltration of contaminated surface water, broken or leaky sewer pipes, animal feedlot operations, and uncontrolled landfill leachate.

SURFACE-WATER QUALITY

Streams in the study area drain to Barnegat Bay and constitute the primary source of freshwater inputs and various contaminant loads to the northern part of this moderately eutrophic estuary (Hunchak-Kariouk and Nicholson, 2001). The Metedeconk River also is the source of water for the public supply intake operated by the BTMUA. In 1998, surface withdrawals by BTMUA from the Metedeconk River totaled 2.185 billion gallons (6 Mgal/d) and provided the primary water supply for a resident population of more than 75,000 and an additional seasonal population of about 10,000 (Camp Dresser & McKee, 2000). Streamflow in the study area and throughout most of the New Jersey Coastal Plain is derived mostly from ground-water discharge. As a result, ground-water quality is an important determinant of surface-water quality.

Recent overviews of surface-water quality in the study area are provided by Watt and others (1994), New Jersey Department of Environmental Protection (1996a, 1998, 2001b), Camp Dresser & McKee (2000), and Hunchak-Kariouk and Nicholson (2001). An earlier water-quality assessment is summarized by Rogers, Golden, and Halpern, Inc. (1990). Monitoring in the Pinelands section of the Toms River Basin (fig. 3) has been conducted as part of a regional Pinelands surface-water monitoring and data-management program (Windisch and Zampella, 1989; Windisch, 1990; Windisch, 1991). Interpretation of selected data collected during 1988-91 is presented in Zampella and others (1994); samples from the monitored streams met New Jersey surface-water quality criteria for Pinelands waters for nitrate-nitrogen (2 mg/L) and total phosphorus (0.1 mg/L). Water-quality characteristics of some of the monitored streams were typical for undisturbed Pinelands streams, whereas one or more characteristics of other streams, such as Wrangel Brook (fig. 1), were more typical of Pinelands streams considered moderately disturbed along the disturbance gradient described by Zampella (1994).

The NJDEP conducts periodic surface-water-quality assessments of the Barnegat Bay watershed

(New Jersey Watershed Management Area 13), which includes the study area (fig. 1). A recent assessment, described in the New Jersey 1996 State Water Quality Inventory Report (SWQIR) (New Jersey Department of Environmental Protection, 1996a), includes a summary of ambient physical and chemical conditions at a monitoring site in the study area. The assessment of water-quality data for the monitoring site on the Toms River indicated that temperature, and dissolved oxygen and nutrient concentrations were within acceptable limits for the stream classification (FW-2, Nontrout waters) and that bacteria levels were considered "very low" and appeared to be decreasing in recent years. No statistically significant trend in fecal coliform bacteria was found at this site during 1974-94, however, as reported by Carter (2001). The 1996 SWQIR report includes results of macroinvertebrate monitoring in the Toms River Basin at 61 surface-water sites in the study area during 1991-95, in which biological impairment ratings are assigned to each monitoring site. Non-impaired conditions were identified at 35 sites, moderately impaired conditions at 22 sites, and severely impaired conditions at 4 sites. Current assessments are available at the NJDEP Watershed Specific Surface Water Assessment Web site (URL http://www.state.nj.us/dep/dsr/watershed/305-b.htm). A NJDEP Designated Use Assessment stated that "the Toms River itself and most of the local tributaries fully support the aquatic life use; partial support is assigned to those tributaries assessed as partially impaired…" (New Jersey Department of Environmental Protection, 1996a). State Water Quality Inventory Reports published during 1997-2001 (New Jersey Department of Environmental Protection, 1998, 2001) use different formats and do not include further information specific to Watershed Management Area 13.

Inorganic Constituents

Long-term monitoring (conducted during a period of many years) provides a basis for evaluating trends in water quality that may accompany changes in land use and human activities. Trends of selected inorganic constituents were determined at the long-term USGS water-quality station on the Toms River near Toms River for Water Years 1976-95 for all flow conditions. During Water Years 1976-86, concentrations of dissolved chloride and total nitrogen increased, and concentrations of dissolved magnesium, potassium, lead, chromium, and iron decreased (Hay and Campbell, 1990). No significant trends were observed for specific conductance, pH, dissolved sodium, calcium, total ammonia, total phosphorus, and instantaneous streamflow. Robinson and others (1996) related water-quality trends at this station during this time period to four drainage-basin characteristics (population, effluent discharge, road-salt application, and agricultural activities) and found no statistically significant associations. For water years 1986-95, Hickman and Barringer (1999) found that pH, specific conductance, and concentrations of total nitrate plus nitrite and ammonia increased, and that concentrations of total organic nitrogen decreased. The maximum nitrate plus nitrite concentration during this time period was 0.95 mg/L as N (n=56), well below the 10-mg/L MCL. Trends were insignificant for total nitrogen and phosphorus. During the same period, instantaneous streamflows descreased. Hunchak-Kariouk and Nicholson (2001) examined all data for water years 1960-97 and concluded that pH, specific conductance, and nitrate plus nitrite appeared to be increasing at the Toms River station. During November to April when flow tends to be high, pH is lower than during May to October when flow tends to be lower (Zampella, 1994).

Hunchak-Kariouk and others (1999) evaluated changes in water-quality in the Toms River Basin in water years 1976-93 during high- and low-flow conditions, which can indicate changes in drainage-basin characteristics. Concentrations of dissolved sodium and chloride increased during low flow, indicating an increase in the contributions of these constituents from point sources and (or) ground water. Concentrations of total phosphorus decreased during low flow, indicating a decrease in the contributions of phosphorus from point sources and (or) ground water. Trends were insignificant for dissolved

solids, total hardness, total suspended solids, total nitrogen, dissolved nitrate plus nitrite, and total ammonia plus organic nitrogen. Concentrations of dissolved chloride increased during high flow, indicating an increase in the contribution of dissolved chloride from storm runoff. Concentrations of total hardness and phosphorus decreased during high flow, indicating a decrease in contributions of total hardness and phosphorus from storm runoff. Trends were insignificant for total suspended solids, dissolved solids and sodium, total nitrogen, dissolved nitrate plus nitrite, and total ammonia plus organic nitrogen.

Studies of the relations between land use and water quality in the study area indicate that pH, specific conductance, and nitrate concentrations in surface water tend to increase with increasing percentages of developed land in upstream drainage areas (Zampella, 1994; Hunchak-Kariouk and Nicholson, 2001). The Barnegat Bay estuary is considered moderately eutrophic. Nutrient enrichment is a particular concern in estuary resource management (Kennish, 2001). Nitrogen inputs from tributary streams, ground-water discharge, atmospheric deposition, and the Atlantic Ocean constitute the nitrogen load to the estuary. Nutrient loads to the estuary were estimated as part of the studies described by Moser (1997), and Hunchak-Kariouk and Nicholson (2001).

Hunchak-Kariouk and Nicholson (2001) report concentrations of trace elements in samples from surface-water monitoring sites in the study area from available data for 1960-97, including data contained in the USGS National Water Information System database. Concentrations of arsenic, chromium, copper, and zinc were less than the respective MCLs, ALs, or RULs. Lead concentrations exceeded the 15-µg/L AL eight times at four sites within the study area. (A total of 65 samples collected during 1960-97 from 16 sites were analyzed.) Iron concentrations exceeded the RUL of 300 µg/L in all samples except two at two sites. (A total of 69 samples collected during 1960-97 from 18 sites were analyzed.) Manganese concentrations exceeded the RUL of 50 µg/L 15 times at seven sites. (A total of 78 samples collected during 1960-97 from 18 sites were analyzed.) Results of analyses of samples recently collected from the Toms River (September 1998) and South Branch Metedeconk River (September 1999) (DeLuca and others, 1999; DeLuca and others, 2000a) indicated that concentrations of arsenic, barium, beryllium, cadmium, chromium, copper, lead, manganese, mercury, selenium, silver, and zinc were less than the respective MCLs, ALs, and RULs. Concentrations of iron at these sites were greater than the RUL of 300 µg/L.

Few data are available on radionuclides in surface water in the study area. Data from limited monitoring for radionuclides (dates unspecified) in the Metedeconk River near the BTMUA intake indicate that radionuclide activities were less than MCLs for drinking water (Camp Dresser & McKee, 2000).

Volatile Organic Compounds

The NAWQA studies in the coastal basins of Long Island, New York, and New Jersey found that VOCs were detected frequently in streams, but that concentrations were less than the MCLs, HAs, or AQLs (O'Brien and others, 1997; Terracciano and O'Brien, 1997; and Reiser and O'Brien, 1998). The most frequently detected VOCs in surface waters were MTBE, chloroform, trichlorethene (TCE), 1,1,1-trichloroethane (TCA), and tetrachloroethene (PCE)-- compounds used in gasoline or commercial and industrial processes, or by-products of the chlorination of water (Ayers and others, 2000). MTBE is a fuel oxygenate added to gasoline to enhance combustion and reduce atmospheric concentrations of carbon monoxide and ozone. Chloroform can be formed as a by-product of the chlorination of water and is used as an industrial solvent. TCE, TCA, and PCE are three of the VOCs most extensively used in commercial and industrial applications.

The BTMUA monitors the Metedeconk River and its tributaries for VOCs. This monitoring effort has resulted in the possible detection of small concentrations of a variety of VOCs in samples collected from a network of 30 sites on the North and South Branches of the

Metedeconk River (John Rissel, Brick Township Municipal Utilities Authority, written commun., 1998). Thirteen VOCs were detected in stream samples analyzed by the BTMUA in 1998 (four additional compounds were detected only in trip blanks); 11 of these compounds were detected in samples collected during 1997 (O'Brien and others, 1997) and 9 during 1996-97 (Reiser and O'Brien, 1998) at various sites throughout New Jersey as part of NAWQA program VOC synoptic studies.

The four VOCs most frequently detected in stream samples analyzed by the BTMUA were MTBE, PCE, naphthalene, and 1,1-dichloroethene. (The concentration of 1,1-dichloroethene exceeded the MCL once at one site.) Further interpretation of the data is not possible because of the presence of MTBE and 1,1-dichloroethene in several trip blanks and the low concentrations of all VOCs in the stream samples, which is typical of concentrations reported throughout New Jersey streams (DeLuca and others, 1999, 2000a, and 2000b).

Six sites have been sampled by the USGS along the Toms River mainstem and its tributaries (fig. 1) as part of the Ambient Stream Monitoring Network. In March 1998 analyses were conducted for 29 VOCs in samples from the mainstem Toms River and the Shannoc Brook (drainage area is 3.15 mi^2), and none were detected (DeLuca and others, 1999; table 4). The South Branch Metedeconk River was sampled in February 1999, and analyses were conducted for 34 VOCs. One VOC (MTBE) was detected at a concentration of 1.7 µg/L (MCL is 70 µg/L; DeLuca and others, 2000a). Maple Root Branch, a small (drainage area is 5.63 mi^2; fig. 1) tributary to the Toms River, was sampled in February 2000. None of the 34 VOCs were detected (DeLuca and others, 2000b).

Pesticides

Studies in other nearby areas have shown that concentrations of pesticides in streams vary spatially with land use and temporally in response to seasonal patterns in pesticide applications (U.S. Geological Survey, 1999). A study by Reiser (1999) shows that pesticide concentrations in surface water that drains agricultural areas in New Jersey can be considerably higher during high flows soon after crop application than during low flows. Ayers and others (2000) report that pesticides are more frequently detected in New Jersey streams than in shallow ground water.

Pesticide compounds have been detected at low concentrations in samples from some streams in the study area at various sampling locations. In a synoptic investigation as part of a NAWQA study in June 1997, pesticides were detected in water samples from 50 New Jersey streams, including the Toms River. Samples were analyzed for 47 pesticide compounds, and 6 of these compounds (malathion, metolachlor, desethyl atrazine, DCPA, chlorpyrifos, and tebuthiuron) were detected in samples from the Toms River near Toms River at concentrations of less than 0.05 µg/L (Reed and others, 1998; Reiser and O'Brien, 1999). The concentrations of these detected compounds were at or below established criteria for both human health and aquatic life (Reiser and O'Brien, 1999).

In June 1998, 12 of 48 pesticide compounds were detected in samples from the Toms River at similarly low levels (less than 0.06 µg/L), lower than the criteria. These compounds were alachlor, atrazine, carbaryl, DCPA, deethylatrazine, diazanon, metolachlor, pendimethalin, prometon, simazine, tebuthiuron, and trifluralin (DeLuca and others, 1999). In May 1998, three tributaries to Toms River (Wrangel Brook near Toms River, Long Swamp Creek at Toms River, and Shannoc Brook tributary at Colliers Mills; fig. 1) were sampled, and samples were analyzed for 47 pesticide compounds. Seven to 10 of these compounds were detected at concentrations of less than 0.05 µg/L (DeLuca and others, 1999). These compounds are atrazine, benfluralin, chlorpyrifos, diazinon, metolachlor, prometon, and trifluralin in Wrangel Brook; atrazine, carbaryl, chlorpyrifos, cyanazine, diazinon, metolachlor, pendimethalin, prometon, simazine, and trifluralin in Long Swamp Creek; and alachlor, atrazine, deethylatrazine, diazinon, metolachlor, prometon, and simazine in Shannoc Brook (DeLuca and others, 1999).

Table 4. Data on pesticides and volatile organic compounds in samples from the Ambient Stream Monitoring Network sites, New Jersey, 1997-2000

[All reported pesticide concentrations were less than 0.06 microgram per liter. The concentration of the single detected VOC (methyl tert-butyl ether) was 1.7 micrograms per liter. --, no sample collected; Site locations are shown in figure 1. Information listed below compiled from Reed and others (1998) and DeLuca and others (1999, 2000a, 2000b)]

	Pesticides			Volatile organic compounds		
Site name and number	Date sampled	Number of compounds analyzed	Number of compounds detected	Date sampled	Number of compounds analyzed	Number of compounds detected
Toms River near Toms River 01408500	6/9/1997	47	6	3/11/1998	29	0
	6/2/1998	48	12			
Wrangel Brook near Toms River 01408600	5/28/1998	48	7	--	--	--
Long Swamp Creek at Toms River 01408728	5/28/1998	48	10	--	--	--
Shannoc Brook Tributary at Colliers Mills 01408480	5/13/98	48	7	3/11/98	29	0
Maple Root Branch Branch at Bowman Road Near Holmansville 01408285	6/1/2000	48	0	2/9/00	34	0
South Branch Metedeconk River at Laurelton 01408152	5/12/1999	48	7	2/4/99	34	1

In May 1999, samples were collected from the South Branch Metedeconk River near Laurelton and analyzed for 48 pesticide compounds; 7 of these compounds were detected at concentrations of less than 0.05 µg/L. The detected compounds are atrazine, carbaryl, deethyl atrazine, diazinon, metolachlor, prometon, and simazine (DeLuca and others, 2000a). Of the pesticides detected at these five sites in the Toms River and South Branch Metedeconk River Basins, four compounds were common to all five sites. These compounds are atrazine, metolachlor, diazinon, and prometon. Three of these compounds, atrazine, metolachlor, and prometon are herbicides, and diazinon is an insecticide. All four of these compounds are detected frequently in other streams in New Jersey and Long Island, New York (Ayers and others, 2000; Reiser and O'Brien, 1999).

Maple Root Branch was sampled in June 2000, and samples were analyzed for 48 pesticide compounds. None of these compounds were detected (DeLuca and others, 2000b).

Pathogen Indicators

Data on fecal coliform bacteria in samples collected from the Toms River near Toms River as part of the USGS/NJDEP cooperative Ambient Stream Monitoring Program are assessed every 2 years by the NJDEP. Samples for fecal coliform bacteria analysis typically are collected 3-5 times during summer months. A comparison of the water-quality index values reported in 1988 and 1992 show an improvement in the sanitary water quality of the Toms River (New Jersey Department of Environmental Protection, 1995), and this improvement has continued. Fecal coliform bacteria counts that exceed the State criterion of 200 MPN/100 mL (most probable number per 100 milliliters) occurred in 38 percent of the samples documented in 1988 (New Jersey Department of Environmental Protection, 1990), in 14 percent of the samples documented in 1992 (New Jersey Department of Environmental Protection, 1995), and in none of the samples documented in 1996 (New Jersey Department of Environmental Protection, 1996a). The highest fecal coliform bacteria counts in samples collected from the North Branch Metedeconk River during seven summer sampling events in 1998 and 2000 consistently exceeded this criterion (Deluca and others, 1999, 2000b). Fecal coliform bacteria counts had wide variability among multiple monitoring sites along the North and South Branch Metedeconk Rivers (Camp Dresser & McKee, 2000)

Fecal coliform bacteria were measured as part of a nonpoint storm runoff study of four tributary streams in the Toms River Basin (Hunchak-Kariouk, 1999). Fecal coliform bacteria counts were greatest (generally greater than 300 MPN/100 mL) in samples collected just before or at peak streamflow. Concentrations during the growing season were larger during stormflow than during base flow at all sites monitored. During base flow in the growing season, concentrations were largest at a site on Long Swamp Creek that drains a highly developed area and smallest at sites on Wrangel Brook that drain moderately developed areas. During stormflow, counts in the growing season were similar at sites on Long Swamp Creek and Wrangel Brook and greater than at a site on Davenport Branch (fig. 1) that drains a slightly developed area. During the nongrowing season, counts were largest at the site on Long Swamp Creek and smallest at the site on Davenport Branch. At sites on all three streams, fecal coliform bacteria counts were greater in the growing season than in the nongrowing season. Results of this study show that fecal coliform bacteria counts and yields were weakly related to the intensity of upstream development and that bacteria yields were strongly related to streamflow and season.

Disinfection By-Product Formation Potential

Organic matter in natural waters reacts with chlorine during disinfection by chlorination to form trihalomethanes and other toxic by-products (Bull, 1982; U.S. Environmental Protection Agency, 2001). Dissolved organic carbon (DOC),

an indicator of the amount of organic matter dissolved in water, typically is higher in surface water in the study area than in ground water in the Kirkwood-Cohansey aquifer system underlying the study area; therefore, the potential for disinfection by-product formation generally can be expected to be higher in surface water than in ground water. Although the potential for the formation of disinfection by-products in processed surface water in the study area is not addressed specifically in the studies described in this report, some information on indicators of disinfection by-product precursors has been reported and is described below.

Recent (1997-2000) monitoring data indicate that DOC concentrations ranged from 2.3 to 10 mg/L in samples from the north and south branches of the Metedeconk River and from 2.5 to 16 mg/L in samples from the Toms River (Reed and others, 1998, DeLuca and others, 1999, 2000a, 2000b). These ranges exceeded the alternative compliance criterion of 2.0 mg/L for total organic carbon, which is used in determining the treatment requirements for source water (U.S. Environmental Protection Agency, 1998). Specific ultraviolet absorbance (SUVA) has been used as an indication of the reactive fraction of organic carbon in water that can form disinfection by-products (Reckhow and others, 1990; U.S. Environmental Protection Agency, 1998). SUVA values for samples from the north and south branches of the Metedeconk River and the Toms River were calculated from ultraviolet absorbance (254 nanometers) and DOC concentrations reported by Reed and others (1998) and DeLuca and others (1999, 2000a, 2000b); these values consistently exceeded the alternative compliance criterion of 0.02 absorbance units-liters per milligram-centimeter for SUVA of source water prior to treatment (U.S. Environmental Protection Agency, 1998). Certain public and nonpublic water supplies that use source water with concentrations of organic carbon and SUVA values that are greater than the respective criteria are required to undergo enhanced coagulation to remove organic compounds from the water (U.S. Environmental Protection Agency, 1998). As a result of organic matter in the Metedeconk River, the formation of disinfection by-products has been identified as an issue in the treatment of surface water from the Metedeconk River (Camp Dresser & McKee, 2000; Agency for Toxic Substances and Disease Registry, 2001).

SUMMARY AND CONCLUSIONS

Numerous ambient water-quality studies and data-collection efforts were conducted in the Toms River, Metedeconk River, and Kettle Creek Basins during 1980-2001. These basins drain 330 mi^2 in the New Jersey Coastal Plain and compose the northern two-thirds of New Jersey Watershed Management Area 13. Forty-eight studies and data reports of water quality in or near the Toms River, Metedeconk River, and Kettle Creek Basins and relevant regional studies published during 1980-2001 provide a summary of water-quality conditions in the study area and a basis for directing future studies and other actions to address water-quality concerns.

Legislation (New Jersey P.L. 1998, c.67) authorized a study to assess water quality throughout the watershed area. The study was conducted by the U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP), and was coordinated by the Barnegat Bay Estuary Program, which is part of a U.S. Environmental Protection Agency (USEPA) initiative to identify "nationally significant" estuaries and to oversee the development of plans to restore and protect their ecological health and biological integrity. This report is an outcome of that study.

The findings of studies on ground-water quality indicate that shallow ground water within the watershed generally meets primary drinking-water standards, with notable exceptions. Volatile organic compounds, mercury, arsenic, radionuclides, and coliform bacteria have been detected in shallow ground water in some areas at levels that exceed drinking-water standards. Reported concentrations of the pesticide chlordane in some areas exceeded the drinking-water standard. Few data are available on the occurrence of other pesticides in shallow ambient ground water. Studies in nearby areas indicate, on the basis

of the land-use history of the study area, that other pesticides could be present in shallow ground water, but that concentrations generally could be expected to be below drinking-water standards. In many areas, the combination of low pH and low dissolved solids results in ground water that is highly corrosive and able to leach trace elements and release asbestos fibers from plumbing materials.

A New Jersey Department of Environmental Protection Designated Use Assessment indicated that most of the Toms River Basin tributaries and the mainstem fully support aquatic use and that many other tributaries partially support this use. Evaluation of long-term (1960-97) trends in water quality of the Toms River mainstem indicated that pH, specific conductance, and nitrate plus nitrite concentrations were increasing, whereas total nitrogen and phosphorus concentrations were stable and organic nitrogen concentrations were decreasing. Reported concentrations of nitrate, volatile organic compounds, trace elements, and pesticides in the few monitored mainstem and tributary streams generally are below maximum contaminant levels or below detection limits. Results of studies in other areas indicate that pesticide concentrations in surface water could be considerably higher during high flows soon after crop application than during low flows. Coliform bacteria counts in monitored streams vary considerably. Changes in fecal coliform counts in samples collected during 1974-94 at the long-term monitoring site on the Toms River mainstem were not statistically significant, although counts have decreased in recent years. Concentrations of these classes of surface-water-quality constituents are likely functions of the intensity and type of upstream development. Limited monitoring for radionuclides in the Metedeconk River near the Brick Township Municipal Utilities Authority intake indicated that radionuclide activities were less than drinking-water standards. As a consequence of organic matter in surface water, the formation of toxic disinfection by-products is an issue in the treatment of surface water.

The summarized reports provide some indication of the likely sources and transport mechanisms of some contaminants present in the study area. Results of studies conducted during 1980-2001 indicate that water quality and treatment issues associated with use of waters in the study area for potable supply are related to human activities and naturally occurring factors. Additional monitoring and analysis of ground water and surface water in the study area would be needed in order to evaluate conclusively the occurrence and distribution of some contaminants and the relative importance of various potential contaminant sources and contaminant transport mechanisms and pathways. In particular, additional study may be needed to adequately characterize sources and transport mechanisms of mercury, arsenic, radionuclides, volatile organic compounds, pesticides, and pathogens in ground water, and radionuclides, pesticides, and volatile organic compounds in surface water.

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APPENDIX

APPENDIX 1.--HISTORY, MIGRATION, DATA-QUALITY ISSUES, AND STATISTICAL ANALYSIS OF THE OCEAN COUNTY WATER-QUALITY DATABASE

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INTRODUCTION

The Ocean County, New Jersey, water-quality database, maintained by the Ocean County Health Department (OCHD), represents a massive source of information on ground-water quality that probably has been underutilized as an environmental assessment resource. In order to utilize the database as part of the study summary and data review described in this report, the Ocean County water-quality database was migrated to a new design; data-quality issues were identified; and a statistical analysis was conducted. The purpose of this appendix is to document the history of the Ocean County water-quality database and the processes of database migration, data-quality evaluation, and statistical analysis conducted to generate information cited in the report.

HISTORY

The Ocean County Board of Health Well and Individual Sewage Disposal System Ordinance, originally passed in 1987, requires water samples from a private well to be tested when the well is completed and when property served by the private well for potable water supply is sold or leased. Water-quality constituents analyzed under this ordinance include inorganic constituents, physical properties, trace elements, volatile organic compounds, the pesticide chlordane, and microbiological constituents. During 1987-99, the testing program resulted in an extensive database, which is maintained by OCHD.

The OCHD water-quality database consists of information about locations of properties served by private wells, the laboratories used to conduct analyses, the dates of sample collection, and results of laboratory analyses for more than 62,000 samples collected from more than 23,000 locations in 33 municipalities throughout Ocean County. Samples are identified as either raw or treated. Raw samples are collected from an indoor plumbing fixture prior to passing through water-treatment equipment; treated samples are collected from a plumbing fixture after passing through a water-treatment device. Sampling is related to two types of circumstances. A relatively small number of samples that were collected in response to known or suspected areas of ground-water contamination are identified as “incident” samples. Most of the database consists of results for “non-incident” samples collected as a result of real-estate activity or new well completion. Properties that have been sold or leased multiple times since 1987 have generated multiple samples, whereas those properties that have not been sold or leased in that time frame do not have associated sample data in the database. The OCHD also maintains some records of domestic well water quality obtained prior to implementation of the water-quality testing ordinance; the earliest database record dates to October 1983.

The water-quality data in the database were summarized in a report by Camp Dresser & McKee (1993); that report includes recommendations for changes to the database structure. The database system had been developed for, and operated for many years on, an IBM System32 computer that was not Year 2000 compliant. OCHD had decided to shut down the database system at the end of 1999. Design limitations of that system also precluded an efficient evaluation of the data as part of the assessment described in this report. For both of these reasons, a database enhancement was needed. Data were extracted from the database to a text file in December 1999. A new database design and data-entry application in Microsoft Access were created by the USGS and delivered to OCHD in March 2000. The new database contains the present data records and corrected many of the database design limitations of the original storage structure.

DATABASE MIGRATION

Migration of the OCHD domestic well water-quality data to the USGS design followed these steps.

1. The full data set from the legacy system was extracted to a single ASCII file (70 fields and 62,938 water-quality records).

2. A relational data model and database design were developed to represent and store the data.

3. In a staging area database, the raw data were loaded, data elements parsed, split data reconstructed (separately stored integer and decimal portions were combined), error conditions identified, and bad records culled.

4. The new database was loaded with 62,798 original water-quality sample records that did not contain fatal errors (see below); this process included many transformations and reconstructions from the original format.

After transfer of the original data to the new design, 99.8 percent of the original sample data was retained (loss of only 140 samples). Sample data that were not retained had at least one of the following fatal errors.

1. Missing or bad location information (Community, Block, Lot values or codes).

2. Missing or bad sample date information.

3. Missing laboratory code. This error is fatal to a record because different columns from the raw data were used for different constituents, depending upon the laboratory; without the laboratory identifier, the constituent for which the value was reported was unknown.

DATA-QUALITY ISSUES

The new relational database eliminated many of the limitations of the original design and added new features to ensure more accurate and complete entry of data. The application has proven successful and has been in use at OCHD since March 2000. The remaining quality issues are discussed in the following sections.

Laboratory Reporting Inconsistencies

Paper copies of laboratory sheets submitted by testing laboratories to OCHD were evaluated. These forms are not standarized across laboratories, and the naming conventions of chemical constituents vary. Inconsistencies in the reporting format are a detriment to accurate data entry, because the OCHD staff is required to find the locations on each laboratory's form for the information that must be entered, to correctly interpret synonym variations for the same chemical constituent and, in some cases, to read a small print typeface.

Vague Location Information

Water-quality sample records in the database are identified as belonging to a particular location. Accurate location information is critical for all of the data; if the source of a sample is unknown, it has no context and, consequently, no value. The location is defined as a Lot or combination of Lots nested within a Block, which is nested further within a Community. Apparent errors occurred in the three location identifiers in the legacy data: Community, Block, and Lot codes. Community codes should start with 15, but originally the codes included other variants (those sample records were discarded). Block coding is highly variable with no standards applied; an evaluation of code values revealed some appreciable typographical errors, especially in the punctuation symbols used, creating false differences because all code variants are considered unique in a data context. Lot coding also appears to have no consistent naming

rules, again particularly in regard to punctuation symbols. These inconsistencies complicate the accurate recognition of the identity and location of the well that was sampled. Another consequence of the reliance on Block and Lot codes for locational purposes is that spatial analysis of the data is hampered. Spatial resolution of well locations varies with parcel size, and the availability of georeferenced, electronic Lot and Block information is limited.

Lack of Parameter Distinction

Reported values for as many as 30 constituents could be stored in fixed columns in the original legacy database application. Depending upon the laboratory, different columns were used for different constituents. No facility was available to create new constituent fields in the legacy database because the system was hard-coded. This interdependence of the fixed column arrangement and laboratory identity to identify the constituent value stored was abandoned in the new database in favor of a more direct, laboratory-independent constituent list with an option for adding new constituents as needed.

A second difficulty with the original database design was that it did not allow any coding of the constituents—only assignment of a value to a column for a laboratory—and, therefore, no distinction was made for different constituent species. Data were entered for the "closest matching constituent" rather than identifying a new constituent. For example, data stored in "Dichlorobenzene(s)" did not distinguish among the isomers, 1,2-dichlorobenzene and 1,3-dichlorobenzene. This lack of distinction among isomers makes analysis difficult because one cannot be sure whether values being statistically evaluated as a group are actually equivalent. Because different isomers can have different ecological and toxicological properties, the distinction is critical.

STATISTICAL ANALYSIS

The statistical analysis discussed in this report was applied to a subset of results from sample analyses contained in the database. Sample results were restricted on the basis of various selection criteria to identify results that represent the most recent quality of the ambient ground water in the Metedeconk River, Toms River, and Kettle Creek Basins. Only samples collected on property within the 19 municipalities that are wholly or partly in the study area were selected. As a result of grouping at the municipality level, some wells included in the subset are near but outside the limits of the study area. Municipalities represented by the sample results selected for statistical analysis are listed below.

Bay Head Borough
Beachwood Borough
Berkeley Township
Brick Township
Dover Township
Island Heights Borough
Jackson Township
Lacey Township
Lakehurst Borough
Lakewood Township
Lavalette Borough
Manchester Township
Mantaloking Borough
Ocean Gate Borough
Plumstead Township
Point Pleasant Borough
Seaside Heights Borough
Seaside Park Borough
South Toms River Borough

Samples identified as "raw", indicating that the water did not pass through a treatment device prior to collection, were selected. Samples with a sample type of "treated" or "unknown" were not selected. Only "non-incident" samples, which were collected as a result of a real-estate transaction or new well completion, were selected. "Incident" samples were omitted. Sample results were sorted by sample date for each well to obtain the most recent analytical result for each water-quality constituent at each well. The sample result from the most recent analysis for a particular well was selected, regardless of the number of times the well was sampled. The subset of sample results identified through this selection process was analyzed statistically to determine detection counts, frequencies of detections, and frequencies of detections at concentrations greater than water-quality criteria, as described in the report.

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