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# Chester County Ground-Water Atlas, Chester County, Pennsylvania

*by Russell A. Ludlow and Connie A. Loper*

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*In cooperation with the*
**CHESTER COUNTY WATER RESOURCES AUTHORITY**
***and the***
**CHESTER COUNTY HEALTH DEPARTMENT**

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**U.S. DEPARTMENT OF THE INTERIOR**
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## CONVERSION FACTORS AND ABBREVIATIONS

| Multiply | By | To obtain |
|---|---|---|
| | Volume | |
| liter (L) | 33.82 | ounce, fluid |
| liter (L) | 2.113 | pint |
| liter (L) | 1.057 | quart |
| liter (L) | 0.2642 | gallon |
| gram (g) | 0.03527 | ounce, avoirdupois |
| | Radioactivity | |
| becquerel per liter (Bq/L) | 27.027 | picocurie per liter |
| | Temperature | |
| degree Celsius (°C) | °F = (1.8 · ° C)+32 | degree Fahrenheit |

Abbreviated water-quality units used in report:

∝g/L, micrograms per liter
∝S/cm, microsiemens per centimeter at 25 degrees Celsius
mg/L, milligrams per liter
pCi/L, picocuries per liter

## ACRONYMS

AL - Action level
AMCL - Alternate Maximum Contaminant Level
ATSDR - Agency for Toxic Substances and Disease Registry (Centers for Disease Control)
AWWA - American Water Works Association
CCHD - Chester County Health Department
CDC - Centers for Disease Control and Prevention
IARC - International Agency for Research on Cancer
MCGL - Maximum Contaminant Level Goal
MCL - Maximum Contaminant Level
MRL - Minimum reporting level
MTBE - Methyl tert-butyl ether
NAS - National Academy of Sciences
PCE - Tetrachloroethylene
PMCL - Primary Maximum Contaminant Level (USEPA)
RDA - Recommended Dietary Allowance
SMCL - Secondary Maximum Contaminant Level (USEPA)
TCA - 1,1,1-trichloroethane
TCE - Trichloroethylene
TDS - Total dissolved solids
USEPA - U.S. Environmental Protection Agency
USGS - U.S. Geological Survey
VOC - Volatile organic compound

# CHESTER COUNTY GROUND-WATER ATLAS, CHESTER COUNTY, PENNSYLVANIA

*by Russell A. Ludlow and Connie A. Loper*

## ABSTRACT

Chester County encompasses 760 square miles in southeastern Pennsylvania. Ground-water-quality studies have been conducted in the county over several decades to address specific hydrologic issues. This report compiles and describes water-quality data collected during studies conducted mostly after 1990 and summarizes the data in a county-wide perspective.

In this report, water-quality constituents are described in regard to what they are, why the constituents are important, and where constituent concentrations vary relative to geology or land use. Water-quality constituents are grouped into logical units to aid presentation: water-quality constituents measured in the field (pH, alkalinity, specific conductance, and dissolved oxygen), common ions, metals, radionuclides, bacteria, nutrients, pesticides, and volatile organic compounds. Water-quality constituents measured in the field, common ions (except chloride), metals, and radionuclides are discussed relative to geology. Bacteria, nutrients, pesticides, and volatile organic compounds are discussed relative to land use. If the U.S. Environmental Protection Agency (USEPA) or Chester County Health Department has drinking-water standards for a constituent, the standards are included. Tables and maps are included to assist Chester County residents in understanding the water-quality constituents and their distribution in the county.

Ground water in Chester County generally is of good quality and is mostly acidic except in the carbonate rocks and serpentinite, where it is neutral to strongly basic. Calcium carbonate and magnesium carbonate are major constituents of these rocks. Both compounds have high solubility, and, as such, both are major contributors to elevated pH, alkalinity, specific conductance, and the common ions. Elevated pH and alkalinity in carbonate rocks and serpentinite can indicate a potential for scaling in water heaters and household plumbing. Low pH and low alkalinity in the schist, quartzite, and gneiss rocks can indicate a potential for corrosive water. The only constituent measured in the field that has a USEPA Secondary Maximum Contaminant Level (SMCL) is pH. The SMCL for pH is 6.5-8.5; 64 percent of samples analyzed for pH were acidic (below pH 6.5). Only 1 percent of samples were basic (above pH 8.5).

Of the common ions, the USEPA has SMCLs for chloride, sulfate, and total dissolved solids. The USEPA has a SMCL and a Primary Maximum Contaminant Level (PMCL) for fluoride. Chloride is more closely related to land use than geology. In Chester County, chloride exceeded the SMCL (250 mg/L) only in 5 percent of the services (commercial services, community services, and military) land-use areas. No samples analyzed for sulfate exceeded the SMCL (250 mg/L). Only 3 percent of samples analyzed for total dissolved solids exceeded the SMCL (500 milligrams per liter) (mg/L). No samples analyzed for fluoride equaled or exceeded the SMCL (2.0 mg/L) or PMCL (4.0 mg/L).

Iron concentrations exceeded the USEPA SMCL in 11 percent of samples and were highest in schist (14 percent) and gneiss (13 percent). Manganese concentrations exceeded the SMCL in 19 percent of samples and were highest in quartzite and schist (both 28 percent). Lead and arsenic were present in low concentrations: the highest concentrations of lead occurred in water from quartzite (8 percent exceeded the USEPA Action Level), and arsenic was detected mostly in Triassic sedimentary rocks (9 percent exceeded the USEPA PMCL). The highest concentrations of copper occurred more frequently in quartzite rocks, and to a lesser extent were evenly distributed between ground water in gneiss, schist, and Triassic sedimentary rocks.

Elevated concentrations of radon-222 and the combined radium-226/radium-228 radionuclides were common in water from quartzite and schist.

Gross alpha and gross beta particle activities were elevated in water from quartzite and carbonate rocks. In contrast, elevated concentrations of uranium primarily were measured in water from Triassic sedimentary and carbonate rocks.

Despite a sampling bias towards agricultural land use, only two samples indicated the presence of fecal coliforms.

Samples analyzed for nutrients generally exhibited low concentrations, but about 11 percent of samples collected for nitrate exceeded the USEPA PMCL. Only one nitrite sample (less than 1 percent) exceeded the respective USEPA PMCL.

Approximately 190 samples were collected for each of the three pesticides in this report: lindane, dieldrin, and diazinon. Sampling was biased towards agricultural, low-medium density residential, and wooded land uses. Approximately 95 percent of samples for each pesticide were below minimum reporting levels (MRL). Only lindane has a USEPA PMCL, and only one sample exceeded the standard. Results for dieldrin and diazinon were similar, except results for two diazinon samples where concentrations were 57.0 and 490 micrograms per liter (∝g/L).

Volatile organic compounds in this report were analyzed in water from 198 samples. Sampling was biased towards agricultural, low-medium density residential, and wooded land uses. Two percent of samples analyzed for trichloroethylene and less than 1 percent of samples analyzed for tetrachloroethylene exceeded their respective USEPA PMCLs (each 5.0 ∝g/L). No samples analyzed for 1,1,1-trichloroethane exceeded the USEPA PMCL (200 ∝g/L). No samples analyzed for methyl tert-butyl ether exceeded the USEPA Drinking Water Advisory (20 ∝g/L).

## INTRODUCTION

Water-quality data can be thought of as *constituents*, such as naturally occurring elements and compounds and human-made compounds, and *indicators*, tools useful for screening and characterizing water quality. The U.S. Geological Survey (USGS) has collected ground-water-quality data in Chester County since 1925. Collection of ground-water-quality data by the USGS, in cooperation with Chester County Water Resources Authority and the Chester County Health Department (CCHD), began in 1973 as an on-going annual program. The initial objective of the program was to sample for industrial organic chemicals in ground water near landfills and industrial sites. The sampling program later was broadened to include many other ground-water-quality data throughout Chester County. In addition to the annual sampling program, specialized USGS studies collected and analyzed ground-water-quality data from Chester County. In 1994, data sets from the annual sampling program and the specialized studies were combined, and a county-wide statistical analysis was performed on all data collected through 1989.

This report is a new county-wide analysis for data collected from 1990 through 2001, but it includes select data collected in earlier years because recent data are limited. Ground-water-quality data are included in this report either because they are constituents that can effect human health (and may have drinking-water standards), they are constituents that may affect home maintenance issues, or they are indicators useful for characterizing ground-water quality in Chester County (table 1). In any case, data are presented in a manner intended to be useful to land-management decision makers and the citizens of Chester County.

### Purpose and Scope

This report identifies where constituents and indicators have elevated (or low) concentrations in Chester County in relation to geology or land use. Also, statistics were used to describe the level or degree of elevated concentrations with respect to existing standards and the range of values present in the data. Studies commonly collect field data on pH, alkalinity, specific conductance, and dissolved oxygen, with the focus of each study also involving the investigation of water-quality constituents that are in one or more of seven classes of constituents: common ions, metals, radionuclides, bacteria, nutrients, pesticides, and volatile organic compounds (VOCs).

The USGS has information on over 6,000 wells in Chester County. USGS has collected water-quality samples from over 1,000 of those wells, and data from about 900 wells are compiled in this report. Each well has at least 1 sample, and a few wells have as many as 36 samples. If more than one sample was collected at a well, only the most recent results were used for statistical analysis of a given constituent.

**Table 1.** *Water-quality constituents and indicators, source agencies, and standards*
*(The USEPA sets water-quality standards for community water systems. The Chester County Health Department sets water-quality standards for wells used by homeowners for domestic supply. The Chester County Health Department also has standards for constituents and indicators not discussed in this report and not routinely collected by the U.S. Geological Survey.)*

[su, standard units; mg/L, milligrams per liter; pCi/L, picocuries per liter; mg/L, micrograms per liter; mrem/yr, millirems per year; col/100 mL, colonies per 100 milliliters; —, no standard exists]

| Constituents and indicators | U.S. Environmental Protection Agency |  | Chester County Health Department [1] |
|---|---|---|---|
|  | Primary maximum contaminant level (PMCL) | Secondary maximum contaminant level (SMCL) |  |
| **Field-measured constituents** |  |  |  |
| pH | — | 6.5 - 8.5 su | 6.5 - 8.5 su |
| Alkalinity | — | — | — |
| Specific conductance | — | — | — |
| Dissolved oxygen | — | — | — |
| **Common ions** |  |  |  |
| Chloride | — | 250 mg/L | 250 mg/L |
| Sulfate | — | 250 mg/L | — |
| Total dissolved solids | — | 500 mg/L | — |
| Calcium | — | — | — |
| Magnesium | — | — | — |
| Sodium | — | — | — |
| Fluoride | 4.0 mg/L | 2.0 mg/L | — |
| Strontium | — | — | — |
| **Metals** |  |  |  |
| Iron | — | 0.3 mg/L | 0.3 mg/L |
| Manganese | — | 0.05 mg/L | 0.05 mg/L |
| Lead | [2] 0.015 mg/L | — | — |
| Arsenic | 0.01 mg/L | — | — |
| Copper | [3] 1.3 mg/L | 1.0 mg/L | — |
| **Radionuclides** |  |  |  |
| Radon-222 | [4] 300; 4,000 pCi/L | — | — |
| Radium-226/radium-228 | 5.0 pCi/L | — | — |
| Radium-224 | — | — | — |
| Uranium | 30 ∝g/L | — | — |
| Gross alpha | 15 pCi/L | — | — |
| Gross beta | [5] 4 mrem/yr; 50 pCi/L | — | — |
| **Bacteria** |  |  |  |
| Fecal coliforms | [6] 0 col/100 mL | — | [7] 0 col/100 mL |
| **Nutrients** |  |  |  |
| Nitrate | 10 mg/L | — | [8] 10 mg/L |
| Nitrite | 1 mg/L | — | [8] 1 mg/L |
| Phosphorus | — | — | — |
| **Pesticides** |  |  |  |
| Lindane | 0.2 ∝g/L | — | — |
| Dieldrin | — | — | — |
| Diazinon | — | — | — |

**Table 1.** *Water-quality constituents and indicators, source agencies, and standards—Continued*
*(The USEPA sets water-quality standards for community water systems. The Chester County Health Department sets water-quality standards for wells used by homeowners for domestic supply. The Chester County Health Department also has standards for constituents and indicators not discussed in this report and not routinely collected by the U.S. Geological Survey.)*

[su, standard units; mg/L, milligrams per liter; pCi/L, picocuries per liter; mg/L, micrograms per liter; mrem/yr, millirems per year; col/100 mL, colonies per 100 milliliters; —, no standard exists]

| Constituents and indicators | U.S. Environmental Protection Agency | | Chester County Health Department [1] |
|---|---|---|---|
| | Primary maximum contaminant level (PMCL) | Secondary maximum contaminant level (SMCL) | |
| **Volatile organic compounds** | | | |
| Tricholoethylene | 5.0 ∝g/L | — | — |
| Tetracholoethylene | 5.0 ∝g/L | — | — |
| 1,1,1-Tricholoethane | 200 ∝g/L | — | — |
| MTBE | — | [9] 20 and 40 ∝g/L | — |

[1] Chester County Health Department, 2002.

[2] 0.015 mg/L: action level at which community water suppliers must treat water to reduce corrosivity.

[3] 1.3 mg/L: action level at which community water suppliers must treat water to reduce corrosivity.

[4] Proposed at both 300 pCi/L and at Alternate Maximum Contaminant Level (AMCL) of 4,000 pCi/L.

[5] Gross beta PMCL based on exposure (dose) of 4 millirems/year, but gross beta water-quality samples are a measure of activity and not exposure; radionuclide speciation is required above 50 pCi/L.

[6] 0 col/100 mL is a Maximum Contaminant Level Goal (MCLG).

[7] Chester County Health Department water-quality standards for bacteria are for ‘Total Coliform’ at less than 1 colony per 100 mL.

[8] Chester County Health Department water-quality standards are for nitrates *plus* nitrites at 10 mg/L.

[9] U.S. Environmental Protection Agency Drinking Water Advisory—respective odor and taste thresholds that most consumers can both sense and find objectionable.

## GROUND-WATER DATA COLLECTION, MANAGEMENT, AND ANALYSIS

The water-quality database was reviewed for all available ground-water data for Chester County collected from 1925 through 2001. Most data were collected from 1980 to the present. Generally, data between 1980 and 1990 were excluded from this report because (1) data prior to 1990 are summarized in Sloto (1994), (2) for certain constituents, earlier methods and method detection limits only allowed the reporting of results at levels that are now above drinking-water or other standards, and (3) the concentrations of many constituents vary with time, so a water sample collected 20 years ago may not be representative of water recently collected from the same well (table 2).

**Table 2.** *Period of record for water-quality constituents summarized in this report*

| Constituent groups | Samples collected in years | Constituents related to |
|---|---|---|
| Field-measured | 1990 - 2001 | geology |
| Common ions | [1]1990 - 2001 | geology[2] |
| Metals | 1990 - 2001 | geology |
| Radionuclides | (varies) | geology |
| Radon-222 | 1986 - 2001 | |
| Radium-226/radium-228 | 1985 - 1999 | |
| Radium-224 | 1999 | |
| Uranium | 1984 - 2001 | |
| Gross alpha | 1985 - 1988 | |
| Gross beta | 1985 - 1999 | |
| Bacteria (fecal coliform and *E. coli*) | 1994 - 2001 | land use |
| Nutrients | (varies) | land use |
| Nitrate | 1980 - 2001 | |
| Nitrite | 1980 - 2001 | |
| Phosphorus | 1982 - 2001 | |
| Pesticides | 1990 - 2001 | land use |
| Volatile organic compounds | 1990 - 2001 | land use |

[1] Except strontium, 1990 - 2000.

[2] Except chloride, which was related to land use.

Data are collected on the basis of the kinds of questions a study needs to answer, such as: What are the water-quality characteristics of a rock type, aquifer, or watershed? What are the water-quality characteristics of a township, a watershed, or the entire county? Why is it important to the people who live there? When sufficient data have been collected for a study, the data are analyzed, and a report is written. Reports are important products of studies and answer questions like those just mentioned. Geology, ground-water quality, water quality, and radionuclides are a few of the many themes discussed in reports that include geologic, watershed, or land-use maps, geological references, and analytical data. A select list of reports for Chester County is presented in table 3.

**Table 3.** *Reports discussing geology, ground-water quality, water quality, and radionuclides in ground water in Chester County*
*(See the References section in the back of the report for further information.)*

| Geographic area | Author | Year published |
|---|---|---|
| | Geology | |
| Countywide | Sloto | 1994 |
| | Ground-water quality | |
| Countywide | Hall | 1934 |
| Metamorphic rocks | Poth | 1968 |
| Countywide | McGreevy and Sloto | 1977 |
| Hammer Creek Formation | Wood | 1980 |
| Eastern Chester County | Sloto | 1987 |
| Valley Creek Watershed | Sloto | 1990 |
| Red Clay Creek Watershed | Vogel and Reif | 1993 |
| Countywide | Sloto | 1994 |
| Red Clay Creek Watershed | Senior | 1996 |
| West Valley Creek Watershed | Senior and others | 1997 |
| Malvern TCE Superfund Site | Sloto | 1997 |
| Elk Creek Watershed | Sloto | 2002a,<br>2002b |
| | Water quality | |
| Countywide | McGreevy and Sloto | 1976 |
| Countywide | Sloto | 1989 |
| Countywide | Sloto | 1994 |
| | Radionuclides | |
| Chickies Quartzite in southeastern Pennsylvania, including Chester County | Senior and Vogel | 1995 |
| Countywide | Senior | 1998 |
| Countywide | Sloto and Senior | 1998 |
| Southeast Pennsylvania, including Chester County | Sloto | 2000 |
| Countywide | Senior and Sloto | 2000 |

## Sample-Collection Procedures

In general, water samples are collected from wells at faucets or taps (1) where the water has not been treated in any way and (2) only after the water has run for several minutes and water temperature, pH, and specific conductance measurements have stabilized. This ensures that water being sampled is not the water that has been sitting in connecting pipes and tanks but is water from the aquifer. Ground-water sampling methods are specifically described in the U.S. Geological Survey National Field Manual for the Collection of Water Quality Data, Technical Water Resource Investigation (TWRI) Book 9.

## Data Management

The data in this report are stored in the USGS Site Inventory and Water-Quality databases. Any site where water-quality samples are collected must first have basic information about the site registered in the Site Inventory. Much of the data in the Site Inventory is not expected to change, and includes site elevation, latitude and longitude, county, aquifer, watershed, and other information. All water-quality data collected by USGS projects based in the Pennsylvania District are permanently maintained in the USGS Water-Quality database.

Data collected as part of the annual sampling program are published each year in the USGS annual reports; data collected as part of specialized studies, which may span several years, typically are published at the conclusion of the study. Whether collected through the annual program or through specialized studies, Chester County water-quality data are available to the public by way of the Internet (*pa.water.usgs.gov*), e-mail, telephone, or written request.

Maps in this report were generated from original USGS data (well locations, water-quality, and geology) or were provided by the Chester County Department of Computing and Information Services (municipal and watershed boundaries) or the Delaware Valley Regional Planning Commission (1995 land use) in cooperation with the Chester County Water Resources Authority.

## Data Analysis and Presentation

The data for all constituents include total number of samples, minimum and maximum values, and if applicable, the percentage of samples with values that exceed drinking-water quality standards. If at least 10 samples were available, the data were analyzed for percentiles: the 25th, the 50th (the *median*) and the 75th. For example, a water-quality data set is sorted from lowest to highest values. The values of the samples that occur one-fourth, one-half, and three-quarters between the lowest and highest values represent the 25th, 50th, and 75th percentile, respectively. If only one sample was collected from a given area, the data value is reported as the minimum. Constituents related to geology (water-quality constituents measured in the field, common ions, metals, and radionuclides) are statistically and spatially analyzed and presented for (1) all samples of the constituent and (2) samples of the constituent from wells that are in carbonate, diabase, gneiss, quartzite, schist, Triassic sedimentary, and serpentinite rock types. Similarly, constituents related to land use (bacteria, nutrients, pesticides, and VOCs) are statistically and spatially analyzed and presented for (1) all samples of the constituent and (2) samples of the constituent from wells that are in low or medium density residential (residential); high-density residential (dense residential)[1]; agricultural or vacant (agricultural); wooded or recreational (wooded); manufacturing, utility, mining, or transportation (manufacturing); and commercial services, community services, or military (services) land uses.

Constant improvements in chemical analyses have changed the methods and measurement precision for many constituents. During the period discussed in this report, data for many constituents show different levels of precision. Different levels of precision affect reporting levels. Reporting levels generally reflect the lowest concentration at which a constituent is reliably measured and reported. Data for most constituents contain multiple reporting levels and measured values can occur between them. In other words, the same data set may contain reporting levels such as <1.00, <2.00, and <4.00, along with measured values such as 0.50, 1.60, 3.20.

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[1] High-density residential is included with low-medium density residential land uses, under the single category *residential* in the maps and map explanations.

Many of the maps used to aid the discussion of constituents in this report use symbols that are keyed to U.S. Environmental Protection Agency (USEPA) drinking-water standards. The USEPA sets forth legally enforceable quality standards for water produced by community water systems[2] in the National Primary Drinking Water Regulations. The USEPA also sets forth non-enforceable quality standards in the National Secondary Drinking Water Regulations. Both standards specify Maximum Contaminant Levels (MCL), or the maximum concentration at which a constituent can (primary regulations) or should (secondary regulations) be present in the finished water. Collectively, the standards are loosely referred to as Primary Maximum Contaminant Levels (PMCLs) and Secondary Maximum Contaminant Levels (SMCLs). PMCLs apply to constituents, which at specific concentrations, have been shown to pose a level of risk to human health. SMCLs apply to constituents, which at specific concentrations, may cause cosmetic (such as discoloration of teeth), aesthetic (such as odor, taste, or color), or technical effects (such as corrosion, staining, or scale). PMCLs and SMCLs are *neither* designed for *nor* intended as legally enforceable water-quality standards for wells used by homeowners for domestic supply. The USEPA standards are useful as guidelines for well owners who are interested in the quality of the water drawn from their wells. However, the CCHD has water-quality standards that apply to wells used by homeowners for domestic supply. The constituents in the Health Department standards, though relatively few in number, mirror the USEPA standards (table 1). Residents should contact the Health Department for information about water-quality regulations for wells used by homeowners in Chester County.

For this report, information about each constituent is presented on facing pages. Left pages contain discussion describing what the constituent is, why the constituent is important, the constituent's characteristics of distribution in the county, and a table containing statistics for the constituent. Right pages display a map of Chester County, including municipal and watershed boundaries, set on a generalized geology or land-use background appropriate to the discussion. When PMCLs or SMCLs are useful to the discussion of a constituent, the symbols on the constituent map are keyed to those standards. Alternatively, symbols on a constituent map are keyed to the constituent's minimum reporting level, median concentration, 75th percentile concentration, or other significant data characteristics.

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[2] Community water systems are defined as systems having 15 or more service connections or systems that serve 25 or more people throughout the year.

## WATER-QUALITY CHARACTERISTICS MEASURED IN THE FIELD

### pH

pH is a measure of the acidic or alkaline character of water. pH is reported on a scale ranging from 0 to 14, where 7.0 is neutral, less than 7.0 is acidic, and greater than 7.0 is basic or alkaline. The pH of ground water is influenced primarily by the chemistry of the rock through which the ground water moves. The magnitude of the acidic or basic characteristic of ground water affects practical issues such as water conditioning in homes.

Acidic water can contribute to corrosion and dissolve copper pipes and solder joints used for household plumbing; basic water can contribute to scaling and clogging of pipes and water heaters. The USEPA SMCL for pH is 6.5 - 8.5. Below pH 6.5, water may have a bitter metallic taste, and above pH 8.5, water may have a slippery feel or soda taste. The CCHD requires pH measurements for new and re-constructed homeowner wells and utilizes the same range of pH (6.5 to 8.5) as a standard for acceptable drinking-water quality. If the pH in well water is above 8.5, the CCHD requires water treatment; if the pH is less than 6.5, the CCHD recommends treatment.

Since 1990, pH was measured at 467 Chester County wells. The median pH for all the samples was 6.2, which means that water is acidic and is below the USEPA SMCL and CCHD standards in more than half of all wells sampled. The median pH of water collected from wells in carbonate and serpentinite rocks was neutral (7.1) to basic (8.5) (fig. 1). In gneiss, quartzite, schist, and Triassic sedimentary rocks, the median pH was acidic (table 4). In Chester County, ground water is most acidic in quartzite (5.5) and most basic in serpentinite (8.5). Neutral to basic pH values in the carbonate and serpentinite rocks are because of the calcium carbonate and magnesium carbonate content in these rocks; both compounds readily enter into solution with water, and acid is neutralized by carbonate (see *Alkalinity, Total Dissolved Solids*, *Calcium*, and *Magnesium*).

**Table 4.** *Summary statistics for pH in ground water, by rock type, based on samples collected from 1990 to 2001*

[SMCL, secondary maximum contaminant level; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | pH, in standard units | | | | | Percentage of samples below or above the SMCL (below/above) |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 467 | 4.0 | 5.8 | 6.2 | 6.8 | 10.4 | 64/1 |
| Carbonate | 56 | 5.0 | 6.9 | 7.1 | 7.3 | 8.0 | 11/0 |
| Diabase | 1 | 7.2 | — | — | — | — | — |
| Gneiss | 153 | 4.0 | 5.8 | 6.1 | 6.4 | 8.3 | 76/0 |
| Quartzite | 39 | 4.2 | 4.9 | 5.5 | 6.0 | 7.3 | 97/0 |
| Schist | 171 | 4.3 | 5.7 | 6.1 | 6.5 | 8.0 | 71/0 |
| Triassic sedimentary | 34 | 5.0 | 5.7 | 6.3 | 7.0 | 7.6 | 53/0 |
| Serpentinite | 13 | 5.8 | 6.8 | 8.5 | 9.5 | 10.4 | 15/46 |

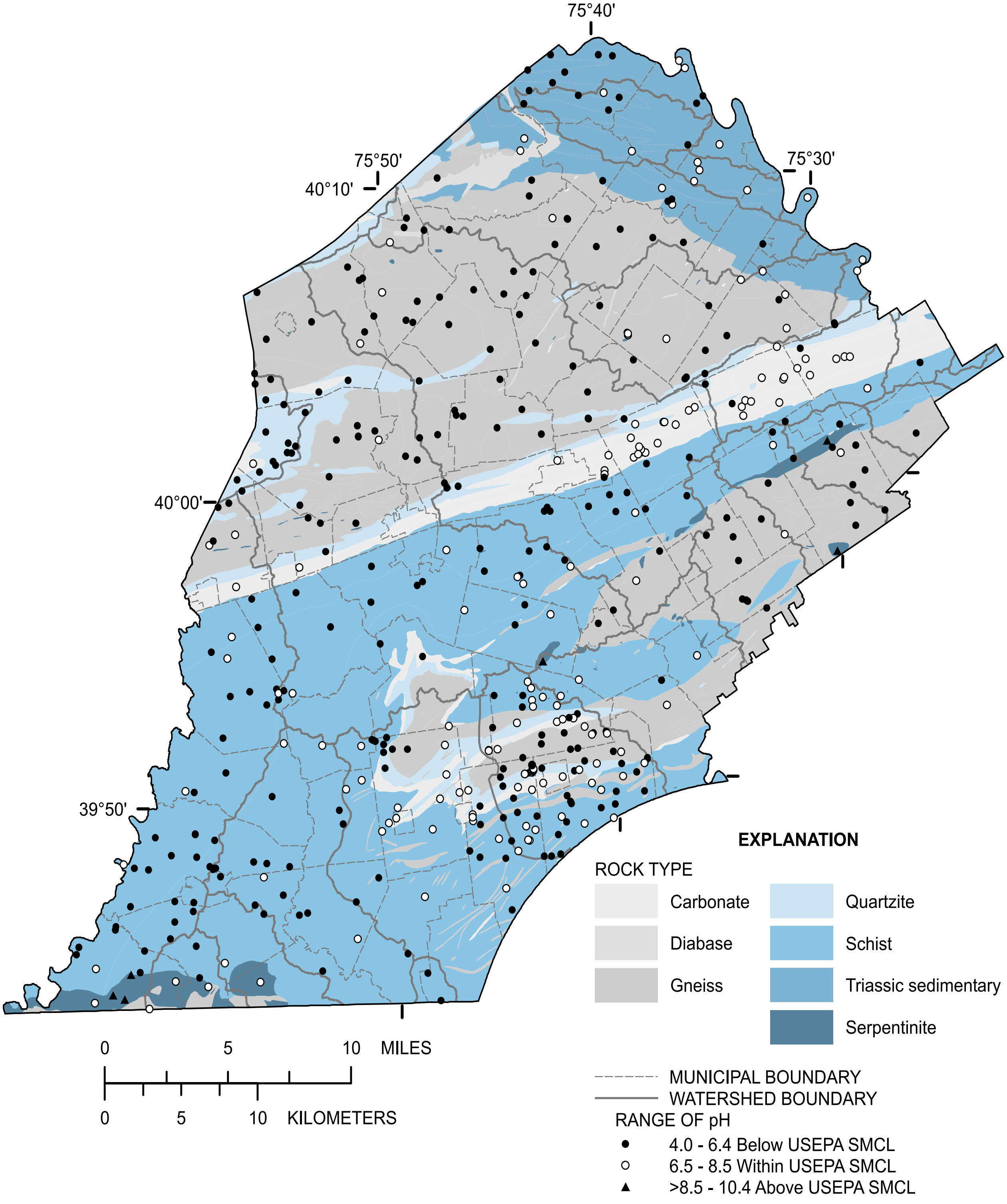

**Figure 1.** Distribution of pH relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; SMCL, Secondary Maximum Contaminant Level)

## Alkalinity

Alkalinity describes the capacity of water and solutes in the water to react with and neutralize acid. The primary contributors to alkalinity in ground water are carbon dioxide, bicarbonate, and carbonate (Hem, 1992). The sources of carbon dioxide are the atmosphere, respiration by plants, and the decay of organic matter in soil. Bicarbonate and carbonate may concentrate carbon dioxide gas in the soil. Two minerals, calcium carbonate and magnesium carbonate, contribute to elevated alkalinity. The sources of these minerals are the carbonate rocks, such as the limestone and dolomite in Chester Valley.

Alkalinity is expressed as a concentration in milligrams per liter as calcium carbonate. Low alkalinity, or poorly buffered, water is susceptible to large changes in pH from biological and chemical influences. Well water with low pH and low alkalinity can be corrosive and can dissolve copper, lead, and other metals from household plumbing. Public water suppliers whose source waters have corrosive characteristics are required by the USEPA to use treatment techniques to prevent copper and lead from dissolving into drinking water. In Chester County, low alkalinity ground water (less than 38 mg/L) is characteristic of quartzite, schist, and gneiss (table 5). Where calcium and magnesium carbonates contribute to high alkalinity water, the water may be characteristically “hard” and effectively cause soap to not lather or rinse, and cause deposits in hot water heaters. In Chester County, these conditions may occur in water from wells in carbonate and serpentinite rocks (fig. 2) and may prompt homeowners to install water-softening systems.

The median alkalinity concentration of 426 samples was 35 mg/L. Water from wells in carbonate rocks had the highest median alkalinity concentration (210 mg/L). The median concentration of ground water from carbonate rocks is nearly twice the median concentration from serpentinite rocks (119 mg/L) and several times higher than the median concentrations from wells in gneiss, quartzite, schist, and Triassic sedimentary rocks (table 5).

**Table 5.** *Summary statistics for dissolved alkalinity in ground water, by rock type, based on samples collected from 1990 to 2001*

[—, too few samples to compute statistics]

| Rock type | Total number of samples | Dissolved alkalinity, in milligrams per liter as calcium carbonate | | | | |
|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum |
| All wells | 426 | 0 | 20 | 35 | 67 | 398 |
| Carbonate | 52 | 15 | 150 | 210 | 252 | 398 |
| Diabase | 0 | — | — | — | — | — |
| Gneiss | 138 | 0 | 22 | 38 | 59 | 149 |
| Quartzite | 32 | 0 | 6 | 19 | 44 | 160 |
| Schist | 161 | 1 | 15 | 23 | 39 | 258 |
| Triassic sedimentary | 32 | 2 | 22 | 46 | 89 | 165 |
| Serpentinite | 11 | 25 | 72 | 119 | 144 | 243 |

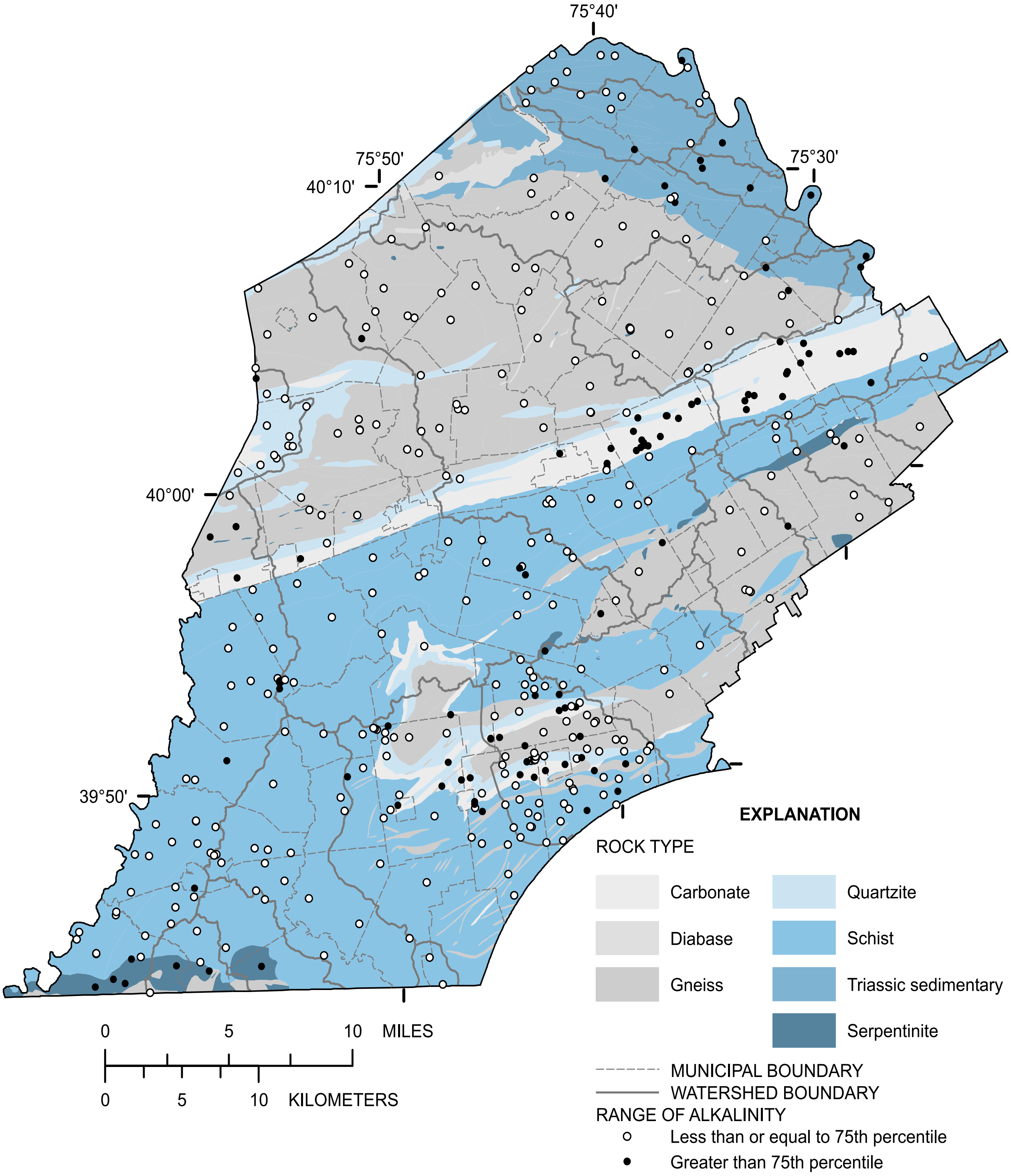

**Figure 2.** Distribution of alkalinity relative to generalized rock types.

## Specific Conductance

Electrical conductance (conductivity) is a measure of the capacity of water or other substances to conduct electrical current. Specific conductance refers to conductance of a solution cell with a volume of one cubic centimeter (1 $cm^3$) at a temperature of 25°C. The USGS reports conductivity in microsiemens per centimeter at 25°C.

Pure water is a poor conductor of electricity because it does not contain any dissolved substances. Water becomes a more efficient conductor when both positive and negative ions are present, and as ion concentrations increase, the conductance of the solution increases. Conductance can, therefore, provide information about the concentration of total dissolved solids in a water sample. Elements whose ionic forms contribute the most to the measurement of specific conductance include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride. The conductance of ground water varies greatly and may be as low as 50 ∝S/cm where rocks are resistant to weathering. Specific conductance serves as a valuable tracer of water movement in aquatic systems.

Human-related sources add constituents such as road salt and agricultural and industrial chemicals to water. The USEPA has no drinking-water standards for specific conductance because specific conductance is an indicator of all solutes in water and is not an indicator of a specific hazardous element or compound.

Specific conductance was measured in water samples from 457 wells. The median conductance was 228 ∝S/cm (table 6). Water from wells in carbonate rocks had the highest median conductance (648 ∝S/cm) and wells in the serpentinite had the next highest median conductance (298 ∝S/cm) (table 6). Specific conductance values above the 75th percentile for all water samples were mostly in carbonate rocks (fig. 3) because calcium and magnesium minerals (which constitute the bulk of carbonate rocks) dissolve readily in water and provide an ample source of conductive ions. Quartzite had the lowest specific conductances because of its resistance to weathering.

**Table 6.** *Summary statistics for specific conductance in ground water, by rock type, based on samples collected from 1990 to 2001*

[—, too few samples to compute statistics]

| Rock type | Total number of samples | Specific conductance, in microsiemens per centimeter at 25° Celsius | | | | |
|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum |
| All wells | 457 | 23 | 154 | 228 | 358 | 1,460 |
| Carbonate | 54 | 132 | 415 | 648 | 804 | 1,460 |
| Diabase | 1 | 396 | — | — | — | — |
| Gneiss | 150 | 50 | 159 | 218 | 317 | 740 |
| Quartzite | 37 | 23 | 100 | 157 | 266 | 1,010 |
| Schist | 170 | 52 | 146 | 194 | 257 | 849 |
| Triassic sedimentary | 34 | 66 | 162 | 249 | 343 | 608 |
| Serpentinite | 11 | 69 | 228 | 298 | 431 | 938 |

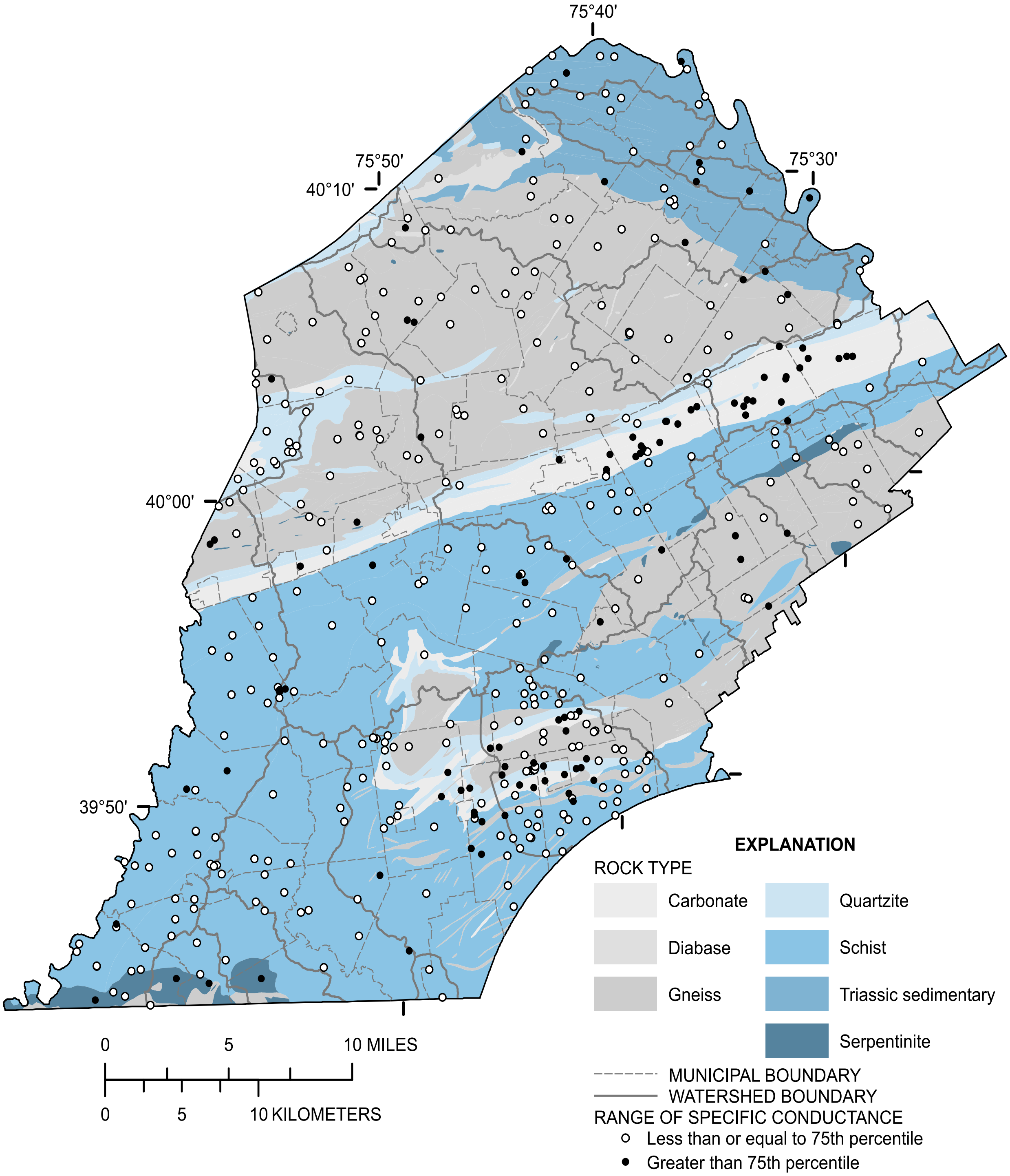

**Figure 3.** Distribution of specific conductance relative to generalized rock types.

## Dissolved Oxygen

Oxygen is supplied to ground water by air moving through unsaturated soils above the water table and by the dissolved-oxygen content in precipitation infiltrating the ground. Most oxygen dissolved in ground water originates in the atmosphere. Because concentrations of dissolved oxygen in ground water do not affect human health directly, the USEPA has not established a PMCL or SMCL.

The concentration of dissolved oxygen is one of the most important aspects of water quality. Dissolved oxygen regulates biological activity in ground water by controlling the types and numbers of bacteria present in the water. These bacteria can either decompose or produce organic contaminants through their growth. Dissolved oxygen also plays an important role in controlling the solubility of other constituents in ground water such as nitrate, iron, and manganese that can affect human health and water use. In water with high dissolved-oxygen content, iron concentrations usually meet drinking-water standards because of the precipitation of iron.

Dissolved oxygen was measured in samples collected from 446 wells. The median concentration was 7.0 mg/L (table 7). Ground water from wells in serpentinite had the lowest median dissolved-oxygen concentration, and water from wells in carbonate had the second lowest median concentration. Samples with dissolved-oxygen concentrations equal to or less than the 25th percentile for all samples (3.8 mg/L) (fig. 4) include 55 percent of wells in serpentinite rocks (0.1 - 3.0 mg/L), 36 percent of wells in carbonate rocks (range 0.2 - 3.8 mg/L), 24 percent of wells in schist rocks (range 0 - 3.6 mg/L), and 21 percent or less of wells in gneiss, Triassic sedimentary, and quartzite rocks. The highest median concentration for dissolved oxygen (7.8 mg/L) was in the quartzite rock.

**Table 7.** *Summary statistics for dissolved oxygen in ground water, by rock type, based on samples collected from 1990 to 2001*

[—, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved oxygen, in milligrams per liter | | | | | Percentage of samples equal to or less than 3.8 milligrams per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 446 | 0.0 | 3.8 | 7.0 | 8.4 | 11.0 | 25 |
| Carbonate | 52 | .2 | 3.2 | 4.8 | 7.1 | 9.5 | 36 |
| Diabase | 1 | .3 | — | — | — | — | — |
| Gneiss | 148 | 0 | 4.2 | 7.0 | 8.3 | 10.4 | 21 |
| Quartzite | 36 | .2 | 5.8 | 7.8 | 8.5 | 11.0 | 17 |
| Schist | 165 | 0 | 4.4 | 7.2 | 8.8 | 10.7 | 24 |
| Triassic sedimentary | 33 | .1 | 4.1 | 6.1 | 7.6 | 10.3 | 21 |
| Serpentinite | 11 | .1 | 1.4 | 3.0 | 7.4 | 9.4 | 55 |

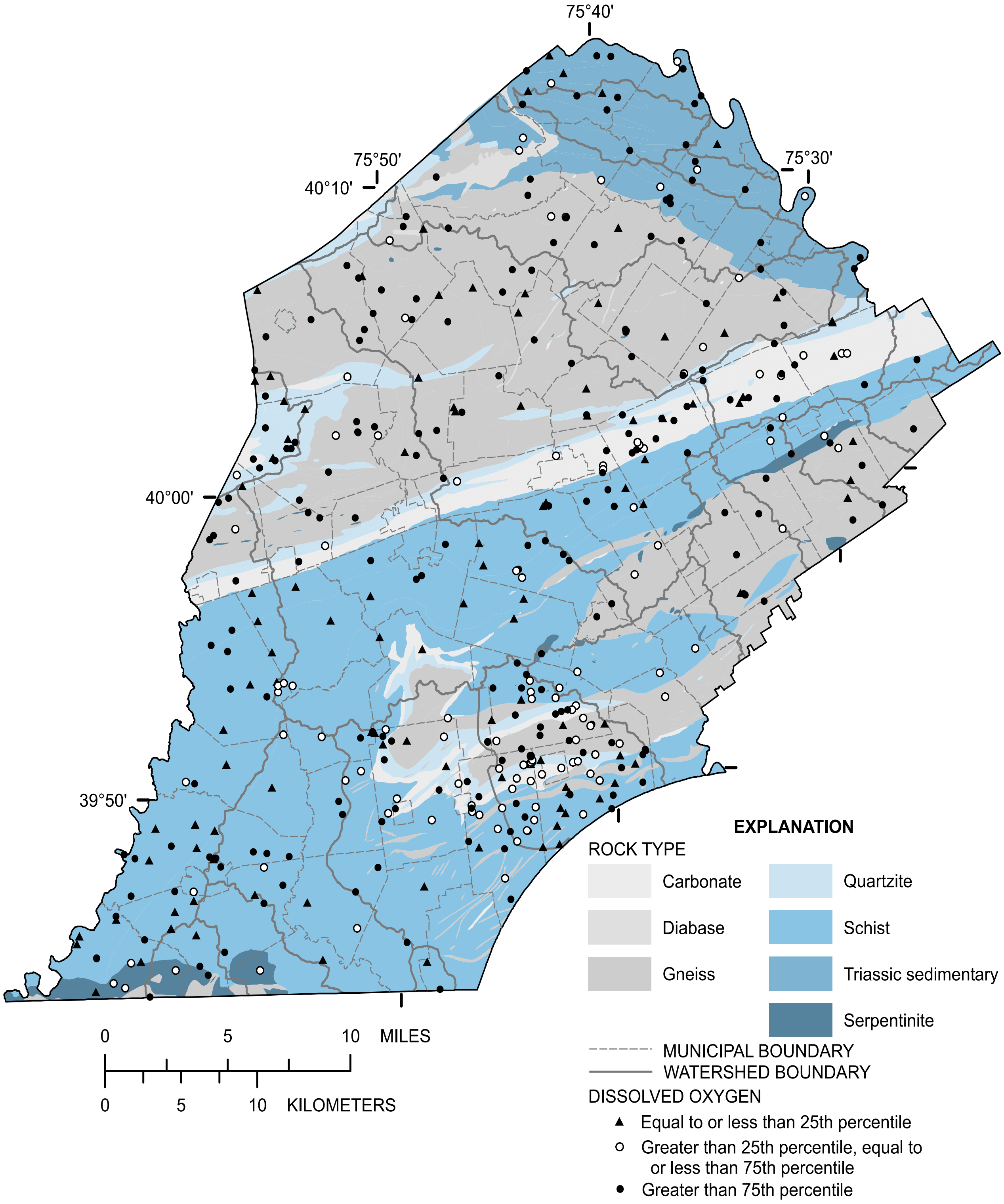

**Figure 4.** Distribution of dissolved oxygen relative to generalized rock types.

## COMMON IONS

### Chloride

The element chlorine is the most abundant in a group of chemically related nonmetallic elements called halogens. Other elements in this group include fluorine, bromine, and iodine. Chlorine is present in small amounts in precipitation, soils, rocks, and water as an atom with a net negative charge, or anion ($Cl^-$). In this form, it is known as *chloride*. Chloride is present in all natural waters, but the concentration usually is low.

Elevated concentrations of chloride indicate anthropogenic (human-made) effects such as pollution from failing septic systems, road salt, or industrial waste (Sloto, 1994). Chloride concentrations and distribution are shown relative to land use (table 8, fig. 5). Elevated concentrations of chloride can increase the corrosiveness of water. If combined with sodium, elevated concentrations of chloride give water a salty taste. The USEPA SMCL for chloride is 250 mg/L. Above this concentration, taste and corrosion of household plumbing may become issues. The CCHD requires chloride measurements for new and re-constructed homeowner wells and utilizes the same (250 mg/L) standard for drinking-water quality. If the chloride concentration in well water exceeds 250 mg/L, the CCHD recommends treatment.

Dissolved chloride was measured in samples collected from 440 wells. Chloride concentrations for half of the samples were 13.0 mg/L or less. The highest chloride concentrations were from the services land-use area; 13 samples (59 percent of samples from services land use) had concentrations above the 75th percentile (28.2 mg/L) for all land-use areas (table 8). These concentrations are low and do not affect domestic water use. Only one sample (5 percent of samples from services land use) exceeded the USEPA SMCL (fig. 5). In the same well, the sodium concentration and specific conductance also were elevated. The well is adjacent to the Pennsylvania Turnpike, and the elevated concentration of chloride probably is a result of the use of deicing salt (Sloto, 1987).

**Table 8.** *Summary statistics for dissolved chloride in ground water, by land use, based on samples collected from 1990 to 2001*

[SMCL, secondary maximum contaminant level; <, less than; —, too few samples to compute statistics]

| Land use | Total number of samples | Dissolved chloride, in milligrams per liter | | | | | Percentage of samples exceeding the SMCL |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 440 | 1.1 | 6.0 | 13.0 | 28.2 | 350 | < 1 |
| Low-medium density residential | 150 | 1.1 | 5.2 | 11.5 | 23.0 | 150 | 0 |
| High density residential | 2 | 17.0 | — | — | — | 48.0 | 0 |
| Agricultural | 185 | 1.8 | 6.7 | 12.5 | 25.0 | 184 | 0 |
| Wooded | 72 | 1.5 | 5.4 | 14.6 | 35.2 | 150 | 0 |
| Manufacturing | 9 | 7.0 | — | — | — | 50.0 | 0 |
| Services | 22 | 3.9 | 15.2 | 32.5 | 50.9 | 350 | 5 |

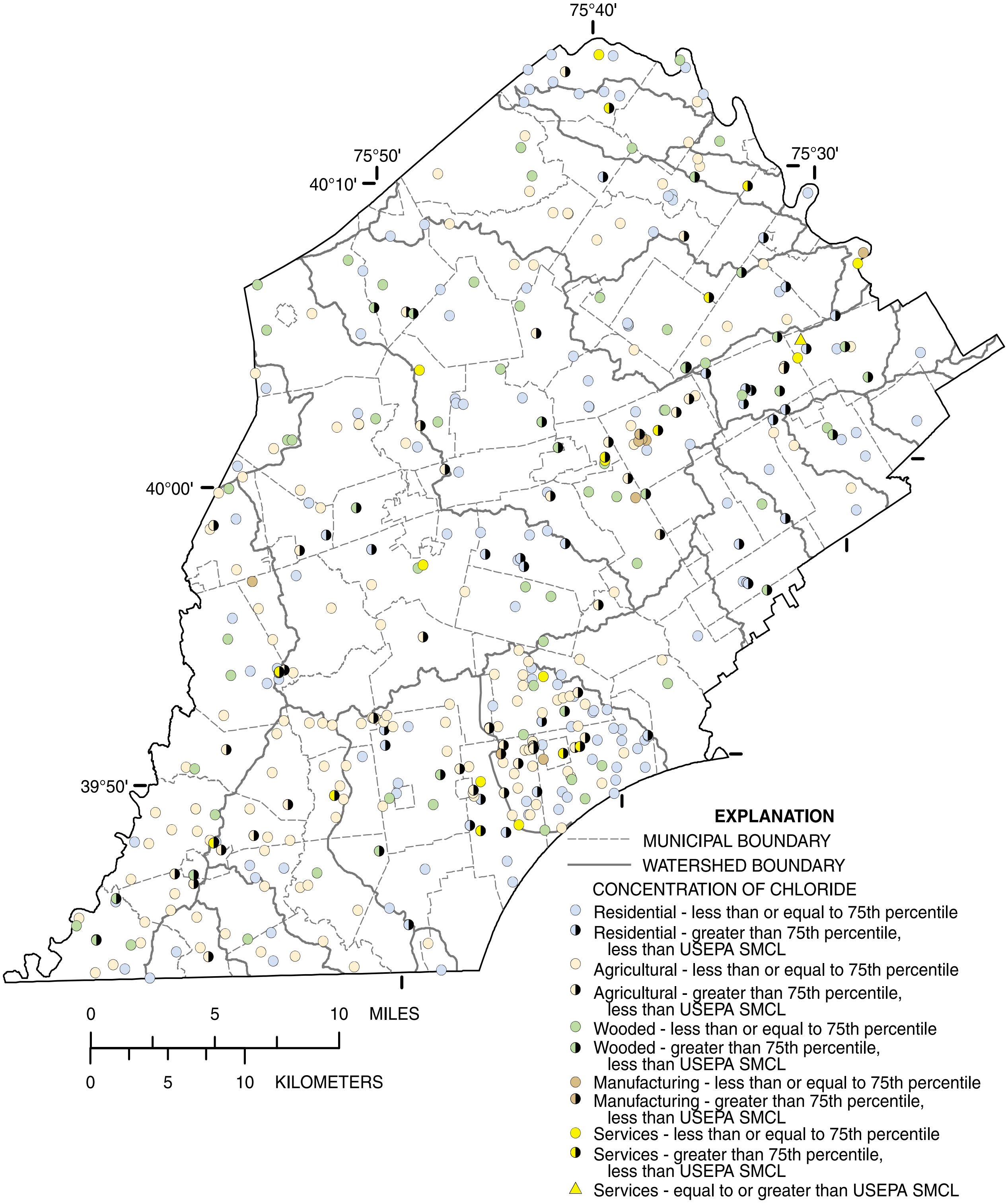

**Figure 5.** Distribution of chloride relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; SMCL, Secondary Maximum Contaminant Level)

## Sulfate

Sulfur is not a large part of the earth's outer crust but is common as metal sulfides in sedimentary and metamorphic rocks (such as carbonate and gneiss). As dissolved oxygen moves with ground water, the metal sulfides mix with the oxygen and sulfate ions ($SO_4$) are released into solution with the water. Hydrogen ions also are produced in this process (Hem, 1992). Hydrogen ions can combine with sulfur and form hydrogen sulfide ($H_2S$), which results in the "rotten-egg" smell present in some waters. Precipitation also can contribute sulfate to the ground water. The sources of sulfate in the atmosphere are from fossil-fuel combustion and sulfur emitted by volcanoes and springs.

Sulfate can create a bitter taste in water at concentrations between 300-400 mg/L. Sulfate was believed to have a laxative effect at concentrations between 600-1,000 mg/L (van der Leeden and others, 1990). Infants ingesting their first bottles of water or water mixed with formula and transient populations (tourists, business travelers, students) were thought to be the most susceptible to these laxative effects. However, a study by USEPA and the Centers for Disease Control and Prevention (CDC) found that sulfate doses did not have laxative effects at concentrations up to 1,200 mg/L (U.S. Environmental Protection Agency, 1999a). The USEPA SMCL for sulfate is 250 mg/L. No samples met or exceeded the SMCL, and only one sample in the carbonate rocks (240 mg/L) approached the SMCL.

Dissolved sulfate was measured in water samples collected from 363 wells. The median sulfate concentration was 19.0 mg/L. Water from carbonate rocks had the highest median concentration (31.0 mg/L), and water from gneiss had the second highest median concentration (24.0 mg/L) (table 9). Sulfate concentrations above the 75th percentile for all water samples (30.2 mg/L) were measured in 54 percent of wells in carbonate rocks (range 31.0 - 240 mg/L), 31 percent of wells in gneiss rocks (range 30.7 - 172 mg/L), 20 percent of wells in quartzite rocks (range 42.0 - 165 mg/L), 16 percent of wells in schist rocks (range 30.5 - 150 mg/L), 15 percent of wells in Triassic sedimentary rocks (range 31.0 - 95.0 mg/L), and 8 percent of wells in serpentinite rocks (32.5 mg/L) (fig. 6). The one sample collected from diabase had a sulfate concentration of 86.2 mg/L (table 9).

**Table 9.** *Summary statistics for dissolved sulfate in ground water, by rock type, based on samples collected from 1990 to 2001*

[<, less than; —, too few samples to compute statistics or percentages; E, estimated]

| Rock type | Total number of samples | Dissolved sulfate, in milligrams per liter | | | | | Percentage of samples greater than 30.2 milligrams per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 363 | <0.1 | 7.7 | 19.0 | 30.2 | 240 | 25 |
| Carbonate | 52 | 1.4 | 21.5 | 31.0 | 42.2 | 240 | 54 |
| Diabase | 1 | 86.2 | — | — | — | — | — |
| Gneiss | 87 | .6 | 15.5 | 24.0 | 34.8 | 172 | 31 |
| Quartzite | 25 | <.1 | 2.6 | 18.4 | 25.0 | 165 | 20 |
| Schist | 151 | .1 | 4.2 | 12.4 | 24.0 | 150 | 16 |
| Triassic sedimentary | 34 | 1.1 | 11.9 | 17.7 | 23.0 | 95.0 | 15 |
| Serpentinite | 13 | E .2 | 3.5 | 7.7 | 8.8 | 32.5 | 8 |

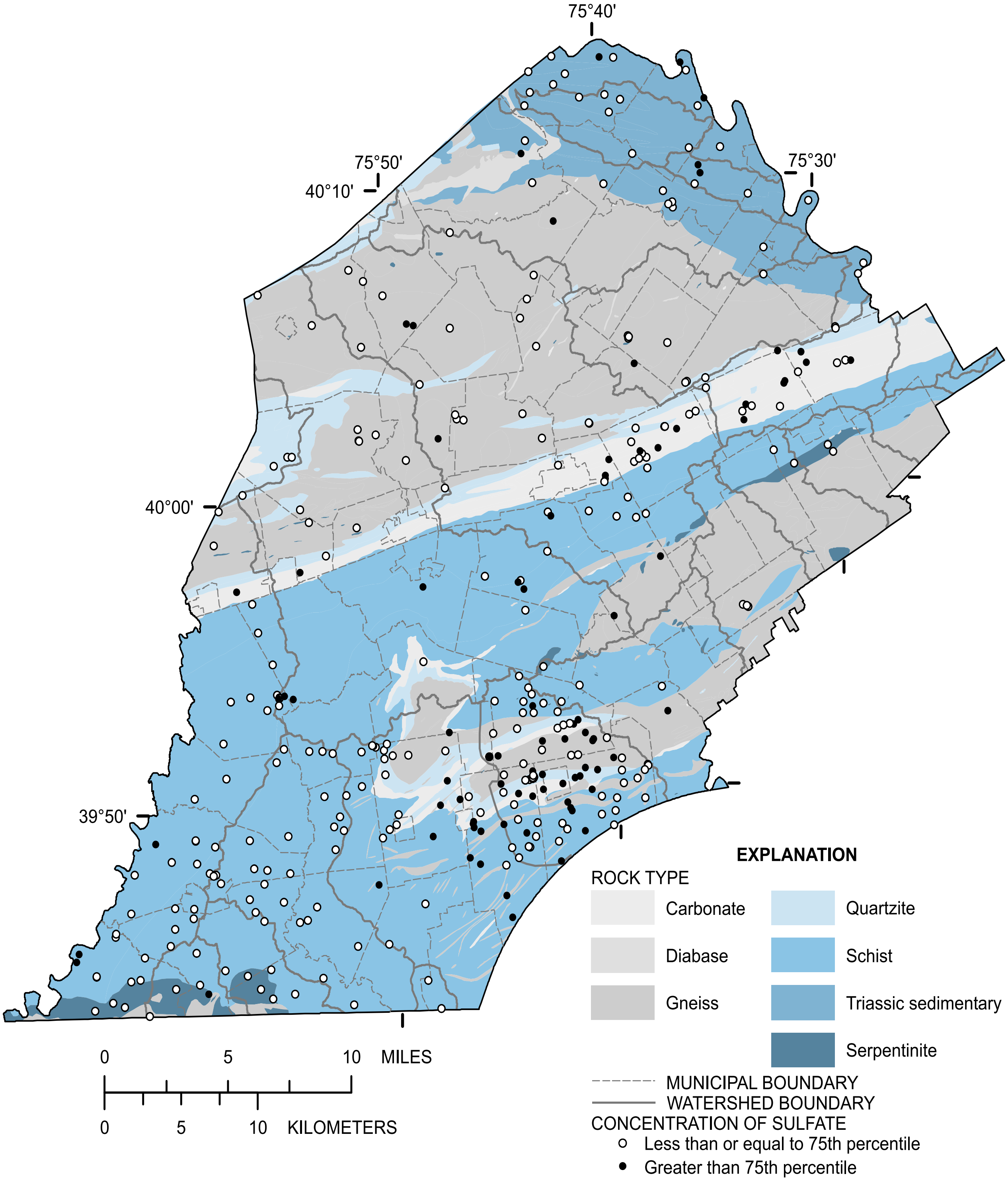

**Figure 6.** Distribution of sulfate relative to generalized rock types.

## Total Dissolved Solids

Total solids, total dissolved solids (TDS), or dissolved solids are terms used synonymously for the total amount of dissolved minerals in water. TDS is expressed as a concentration and can be calculated by evaporating a known volume of water at a specific temperature and measuring the mass of the material that remains. Specific types of minerals present are not determined. Specific conductance, discussed earlier, is an indirect measure of TDS because electric current moves through water more readily with higher concentrations of dissolved solids.

The concentration of TDS provides a general indication of water quality and may demonstrate the suitability of the water for certain water uses. TDS concentrations below 500 mg/L are acceptable for drinking water. The USEPA SMCL for TDS is 500 mg/L. Above this concentration, the water becomes less palatable and causes clogging of pipes and deposits in water heaters. Water with a TDS concentration of 1,000 mg/L or higher is salty or saline (Hem, 1992). Three percent of the samples exceeded the SMCL, but no samples were saline.

Water samples from 344 wells were analyzed for TDS. The median concentration was 144 mg/L (table 10). The median concentration in water from carbonate rocks is more than twice that amount (357 mg/L) because the calcium and magnesium minerals that form carbonate rocks dissolve readily in water compared to minerals in other rocks. The TDS concentration in 11 samples exceeded the SMCL (fig. 7), including 12 percent of wells in carbonate rocks (range 553 - 746 mg/L), 14 percent of wells in quartzite rocks (range 503 - 712 mg/L), and 2 percent of wells in gneiss rocks (528 and 639 mg/L). TDS concentrations above the 75th percentile for all samples (226 mg/L) were measured in 79 percent of wells in carbonate rocks (range 235 - 746 mg/L), 42 percent of wells in serpentinite rocks (range 230 - 474 mg/L), 21 percent of wells in Triassic sedimentary rocks (range 229 - 331 mg/L), and 20 percent of wells in gneiss (228 - 639 mg/L).

**Table 10.** *Summary statistics for total dissolved solids in ground water, by rock type, based on samples collected from 1990 to 2000*

[SMCL, secondary maximum contaminant level; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Total dissolved solids, in milligrams per liter | | | | | Percentage of samples exceeding the SMCL |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 344 | 30 | 108 | 144 | 226 | 746 | 3 |
| Carbonate | 52 | 86 | 248 | 357 | 456 | 746 | 12 |
| Diabase | 0 | — | — | — | — | — | — |
| Gneiss | 81 | 42 | 120 | 146 | 185 | 639 | 2 |
| Quartzite | 22 | 30 | 81 | 134 | 217 | 712 | 14 |
| Schist | 144 | 37 | 94 | 118 | 154 | 494 | 0 |
| Triassic sedimentary | 33 | 51 | 124 | 159 | 215 | 331 | 0 |
| Serpentinite | 12 | 57 | 124 | 188 | 246 | 474 | 0 |

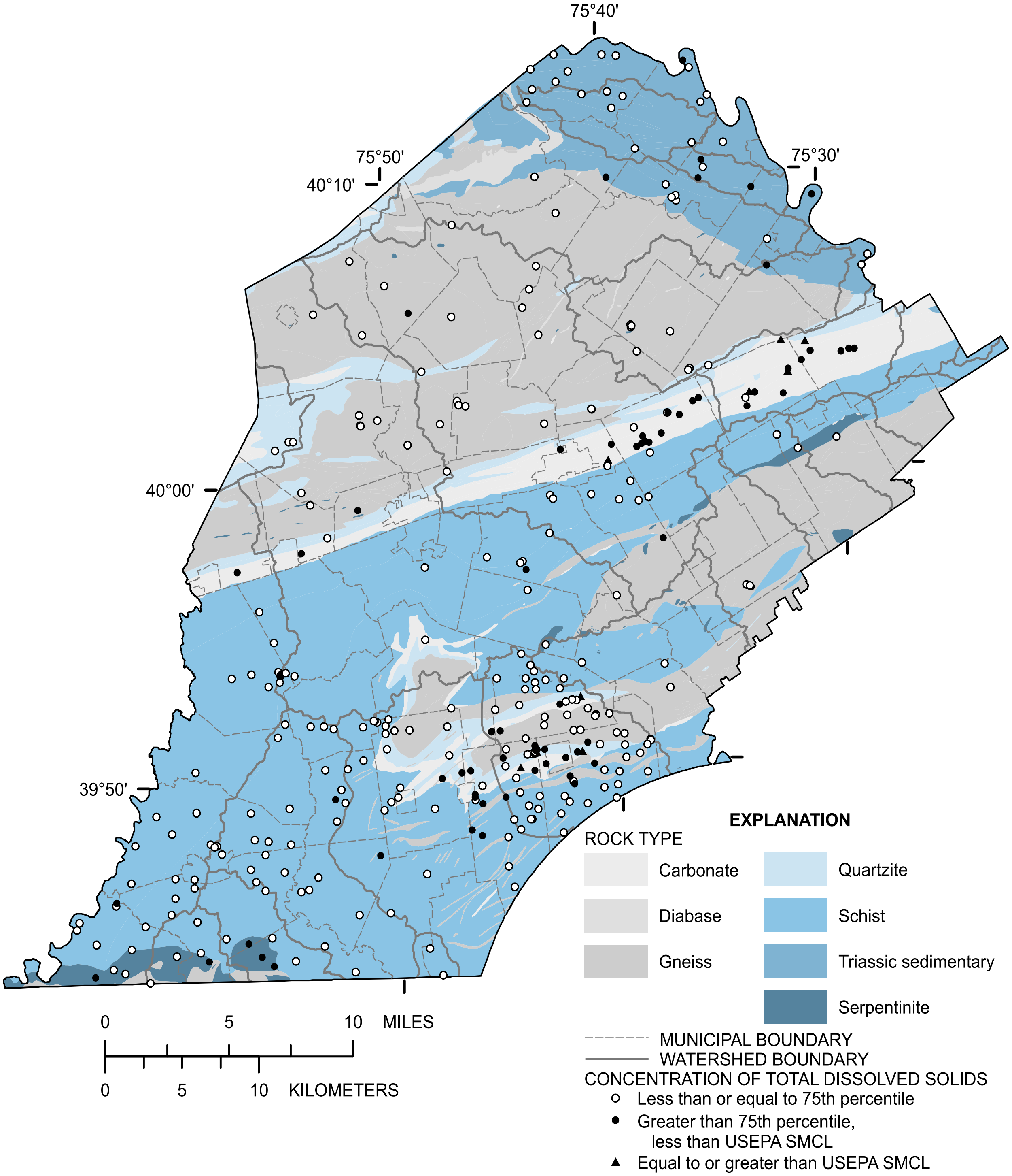

**Figure 7.** Distribution of total dissolved solids relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; SMCL, Secondary Maximum Contaminant Level)

## Calcium

Calcium is an alkaline earth metal. Calcium carbonate is a major component of limestone, dolomite, calcite, and marble (carbonate rocks). Calcium is also a major constituent of many igneous-rock (diabase) minerals and some metamorphic rocks (gneiss). Some calcium, therefore, is expected in water that has been exposed to sedimentary, igneous, and metamorphic rocks. In most freshwater, calcium ($Ca^+$) is the principal cation (atom with a net positive charge). Most natural waters contain either calcium carbonate and (or) calcium sulfate. Calcium is an essential element for living organisms. Many organisms concentrate calcium compounds in their skeletons.

"Hard" water commonly is caused by elevated concentrations of calcium, magnesium, and other dissolved minerals and can be referred to as *carbonate* or *temporary* hardness. Temporary hardness may be lessened by heating, but this process causes the accumulation of scale on heating elements and water heaters. Hard water is treated with water-softening treatment systems. Hard water is not a health hazard, but water-softening treatment systems that use salt may pose health risks for people with restricted diets. Hard water characteristics such as poor soap performance are a nuisance, and mineral accumulation in pipes, fixtures, and water heaters can create maintenance and repair expenses for household water uses. The USEPA does not have a PMCL or an SMCL for calcium.

The median calcium concentration measured in samples collected from 323 wells was 19.0 mg/L (table 11). The median calcium concentration in water from carbonate rocks was 67.5 mg/L (table 11). In contrast, the median calcium concentration in water from serpentinite, a calcium poor and magnesium rich rock, was much less (4.4 mg/L) than for the other rock types. Samples with concentrations above the 75th percentile for all samples (38.2 mg/L) included 87 percent of wells in carbonate rocks (range 42.0 - 130 mg/L), 1 sample from diabase (53.9 mg/L), 15 percent of wells in gneiss (range 39.0 - 91.9 mg/L), 12 percent of wells in quartzite (range 56.0 - 120 mg/L), 9 percent of wells in schist (range 38.3 - 86.0 mg/L), and 30 percent of samples in Triassic sedimentary rocks (range 39.0 - 71.0 mg/L) (fig. 8).

**Table 11.** *Summary statistics for dissolved calcium in ground water, by rock type, based on samples collected from 1990 to 2001*

[—, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved calcium, in milligrams per liter | | | | | Percentage of samples greater than 38.2 milligrams per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 323 | 0.04 | 10.0 | 19.0 | 38.2 | 130 | 25 |
| Carbonate | 52 | 9.1 | 53.2 | 67.5 | 81.2 | 130 | 87 |
| Diabase | 1 | 53.9 | — | — | — | — | — |
| Gneiss | 78 | .66 | 14.2 | 21.3 | 30.4 | 91.9 | 15 |
| Quartzite | 24 | .58 | 4.3 | 14.4 | 25.2 | 120 | 12 |
| Schist | 126 | 2.6 | 8.8 | 13.5 | 19.0 | 86.0 | 9 |
| Triassic sedimentary | 30 | .04 | 12.4 | 22.8 | 45.0 | 71.0 | 30 |
| Serpentinite | 12 | 1.1 | 2.0 | 4.4 | 7.3 | 26.2 | 0 |

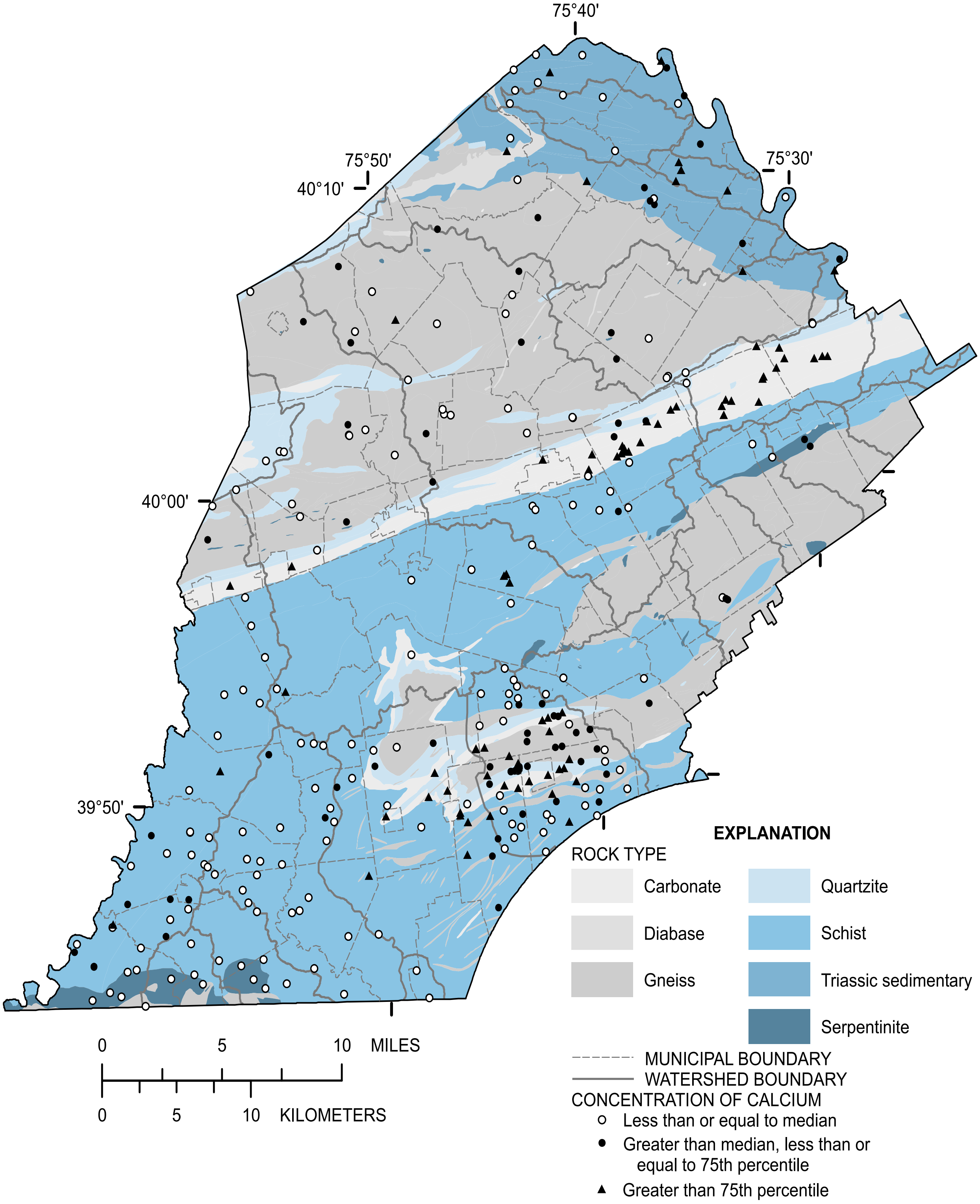

**Figure 8.** Distribution of calcium relative to generalized rock types.

## Magnesium

Magnesium (Mg), like calcium, is an alkaline earth metal. Magnesium is the eighth most abundant element in the earth's crust. It is not found in the elemental form but usually is in the form of the minerals magnesite and dolomite. Dolomite is a sedimentary carbonate rock containing magnesium and calcium in nearly equal amounts. Magnesium is a major component of serpentinite. Magnesium also is found in lesser amounts in over 60 minerals (Kramer, 2002). In igneous rocks, magnesium is a significant component of ferromagnesian minerals (Hem, 1992). It is also a component of most limestones. Magnesium contributes to water hardness, with the same effects as calcium.

Magnesium is vital to both plant and animal life. Most magnesium is found in the bones and teeth and makes up about 0.05 percent of human body weight. It is necessary for proper brain and spinal cord functioning. In plants, the central atom of chlorophyll structure is magnesium. Elevated concentrations of magnesium contribute to water hardness in the same manner as elevated concentrations of calcium and present the same problems. The USEPA does not have a PMCL or an SMCL for magnesium.

Water samples from 323 wells were analyzed for dissolved magnesium. The median magnesium concentration was 7.0 mg/L (table 12). Water samples from serpentinite had the highest median concentration (46.5 mg/L). The second highest median concentration was 25.5 mg/L in samples from carbonate rocks (table 12). Magnesium concentrations above the 75th percentile for all water samples (fig. 9) ranged from 13.2 to 69.0 mg/L, including 85 percent of wells in carbonate rocks (range 13.3 - 69.0 mg/L), 75 percent of wells in serpentinite rocks (range 30.0 - 66.1 mg/L), 17 percent of wells in gneiss rocks (range 14.3 - 35.0 mg/L), 17 percent of wells in quartzite rocks (range 19.4 - 33.0 mg/L), 7 percent of wells in Triassic sedimentary rocks (17.0 and 24.0 mg/L), and 6 percent of wells in schist rocks (range 13.2 - 50.0 mg/L). The magnesium concentration for the one sample collected from a well in diabase (14.3 mg/L) also exceeded the 75th percentile (13.1 mg/L) for all 323 wells.

**Table 12.** *Summary statistics for dissolved magnesium in ground water, by rock type, based on samples collected from 1990 to 2001*

[—, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved magnesium, in milligrams per liter | | | | | Percentage of samples greater than 13.1 milligrams per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 323 | 0.030 | 4.10 | 7.00 | 13.1 | 69.0 | 25 |
| Carbonate | 52 | 4.83 | 15.0 | 25.5 | 40.2 | 69.0 | 85 |
| Diabase | 1 | 14.3 | — | — | — | — | — |
| Gneiss | 78 | 1.50 | 4.42 | 6.92 | 9.98 | 35.0 | 17 |
| Quartzite | 24 | 1.70 | 3.12 | 5.08 | 7.66 | 33.0 | 17 |
| Schist | 126 | .75 | 3.60 | 5.50 | 8.09 | 50.0 | 6 |
| Triassic sedimentary | 30 | .030 | 3.42 | 5.95 | 9.80 | 24.0 | 7 |
| Serpentinite | 12 | .173 | 23.7 | 46.5 | 53.7 | 66.1 | 75 |

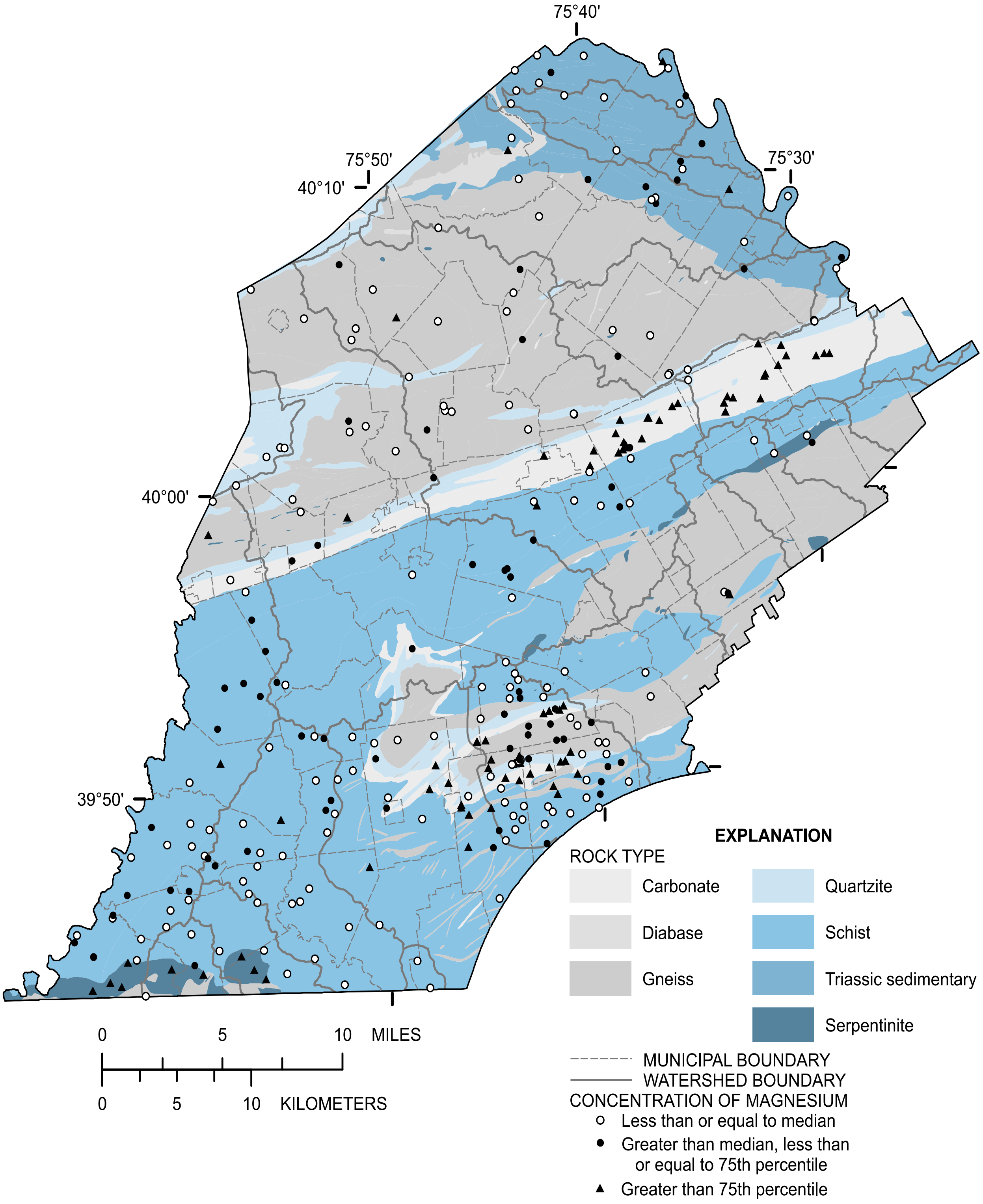

**Figure 9.** Distribution of magnesium relative to generalized rock types.

## Sodium

Sodium is the sixth most abundant element on earth. Sodium ($Na^+$) is a cation that reacts readily with other elements to form compounds; sodium chloride (NaCl), or salt, is the most common compound (Thrush, 1968). Sodium compounds are used in petroleum refining, ore processing, water treatment, and road deicing.

Sodium is essential in regulating many body processes, and sodium compounds are important pharmaceutical components. Sodium concentrations of more than 50 mg/L may cause foaming in steam boilers and can limit the usefulness of the water for irrigation. The usefulness of water is not affected in most cases at concentrations under 50 mg/L (McElroy, 1998). The USEPA does not have a PMCL or SMCL for sodium.

Water samples from 323 wells were analyzed for dissolved sodium. The median sodium concentration was 8.2 mg/L (table 13). Sodium concentrations for water samples collected from carbonate and Triassic sedimentary rocks had the highest and second highest median concentrations (12.5 and 11.0 mg/L) (table 13). Sodium concentrations above the 75 percentile for all water samples (12 mg/L) (fig. 10) included 50 percent of wells in carbonate rocks (range 13.0 - 160 mg/L), 15 percent of wells in gneiss rocks (range 12.0 - 25.8 mg/L), 29 percent of wells in quartzite rocks (range 14.8 - 35.0 mg/L), 19 percent of wells in schist rocks (range 12.0 - 33.3 mg/L), 40 percent of wells in Triassic sedimentary rocks (range 12.0 - 89.0 mg/L), and a single sample from serpentinite rock (58.3 mg/L).

**Table 13.** *Summary statistics for dissolved sodium in ground water, by rock type, based on samples collected from 1990 to 2001*

[—, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved sodium, in milligrams per liter | | | | | Percentage of samples greater than 12.0 milligrams per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 323 | 1.0 | 5.8 | 8.2 | 12.0 | 160 | 25 |
| Carbonate | 52 | 3.3 | 7.9 | 12.5 | 22.5 | 160 | 50 |
| Diabase | 1 | 7.8 | — | — | — | — | — |
| Gneiss | 78 | 2.7 | 5.6 | 7.2 | 9.7 | 25.8 | 15 |
| Quartzite | 24 | 1.8 | 5.2 | 8.6 | 15.4 | 35.0 | 29 |
| Schist | 126 | 2.4 | 6.0 | 8.0 | 11.0 | 33.3 | 19 |
| Triassic sedimentary | 30 | 4.2 | 8.6 | 11.0 | 14.0 | 89.0 | 40 |
| Serpentinite | 12 | 1.0 | 1.9 | 2.7 | 3.7 | 58.3 | 8 |

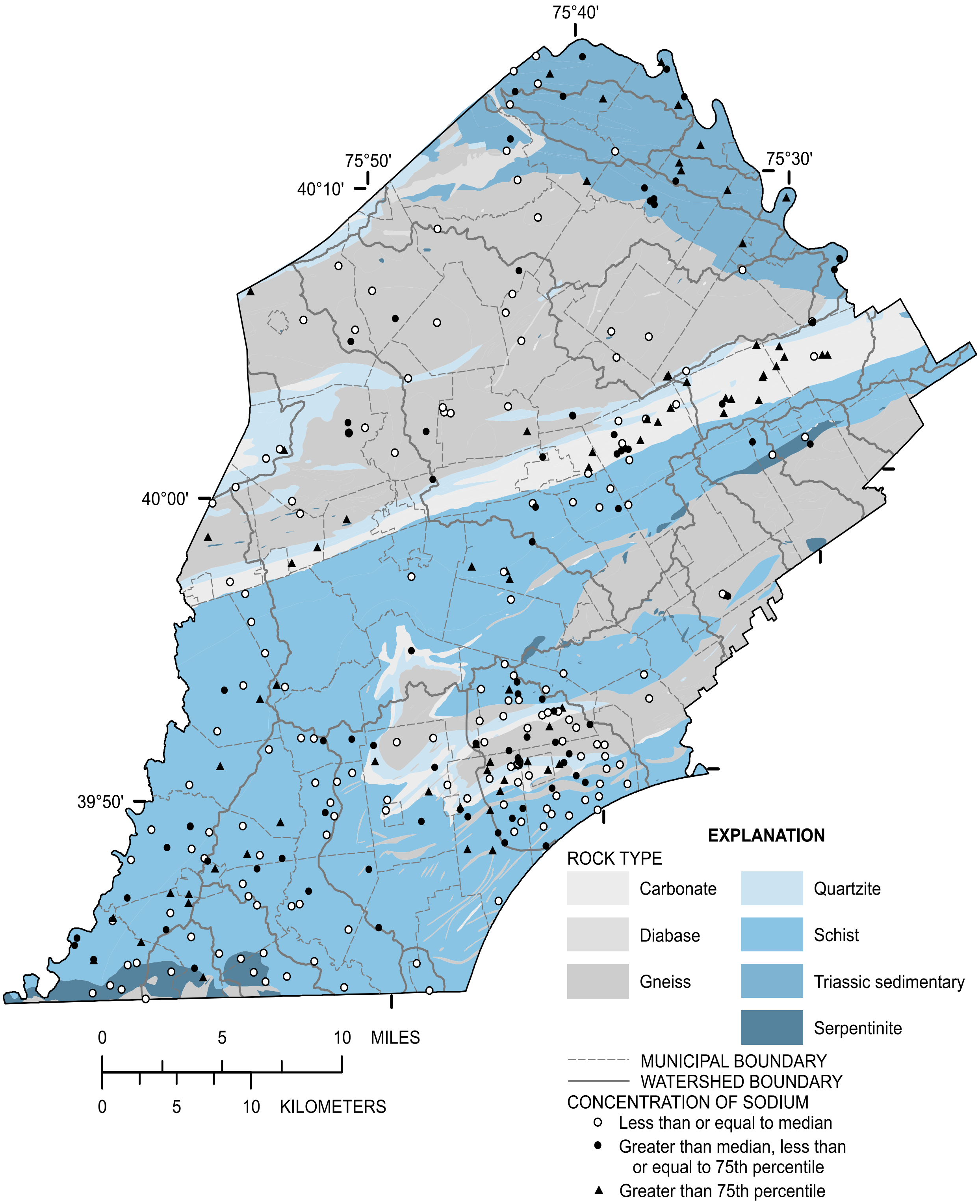

**Figure 10.** Distribution of sodium relative to generalized rock types.

## Fluoride

Calcium fluoride ($CaF_2$) is found naturally in water, because fluoride has a natural attraction for calcium. This mineral is found in sedimentary rocks such as the carbonate rocks that bisect the county. Fluorite ($CaF_2$), a mineral found in association with lead, tin, and zinc (Bates and Jackson, 1987), is associated with the lead ore deposits in northern Chester County (Phoenixville), but it is more commonly associated with carbonate rocks. Fluoride is dissolved in small quantities from most rocks and soils, usually at concentrations less than 1.0 mg/L.

The element fluorine (as fluoride) is important in the formation of teeth; fluoride intake from drinking water and its influence on the character of tooth structure was recognized as early as the 1930s (Hem, 1992). However, at concentrations greater than 6.0 mg/L, fluoride can have harmful effects on human health (van der Leeden and others, 1990). The USEPA PMCL for fluoride is 4.0 mg/L; the SMCL is 2.0 mg/L. No samples met or exceeded either standard.

Fluoride concentrations were less than 1.0 mg/L for all samples collected from 334 wells. The median fluoride concentration for all samples was less than 0.1 mg/L (table 14). Only 24 samples (7 percent) had detectable concentrations, including 16 percent of wells in carbonate rocks (range 0.2 - 0.9 mg/L), 5 percent of wells in gneiss (all 0.2 mg/L), 12 percent of wells in quartzite (range 0.1 - 0.2 mg/L), and 27 percent of wells in schist (range 0.1 - 0.5 mg/L). Three of the four samples with concentrations greater than 0.2 mg/L were from carbonate rocks (range 0.4 - 0.9 mg/L); the other sample was from schist (0.5 mg/L)(fig. 11).

**Table 14.** *Summary statistics for dissolved fluoride in ground water, by rock type, based on samples collected from 1990 to 2001*

[SMCL, secondary maximum contaminant level; PMCL, primary maximum contaminant level; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved fluoride, in milligram per liter | | | | | Percentage of detections | Percentage of samples exceeding the SMCL/PMCL |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | | |
| All wells | 334 | <0.1 | <0.1 | <0.1 | 0.1 | 0.9 | 7 | 0/0 |
| Carbonate | 50 | <.1 | <.1 | <.1 | .1 | .9 | 16 | 0/0 |
| Diabase | 1 | <.2 | — | — | — | — | — | — |
| Gneiss | 80 | <.1 | <.1 | <.1 | <.2 | .2 | 5 | 0/0 |
| Quartzite | 24 | <.1 | <.1 | <.1 | .1 | .2 | 12 | 0/0 |
| Schist | 140 | <.1 | <.1 | <.1 | .1 | .5 | 27 | 0/0 |
| Triassic sedimentary | 26 | <.1 | <.1 | <.1 | <.1 | .1 | 0 | 0/0 |
| Serpentinite | 13 | <.1 | <.1 | <.1 | <.1 | <.2 | 0 | 0/0 |

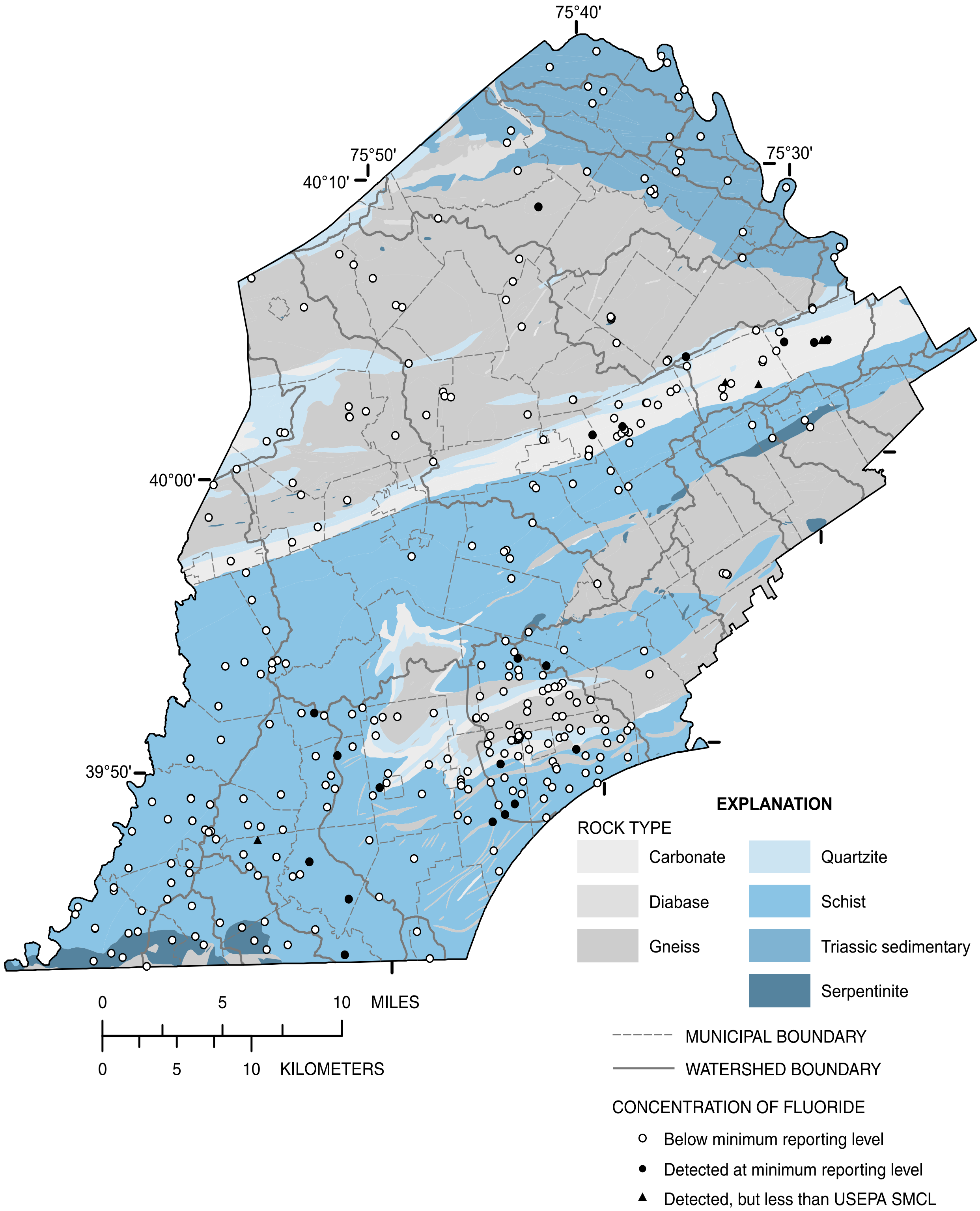

**Figure 11.** Distribution of fluoride relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; SMCL, Secondary Maximum Contaminant Level)

## Strontium

Strontium is an alkaline earth metal that also is a rare earth element. It is present in minor amounts in metamorphic rocks such as gneiss and schist. It also is present in small amounts in carbonate rocks (less than 1:1,000) (Kulp and others, 1952). Because strontium usually is present in small concentrations, measurements of strontium are expressed as a concentration in micrograms per liter, or 1/1,000th that of a milligram per liter. The USEPA does not have a SMCL or PMCL for strontium.

Of water samples collected from 183 wells, half of the samples had dissolved strontium concentrations less than 99.0 ∝g/L (table 15). The median strontium concentration for water samples collected from wells in gneiss rocks is 133 ∝g/L, one third higher than the median for all sampled wells. Strontium concentrations above the 75th percentile for all samples (150 ∝g/L) ranged from 150 - 900 ∝g/L, including 20 percent of wells in carbonate rocks (range 180 - 400 ∝g/L), 36 percent of wells in gneiss (range 150 - 840 ∝g/L), 21 percent of wells in quartzite (range 280 - 900 ∝g/L), 21 percent of wells in schist (range 157 - 550 ∝g/L), and 19 percent of wells in Triassic sedimentary rocks (range 380 - 600 ∝g/L) (fig. 12).

**Table 15.** *Summary statistics for dissolved strontium in ground water, by rock type, based on samples collected from 1990 to 2000*

[<, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved strontium, in micrograms per liter | | | | | Percentage of samples greater than 150 micrograms per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 183 | 6.00 | 61.5 | 99.0 | 150 | 900 | 25 |
| Carbonate | 30 | <10.0 | 55.5 | 75.0 | 118 | 400 | 20 |
| Diabase | 0 | — | — | — | — | — | — |
| Gneiss | 50 | 10.3 | 78.0 | 133 | 192 | 840 | 36 |
| Quartzite | 14 | 6.00 | 25.5 | 69.0 | 129 | 900 | 21 |
| Schist | 70 | 16.0 | 69.1 | 100 | 140 | 550 | 21 |
| Triassic sedimentary | 16 | 39.0 | 56.8 | 78.5 | 130 | 600 | 19 |
| Serpentinite | 3 | 16.0 | — | — | — | 24.7 | — |

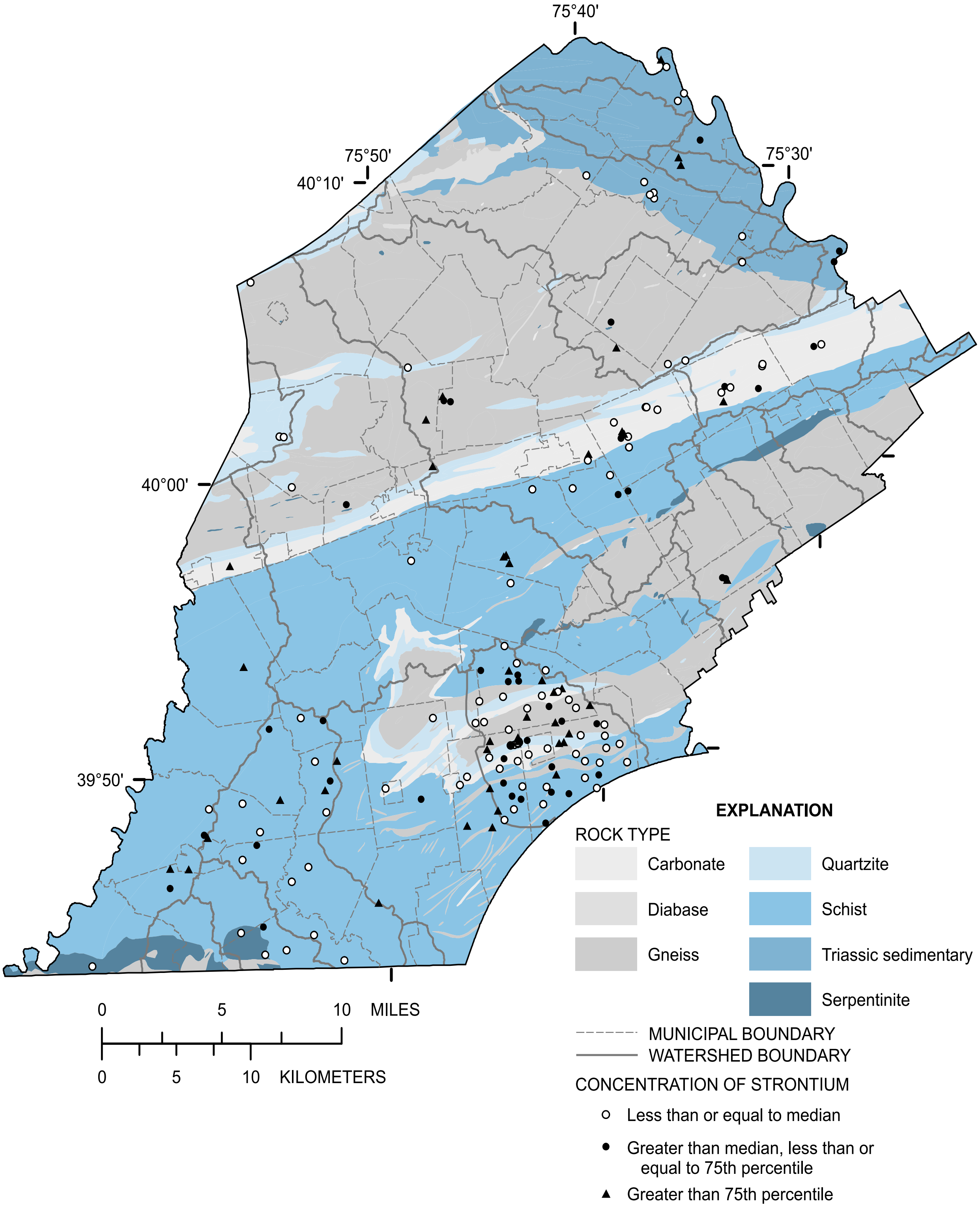

**Figure 12.** Distribution of strontium relative to generalized rock types.

# METALS

## Iron

Iron is the second most abundant metallic element in the Earth's outer crust. Igneous rock minerals with high iron contents include the pyroxenes, the amphiboles, biotite, magnetite, and olivine. In Chester County, igneous rocks underwent metamorphic change to become gneiss and schist. Therefore, areas of Chester County having a geological base of gneiss and schist would be expected to have high iron concentrations in the ground water. Other than these natural sources, iron also can be derived from pumps, pipes, and other equipment. The solubility of iron in water depends predominantly on pH and the dissolved-oxygen concentration of the system. The most common form of iron in solution in ground water is the ferrous ion $Fe^{2+}$ (Hem, 1992).

Iron is important to plants as a micronutrient but in small amounts. In animals, iron is important to the oxygen-bearing protein hemoglobin in the blood. At concentrations above 0.1 mg/L (100 ∝g/L), iron precipitates when exposed to the air and stains laundry, plumbing fixtures, and washing machines a red to brown color. At these concentrations, iron influences the color and taste of drinks and foods. Above 0.3 mg/L (300 ∝g/L), iron becomes a problem for industrial processes such as dyeing, bleaching, brewing, and ice manufacturing (van der Leeden and others, 1990). The USEPA SMCL for iron is 0.3 mg/L (or 300 ∝g/L).

The median concentration of dissolved iron in samples collected from 290 wells was 10 ∝g/L (table 16). Iron concentrations in 31 samples (11 percent) exceeded the SMCL, including 5 percent of wells in carbonate rocks (3,200 and 11,000 ∝g/L), 13 percent of wells in gneiss (range 440 - 7,500 ∝g/L), 9 percent of wells in quartzite (range 450 - 630 ∝g/L), 14 percent of wells in schist (range 310 - 44,000 ∝g/L), and 9 percent of wells in Triassic sedimentary rocks (1,700 and 1,900 ∝g/L) (fig. 13).

**Table 16.** *Summary statistics for dissolved iron in ground water, by rock type, based on samples collected from 1990 to 2001*

[SMCL, secondary maximum contaminant level; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved iron, in micrograms per liter | | | | | Percentage of samples exceeding the SMCL |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 290 | <3.0 | <10 | 10 | 40 | 44,000 | 11 |
| Carbonate | 41 | <3.0 | <3.0 | <3.0 | <10 | 11,000 | 5 |
| Diabase | 1 | <10 | — | — | — | — | — |
| Gneiss | 68 | <3.0 | <10 | 20 | 50 | 7,500 | 13 |
| Quartzite | 56 | <3.0 | <10 | 10 | 32 | 630 | 9 |
| Schist | 92 | <3.0 | <10 | 20 | 72 | 44,000 | 14 |
| Triassic sedimentary | 22 | <3.0 | <3.0 | 6.5 | 28 | 1,900 | 9 |
| Serpentinite | 10 | <3.0 | <4.8 | <10 | 18 | 30 | 0 |

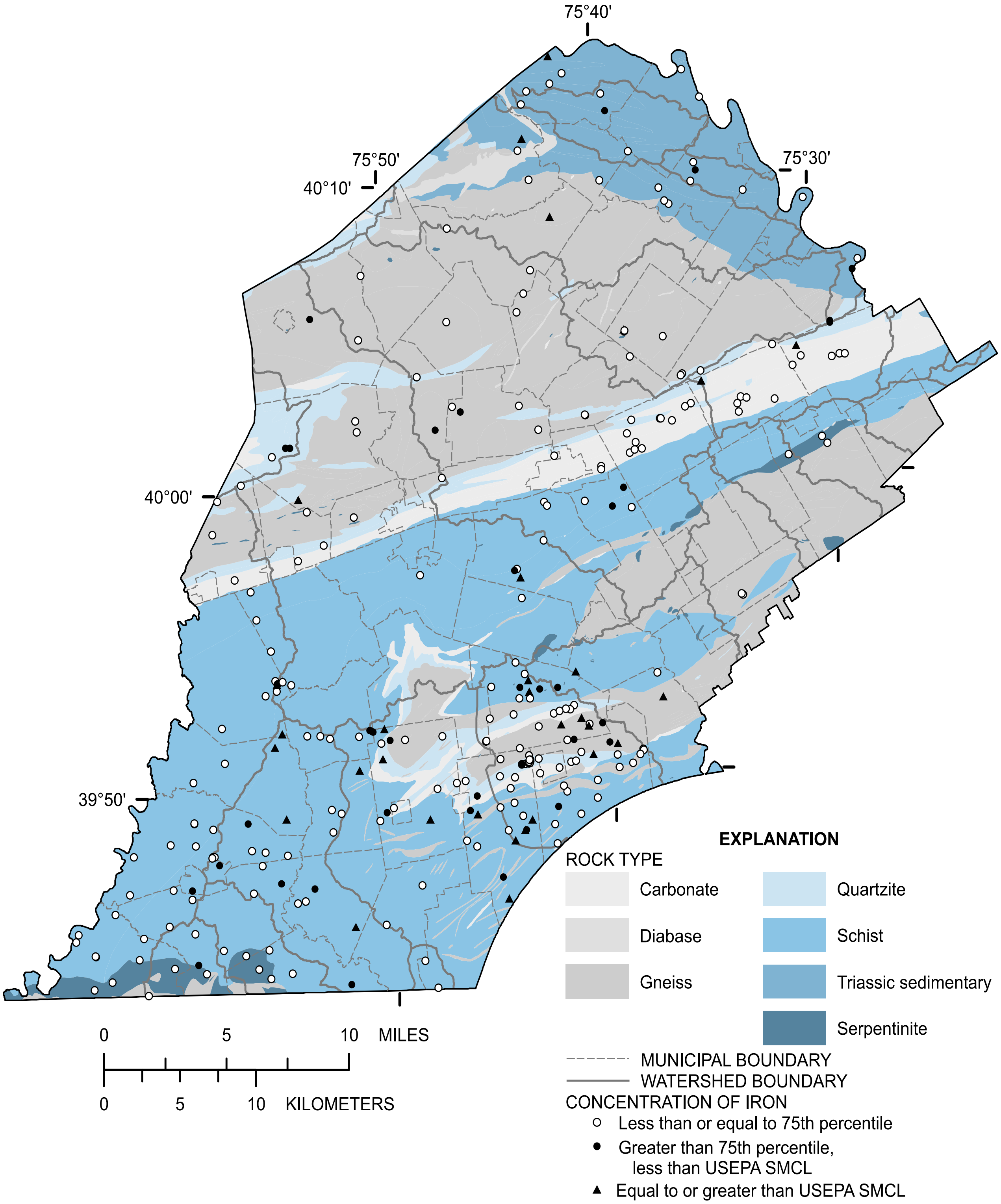

**Figure 13.** Distribution of iron relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; SMCL, Secondary Maximum Contaminant Level)

## Manganese

Manganese (Mn) is a metallic element. It does not occur alone in nature, but it is found in many minerals. Manganese is a minor constituent in many metamorphic and igneous minerals. In Chester County, these minerals are found in schist, quartzite, gneiss, and diabase.

At concentrations above 0.2 mg/L (200 ∝g/L), manganese precipitates when exposed to the air and stains laundry, plumbing fixtures, and washing machines dark brown to black. At these concentrations, manganese can influence the color and taste of drinks and foods; the water may taste bitter. The USEPA SMCL for manganese is 0.05 mg/L (50 ∝g/L). The CCHD requires manganese measurements for new and re-constructed homeowner wells and utilizes the same (0.05 mg/L) standard for drinking-water quality. If the manganese concentration in well water exceeds 0.05 mg/L, the CCHD recommends treatment.

The median concentration of dissolved manganese in samples collected from 360 wells was 8.0 ∝g/L (table 17). Manganese concentrations from 69 samples (19 percent) exceeded the SMCL (table 17). Manganese concentrations were highest in schist, where 42 samples (28 percent) exceeded the SMCL (51.5 - 3,200 ∝g/L) (fig 14). Other samples exceeding the SMCL included samples from 28 percent of wells in quartzite (54.0 - 177 ∝g/L), 15 percent of wells in gneiss (52.0 - 270 ∝g/L), 9 percent of wells in Triassic sedimentary rocks (86 - 238 ∝g/L); and 6 percent of wells in carbonate rocks (70.2 - 341 ∝g/L). The one sample collected from diabase had a manganese concentration (51.7 ∝g/L) that exceeded the SMCL.

**Table 17.** *Summary statistics for dissolved manganese in ground water, by rock type, based on samples collected from 1990 to 2001*

[SMCL, secondary maximum contaminant level; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved manganese, in micrograms per liter | | | | | Percentage of samples exceeding the SMCL |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 360 | <1.0 | 2.0 | 8.0 | 26.9 | 3,200 | 19 |
| Carbonate | 52 | <1.0 | <1.0 | 1.5 | 3.0 | 341 | 6 |
| Diabase | 1 | 51.7 | — | — | — | — | — |
| Gneiss | 86 | <1.0 | 2.0 | 10.0 | 21.8 | 270 | 15 |
| Quartzite | 25 | <1.0 | 4.0 | 20.1 | 54.0 | 177 | 28 |
| Schist | 149 | <1.0 | 4.0 | 15.0 | 58.1 | 3,200 | 28 |
| Triassic sedimentary | 34 | <1.0 | <1.0 | 2.5 | 8.3 | 238 | 9 |
| Serpentinite | 13 | <1.0 | <1.0 | 1.0 | 3.0 | 9.0 | 0 |

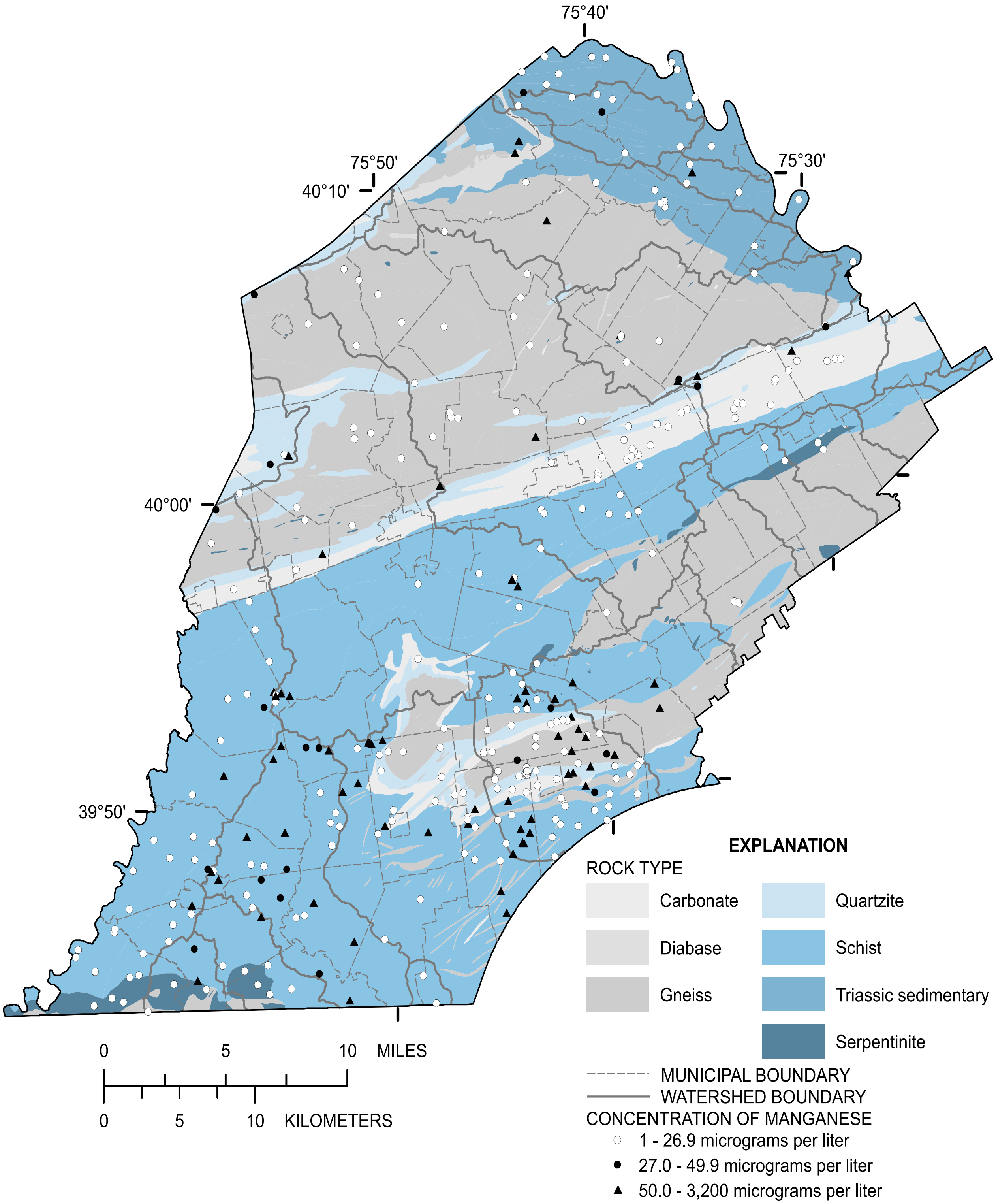

**Figure 14.** Distribution of manganese relative to generalized rock types.

## Lead

Lead is the final decay product of uranium and thorium. Lead is found widely in small amounts in all the rock types in Chester County. It is dissolved in small quantities because of its low solubility (Hem, 1992). Prior to the 1980s, lead used as a gasoline additive was released as an aerosol in engine exhaust. Large quantities also are released to the atmosphere in the burning of coal and smelting of ores. These sources may have contributed lead to precipitation and soils and, therefore, to ground water.

Water that has a pH less than 7.0 (see *pH*) or that has low alkalinity (see *Alkalinity*) can dissolve lead from lead solder used to join copper pipe and fittings. In 1991, Pennsylvania banned the sale and use of 50/50 tin/lead and 85/15 tin/lead solders for plumbing systems and restricted the use of other lead-containing solders to non-plumbing applications. Lead is toxic to humans and may cause kidney problems, high blood pressure, and even death. In infants and children, lead in drinking water can cause delays in physical and mental development. Lead can also be accumulated in the body. The USEPA set an action level (a form of PMCL) for lead. If more than 10 percent of tap-water samples from community water systems exceed 0.015 mg/L (15 ∝g/L) of lead, treatment techniques must be applied to control corrosivity of the water to meet drinking-water standards.

Samples collected from 258 wells were analyzed for dissolved lead (table 18). Only 24 samples had concentrations equal to or above the highest MRL (10.0 ∝g/L) (fig. 15). Lead concentrations exceeded the USEPA action level in 11 samples (4 percent), including 8 percent of wells in quartzite (range 15.2 - 30.0 ∝g/L), 5 percent of wells in carbonate rocks (20.0 and 24.0 ∝g/L), 5 percent of wells in schist (range 20.0 - 70 ∝g/L), 4 percent of wells in Triassic sedimentary rocks (20.2 ∝g/L), and 3 percent of wells in gneiss (20.0 and 23.6 ∝g/L).

**Table 18.** *Summary statistics for dissolved lead in ground water, by rock type, based on samples collected from 1990 to 2001*

[AL, action level; E, estimated; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved lead, in micrograms per liter | | | | | Percentage of samples exceeding 10.0 micrograms per liter | Percentage of samples exceeding the AL |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | | |
| All wells | 258 | E 0.05 | <1.00 | <10.0 | <10.0 | 70.0 | 9 | 4 |
| Carbonate | 42 | <1.00 | <1.00 | <10.0 | <10.0 | 24.0 | 12 | 5 |
| Diabase | 1 | .14 | — | — | — | — | — | — |
| Gneiss | 78 | E .05 | <1.00 | 2.00 | 10.0 | 23.6 | 5 | 3 |
| Quartzite | 25 | <1.00 | 3.48 | <10.0 | <10.0 | 30.0 | 12 | 8 |
| Schist | 79 | .26 | <1.00 | <10.0 | <10.0 | 70.0 | 6 | 5 |
| Triassic sedimentary | 25 | E .07 | <1.00 | <10.0 | <10.0 | 20.2 | 4 | 4 |
| Serpentinite | 8 | .12 | — | — | — | 10.0 | 0 | 0 |

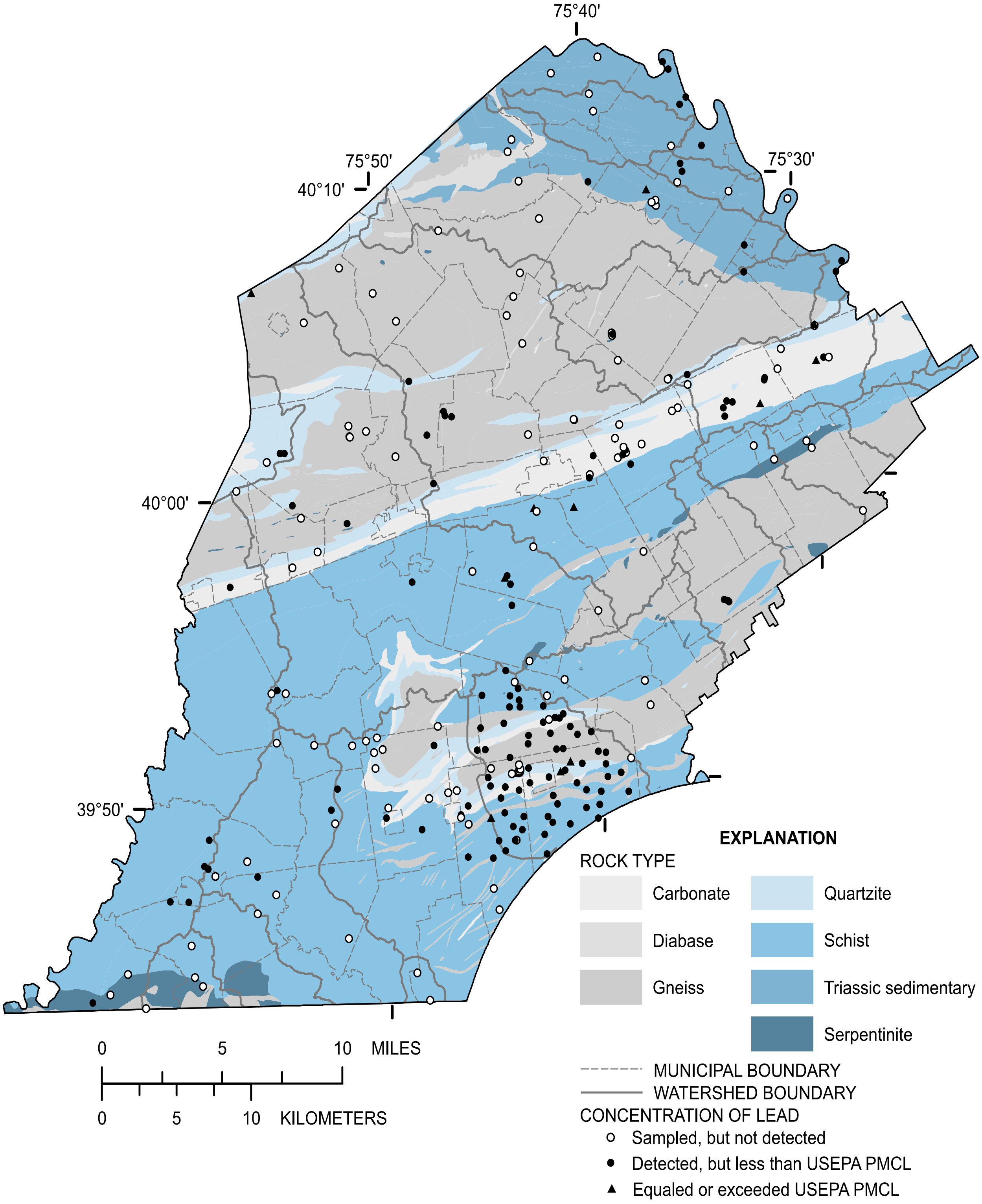

**Figure 15.** Distribution of lead relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Arsenic

Arsenic can form compounds with metals and is an element in sulfide ore deposits; it is also a minor impurity in phosphate rock and is released during coal combustion. Arsenic can be dissolved from rocks in small quantities (usually less than 0.001 mg/L), but elevated concentrations are usually the result of improper disposal of pesticides containing arsenic or from agricultural runoff.

Low concentrations of arsenic can be toxic to humans over long-term exposure. The USEPA PMCL for arsenic is 0.01 mg/L (10 ∝g/L). Arsenic concentration criteria also have been set at 0.1 mg/L of arsenic for irrigation of crops (U.S. Environmental Protection Agency, 1976), and 0.2 mg/L for livestock water (National Academy of Sciences, 1972).

The median and 75th percentile concentrations for dissolved arsenic in samples collected from 166 wells were less than 1.0 and less than 2.0 ∝g/L, respectively (table 19). Arsenic was detected in only 14 samples (8 percent). Of those samples, 13 had concentrations ranging from 0.1 - 3.0 ∝g/L, and 1 sample exceeded the USEPA PMCL at 69.0 ∝g/L. It has not been determined whether the high concentration is from a natural or anthropogenic (human-made) source. Of the samples with detectable arsenic concentrations, six were from the Triassic sedimentary rocks, including the sample that exceeded the PMCL (fig. 16). Two samples from the same rock type in Bucks County had concentrations of 24.0 and 28.0 ∝g/L (Schreffler and others, 1994).

**Table 19.** *Summary statistics for dissolved arsenic in ground water, by rock type, based on samples collected from 1990 to 2001*

[PMCL, primary maximum contaminant level; E, estimated; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved arsenic, in micrograms per liter | | | | | Percentage of samples with detectable arsenic | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | | |
| All wells | 166 | E 0.1 | <1.0 | <1.0 | <2.0 | 69.0 | 8 | <1 |
| Carbonate | 21 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 0 | 0 |
| Diabase | 1 | 2.7 | — | — | — | — | — | — |
| Gneiss | 47 | E .1 | <1.0 | <1.0 | <4.0 | <4.0 | 4 | 0 |
| Quartzite | 9 | <1.0 | — | — | — | <2.0 | 0 | 0 |
| Schist | 67 | <.2 | <1.0 | <1.0 | <2.0 | 2.0 | 6 | 0 |
| Triassic sedimentary | 11 | .5 | <1.0 | <1.0 | 2.0 | 69.0 | 55 | 9 |
| Serpentinite | 10 | <.2 | <1.0 | <1.0 | <1.0 | 2.0 | 10 | 0 |

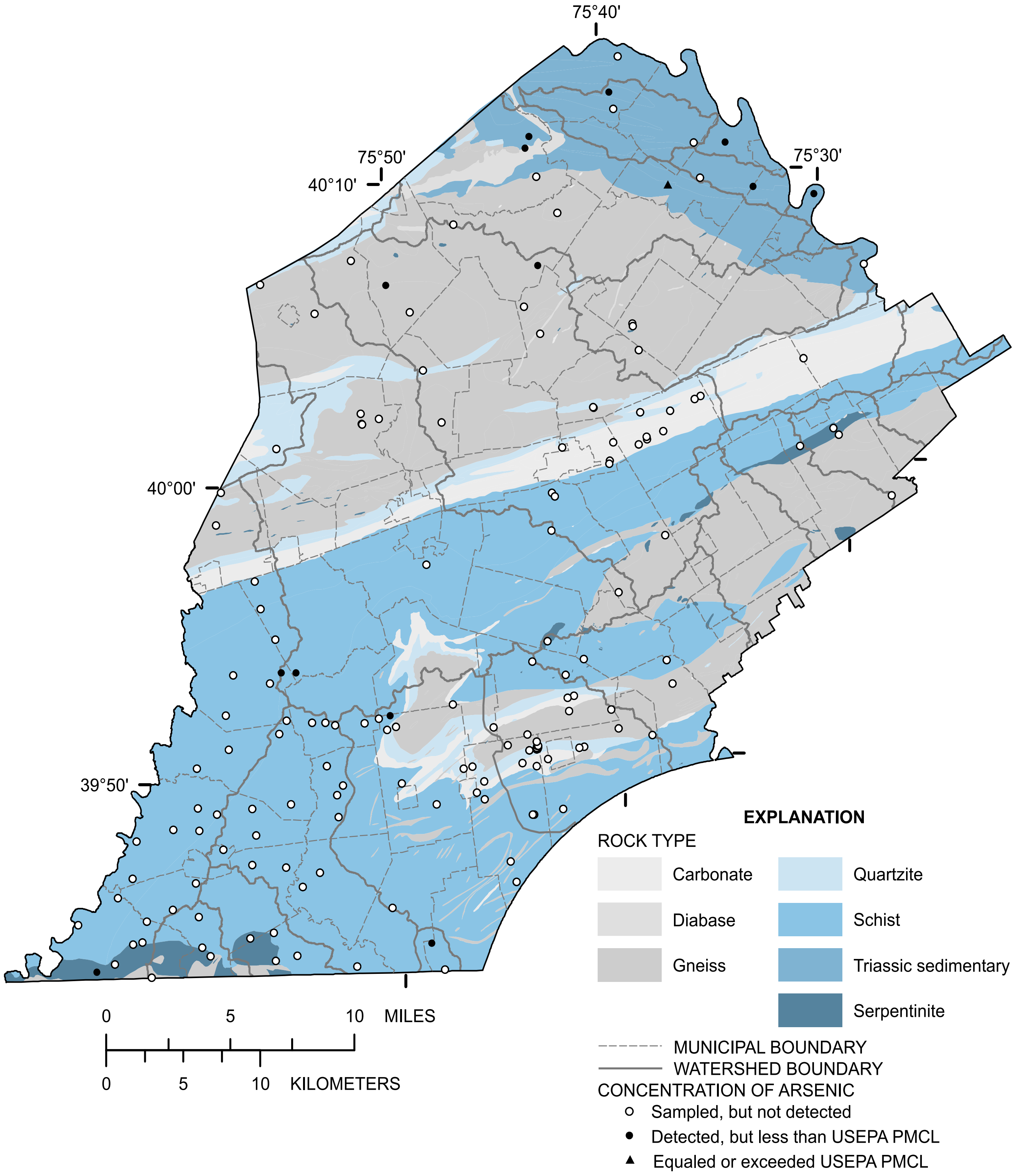

**Figure 16.** Distribution of arsenic relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Copper

Copper (Cu) is the 27th most abundant element in the Earth’s crust. Although copper is an important micronutrient for plants, it has been applied as organic and inorganic copper compounds in pesticide sprays and sometimes is added to water-supply reservoirs to suppress algae growth (Hem, 1992).

Copper is used extensively in plumbing. When the pH of water is less than 7.0, copper may be dissolved from pipes and plumbing fixtures and stain plumbing fixtures with green or blue-green deposits. The USEPA has set an action level (a form of PMCL) for copper: if more than 10 percent of tap-water samples exceed 1.3 mg/L of copper in community water systems, treatment techniques must be applied to control corrosivity of the water to meet drinking-water standards.

Copper is important for metabolism and the Recommended Dietary Allowance (RDA) for adults is 900 ∝g/d. At higher concentrations, copper can cause gastrointestinal distress in short-term exposure and liver or kidney damage in long-term exposure. Pennsylvania Department of Environmental Protection has set a MCL of 1.0 mg/L, but the standard applies to bottled, vended, retail, and bulk water hauling systems. The USEPA action level for copper is 1.3 mg/L (1,300 ∝g/L). The USEPA also set an SMCL at 1.0 mg/L (1,000 ∝g/L).

No samples from Chester County wells met or exceeded the standards. The median concentration for dissolved copper in samples collected from 261 wells was less than 10.0 ∝g/L. The highest copper concentration (870 ∝g/L) was from a well in the gneiss rock type (table 20). Other samples with concentrations above the 75th percentile for all samples (20 ∝g/L) included 36 percent of wells in quartzite rocks (range 46.0 - 240 ∝g/L), 34 percent of wells in gneiss (range 20.0 - 870 ∝g/L), 28 percent of wells in Triassic sedimentary rocks (range 20.0 - 290 ∝g/L), and 26 percent of wells in schist rocks (range 26.0 - 210 ∝g/L) (fig. 17). A single sample from serpentinite rocks (76.0 ∝g/L) also exceeded the 75th percentile.

**Table 20.** *Summary statistics for dissolved copper in ground water, by rock type, based on samples collected from 1990 to 2001*

[SMCL, secondary maximum contaminant level; AL, action level; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved copper, in micrograms per liter | | | | | Percentage of samples exceeding 20.0 micrograms per liter | Percentage of samples exceeding the SMCL/AL |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | | |
| All wells | 261 | <1.0 | <10.0 | <10.0 | 20.0 | 870 | 10 | 0/0 |
| Carbonate | 42 | <1.0 | 4.4 | <10.0 | <10.0 | 18.0 | 0 | 0/0 |
| Diabase | 1 | 4.4 | — | — | — | — | — | — |
| Gneiss | 71 | <1.0 | <5.0 | <10.0 | 23.0 | 870 | 34 | 0/0 |
| Quartzite | 25 | 3.0 | <10.0 | <10.0 | 65.6 | 240 | 36 | 0/0 |
| Schist | 77 | <1.0 | <10.0 | <10.0 | 27.0 | 210 | 26 | 0/0 |
| Triassic sedimentary | 25 | 1.2 | <10.0 | <10.0 | 30.0 | 290 | 28 | 0/0 |
| Serpentinite | 10 | <1.0 | <1.0 | <5.8 | <10.0 | 76.0 | 10 | 0/0 |

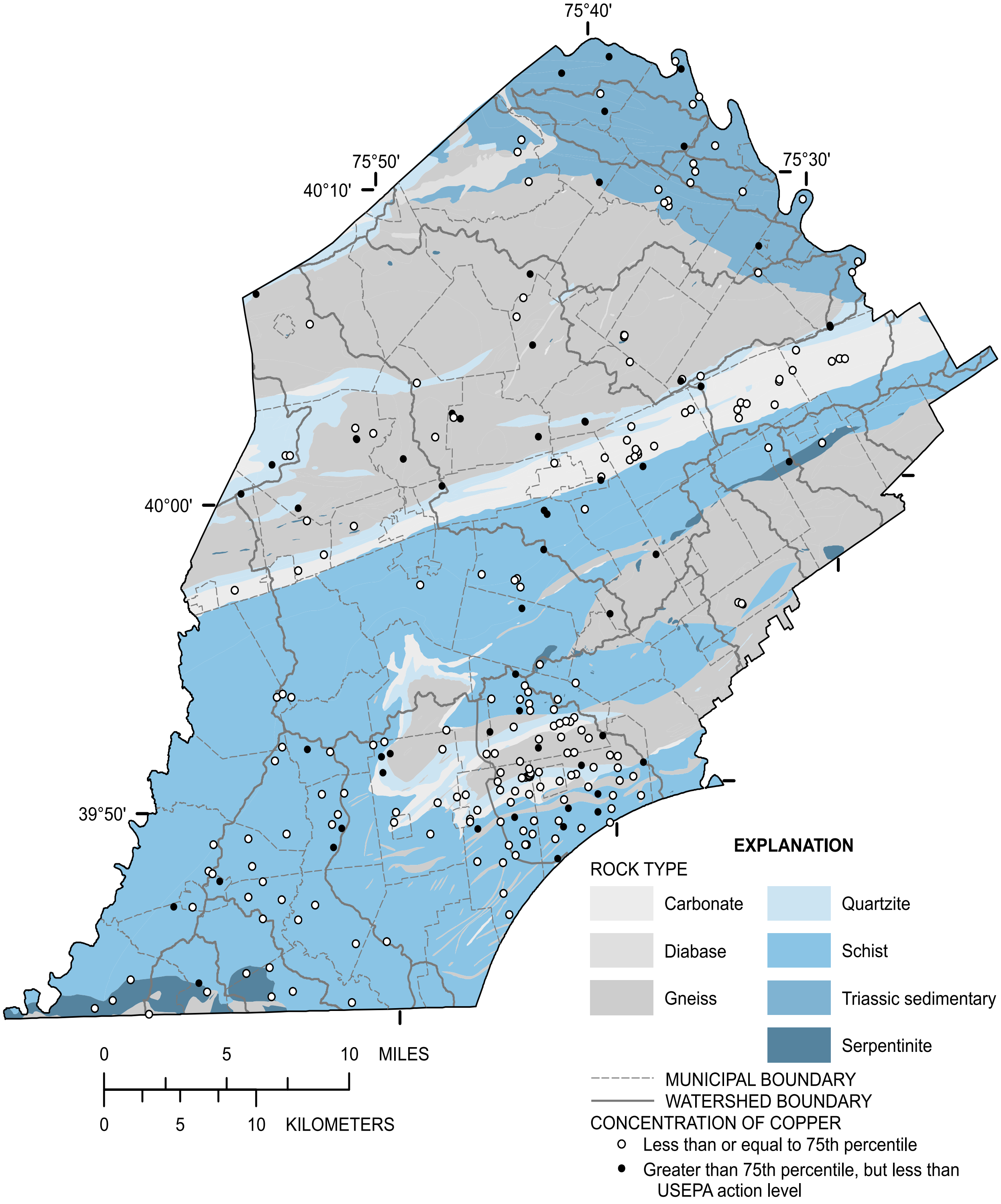

**Figure 17.** Distribution of copper relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency)

## RADIONUCLIDES

### Radon-222

Radon-222 is an odorless, colorless, inert, naturally occurring, radioactive gas that is soluble in water. Uranium-238 decays to produce radium-226, which in turn decays to produce radon-222. Radon-222 has a half-life of 3.8 days and decays to the isotope lead-210, which has a half-life of 21.8 years (Hem, 1992, p. 149). The largest quantities of radon occur underground, and most ground water contains detectable radon. The magnitude of radon-222 activities in ground water are controlled predominantly by physical phenomena, such as variations in the occurrence of parent material, aquifer porosity, permeability, and fluctuations in ground-water levels (Senior, 1998). These features vary with rock type, and therefore, radon-222 activities are expected to vary with rock type. The report, “Radon-222 in the Ground Water of Chester County, Pennsylvania,” and a fact sheet, “Radon in the Ground Water of Chester County, Pennsylvania,” prepared by USGS, in cooperation with the Chester County Water Resources Authority and the CCHD, discuss radon in much greater detail.

Well water that contains elevated activities of radioactive minerals may increase the level of radon in the air inside a home through actions like taking showers, doing laundry, and running a dishwasher. The USEPA (1999b, 1999c) estimated that radon in water contributes 1-2 percent to the radon in indoor air. Long-term exposure to radon increases a person’s risk of developing lung cancer. The USEPA currently does not have a PMCL for radon in water, however, 300 pCi/L and an Alternate Maximum Contaminant Level (AMCL) at 4,000 pCi/L are proposed levels (U.S. Environmental Protection Agency, 1999b, 1999c). Amendments to the Safe Drinking Water Act in 1996 provided the USEPA with a mandate to determine a risk assessment of radon in drinking water and to develop an AMCL, through the National Academy of Sciences (NAS). The NAS Radon in Drinking Water committee findings include (1) the transfer factor of radon gas from water to air is about 1 in 10,000, (2) the national average outdoor air radon activity is approximately 0.4 pCi/L, and (3) radon activities of 4,000 pCi/L in drinking water should yield radon activities of 0.4 pCi/L in indoor air, an inhalation risk no worse than that of outdoor air (Federal Register, 1999).

In Chester County, the median activity for radon in samples collected from 605 wells was 1,500 pCi/L (table 21). The highest median activities were in schist and quartzite, at 2,500 pCi/L and 2,140 pCi/L, respectively. Radon activities were above 300 pCi/L in 536 samples (89 percent of all wells) and above 4,000 pCi/L in 111 samples (18 percent of all wells; fig. 18). Radon activities in wells above 4,000 pCi/L include 29 percent of wells in schist (range 4,150 - 15,000 pCi/L), 27 percent of wells in quartzite (range 4,280 - 32,300 pCi/L), 13 percent of wells in gneiss (range 4,040 - 53,000 pCi/L), and 3 percent of wells in carbonate rocks (range 4,700 - 5,810 pCi/L).

**Table 21.** *Summary statistics for radon-222 in ground water, by rock type, based on samples collected from 1986 to 2001*

[—, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Radon-222, in picocuries per liter | | | | | Percentage of samples equal or exceeding 300 picocuries per liter | Percentage of samples equal or exceeding 4,000 picocuries per liter |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | | |
| All wells | 605 | 42.0 | 590 | 1,500 | 3,210 | 53,000 | 89 | 18 |
| Carbonate | 70 | 49.0 | 275 | 540 | 1,070 | 5,810 | 73 | 3 |
| Diabase | 1 | 1,280 | — | — | — | — | — | — |
| Gneiss | 149 | 48.0 | 460 | 884 | 2,450 | 53,000 | 84 | 13 |
| Quartzite | 118 | 157 | 956 | 2,140 | 4,400 | 32,300 | 97 | 27 |
| Schist | 197 | 130 | 1,190 | 2,500 | 4,200 | 15,000 | 95 | 29 |
| Triassic sedimentary | 57 | 200 | 940 | 1,300 | 1,700 | 3,500 | 96 | 0 |
| Serpentinite | 13 | 42.0 | 80.0 | 122 | 190 | 2,700 | 23 | 0 |

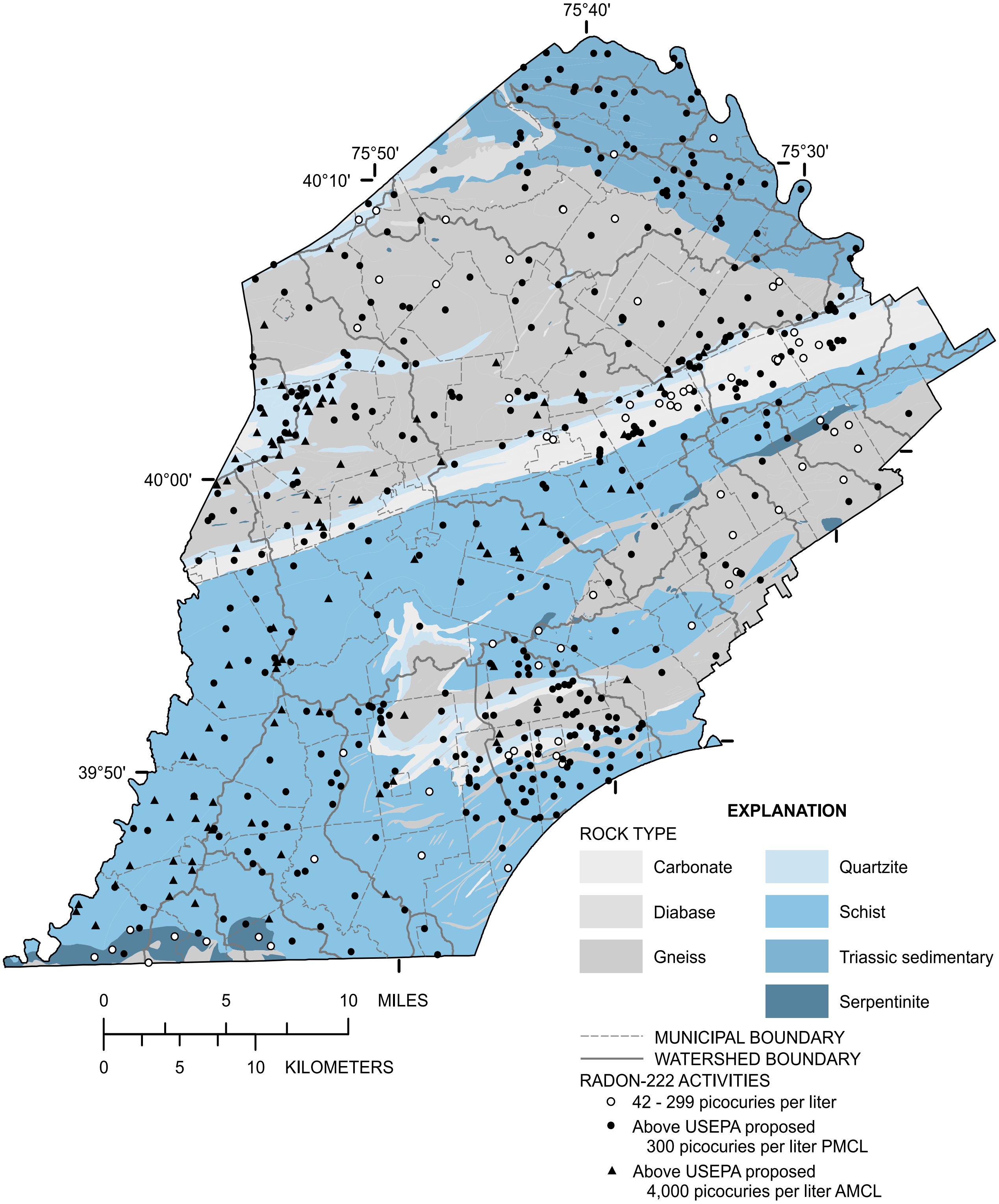

**Figure 18.** Distribution of radon-222 relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level; AMCL, Alternate Maximum Contaminant Level)

## Radium-226 and Radium-228

Radium is an alkaline-earth metal. Radium isotopes are strongly radioactive and are readily detected at low activities. Radium-226 is a disintegration product of uranium-238. Radium-226, an alpha-emitter, has a longer half-life (1,620 years) than the other naturally occurring radium isotopes, and it is usually the predominant form in water. Radium-226 decays to produce radon-222 (Hem, 1992, p. 148). The activity of radium-226 in ground water generally is controlled by the chemical environment that affects its solubility.

Radium-228 is a disintegration product of thorium-232. Radium-228 decays by releasing beta-particles, which are ejected from the nucleus of the atom. Beta-radiation is more penetrating than alpha-radiation. The USEPA PMCL for combined radium-226 and radium-228 isotopes is 5 pCi/L. The potential health effects from ingestion of water containing activities equal to or greater than 5 pCi/L are an increased risk of cancer. In Chester County, in quartzite, and in particular the Chickies Formation, 56 percent of wells had radium activities above the PMCL. The pH was less than 4.7 for all samples that exceeded the PMCL. Homeowners with wells in the Chickies Formation should have their wells tested. If tests indicate radium activities above the PMCL, homeowners should contact the CCHD for recommended water-treatment methods. The report, "Radium and Radon in Ground Water in the Chickies Quartzite, Southeastern Pennsylvania," prepared by USGS, in cooperation with the Pennsylvania Department of Environmental Resources, discusses radium and radon in much greater detail.

Data are from 161 samples where radium-226 and radium-228 were analyzed, and the results for each constituent were summed for each sample. The median activity for the combined data is less than 3.0 pCi/L (table 22). However, combined activities for 57 samples (35 percent) equalled or exceeded the PMCL with activities between 5 and 210 pCi/L (fig. 19). Combined radium concentrations above the PMCL include 56 percent of wells in quartzite (range 5 - 210 pCi/L), 18 percent of wells in carbonate rocks (120 pCi/L), and 8 percent of wells in schist (13 pCi/L).

**Table 22.** *Summary statistics for radium-226/radium-228 in ground water, by rock type, based on samples collected from 1985 to 2001*

[PMCL, primary maximum contaminant level; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Radium-226/radium-228, in picocuries per liter | | | | | Percentage of samples equal or exceeding the PMCL |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 161 | 0.2 | <2.0 | <3.0 | 10 | 210 | 35 |
| Carbonate | 11 | <1.0 | <2.0 | <2.0 | <3.0 | 120 | 18 |
| Diabase | 0 | — | — | — | — | — | — |
| Gneiss | 19 | .9 | <1.5 | <3.0 | <3.0 | 4.7 | 0 |
| Quartzite | 96 | .2 | <2.0 | 5.7 | 19 | 210 | 56 |
| Schist | 13 | .3 | <2.0 | 2.8 | <3.0 | 13 | 8 |
| Triassic sedimentary | 22 | .4 | <1.0 | <1.0 | <2.0 | 3.4 | 0 |
| Serpentinite | 0 | — | — | — | — | — | — |

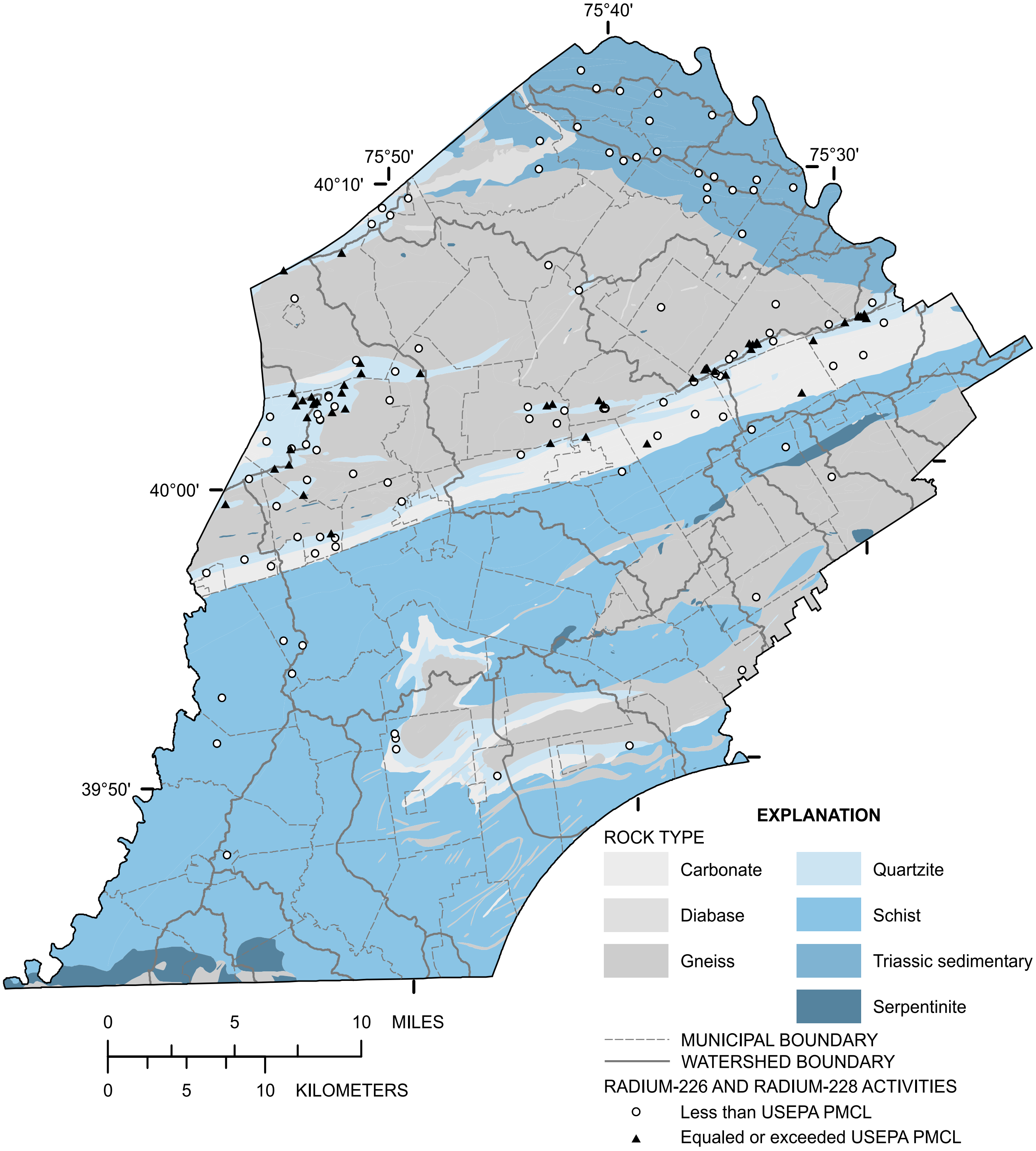

**Figure 19.** Distribution of radium-226 and radium-228 relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Radium-224

Radium-224 is a short-lived (half-life of 3.6 days), alpha-emitting decay product of radium-228 that originates from thorium-232. Like radium-226, radium-224 decays to produce radon. The short half-life of radium-224 indicates that analysis of this constituent must occur soon after a sample is collected (within 48 hours) for an accurate determination of activity. Radium-224 is not extensively studied because of its rapid decay rate and the practical difficulties of shipping and analyzing samples within time constraints.

Radium-224 is a potential health risk in drinking water. The USEPA does not have a PMCL specifically for radium-224, but radium-224 is an alpha emitter, and the USEPA PMCL for gross alpha particles is 15 pCi/L. However, because radium-224 decays quickly, the contribution of radium-224 to gross-alpha activity typically is not determined and gross alpha measurements are reported at activities less than what actually was present in the sample at collection.

In a nationwide USGS study, in cooperation with USEPA and the American Water Works Association (AWWA), samples were collected from 104 wells in 27 states, including 8 physiographic regions. Activities of radium-224 in that study ranged from less than 1.0 to 73.6 pCi/L; the median activity was 0.3 pCi/L. Only 5 percent of the samples exceeded 10 pCi/L; the highest activities were measured in highly acidic water (pH less than 4) of the Coastal Plain aquifers in Maryland and South Carolina (Focazio and others, 2001).

Most radium-224 samples in this report were collected as part of a study focusing on geologic units likely to have elevated radium activities. Wells sampled for radionuclides between 1986 and 1989 were resampled for the same radionuclides plus radium-224 in 1999. Analyses were performed within 48 hours. Wells in the Chickies Quartzite and the Harpers Quartzite had the highest activities (range 15.1 - 265 pCi/L) (fig. 20). Statistics were not computed for this radionuclide because of the limited number of samples.

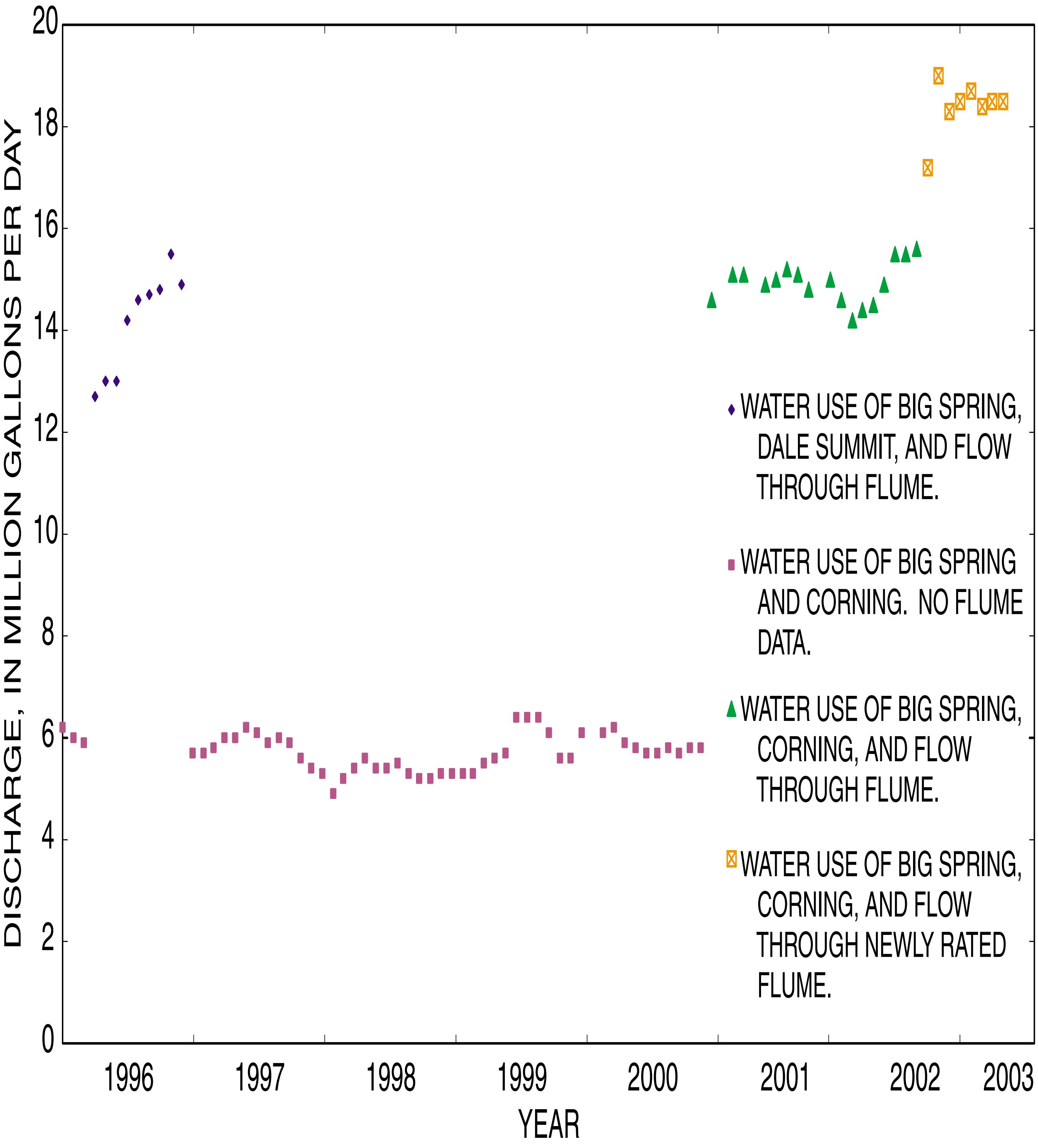

**Figure 20.** Distribution of radium-224 relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Uranium

Uranium-238 is the predominant isotope of natural uranium and is the first step (parent material) in a radioactive decay series that produces radium-226 and radon-222 (among other radionuclides) and ends with stable isotope lead-206. The half-life of uranium-238 is very long ($4.5 \cdot 10^9$ years) and therefore uranium-238 is only slightly reactive.

Although uranium occurs widely, it most commonly is detected in low concentrations. Uranium is present in most natural water at concentrations between 0.0001 and 0.010 mg/L; however, concentrations ranging from 1 to 15 mg/L can be found in wells near uranium ore deposits. The USEPA PMCL for uranium is 0.03 mg/L (30 ∝g/L), because concentrations of uranium at this level and higher cause an increased risk of cancer and kidney toxicity.

Samples from 201 wells were analyzed for uranium concentration. The median concentration for all samples was less than 0.40 ∝g/L (table 23); 89 percent of all samples had concentrations less than 1.0 ∝g/L. Only one sample from a well in carbonate rock exceeded the USEPA PMCL at 97 ∝g/L. Samples with concentrations above 1.0 ∝g/L included 44 percent of wells in Triassic sedimentary rocks (range 1.2 - 11 ∝g/L), 40 percent of wells in carbonate rocks (range 1.08 - 97 ∝g/L), 3 percent of wells in gneiss (1.76 ∝g/L), and 3 percent of wells in quartzite (range 1.0 - 6.6 ∝g/L). Although the number of samples collected from carbonate and Triassic sedimentary rocks constitutes 22 percent of the data set, 83 percent of the samples with uranium concentrations equal to or greater than 1.0 ∝g/L are from these two rock types (fig. 21).

**Table 23.** *Summary statistics for uranium in ground water, by rock type, based on samples collected from 1984 to 2001*

[PMCL, primary maximum contaminant level; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Uranium, in micrograms per liter | | | | | Percentage of samples equal or exceeding 1.0 microgram per liter | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | | |
| All wells | 201 | <0.01 | <0.05 | <0.40 | <1.00 | 97.0 | 11 | <1 |
| Carbonate | 20 | .01 | <.40 | <1.00 | 2.10 | 97.0 | 40 | 5 |
| Diabase | 1 | .28 | — | — | — | — | — | — |
| Gneiss | 32 | .01 | <.12 | <.40 | <1.00 | 1.76 | 3 | 0 |
| Quartzite | 88 | <.01 | <.05 | .12 | .30 | 6.60 | 3 | 0 |
| Schist | 29 | <.02 | <.40 | <1.00 | <1.00 | <1.00 | 0 | 0 |
| Triassic sedimentary | 25 | <.02 | <.05 | <1.00 | 1.70 | 11.0 | 44 | 0 |
| Serpentinite | 6 | .01 | — | — | — | <1.0 | 0 | 0 |

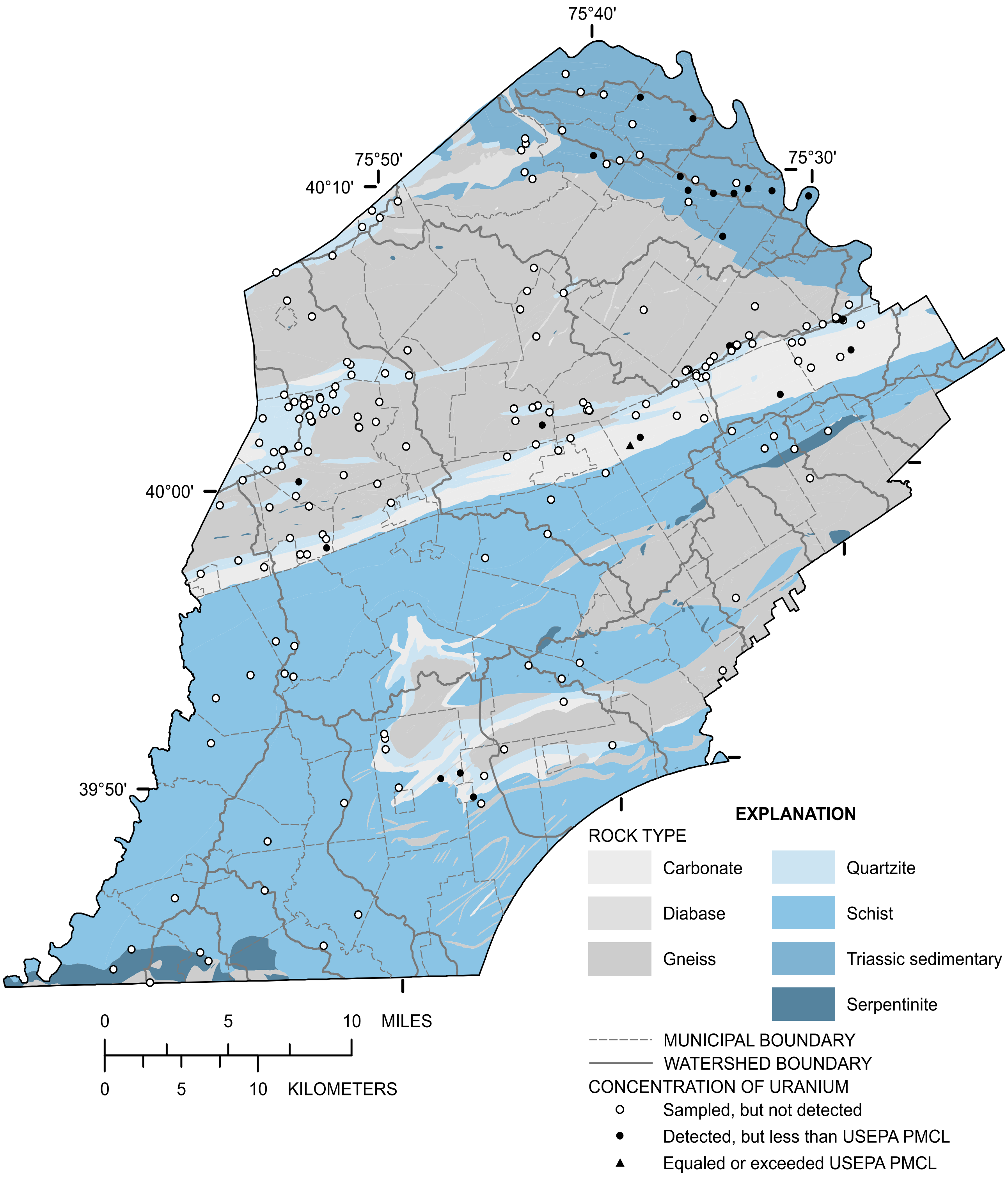

**Figure 21.** Distribution of uranium relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Gross Alpha Particle Activity

Alpha particles are positively charged helium nuclei. Alpha particle activity is a form of energy released through the breakdown of radioactive elements, such as uranium and thorium, which are found in varying amounts in bedrock. These two elements produce radioactive decay products, such as radium and radon. As the decay continues, alpha radiation continues to be released into ground water. Alpha particle emitters in drinking water can take the form of a gas (radon) or dissolved minerals.

Public supply wells are tested for alpha radioactivity by using an analysis referred to as “gross alpha activity.” The analysis is a screening tool, or indicator, for elevated radionuclide activity in ground water. If gross alpha activities equal or exceed 15 pCi/L, public water suppliers are required to determine the particular radionuclides present in their source water. The USEPA PMCL for gross alpha is 15 pCi/L, because concentrations of gross alpha at this activity and higher cause an increased risk of cancer. Gross alpha is calculated as the total alpha activity *minus* uranium and radon activities. Gross alpha screening can include radium-224 activities if the analysis is performed within 48 hours of sample collection.

The median gross alpha particle activity in samples collected from 59 wells was 5.5 pCi/L (table 24). Gross alpha particle activities from 19 samples exceeded the USEPA PMCL (range 19 - 360 pCi/L), including 62 percent of wells in quartzite rocks (range 19 - 360 pCi/L) and 11 percent of wells in carbonate rocks (31 pCi/L) (fig. 22). All samples from quartzite that exceeded the USEPA PMCL were from wells in the Chickies Quartzite. Too few samples were collected to compute summary statistics for wells in carbonate, schist, and Triassic sedimentary rocks. No samples were collected from wells in the diabase and serpentinite rock types.

**Table 24.** *Summary statistics for dissolved gross alpha particle activity in ground water, by rock type, based on samples collected from 1985 to 2001*

[PMCL, primary maximum contaminant level; <, less than; —, too few samples to compute statistics or percentages]

| Rock type | Total number of samples | Dissolved gross alpha, in picocuries per liter | | | | | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 59 | <0.60 | 1.7 | 5.5 | 30 | 360 | 32 |
| Carbonate | 9 | <.60 | — | — | — | 31 | 11 |
| Diabase | 0 | — | — | — | — | — | — |
| Gneiss | 12 | <.60 | <.60 | .60 | 1.6 | 7.2 | 0 |
| Quartzite | 29 | .90 | 8.8 | 28 | 70 | 360 | 62 |
| Schist | 5 | 1.3 | — | — | — | 8.6 | 0 |
| Triassic sedimentary | 4 | 1.9 | — | — | — | 11 | 0 |
| Serpentinite | 0 | — | — | — | — | — | — |

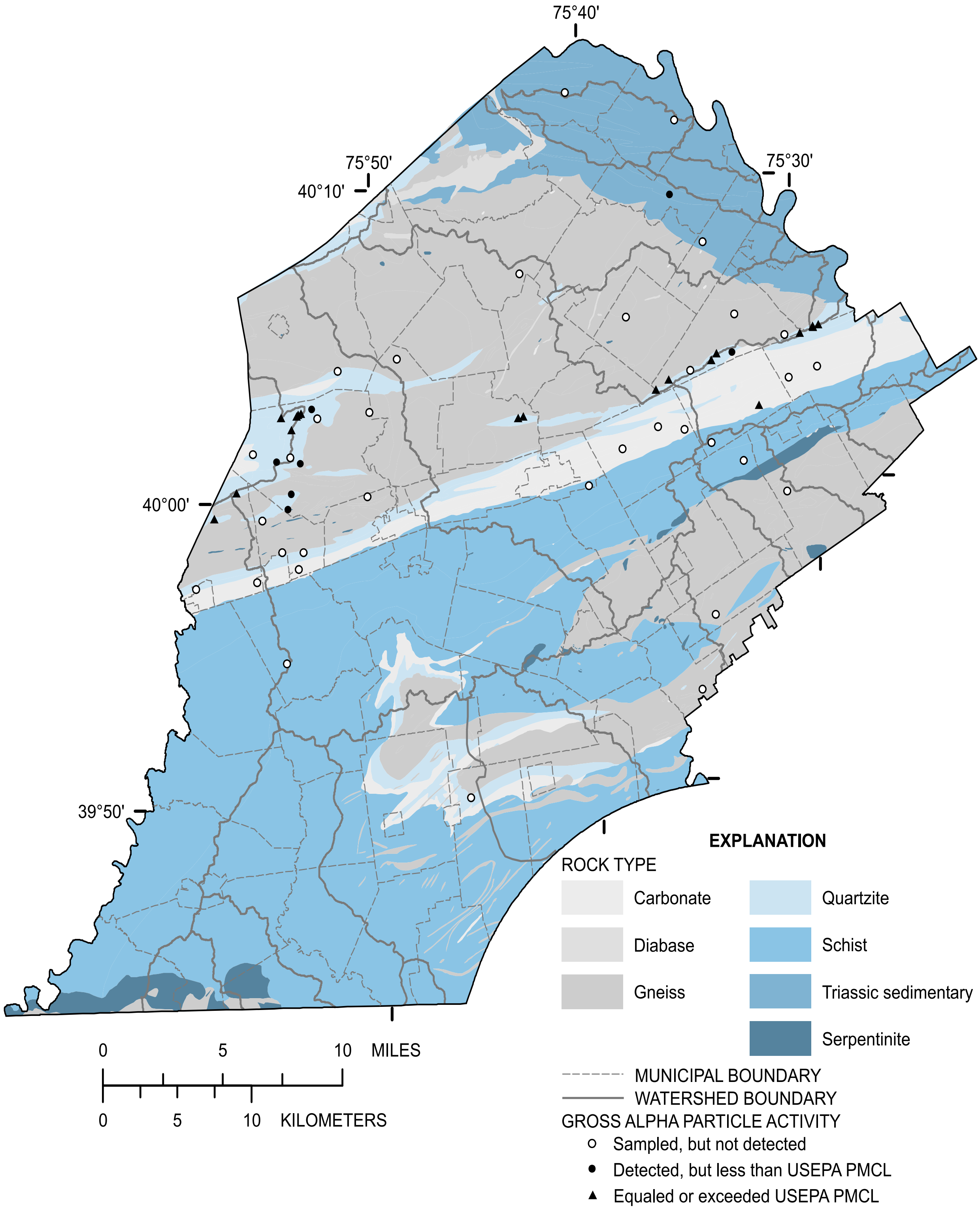

**Figure 22.** Distribution of gross alpha relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Gross Beta Particle Activity

Beta particles are electrons or positrons ejected from the nuclei of unstable elements. Gross beta particle activity is the energy released by all beta particle emitters, resulting from the natural decay of uranium in rocks and soil.

Public supply wells are tested for beta radioactivity by using an analysis referred to as "gross beta activity." Gross beta activity is a screening tool to determine if beta activities are above background levels. Gross beta is calculated as the total beta activity *minus* naturally occurring potassium-40 activity. If gross beta activities equal or exceed 50 pCi/L, USEPA requires public water suppliers to determine the particular radionuclides present in their source water.

The USEPA PMCL for gross beta particles is 4 millirems per year (mrem/yr), a dose shown to pose an increased risk of cancer. Millirems per year is a measure of *exposure* to ionizing radiation, rather than a measure of concentration (such as micrograms per liter for uranium) or measure of radioactivity (such as picocuries per liter for radon-222).

Samples from 154 wells were analyzed for gross beta activity. The median activity for all samples was 5.10 pCi/L. Samples from wells in quartzite had the highest median activity (9.25 pCi/L) of any of the rock types (table 25). Gross beta particle activities from 14 samples (9 percent) exceeded the USEPA screening level of 50 pCi/L, including 14 percent of wells in quartzite rocks (range 51 - 697 pCi/L), and 9 percent of wells in carbonate rocks (58 pCi/L) (fig. 23). All samples from quartzite that exceeded the USEPA screening level were from wells in the Chickies Quartzite.

**Table 25.** *Summary statistics for dissolved gross beta particle activity in ground water, by rock type, based on samples collected from 1985 to 2001*

[—, too few samples to compute statistics or percentages; <, less than]

| Rock type | Total number of samples | Dissolved gross beta, in picocuries per liter as Cs-137 | | | | | Percentage of samples equal or exceeding 50 picocuries per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 154 | 0.60 | 2.80 | 5.10 | 17.0 | 697 | 9 |
| Carbonate | 11 | 1.60 | 2.60 | 3.80 | 10.5 | 58.0 | 9 |
| Diabase | 0 | — | — | — | — | — | — |
| Gneiss | 19 | .60 | 1.35 | 2.50 | 3.75 | 34.0 | 0 |
| Quartzite | 90 | <1.00 | 5.00 | 9.25 | 29.8 | 697 | 14 |
| Schist | 12 | 1.30 | 2.02 | 3.35 | 6.40 | 40.4 | 0 |
| Triassic sedimentary | 22 | .96 | 1.85 | 2.35 | 4.08 | 6.00 | 0 |
| Serpentinite | 0 | — | — | — | — | — | — |

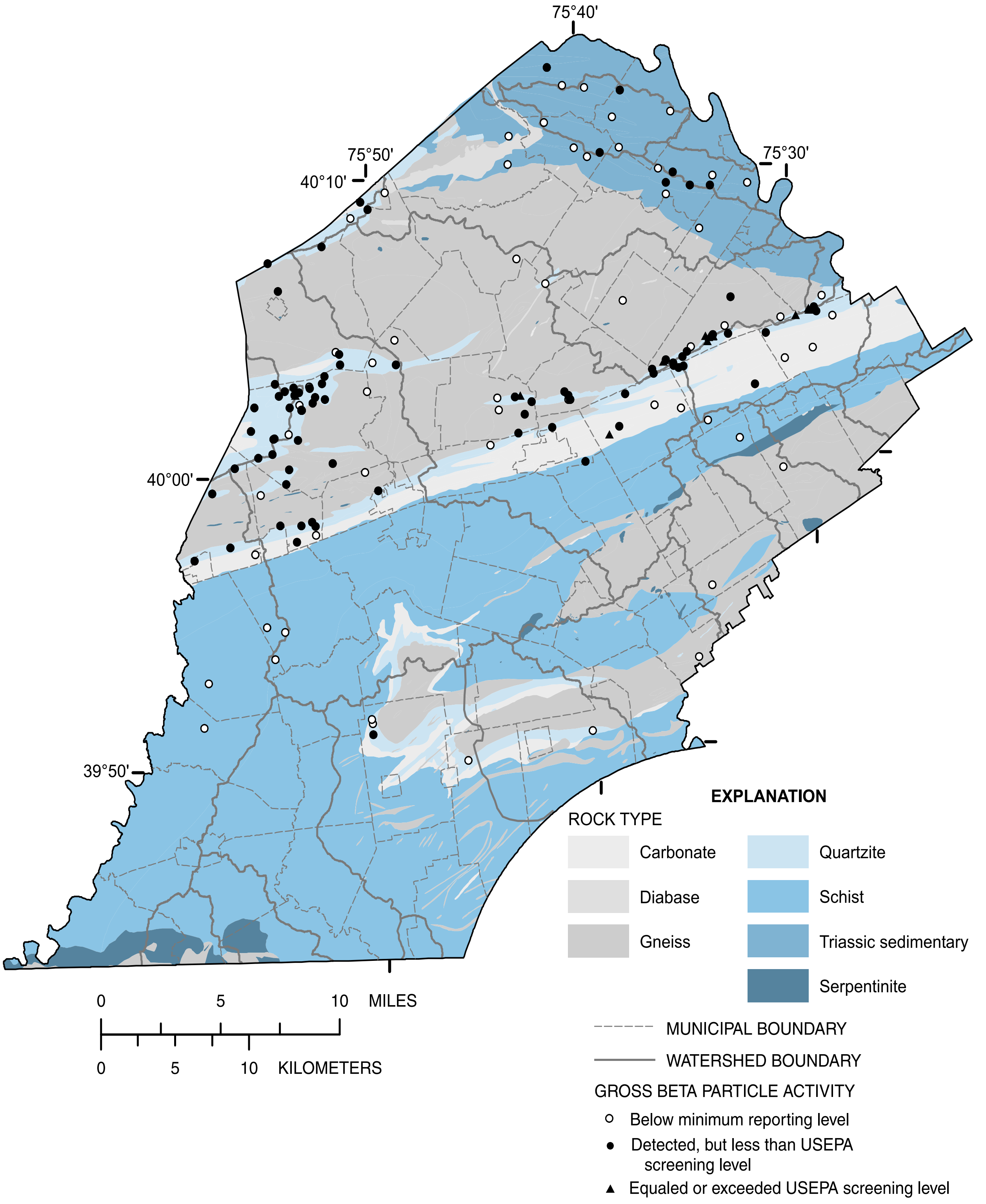

**Figure 23.** Distribution of gross beta relative to generalized rock types. (USEPA, U.S. Environmental Protection Agency)

## BACTERIA

### Fecal Coliforms

Fecal coliforms are among the most widely used indicator bacteria. One species of fecal coliform, *Escherichia coli* (*E. coli*) is found solely in the feces of warm-blooded animals. Its presence in water indicates contamination of intestinal origin. These bacteria can enter ground water from animal wastes infiltrating the surface or from failing or improperly located septic systems, sand-mounds, and sewage lagoons. Most fecal coliforms are not dangerous, but their presence is an indicator that disease-causing (pathogenic) organisms such as bacteria, viruses, and parasites also may be present.

Fecal coliforms and *E. coli* are members of a larger group of bacteria collectively referred to as total coliforms. The USEPA Maximum Contaminant Level Goal (MCLG) for total coliforms is zero colonies per 100 mL (sometimes expressed as less than 1 colony per 100 mL or simply <1/100 mL). If a water sample tests positive for total coliforms, the sample also must be tested for fecal coliform and *E. coli.* The CCHD requires total coliform measurements for new and re-constructed homeowner wells and utilizes the same goal for drinking-water quality. If well water tests positive for total coliform, the CCHD requires water treatment.

Of 69 samples collected from 42 wells, 42 samples were analyzed for fecal coliform and 27 samples were analyzed for *E. coli* bacteria. Only two samples analyzed for fecal coliform exceeded the USEPA MCLG for total coliform bacteria; one sample had an estimated 1 col/100 mL and the other had 5 col/100 mL (fig. 24). Both samples were in agricultural areas. No samples from 27 wells (including 17 of the same wells sampled for fecal coliform) analyzed for *E. coli* exceeded the USEPA MCLG. Statistics were not computed for these indicators because all but two samples had less than 1 col/100 mL.

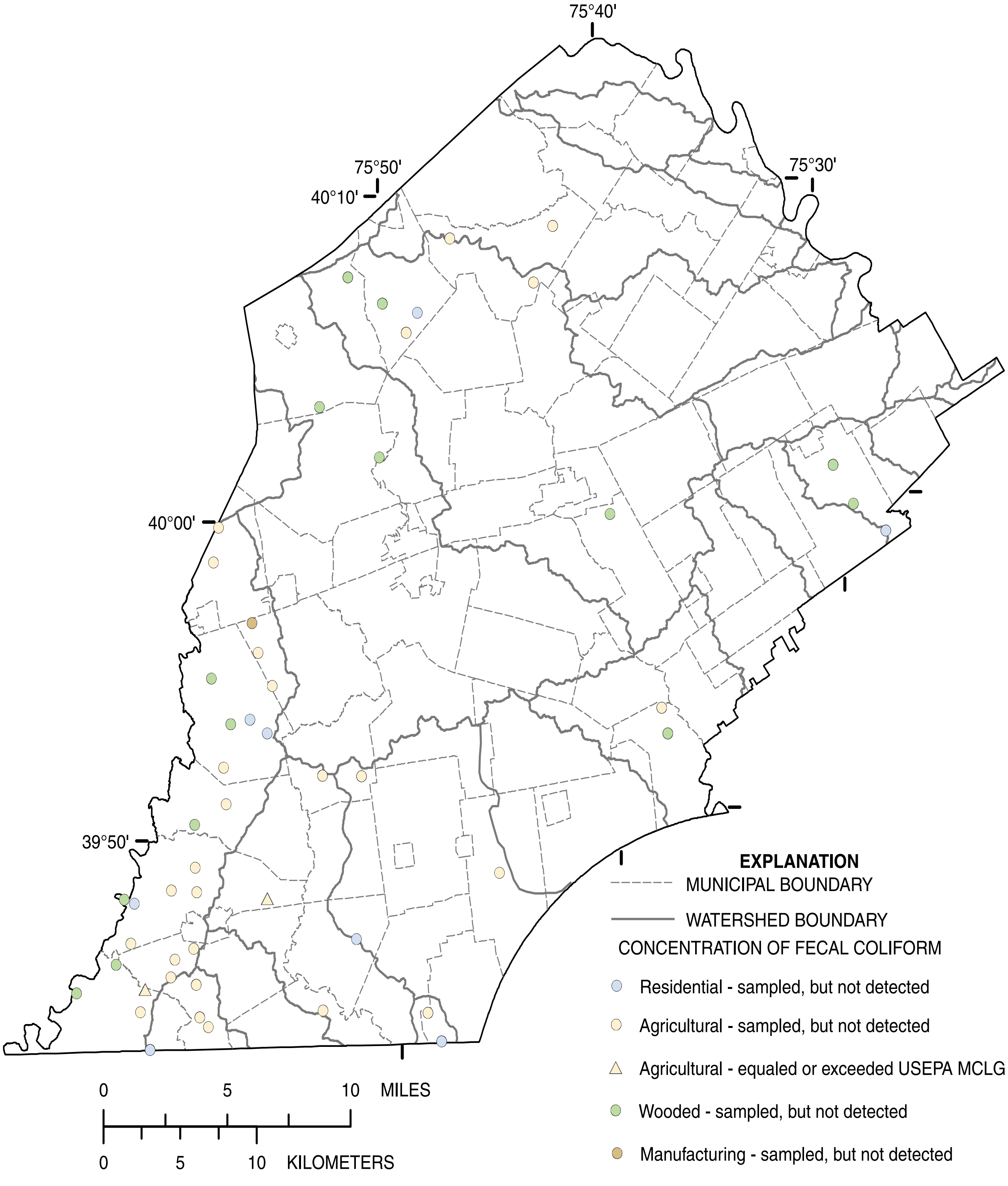

**Figure 24.** Distribution of fecal coliforms relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; MCLG, Maximum Contaminant Level Goal)

# NUTRIENTS

## Nitrate

Nitrate is the predominant form of nitrogen found in ground water. Elevated nitrate concentrations are caused by human activities; nitrate can enter ground-water supplies through municipal and industrial wastewaters, septic systems, feedlot discharges, farm and lawn fertilizers, animal wastes, leachate from waste disposal in dumps or sanitary landfills, atmospheric fallout, nitric oxide and nitrite emissions from vehicle exhaust, discharges from other combustion processes, and losses from mineralization of soil organic matter and other natural sources (National Academy of Sciences, 1972; U.S. Environmental Protection Agency, 1976).

Small concentrations of nitrate do not cause any public health problems in drinking water and do not affect water use. However, the USEPA PMCL for nitrate is 10 mg/L. If concentrations of nitrate exceed 10 mg/L as nitrogen (N), infants under 6 months can develop “blue baby syndrome” (methemoglobinemia), which can be life-threatening. In this condition, oxygen transport in the bloodstream is impaired by the effects of the reduced form of nitrate (nitrite) on the hemoglobin. Concentrations that approach or exceed 10 mg/L are not unusual in rural water supplies because of the proximity of nitrogen sources (U.S. Environmental Protection Agency, 1976, p. 108).

The median concentration for dissolved nitrate in samples from 607 wells was 3.38 mg/L (table 26). Nitrate concentrations in 68 samples (11 percent) met or exceeded the USEPA PMCL (fig. 25), including 18 percent of wells in agricultural land-use areas (10 - 38 mg/L), 12 percent of wells in services land-use areas (10.8 - 45 mg/L), 7 percent of wells in low-medium density residential land-use areas (10 - 36 mg/L), 7 percent of wells in wooded land-use areas (10.4 - 23 mg/L), and 5 percent of wells in manufacturing land-use area (15 mg/L). The highest median concentration is in the agricultural land-use area (4.40 mg/L).

**Table 26.** *Summary statistics for dissolved nitrate in ground water, by land use, based on samples collected from 1980 to 2001*

[PMCL, primary maximum contaminant level; <, less than; —, too few samples to compute statistics; E, estimated]

| Land use | Total number of samples | Dissolved nitrate, in milligrams per liter | | | | | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 607 | <0.020 | 1.20 | 3.38 | 6.50 | 45.0 | 11 |
| Low-medium density residential | 188 | <0.020 | 1.20 | 3.35 | 5.72 | 36.0 | 7 |
| High-density residential | 3 | .380 | — | — | — | 4.50 | 0 |
| Agricultural | 227 | E .030 | 1.80 | 4.40 | 8.38 | 38.0 | 18 |
| Wooded | 118 | E .030 | .748 | 2.20 | 4.95 | 23.0 | 7 |
| Manufacturing | 22 | .020 | .298 | 2.00 | 5.96 | 15.0 | 5 |
| Services | 49 | .060 | 1.60 | 2.70 | 7.00 | 45.0 | 12 |

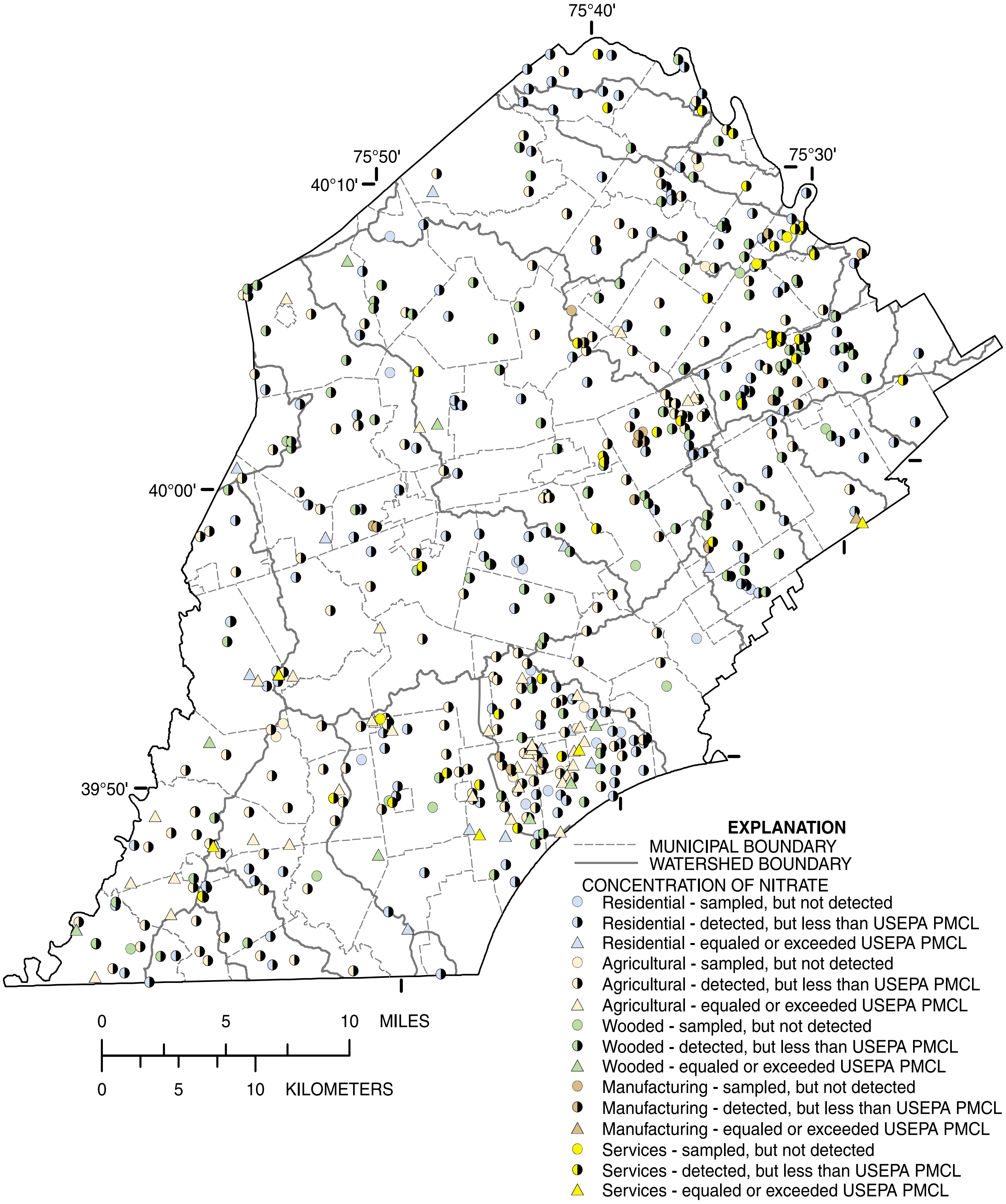

**Figure 25.** Distribution of nitrate relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Nitrite

Nitrite ions are formed from nitrate or ammonium ions by microorganisms in soil, water, sewage, and the digestive tract as part of the nitrogen cycle. The presence of nitrite in ground water indicates organic pollution from fertilizers, animal wastes, or leaching from septic tanks and sewage. It is a short-lived intermediate product in the nitrification process, and in environments where oxygen is present, nitrite ($NO_2$) rapidly changes to nitrate ($NO_3$). Therefore, nitrite usually is present in small amounts unless the source of pollution is nearby or oxygen is not present (Hem, 1992).

Nitrite can become toxic when concentrations are high enough to effect the hemoglobin of infants and result in "blue baby syndrome." The USEPA PMCL for nitrite is 1 mg/L as nitrogen (N).

Water samples from 666 wells were analyzed for dissolved nitrite. The median concentration for all samples was less than 0.010 mg/L (table 27). Only one sample exceeded the USEPA PMCL for nitrite (1.01 mg/L in the services land-use area). Nitrite concentrations at or above the highest minimum reporting level (0.040 mg/L) in 20 samples included 3 percent of wells in residential land-use areas (range 0.040 - 0.330 mg/L), 3 percent of wells in agricultural land-use areas (range 0.060 - 0.823 mg/L), 2 percent of wells in wooded land-use areas (range 0.040 - 0.350 mg/L), 4 percent of wells in manufacturing land-use area (0.550 mg/L), and 5 percent of wells in services land-use areas (range 0.040 - 1.01 mg/L) (fig. 26).

**Table 27.** *Summary statistics for dissolved nitrite in ground water, by land use, based on samples collected from 1980 to 2001*

[PMCL, primary maximum contaminant level; E, estimated; <, less than; —, too few samples to compute statistics]

| Land use | Total number of samples | Dissolved nitrite, in milligrams per liter | | | | | Percentage of samples equal or exceeding 0.040 milligrams per liter | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | | |
| All wells | 666 | E 0.003 | <0.010 | <0.010 | <0.010 | 1.01 | 3 | < 1 |
| Low-medium density residential | 206 | <.006 | <.010 | <.010 | <.010 | .330 | 3 | 0 |
| High-density residential | 2 | <.010 | — | — | — | <.010 | 0 | 0 |
| Agricultural | 246 | E .003 | <.010 | <.010 | <.010 | .823 | 3 | 0 |
| Wooded | 133 | E .003 | <.010 | <.010 | <.010 | .350 | 2 | 0 |
| Manufacturing | 24 | <.010 | <.010 | <.010 | .010 | .550 | 4 | 0 |
| Services | 55 | <.010 | <.010 | <.010 | <.010 | 1.01 | 5 | 2 |

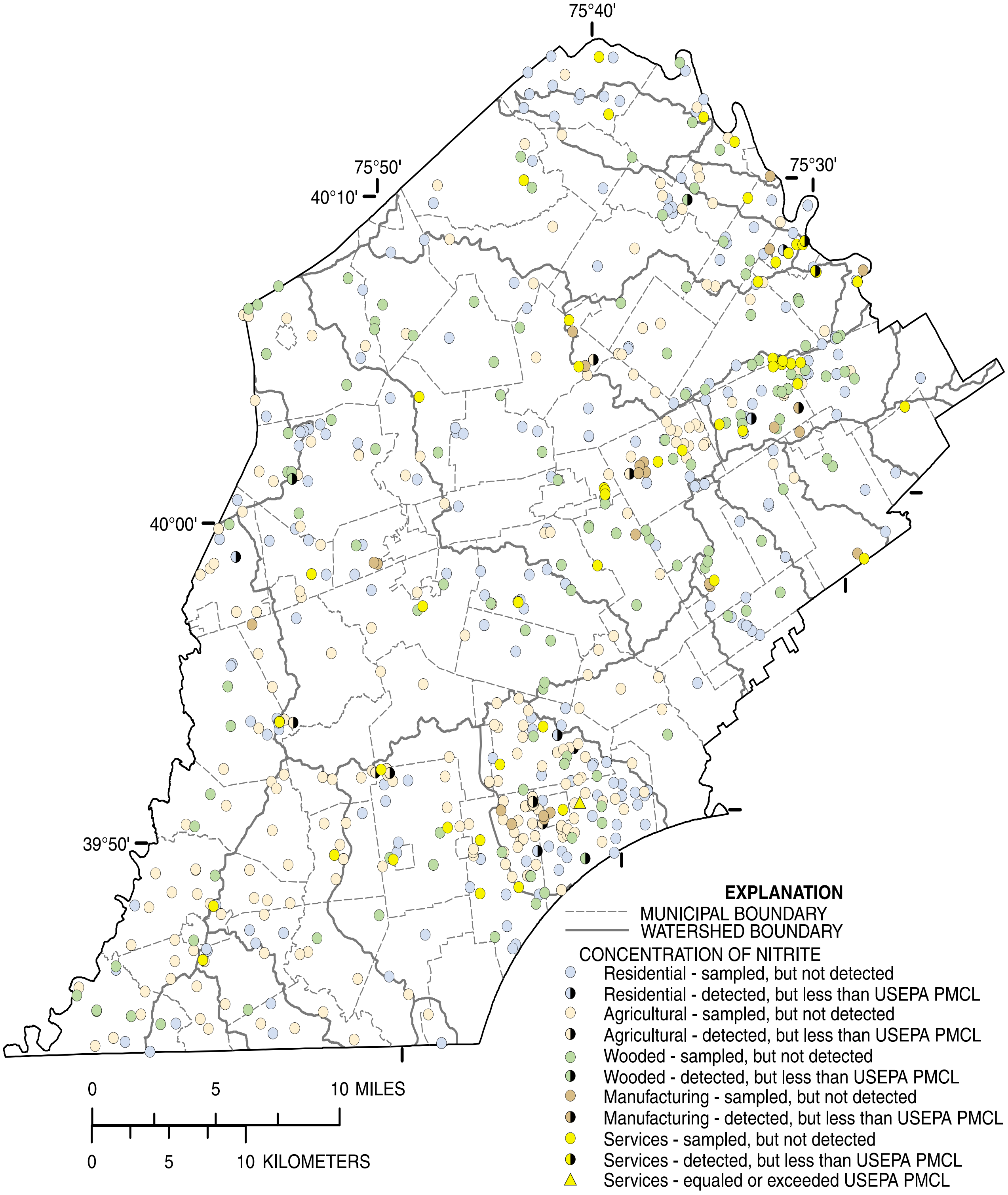

**Figure 26.** Distribution of nitrite relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Phosphorus

Phosphorus is a common element of igneous rock. It is similar to nitrogen in that it can occur at various oxidation states, but the fully oxidized (phosphate) form is the most significant in natural-water systems. Concentrations of phosphorus in natural water are significantly less than nitrate (Hem, 1992). The most common sources of phosphorus are phosphate fertilizers, sewage, and some organic chemicals (Hem, 1992).

The orthophosphate ion is the final breakdown product of phosphoric acid and is the most likely form to occur in natural water. The concentration of dissolved orthophosphate in ground water is important because it can be an indicator of pollution. The USEPA has no PMCL or SMCL for phosphorus.

Samples were collected from 505 wells and analyzed for dissolved phosphorus. The median concentration is 0.010 mg/L. The services land-use area had the highest median concentration at 0.016 mg/L (table 28). Phosphorus concentrations at or above the highest MRL (0.020 mg/L) in 206 samples included 47 percent of wells in services land-use areas (range 0.020 - 0.140 mg/L), 50 percent of wells in manufacturing land-use areas (range 0.020 - 0.120 mg/L), 42 percent of wells in residential land-use areas (range 0.020 - 0.210 mg/L), 42 percent of wells in agricultural land-use areas (range 0.020 - 0.111 mg/L), and 31 percent of wells in wooded land-use areas (range 0.020 - 0.120 mg/L). Phosphorus concentrations in both samples collected from high-density residential land-use areas were above the highest MRL (0.040 and 0.060 mg/L).

**Table 28.** *Summary statistics for dissolved phosphorus in ground water, by land use, based on samples collected from 1982 to 2001*

[<, less than; —, too few samples to compute statistics]

| Land use | Total number of samples | Dissolved orthophosphate, in milligram per liter | | | | | Percentage of samples equal or exceeding 0.020 milligram per liter |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th percentile | Median | 75th percentile | Maximum | |
| All wells | 505 | <0.001 | <0.010 | 0.010 | 0.022 | 0.210 | 41 |
| Low-medium density residential | 170 | <.001 | <.010 | .010 | .028 | .210 | 42 |
| High-density residential | 2 | .040 | — | — | — | .060 | 100 |
| Agricultural | 184 | .001 | <.010 | .012 | .021 | .111 | 42 |
| Wooded | 99 | .002 | <.010 | .010 | .020 | .120 | 31 |
| Manufacturing | 16 | <.010 | <.010 | .015 | .033 | .120 | 50 |
| Services | 34 | <.010 | <.010 | .016 | .030 | .140 | 47 |

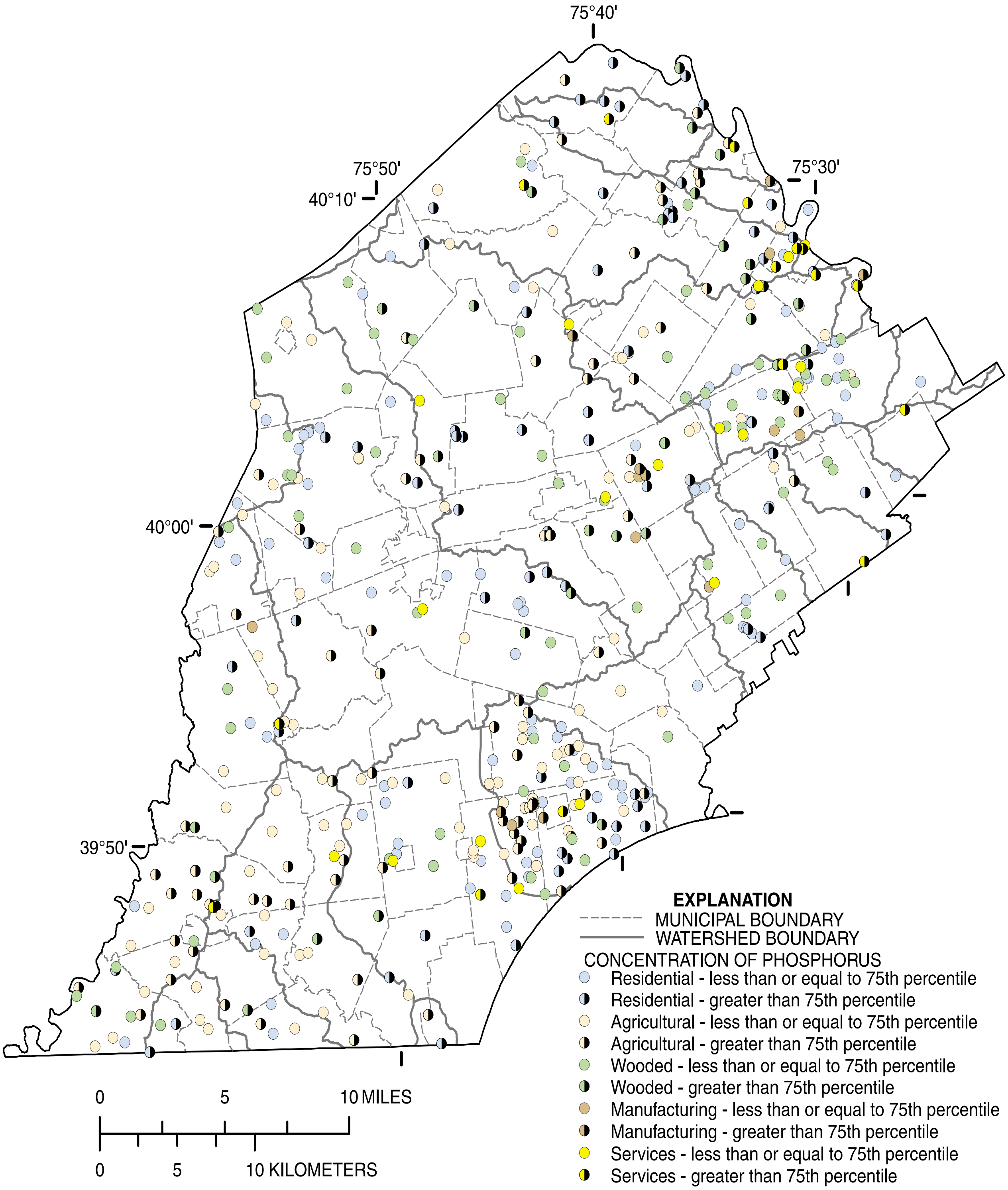

**Figure 27.** Distribution of phosphorus relative to generalized land use.

# PESTICIDES

## Total Pesticides

Pesticide is a term that collectively refers to many types of chemical compounds useful for controlling microbes, fungi, plants, mites, insects, and animals. Pesticides can be classified either by the intended use (such as fungicide, herbicide, or insecticide) or by the active ingredients in the chemical compounds (such as organochlorines, organonitrogens, or organophosphates).

Pesticides in the ground water of Chester County include a few of each from organochlorines, organonitrogens, organophosphates, and organic acids. Organochlorine pesticides are persistent in soil and water, and include aldrin, chlordane, dieldrin, DDT, endrin, heptachlor, lindane, mirex, toxaphene, and other pesticides. Many organochlorine pesticides currently are banned. Organophosphate pesticides are substitutes for banned organochlorine pesticides because they are less persistent in the environment and are more selective to targeted species (Sloto, 1994). Organophosphate pesticides include chlorpyrifos, diazinon, disulfoton, ethion, malathion, parathion, and other pesticides. Both organochlorine and organophosphate pesticides were (are) active ingredients for insecticides used in residential and agricultural settings. Organonitrogen (triazine) herbicides are moderately to highly persistent in soils, and organic acid herbicides are moderately persistent in soils. Both herbicides primarily are degraded by microbes.

In Chester County, lindane and dieldrin were the only organochlorine pesticides detected and were the most commonly detected of the analyzed pesticides (lindane in 16 wells, dieldrin in 9 wells). Organochlorine *metabolites* (new compounds formed from the physiological processes of microbes, plants, or animals exposed to pesticides), heptachlor epoxide and methoxychlor, were detected in three instances, in low concentrations (less than 0.090 µg/L). Ethion, malathion, and diazinon were the only organophosphate pesticides detected. In one well, all three were detected, and malathion and diazinon had relatively elevated concentrations (ethion 0.02 µg/L; malathion 25.0 µg/L, and diazinon 57.0 µg/L). In another well, malathion and diazinon were detected at 0.29 and 490 µg/L, respectively. Of the wells with detected organophosphate pesticides, 80 percent had concentrations less than 1 µg/L. Organonitrogen herbicide pesticides were detected eight times—three detections of atrazine and one detection each of alachlor, cyanazine, deethylatrazine, prometon, and propazine. All compounds had concentrations less than 7 µg/L. Organic acid pesticides were detected five times, including picloram; 2,4-D; and dicamba. All concentrations were less than 1 µg/L.

Since 1990, ground-water samples in Chester County have been analyzed for 57 pesticides, from a total of 204 wells. Not all pesticides were analyzed in water from all wells. Instead, approximately half of those pesticides have been analyzed in water from at least 38 wells, and select pesticides have been analyzed in water from as many as 196 wells. Of the 204 wells sampled, 35 wells (17 percent) had detectable concentrations of pesticides (table 29). Of the wells that tested positive for one pesticide, 14 wells (40 percent) tested positive for more than one pesticide (fig. 28). Detections included insecticides, 42 instances; herbicides, 15 instances; and metabolites, 4 instances. In Chester County, the pesticides most commonly detected were lindane, dieldrin, and diazinon. A list of the pesticides analyzed appears at the end of the report (table 38).

**Table 29.** *Wells analyzed for presence of total pesticides by land use, based on samples collected from 1990 to 2001 (Percentages may not agree because of independent rounding)*

[—, no samples; <, less than]

| Land use | Number of wells | | Percentage of wells testing positive for pesticides | | | | |
|---|---|---|---|---|---|---|---|
| | Sampled | Testing positive for pesticides | Any pesticide | One pesticide | Two pesticides | Three pesticides | Five or more pesticides |
| All wells | 204 | 35 | 17 | 10 | 4 | 1 | 1 |
| Residential | 58 | 10 | 17 | 12 | — | 2 | 3 |
| Agricultural | 106 | 18 | 17 | 8 | 6 | 2 | <1 |
| Wooded | 30 | 5 | 17 | 10 | 7 | — | — |
| Manufacturing | 3 | 0 | — | — | — | — | — |
| Services | 7 | 2 | 29 | 29 | — | — | — |

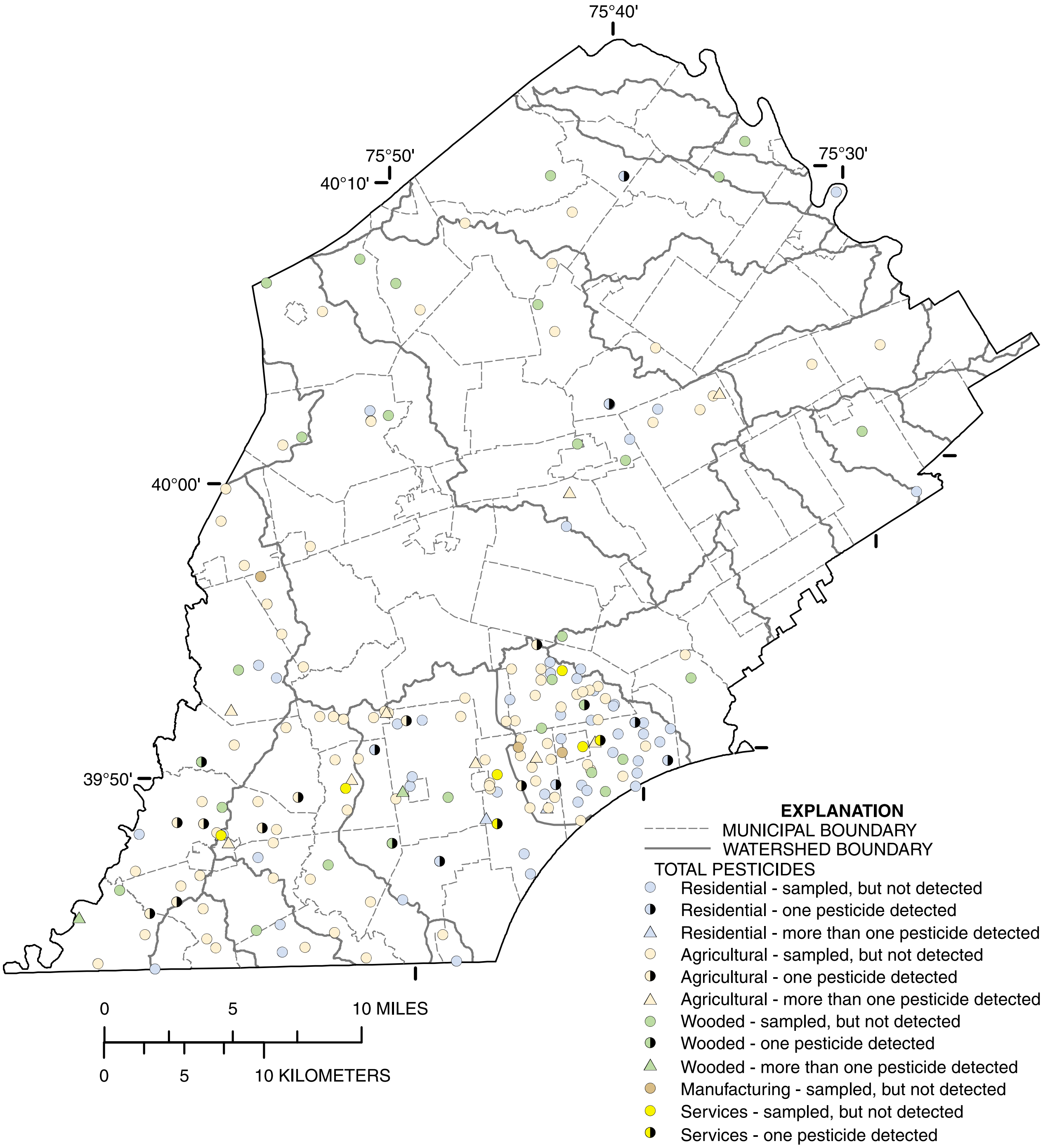

**Figure 28.** Distribution of total pesticides relative to generalized land use.

## Lindane

Lindane is an organochlorine pesticide formerly used as a soil treatment, a termiticide around homes and buildings, and a pesticide on many agricultural crops including grains, fruits, nuts, and vegetables. Lindane commonly was used by the mushroom growing industry in Chester County.

Like most organochlorine pesticides, lindane degrades slowly and accumulates in the fatty tissues of organisms. Fate studies show that lindane is persistent in soils with a half-life of 2.6 years (U.S. Environmental Protection Agency, 2002). The production of lindane in the United States was restricted in 1977 and banned in 1983, but it is still imported for limited uses. Lindane is toxic to the liver and kidneys in humans. The USEPA PMCL is 0.0002 mg/L (0.2 ∝g/L).

Concentrations of total (unfiltered) lindane and dissolved (filtered) lindane were combined for analysis. Samples from 193 wells were analyzed for lindane. Both the median concentration and MRL were less than 0.010 ∝g/L. Only nine samples (5 percent) had concentrations above the MRL and were detected in 8 percent of wells in residential land-use areas (0.010 - 0.100 ∝g/L), 7 percent of wells in wooded land-use areas (0.020 and 0.340 ∝g/L), and 3 percent of wells in agricultural land-use areas (0.010 - 0.027 ∝g/L) (table 30). Only one sample (less than 1 percent) exceeded the USEPA PMCL of 0.2 ∝g/L, the concentration was 0.340 ∝g/L from a well in the wooded land-use area (fig. 29).

**Table 30.** *Total and dissolved lindane in ground water, by land use, based on samples collected from 1990 to 2001*

[∝g/L, micrograms per liter; PMCL, primary maximum contaminant level; <, less than; —, no samples or too few samples to compute percentages]

| Land use | Total number of samples | Percentage of samples with detectable lindane | Maximum total and dissolved lindane (∝g/L) | Percentage of samples exceeding PMCL |
|---|---|---|---|---|
| All wells | 193 | 5 | 0.340 | <1 |
| Low-medium density residential | 53 | 8 | .100 | 0 |
| High-density residential | 0 | — | — | — |
| Agricultural | 103 | 3 | .027 | 0 |
| Wooded | 27 | 7 | .340 | 4 |
| Manufacturing | 3 | 0 | <.010 | 0 |
| Services | 7 | 0 | <.010 | 0 |

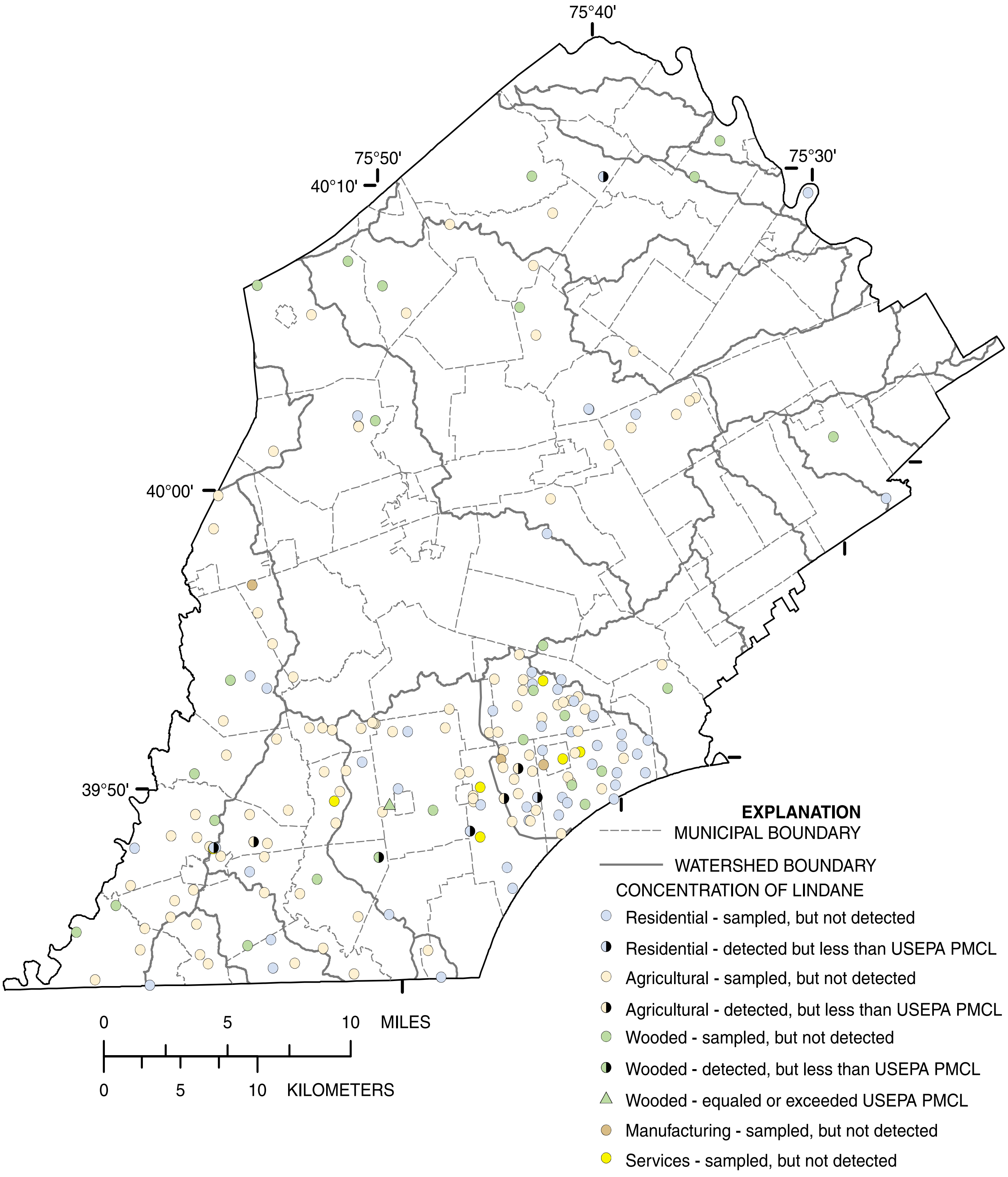

**Figure 29.** Distribution of lindane relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Dieldrin

Dieldrin was a pesticide used from the 1950s to the 1970s in agriculture for soil and seed treatment, as a pesticide for woolen and lumber products, and in the control of termites and mosquitoes. In the United States, dieldrin was banned for most uses in 1975 and banned for all uses in 1987. Dieldrin is no longer produced or imported into the United States.

Dieldrin is toxic and persistent in the environment. Aldrin, a similar pesticide, degrades to become dieldrin. Residual contamination may be present at waste sites from disposal of unused stock. The USEPA has no PMCL for dieldrin.

Concentrations of total and dissolved dieldrin from 196 samples were combined for analysis. No samples were collected from the high-density residential land-use areas, and only a few samples were collected from manufacturing and services land-use areas (fig. 30). The median concentration for all the samples was less than 0.010 µg/L. Dieldrin concentrations, with few exceptions, were reported at the MRL. Only seven samples had detectable dieldrin concentrations, including 4 percent of wells in residential land-use areas (0.010 and 0.015 µg/L), 4 percent of wells in agricultural land-use areas (range 0.010-0.343 µg/L), and 4 percent of wells in wooded land-use areas (0.021 µg/L) (table 31).

**Table 31.** *Total and dissolved dieldrin in ground water, by land use, based on samples collected from 1990 to 2001*

[µg/L, micrograms per liter; —, no samples; <, less than]

| Land use | Total number of samples | Percentage of samples with detectable dieldrin | Maximum total and dissolved dieldrin (µg/L) |
|---|---|---|---|
| All wells | 196 | 4 | 0.343 |
| Low-medium density residential | 55 | 4 | .015 |
| High-density residential | 0 | — | — |
| Agricultural | 104 | 4 | .343 |
| Wooded | 27 | 4 | .021 |
| Manufacturing | 3 | 0 | <.010 |
| Services | 7 | 0 | <.010 |

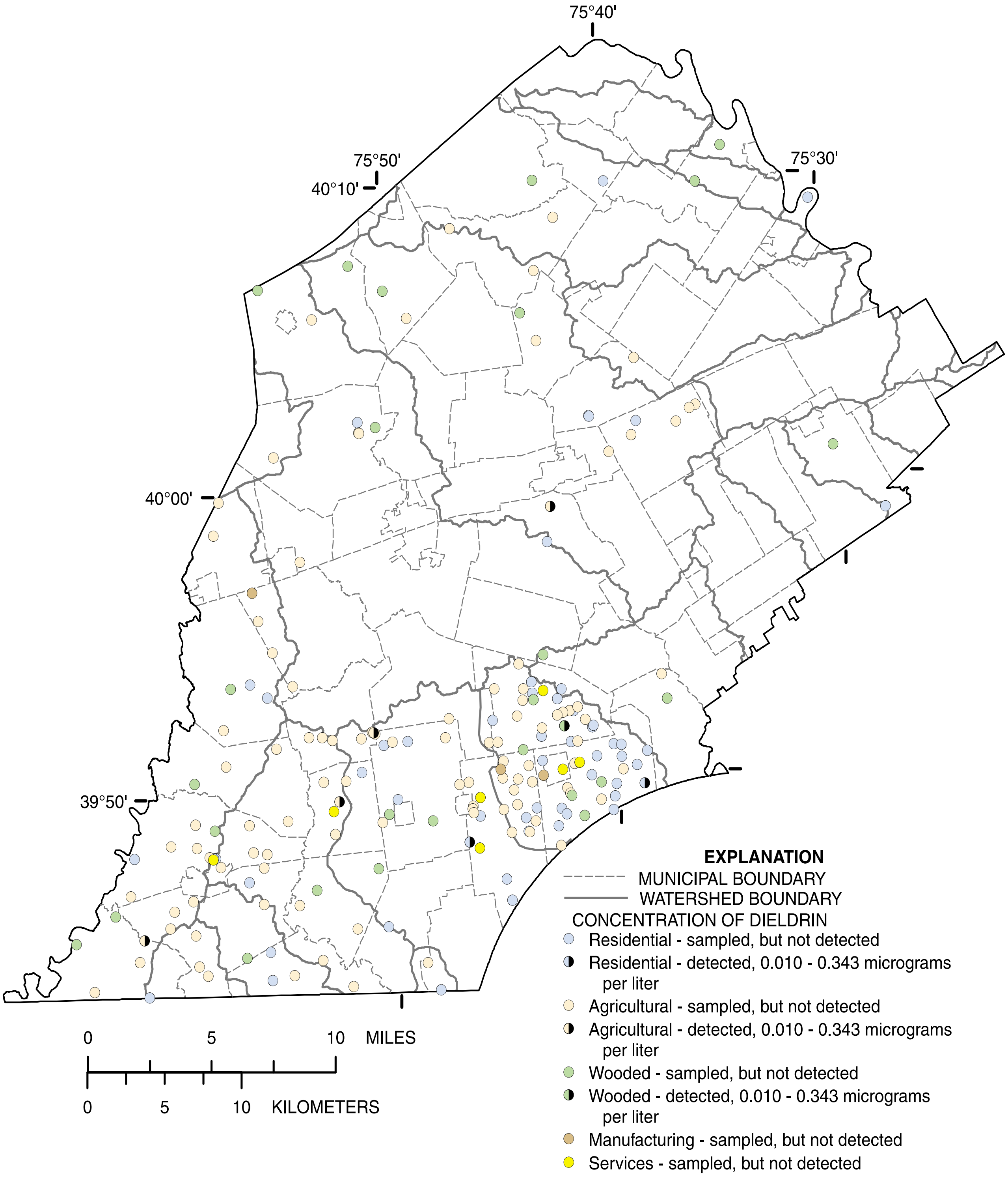

**Figure 30.** Distribution of dieldrin relative to generalized land use.

## Diazinon

Diazinon is an organophosphate pesticide that originally was developed as a nerve gas during World War II. It is used to control pest insects in soil, on fruit and vegetable field crops, on ornamental plants in gardens, and in control of household pests. Diazinon breaks down into other chemicals after application and has a half-life of a few hours to 2 weeks depending on environmental conditions. It has been found in ground water. In 2000, USEPA banned diazinon for indoor use, and a 4-year phase out was planned for outdoor lawn and garden applications.

Diazinon has not been shown to have carcinogenic or bio-accumulation effects. The USEPA does not have a PMCL for diazinon, but it does have a Health Advisory concentration of 20 µg/L. At or above 20 µg/L concentrations, diazinon can effect the function of specific enzymes and the nervous system.

Concentrations of total and dissolved diazinon from 182 samples were combined for analysis. The median concentration was less than 0.002 µg/L. Only 11 samples (6 percent) had detectable concentrations, including 8 percent of wells in residential land-use areas (0.010 - 490 µg/L), 4 percent of wells in agricultural land-use areas (0.012 - 0.022 µg/L), and 13 percent of wells in wooded land-use areas (0.010 - 0.220 µg/L) (fig. 31) (table 32). Of those same samples, two exceeded the USEPA Health Advisory concentration (57 and 490 µg/L). Both samples were from wells in residential land-use areas.

**Table 32.** *Total and dissolved diazinon in ground water, by land use, based on samples collected from 1990 to 2001*

[µg/L, micrograms per liter; —, no samples]

| Land use | Total number of samples | Percentage of samples with detectable diazinon | Maximum total and dissolved diazinon concentration (µg/L) |
|---|---|---|---|
| All wells | 182 | 6 | 490 |
| Low-medium density residential | 53 | 8 | 490 |
| High-density residential | 0 | — | — |
| Agricultural | 97 | 4 | .022 |
| Wooded | 23 | 13 | .220 |
| Manufacturing | 3 | 0 | .002 |
| Services | 6 | 0 | .010 |

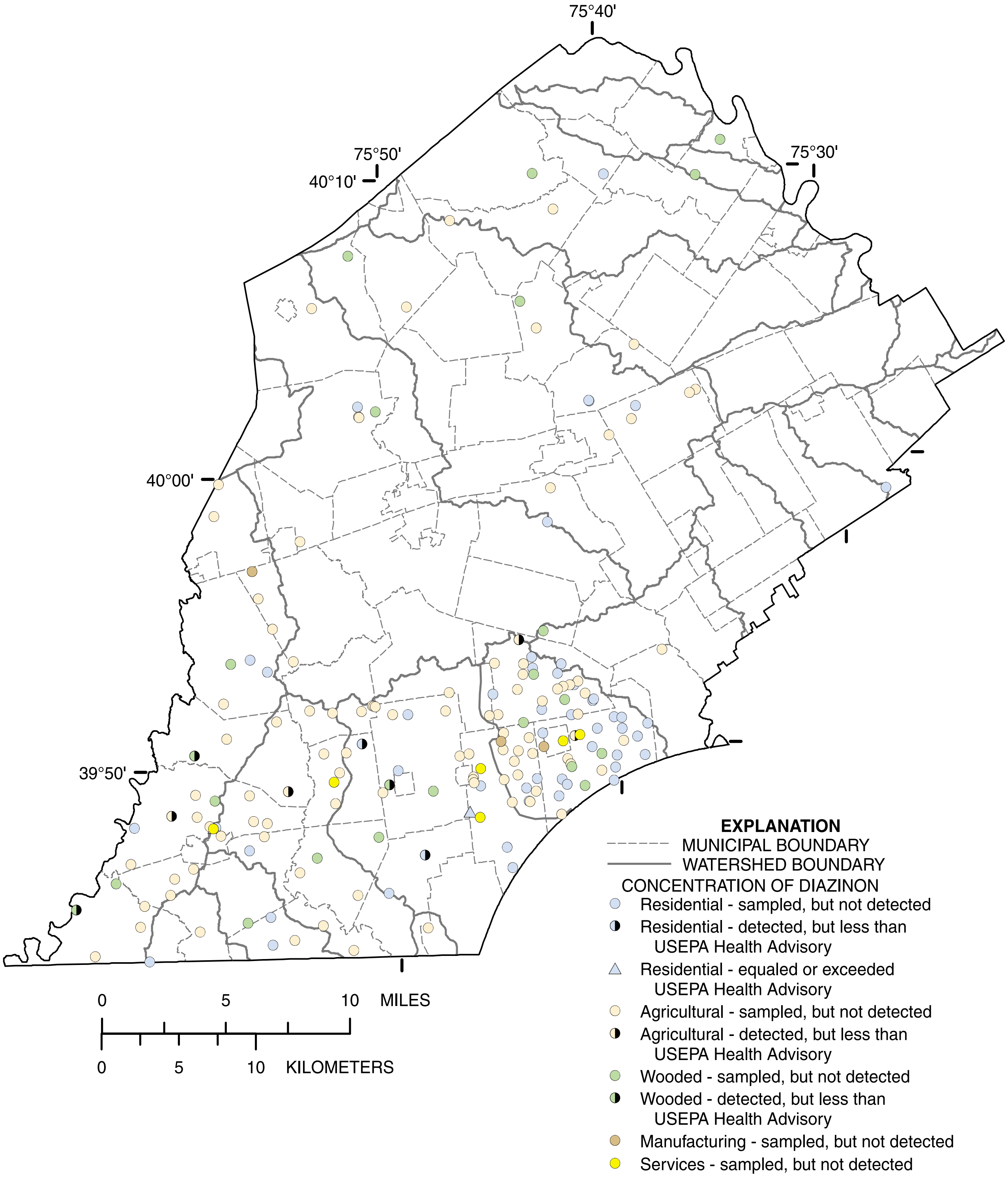

**Figure 31.** Distribution of diazinon relative to generalized land use. (USEPA, U.S. Environmental Protection Agency)

## VOLATILE ORGANIC COMPOUNDS

### Trichloroethylene

Trichloroethylene (TCE) is a nonflammable, colorless liquid with a somewhat sweet odor and a sweet taste. TCE formerly was used as a septic system cleaner. It is currently used as a solvent for cleaning metal parts and as an ingredient in adhesives, paint removers, typewriter correction fluids, and spot removers. TCE also is a degradation by-product of tetrachloroethylene (PCE). Although TCE evaporates quickly, it can find its way into ground-water systems through discharges from industries, treatment plants, septic systems, and hazardous-waste sites. TCE is persistent in ground water.

Low concentrations of TCE in drinking water may cause liver and kidney damage and impair immune system function and fetal development. At elevated concentrations, TCE may also increase the risk of cancer, but the International Agency for Research on Cancer (IARC) determined that TCE is not classifiable as a human carcinogen. Exposure to TCE can result from drinking, swimming, or showering in contaminated water. The USEPA PMCL for TCE is 0.005 mg/L (5.0 ∝g/L).

Samples from 187 wells were analyzed for TCE. Ten percent of the samples had concentrations above the MRL (0.20 ∝g/L), including 2 percent of samples with concentrations that exceeded the USEPA PMCL (table 33). The sample with the highest concentration of TCE was from the residential land-use areas (95.0 ∝g/L), the next highest concentrations were two samples from the wooded land-use areas (37.0 and 45.0 ∝g/L), and one sample from the services land-use areas (14.0 ∝g/L). Detectable TCE concentrations included 36 percent of wells in services land-use areas (range 0.20 - 14.0 ∝g/L), 17 percent of wells in manufacturing land-use areas (0.50 ∝g/L), 10 percent of wells in wooded land-use areas (range 0.14 - 45.0 ∝g/L), 9 percent of wells in agricultural land-use areas (range 0.20 - 0.90 ∝g/L), and 6 percent of wells in residential land-use areas (range 0.40 - 95.0 ∝g/L) (fig. 32).

**Table 33.** *Total trichloroethylene (TCE) in ground water, by land use, based on samples collected from 1990 to 2001*

[∝g/L, micrograms per liter; PMCL, primary maximum contaminant level; <, less than]

| Land use | Total number of samples | Percentage of samples with detectable TCE | Maximum total TCE concentration (∝g/L) | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|
| All wells | 187 | 10 | 95.0 | 2 |
| Low-medium density residential | 68 | 6 | 95.0 | 1 |
| High-density residential | 2 | 0 | <.20 | 0 |
| Agricultural | 69 | 9 | .90 | 0 |
| Wooded | 31 | 10 | 45.0 | 6 |
| Manufacturing | 6 | 17 | .50 | 0 |
| Services | 11 | 36 | 14.0 | 9 |

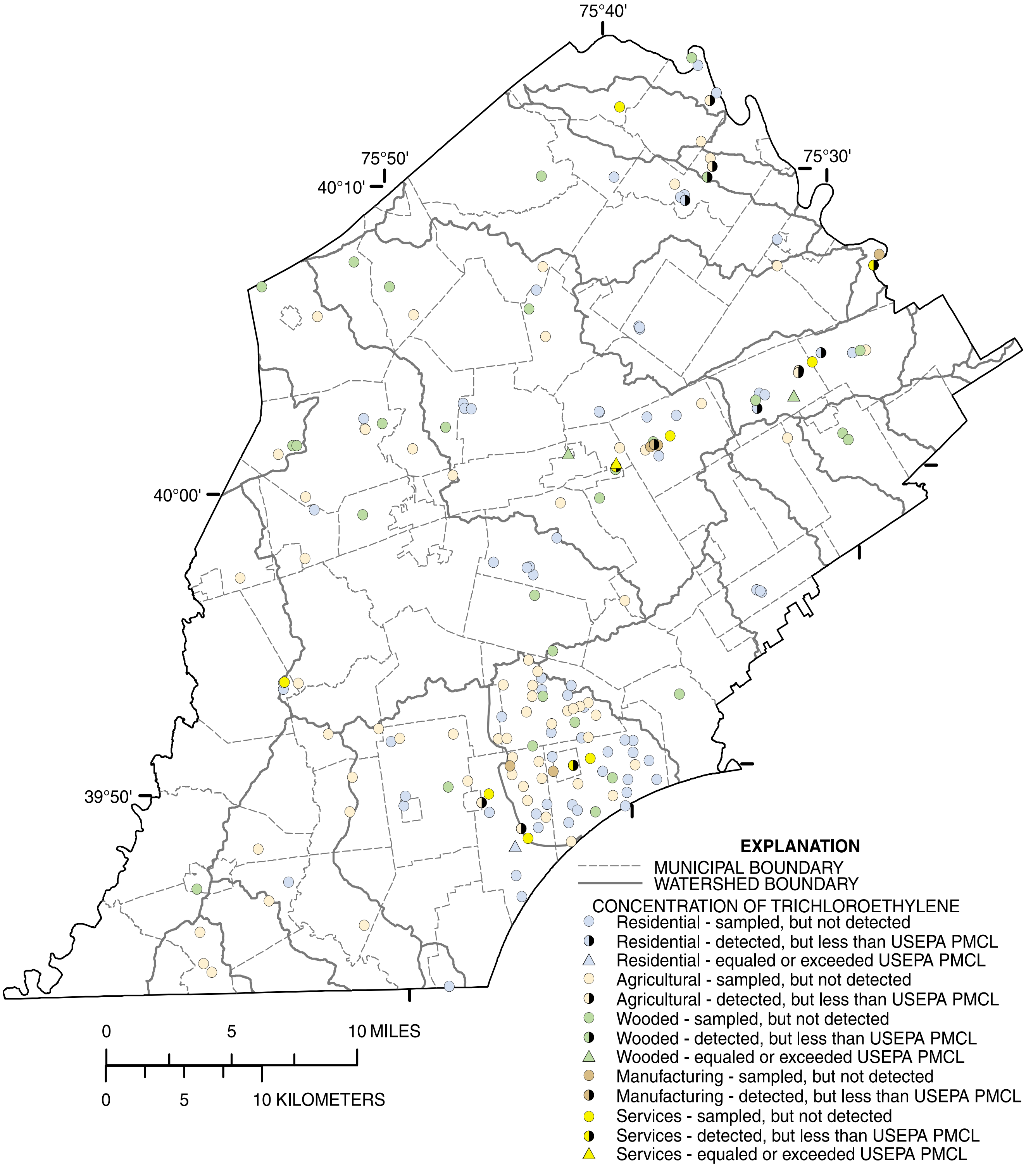

**Figure 32.** Distribution of trichloroethylene relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## Tetrachloroethylene

Tetrachloroethylene (PCE) is a manufactured chemical used for dry cleaning and metal degreasing. Other names for PCE include perchloroethylene and tetrachloroethene. PCE has sources and characteristics similar to TCE. As part of discharges from industrial and treatment plants, septic systems, or leaching from hazardous-waste sites, it evaporates quickly, but once in the ground, it can move readily through soils and enter ground water, where it is persistent.

PCE ingested in small amounts leaves the body mostly through exhalation. The liver processes and removes most of the remaining PCE, but a small amount is stored in body fat. The USEPA PMCL for PCE is 0.005 mg/L (5 ∝g/L), because PCE at this and higher concentrations can cause liver problems and an increased risk of cancer.

Water samples from 185 wells were analyzed for PCE (table 34). PCE concentrations in 10 samples (5 percent) equal to or above the MRL (0.20 mg/L) ranged from 0.20 to 12.0 ∝g/L, including 17 percent of wells in manufacturing land-use areas (0.40 ∝g/L), 10 percent of wells in wooded land-use areas (all 0.20 ∝g/L), 10 percent of wells in services land-use areas (2.1 ∝g/L), 6 percent of wells in residential land-use areas (range 0.80 - 12.0 ∝g/L), and 1 percent of wells in agricultural land-use areas (0.20 ∝g/L). Only one sample from the residential land-use areas (12.0 ∝g/L) exceeded the USEPA PMCL (fig. 33).

**Table 34.** *Total tetrachloroethylene (PCE) in ground water, by land use, based on samples collected from 1991 to 2001*

[∝g/L, micrograms per liter; PMCL, primary maximum contaminant level; <, less than]

| Land use | Total number of samples | Percentage of samples with detectable PCE | Maximum total PCE concentration (∝g/L) | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|
| All wells | 185 | 5 | 12.0 | <1 |
| Low-medium density residential | 68 | 6 | 12.0 | 1 |
| High-density residential | 2 | 0 | <.2 | 0 |
| Agricultural | 69 | 1 | .2 | 0 |
| Wooded | 30 | 10 | .2 | 0 |
| Manufacturing | 6 | 17 | .4 | 0 |
| Services | 10 | 10 | 2.1 | 0 |

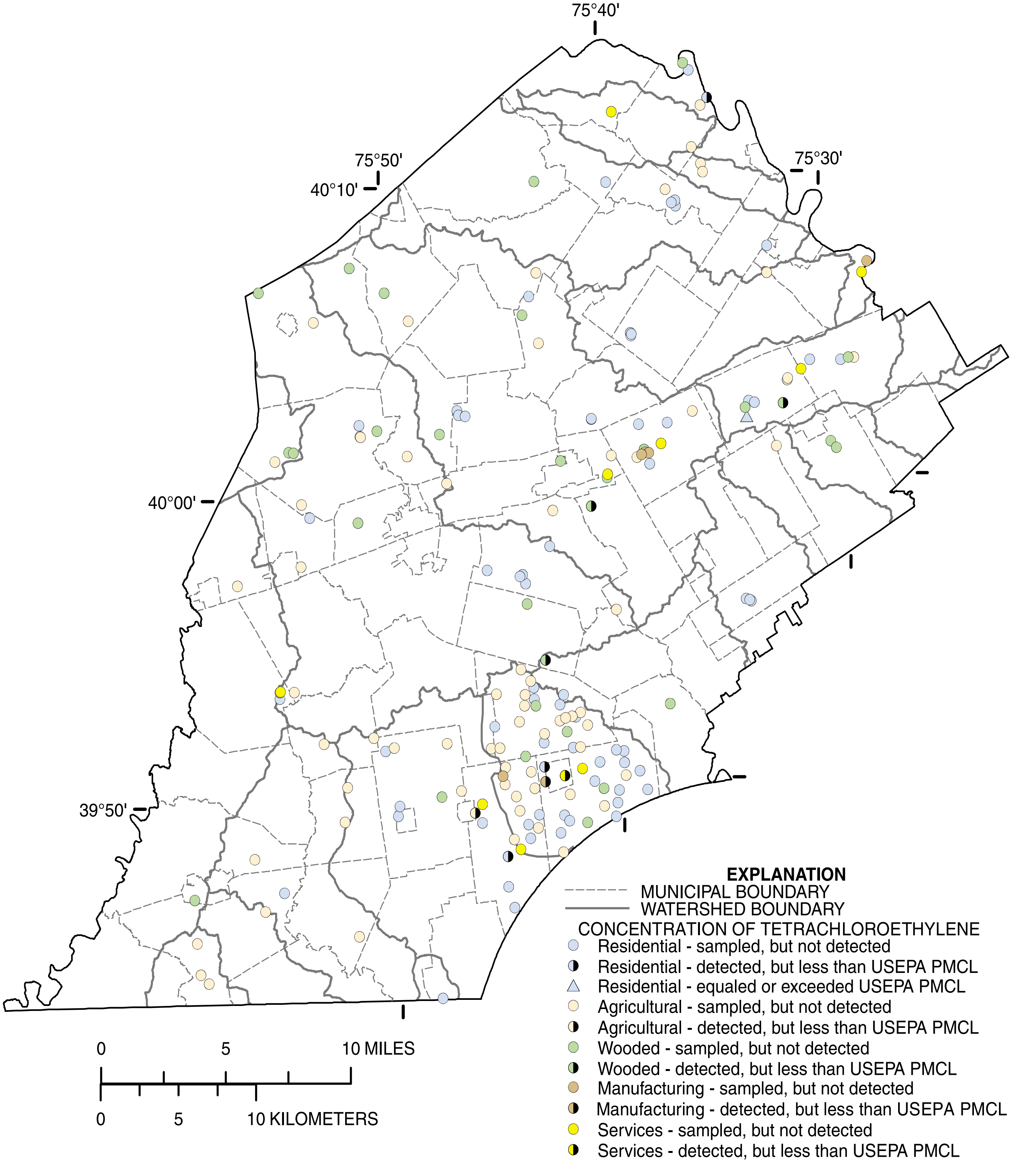

**Figure 33.** Distribution of tetrachloroethylene relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## 1,1,1-Trichloroethane

1,1,1-trichloroethane (TCA) is found in building materials, cleaning products, paints, and metal degreasing agents. It also is known as PCA, methyl chloroform, methyltrichloromethane, and trichloromethylmethane. It can be discharged in waste effluent from metal-degreasing sites and other factories. TCA readily evaporates, but its persistence in soil and ground water is not well defined. It does not bioaccumulate in plants or animals.

The body processes TCA in a manner similar to PCE. If ingested, TCA leaves the body mostly through exhalation (Centers for Disease Control, Agency for Toxic Substances and Disease Registry (CDC/ATSDR), 1995). The liver processes and removes most of the remaining TCA. Exposure to high concentrations can cause liver, nervous system, or circulatory problems. The USEPA PMCL for TCA is 0.2 mg/L (200 µg/L). No samples met or exceeded the USEPA PMCL.

Water samples from 187 wells were analyzed for TCA. Detectable concentrations (equal to or greater than 0.2 µg/L) of TCA were measured in 15 samples (8 percent) (table 35), including 17 percent of wells in manufacturing land-use areas (2.80 µg/L), 10 percent of wells in services land-use areas (0.70 µg/L), 9 percent of wells in residential land-use areas (range 0.20 - 5.30 µg/L), 6 percent of wells in agricultural land-use areas (range 0.30 - 9.10 µg/L), 6 percent of wells in wooded land-use areas (0.80 and 6.80 µg/L) (fig. 34). Of two samples collected from wells in dense residential land-use areas, only one sample had a detectable concentration (0.30 µg/L).

**Table 35.** *Total 1,1,1-trichloroethane (TCA) in ground water, by land use, based on samples collected from 1990 to 2001*

[µg/L, micrograms per liter; PMCL, primary maximum contaminant level]

| Land use | Total number of samples | Percentage of samples with detectable TCA | Maximum total TCA concentration (µg/L) | Percentage of samples exceeding the PMCL |
|---|---|---|---|---|
| All wells | 187 | 8 | 9.10 | 0 |
| Low-medium density residential | 68 | 9 | 5.30 | 0 |
| High-density residential | 2 | 50 | .30 | 0 |
| Agricultural | 70 | 6 | 9.10 | 0 |
| Wooded | 31 | 6 | 6.80 | 0 |
| Manufacturing | 6 | 17 | 2.80 | 0 |
| Services | 10 | 10 | .70 | 0 |

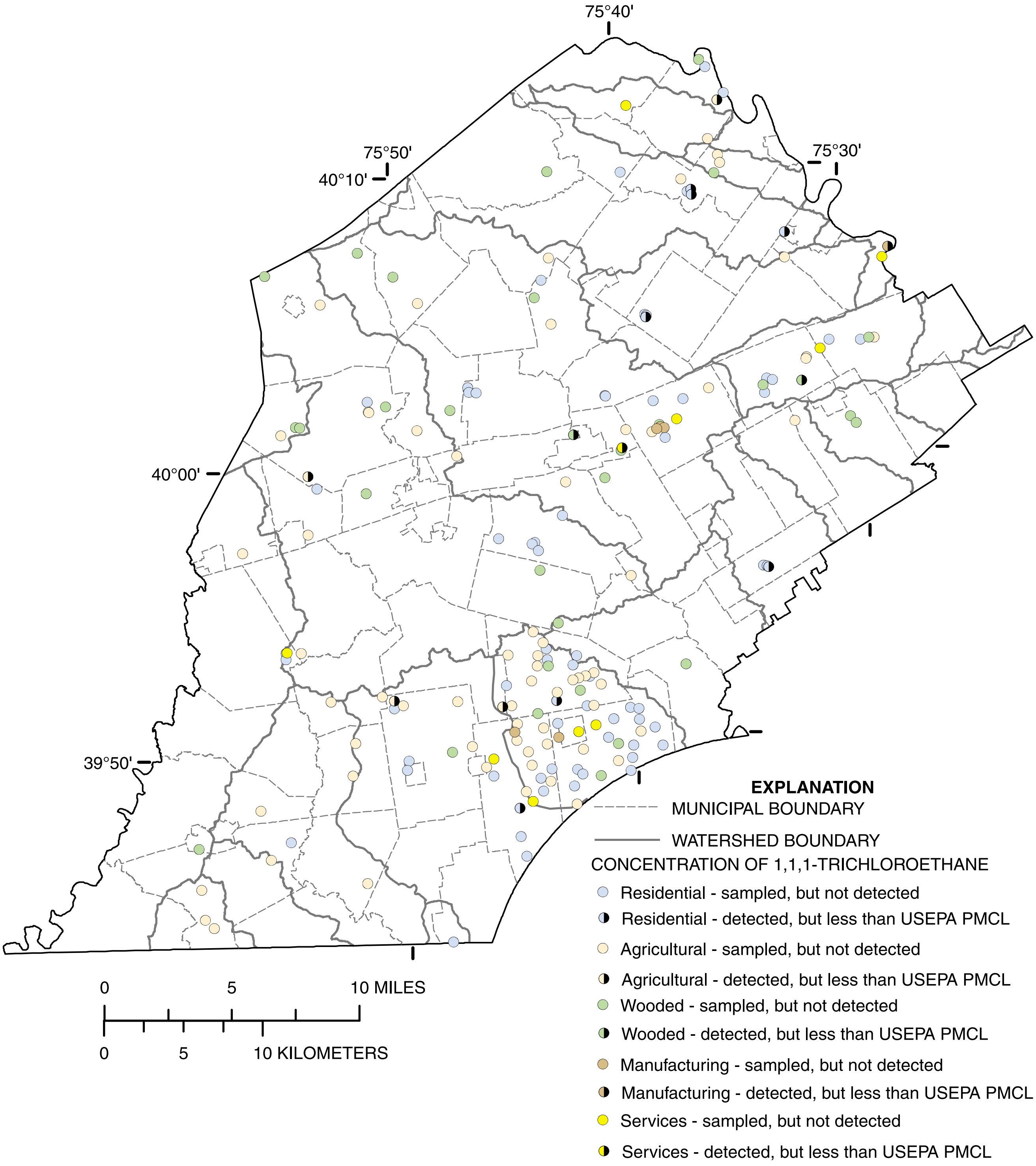

**Figure 34.** Distribution of 1,1,1-trichloroethane relative to generalized land use. (USEPA, U.S. Environmental Protection Agency; PMCL, Primary Maximum Contaminant Level)

## MTBE

Methyl tert-butyl ether (MTBE) is a colorless, synthetic, flammable liquid used as an unleaded gasoline additive since the late 1970s. MTBE is used to promote more efficient burning of gasoline and to reduce ozone and carbon-monoxide emissions. The Clean Air Act of 1990 requires the use of reformulated gasoline to provide relief to the areas of the country most affected by ozone and smog. About 84 percent of reformulated gasoline supplies contain MTBE. Sources of MTBE to ground water include leaking underground storage tanks, petroleum pipelines, above-ground tank systems, surface spills, and atmospheric deposition.

The effects of exposure to MTBE-contaminated water on human health have not been determined. Although USEPA has not set drinking-water standards for MTBE, the USEPA has issued a Drinking Water Advisory for MTBE concentrations at or above 20 and 40 ∝g/L (respective odor and taste thresholds: concentrations of MTBE that most consumers can both sense and find objectionable) (U.S. Environmental Protection Agency, 1997, 2000). No samples equaled or exceeded the USEPA Drinking Water Advisory concentrations.

Water samples from 96 wells were analyzed for MTBE. No samples were collected from the dense residential land-use areas, and few samples were collected from the manufacturing and services land-use areas (table 36). Samples from residential, agricultural, and wooded land-use areas constitute 94 percent of the samples analyzed. Samples with MTBE concentrations equal to or greater than the highest MRL (0.2 ∝g/L) included 28 percent of wells in agricultural land-use areas (range 0.2 - 2.0 ∝g/L), 26 percent of wells in residential land-use areas (range 0.2 - 5.1 ∝g/L), 16 percent of wells in wooded land-use areas (range 0.3 - 1.1 ∝g/L), and 25 percent of wells in services land-use areas (0.3 ∝g/L) (fig. 35). Of two samples collected from manufacturing land-use areas, only one had a detectable concentration (9.1 ∝g/L).

**Table 36.** *Methyl tert-butyl ether (MTBE) in ground water, by land use, based on samples collected from 1993 to 2001*

[∝g/L, micrograms per liter; DWA, drinking water advisory; —, no samples or too few samples to compute percentages]

| Land use | Total number of samples | Percentage of samples with detectable MTBE | Maximum MTBE concentration (∝g/L) | Percentage of samples exceeding DWA |
|---|---|---|---|---|
| All wells | 96 | 25 | 9.1 | 0 |
| Low-medium density residential | 39 | 26 | 5.1 | 0 |
| High-density residential | 0 | — | — | — |
| Agricultural | 32 | 28 | 2.0 | 0 |
| Wooded | 19 | 16 | 1.1 | 0 |
| Manufacturing | 2 | 50 | 9.1 | 0 |
| Services | 4 | 25 | .3 | 0 |

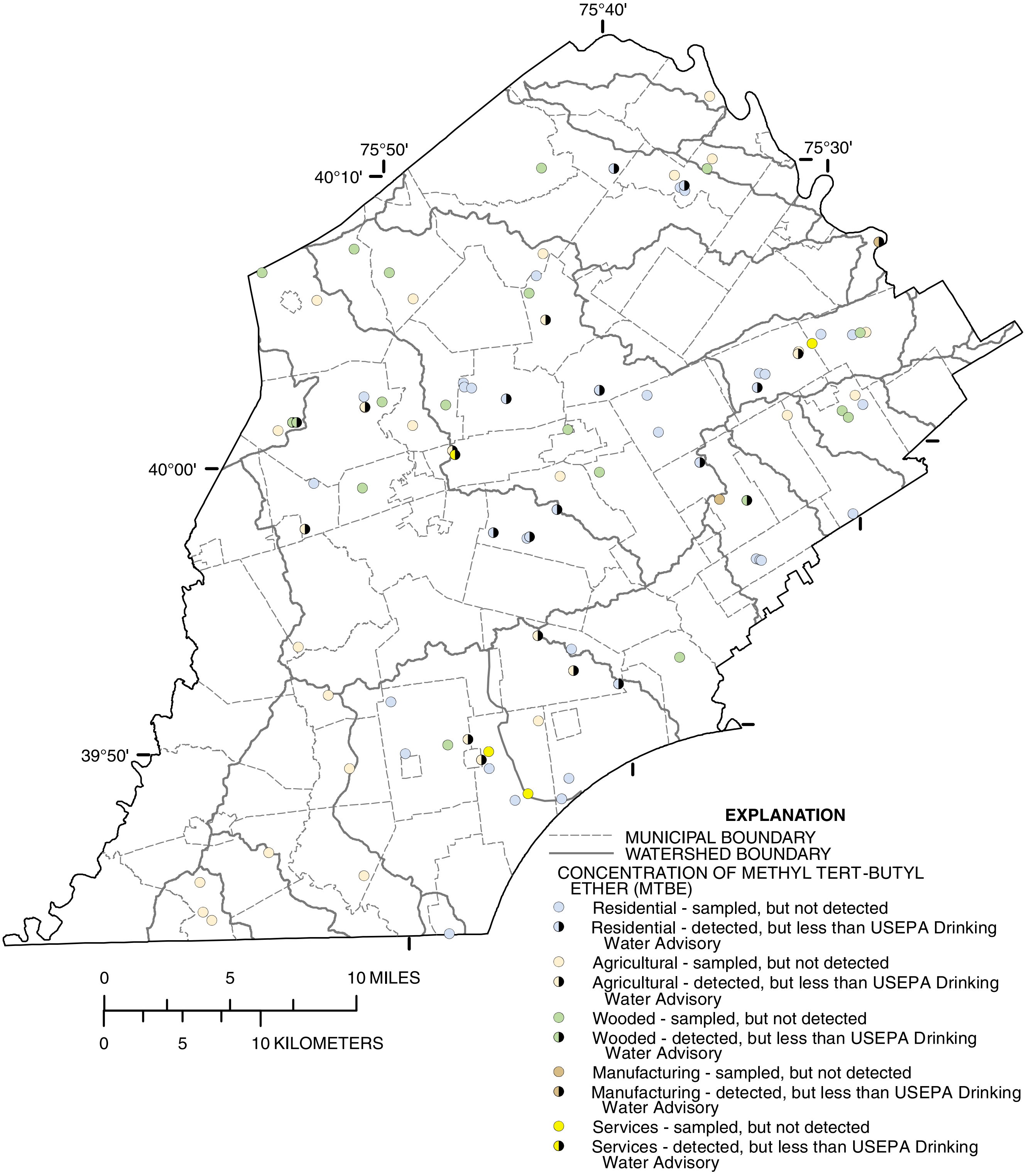

**Figure 35.** Distribution of methyl tert-butyl ether relative to generalized land use. (USEPA, U.S. Environmental Protection Agency)

## SUMMARY

Of water-quality constituents measured in the field (pH, alkalinity, specific conductance, and dissolved oxygen), none have a PMCL and only pH has an SMCL (table 37). In Chester County, water samples collected from wells indicate pH is mostly acidic to neutral. Alkalinity (*carbonate* hardness) is low (median 35 mg/L), except in carbonate rocks (median 210 mg/L) and serpentinite (median 119 mg/L). Specific conductance is also low (median 228 ∝S/cm) except in carbonate rocks (median 648 ∝S/cm). The median dissolved oxygen concentration is 7.0 mg/L.

Common ions are found predominantly in low concentrations except in carbonate rocks. However, elevated chloride concentrations are related to anthropogenic effects (Sloto, 1994). At 350 mg/L, only one sample in services land use exceeds the PMCL of 250 mg/L for chloride, but 59 percent of samples from services land use had chloride concentrations above the 75th percentile for all samples. Only one sample analyzed for sulfate approached the SMCL of 250 mg/L at 240 mg/L. Carbonate and gneiss rocks exhibit the highest concentrations of sulfate, although the only sample collected from diabase has a concentration of 86 mg/L. Total dissolved solids generally are also low, but 11 samples exceed the SMCL of 500 mg/L (range 503 - 746 mg/L), and 6 of those samples are in carbonate rocks. Neither calcium nor magnesium have SMCLs. Both ions are found in low concentrations except in the carbonate rocks, because carbonate rock consists mostly of calcium carbonate and lesser amounts of magnesium carbonate. Magnesium concentrations are highest in serpentinite and carbonate rocks. Sodium and strontium have no SMCL; both occur in low concentrations, but sodium is elevated in carbonate rocks and strontium is elevated in gneiss. Fluoride has both a PMCL and SMCL (4.0 and 2.0 mg/L, respectively); no samples met or exceeded either standard. Fluoride has relatively elevated (but nonetheless low) concentrations in carbonate rocks and schist.

Most metals are found in low concentrations. Seventy-five percent of iron and manganese concentrations were equal to or less than 10 and 8.0 ∝g/L, respectively. However, USEPA SMCLs were exceeded in 11 percent of samples for iron and 19 percent for manganese. Iron and manganese were mostly elevated in the schist and to lesser concentrations in gneiss. Four percent of samples analyzed for lead exceeded the USEPA PMCL; one sample from schist was 70.0 ∝g/L. Samples with detectable concentrations of arsenic were from wells in Triassic sedimentary, and only one sample (69.0 ∝g/L) exceeded the USEPA PMCL. Of 261 samples analyzed for copper, which has both a USEPA PMCL (1,300 ∝g/L) and SMCL (1,000 ∝g/L), none had concentrations that met or exceeded either standard.

Elevated concentrations of radionuclides occur in Chester County. Of 605 samples analyzed for radon-222 activities, 89 percent exceed the proposed USEPA PMCL of 300 pCi/L, except in the carbonate and serpentinite rocks. Of the same 605 samples, 111 (18 percent) exceed the proposed higher USEPA Alternate Maximum Contaminant Level (AMCL) of 4,000 pCi/L. Radon-222 activities are highest in schist and quartzite, where 29 and 27 percent of samples analyzed had activities above 4,000 pCi/L. Radium-226 (an alpha emitter) and Radium-228 (a beta emitter) have a combined USEPA PMCL of 5 pCi/L. Combined Ra-226 and Ra-228 activities exceed the PMCL in 57 samples (35 percent): 56 percent of water samples analyzed for combined activities in quartzite (in particular, the Chickies Formation) exceeded the PMCL, as did 18 percent of samples from carbonate rocks. Only 14 samples were collected for Radium-224. Although there is no PMCL specifically for Radium-224, it is an alpha emitter, and there is a PMCL for gross alpha activity at 15.0 pCi/L. Radium-224 activities exceeded the PMCL for gross alpha activity in 4 of 14 samples: 3 from quartzite and 1 from schist. Because of the short half-life of radium-224, activities at time of sample collection are higher than activities at time of analysis. Samples analyzed for uranium yielded mostly low concentrations (89 percent had concentrations less than 1.0 ∝g/L). Uranium concentrations equal to or greater than 1.0 ∝g/L were found in 23 of 201 samples, or 44 percent of wells in Triassic sedimentary and 40 percent of wells in carbonate rocks. Gross alpha activity samples primarily were collected from quartzite and gneiss rocks, and samples from 62 percent of wells in quartzite exceeded the USEPA PMCL gross alpha standard of 15 pCi/L. Samples analyzed for gross beta particle activity from 14 of 154 wells exceeded the USEPA screening level of 50 pCi/L, at which increased monitoring and speciation is required of community water systems. Of those samples, 13 were from wells in quartzite and 1 sample was from carbonate rocks.

**Table 37.** *Water-quality constituents and indicators, source agencies, standards, and standards exceeded*
*(The USEPA sets water-quality standards for community water systems. The Chester County Health Department sets water-quality standards for wells used by homeowners for domestic supply. The Chester County Health Department also has standards for constituents and indicators not discussed in this report and not routinely collected by USGS.)*

[U.S. Environmental Protection Agency (USEPA); Primary Maximum Contaminant Level (PMCL); Secondary Maximum Contaminant Level (SMCL); standard units (su); milligrams per liter (mg/L); picocuries per liter (pCi/L); micrograms per liter (∝g/L); millirems per year (mrem/yr); colonies per 100 milliliters (col/ml)]

| Constituents and indicators | USEPA PMCL | USEPA SMCL | Chester County Health Dept. | Standards | Standards exceeded |
|---|---|---|---|---|---|
| **Field-measured constituents** | | | | | |
| pH | no | yes | yes | 6.5 - 8.5 su | yes |
| Alkalinity | no | no | no | — | — |
| Specific conductance | no | no | no | — | — |
| Dissolved oxygen | no | no | no | — | — |
| **Common ions** | | | | | |
| Chloride | no | yes | yes | 250 mg/L | yes |
| Sulfate | no | yes | no | 250 mg/L | no |
| Total dissolved solids | no | yes | no | 500 mg/L | yes |
| Calcium | no | no | no | — | — |
| Magnesium | no | no | no | — | — |
| Sodium | no | no | no | — | — |
| Fluoride | yes | yes | no | 4.0 and 2.0 mg/L | no |
| Strontium | no | no | no | — | — |
| **Metals** | | | | | |
| Iron | no | yes | yes | 0.3 mg/L | yes |
| Manganese | no | yes | yes | 0.05 mg/L | yes |
| Lead | yes[1] | no | no | 0.015 mg/L | yes |
| Arsenic | yes | no | no | 0.01 mg/L | yes |
| Copper | yes[2] | yes | no | 1.3 and 1.0 mg/L | no |
| **Radionuclides** | | | | | |
| Radon-222 | no[3] | no | no | 300; 4,000 pCi/L | yes |
| Radium-226 and radium-228 | yes | no | no | 5.0 pCi/L | yes |
| Radium-224 | no | no | no | (15 pCi/L) | yes |
| Uranium | yes | no | no | 30 ∝g/L | yes |
| Gross alpha | yes | no | no | 15 pCi/L | yes |
| Gross beta | yes[4] | no | no | 4 mrem/yr; 50 pCi/L | yes |
| **Bacteria** | | | | | |
| Fecal coliforms | yes | no | yes[5] | 0 col/100 mL | yes |
| **Nutrients** | | | | | |
| Nitrate | yes | no | yes[6] | 10 mg/L | yes |
| Nitrite | yes | no | yes[6] | 1 mg/L | yes |
| Phosphorus | no | no | no | — | — |
| Pesticides | | | | | |
| Lindane | yes | no | no | 0.2 ∝g/L | yes |
| Dieldrin | no | no | no | — | — |
| Diazinon | no | no | no | — | — |

**Table 37.** *Water-quality constituents and indicators, source agencies, standards, and standards exceeded*—*Continued*
*(The USEPA sets water-quality standards for community water systems. The Chester County Health Department sets water-quality standards for wells used by homeowners for domestic supply. The Chester County Health Department also has standards for constituents and indicators not discussed in this report and not routinely collected by USGS.)*

[U.S. Environmental Protection Agency (USEPA); Primary Maximum Contaminant Level (PMCL); Secondary Maximum Contaminant Level (SMCL); standard units (su); milligrams per liter (mg/L); picocuries per liter (pCi/L); micrograms per liter (∝g/L); millirems per year (mrem/yr); colonies per 100 milliliters (col/ml)]

| Constituents and indicators | USEPA PMCL | USEPA SMCL | Chester County Health Dept. | Standards | Standards exceeded |
|---|---|---|---|---|---|
| **Volatile organic compounds** | | | | | |
| Tricholoethylene | yes | no | no | 5.0 ∝g/L | yes |
| Tetracholoethylene | yes | no | no | 5.0 ∝g/L | yes |
| 1,1,1-Tricholoethane | yes | no | no | 200 ∝g/L | no |
| MTBE | no | no | no | 20 and 40 ∝g/L | no |

[1] 0.015 mg/L: action level at which community water suppliers must treat water to reduce corrosivity.

[2] 1.3 mg/L: action level at which community water suppliers must treat water to reduce corrosivity.

[3] Proposed at both 300 pCi/L and at Alternate Maximum Contaminant Level (AMCL) of 4,000 pCi/L.

[4] Gross beta PMCL based on exposure (dose) of 4 millirems/year, but gross beta water-quality samples are a measure of activity, and not exposure; radionuclide speciation is required above 50 pCi/L.

[5] Chester County Health Department water-quality standards are for bacteria are for ‘Total Coliform’ at less than 1 colony per 100 mL.

[6] Chester County Health Department water-quality standards are for nitrates *plus* nitrites at 10 mg/L.

Bacteria samples had a low occurrence of positive (bacteria present) analyses. Only two samples analyzed for fecal coliform from agricultural land use exceeded the USEPA MCLG of zero colonies/100 milliliters; one sample was at an estimated 1 col/100 mL, and the other at 5 col/100 mL. Samples collected from 27 wells and analyzed for *Escherichia coli* had no results that exceeded the USEPA MCLG of zero colonies/ 100 milliliters.

Nutrient concentrations generally were low. Nitrate concentrations in 68 samples (11 percent) exceeded the USEPA PMCL and included: 18 percent of wells in agricultural (range 10.7 - 38 mg/L) and 12 percent of wells in services (range 10.8 - 45 mg/L). Only one sample analyzed for nitrite exceeded the USEPA PMCL with a concentration of 1.01 mg/L. The median concentration of 505 samples analyzed for phosphorus was 0.010 mg/L, and the maximum concentration was 0.210 mg/L. There is no USEPA PMCL or SMCL for phosphorus.

Pesticide analyses indicated low occurrence, with few exceptions and few detectable concentrations. Of the three most often detected pesticides, lindane, dieldrin, and diazinon, respectively 95, 96, and 94 percent of concentrations were less than 0.010 ∝g/L. Only lindane has a USEPA PMCL (0.2 ∝g/L), and only one sample exceeded that concentration at 0.340 ∝g/L from a well in wooded land use. Detectable lindane concentrations were found in 8 other samples (range 0.010 to 0.100 ∝g/L). Samples analyzed for dieldrin yielded only seven samples equal to or greater than the highest minimum reporting level (0.010 ∝g/L): the sample with the highest concentration (0.343 ∝g/L) was from a well in agricultural land use. Samples analyzed for diazinon had results similar to that of lindane and dieldrin, except for two samples with concentrations of 57.0 and 490 ∝g/L. Both samples were from low-medium residential land use.

Volatile organic compounds analyses also indicated low occurrence, with few exceptions and few detectable concentrations. Only four samples analyzed for trichloroethylene (TCE) exceeded the USEPA PMCL (5 ∝g/L). The sample with the highest concentration of TCE is from a well in residential land use (95.0 ∝g/L); the next highest concentrations were from two wells in wooded land use (37.0 and 45.0 ∝g/L); and one well in services land use (14.0 ∝g/L). Of samples analyzed for tetrachloroethylene (PCE), only one sample (12.0 ∝g/L) from a well in residential land use exceeded the USEPA PMCL (5 ∝g/L). 1,1,1-trichloroethane was detected in 8 percent of 187 samples, but no samples equaled or exceeded the USEPA PMCL (200 ∝g/L). No samples analyzed for MTBE equaled or exceeded the USEPA drinking water advisory concentrations of 20 and 40 ∝g/L.

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**Table 38.** *Pesticides analyzed for in the ground water of Chester County*
Metabolites (M) in the Intended Use column are not the original pesticide product,
but are fractions of the original compound broken-down by microbial or plant physiological processes

[Intended use: H, herbicide; F, fungicide; I, insecticide; M, metabolite.
Class: ON, organonitrogens; OP, organophosphates; OC, organochlorines; OA, organic acids; CA, chloroacetanilide]

| Pesticide | Number of samples (wells) | Number of samples (wells) with detecable pesticide | Intended use | Class |
|---|---|---|---|---|
| Bromacil | 2 | — | H | ON |
| Butachlor | 2 | — | H | ON |
| Butylate | 2 | — | H | ON |
| Carboxin | 2 | — | F | ON |
| Cycloate | 2 | — | H | ON |
| Diphenamid | 2 | — | H | ON |
| Hexazinone | 2 | — | H | ON |
| Propachlor | 2 | — | H | ON |
| Terbacil | 2 | — | H | ON |
| Vernolate | 2 | — | H | ON |
| Chlorpyrifos | 38 | — | I | OP |
| Disulfoton | 41 | — | I | OP |
| Phorate | 41 | — | I | OP |
| Propazine | 7 | 1 | H | ON |
| Trifluralin | 7 | — | H | ON |
| Perthane | 132 | — | I | OC |
| S,S,S-Tributylphosphorotrithioate | 41 | — |  | OP |
| Simetryn | 7 | — | H | ON |
| Simazine | 7 | — | H | ON |
| Prometon | 7 | 1 | H | ON |
| Prometryn | 7 | — | H | ON |
| Aldrin | 132 | — | I | OC |
| Lindane, total | 132 | 10 | I | OC |
| Lindane, dissolved | 146 | 3 | I | OC |
| Chlordane, technical mix | 132 | — | I | OC |
| p,p′-DDD | 132 | — | M | OC |
| p,p′-DDE | 132 | — | M | OC |
| p,p′-DDT | 132 | — | M | OC |
| Dieldrin, total | 132 | 4 | I | OC |
| Dieldrin, dissolved | 146 | 7 | I | OC |
| alpha-Endosulfan | 132 | — | I | OC |
| Endrin | 132 | — | I | OC |
| Ethion | 41 | 1 | I | OP |
| Toxaphene | 132 | — | I | OC |
| Heptachlor | 132 | — | I | OC |
| Heptachlor epoxide | 131 | 2 | M | OC |
| p,p′-Methoxychlor | 132 | 1 | M | OC |
| Malathion | 41 | 2 | I | OP |
| Parathion | 41 | — | I | OP |
| Diazinon, total | 41 | 5 | I | OP |
| Diazinon, dissolved | 146 | 10 | I | OP |
| Parathion-methyl | 41 | — | I | OP |

**Table 38.** *Pesticides analyzed for in the ground water of Chester County*
Metabolites (M) in the Intended Use column are not the original pesticide product,
but are fractions of the original compound broken-down by microbial or plant physiological
processes—Continued

[Intended use: H, herbicide; F, fungicide; I, insecticide; M, metabolite.
Class: ON, organonitrogens; OP, organophosphates; OC, organochlorines; OA, organic acids;
CA, chloroacetanilide]

| Pesticide | Number of samples (wells) | Number of samples (wells) with detecable pesticide | Intended use | Class |
|---|---|---|---|---|
| Atrazine | 7 | 3 | H | ON |
| Hexachlorobutadiene | 13 | — | | |
| Picloram | 14 | 1 | H | OA |
| 2,4-D | 14 | 2 | H | OA |
| 2,4,5-T | 14 | — | H | OA |
| Mirex | 132 | — | I | OC |
| Silvex | 14 | — | H | OA |
| Carbophenothion | 41 | — | I | OP |
| Deisopropylatrazine | 2 | — | | |
| Deethylatrazine | 2 | 1 | M | ON |
| Alachlor | 7 | 1 | H | ON |
| Cyanazine | 7 | 1 | H | ON |
| Dicamba | 14 | 2 | H | OA |
| Dichlorprop | 14 | — | H | OA |
| Ametryn | 7 | — | H | ON |
| Metribuzin | 7 | — | H | ON |
| Metolachlor | 7 | 3 | H | CA |
| Fonofos | 38 | — | I | OP |