# Ground-Water Quality in the Eastern Part of the Silurian-Devonian and Upper Carbonate Aquifers in the Eastern Iowa Basins, Iowa and Minnesota, 1996

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98–4224

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By Mark E. Savoca, Eric M. Sadorf, and Kymm K. Akers

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## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

| Multiply | By | To obtain |
|---|---|---|
| feet (ft) | 0.3048 | meter (m) |
| square mile ($mi^2$) | 2.59 | square kilometer ($km^2$) |
| pound (lb) | 0.4536 | kilogram (kg) |
| kilogram (kg) | 0.001 | milligram (mg) |
| milligram (mg) | 0.001 | microgram (µg) |
| gallon (gal) | 3.785 | liter (L) |

Temperature in degree Celsius ($^oC$) can be converted to degree Fahrenheit ($^oF$) as follows:

$$^oF = 1.8\ (^oC) + 32$$

**Sea level**: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

**Abbreviated water-quality units**: Chemical concentrations are given in metric units of milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams per liter and micrograms per liter are units expressing the concentration of chemical constituents in solution as mass (milligrams or micrograms) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value of milligrams per liter is the same as for concentrations in parts per million. The numerical value of micrograms per liter is the same as for concentrations in parts per billion.

# FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

# Ground-Water Quality in the Eastern Part of the Silurian-Devonian and Upper Carbonate Aquifers in the Eastern Iowa Basins, Iowa and Minnesota, 1996

*By* Mark E. Savoca, Eric M. Sadorf, and Kymm K. Akers

## Abstract

Ground-water samples were collected from 33 domestic wells to assess the water quality of the eastern part of the Silurian-Devonian and Upper Carbonate aquifers in the Eastern Iowa Basins National Water-Quality Assessment Program study unit. Samples were collected during June and July 1996 and analyzed for major ions, nutrients, pesticides and pesticide metabolites, volatile organic compounds, tritium, radon-222, and environmental isotopes.

Calcium, magnesium, and bicarbonate were the dominant ions in most samples and were likely derived from the solution of carbonate minerals (calcite and dolomite) present in the aquifer materials. The dominance of sulfate in samples from several wells suggests the dissolution of evaporite minerals. Ammonia and orthophosphorus were the most commonly detected nutrients. Nitrate was detected in about half of the samples and exceeded the U.S. Environmental Protection Agency maximum contaminant level (10 milligrams per liter) in 6 percent of samples. Atrazine and metolachlor were the only pesticides detected and were present in 18 percent and 12 percent of samples, respectively. Alachlor ethanesulfonic acid and deethylatrazine were the most commonly detected pesticide metabolites and were present in 16 percent and 9 percent of samples, respectively. Radon-222 was detected in all samples, and 47 percent had concentrations in excess of the U.S. Environmental Protection Agency previously proposed maximum contaminant level (300 picocuries per liter). Radon-222 concentrations were significantly higher in samples from wells that produced recently recharged water. This relation suggests that uranium-bearing glacial deposits (Schumann, 1993) may be a source of radon-222 in the underlying aquifers.

The presence of regional confining units and thick overlying Quaternary-age deposits have an effect on water quality in the Silurian-Devonian and Upper Carbonate aquifers in the study area. Tritium-based ground-water ages were significantly older, and dissolved-solids concentrations were significantly higher in relatively well protected areas (where the aquifers are overlain by a bedrock confining unit or more than 100 feet of Quaternary-age deposits). Ammonia concentrations were significantly higher in relatively well protected areas and in samples from wells that produced older water. Higher ammonia concentrations also were observed in ground water with dissolved-oxygen concentrations of 0.5 milligram per liter or less, allowing for the anaerobic reduction of nitrate to ammonia. Nitrate concentrations were significantly higher in relatively poorly protected areas (where the aquifers are not overlain by a bedrock confining unit or are overlain by less than 100 feet of Quaternary-age deposits) and in samples from wells that produced recently recharged water. Pesticide and metabolite concentrations were significantly higher in samples from wells that produced recently recharged water. Atrazine, metolachlor, and deethylatrazine were not detected in any samples from relatively well protected areas of the aquifers.

# INTRODUCTION

The goal of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program is to assess the status and trends in the quality of the Nation's surface and ground water and to better understand the natural and human factors affecting water quality (Hirsch and others, 1988). The Eastern Iowa Basins study unit encompasses an area of about 19,500 mi$^2$ in eastern Iowa and southern Minnesota (fig. 1) and is one of 59 study units in the NAWQA Program.

Study-unit surveys are an important component of the NAWQA Program and are designed to provide a broad assessment of the water quality of the major ground-water resources in a study unit (Gilliom and others, 1995). The eastern part of the Silurian-Devonian and Upper Carbonate aquifers is the focus of a study-unit survey in the Eastern Iowa Basins study unit.

## Purpose and Scope

This report presents the results of an assessment of the water quality of the eastern part of the Silurian-Devonian and Upper Carbonate aquifers in the Eastern Iowa Basins study unit (fig. 2). Ground-water samples were collected from 33 domestic wells during June–July 1996 and were analyzed to determine the concentrations of major ions, nutrients, pesticides and pesticide metabolites, volatile organic compounds (VOCs), tritium, radon-222, and environmental isotopes. Field measurements of water temperature, specific conductance, pH, dissolved oxygen, alkalinity, and turbidity also were obtained. The factors affecting ground-water quality are discussed.

## Acknowledgments

The authors thank the residents within the study unit for allowing the USGS to sample their wells. Former USGS employees, Jennifer Tobias and Mathew Bobier, collected much of the data presented in this report. Steve Kalkhoff, Chief of the Eastern Iowa Basins National Water-Quality Assessment study unit, provided guidance and support throughout the project.

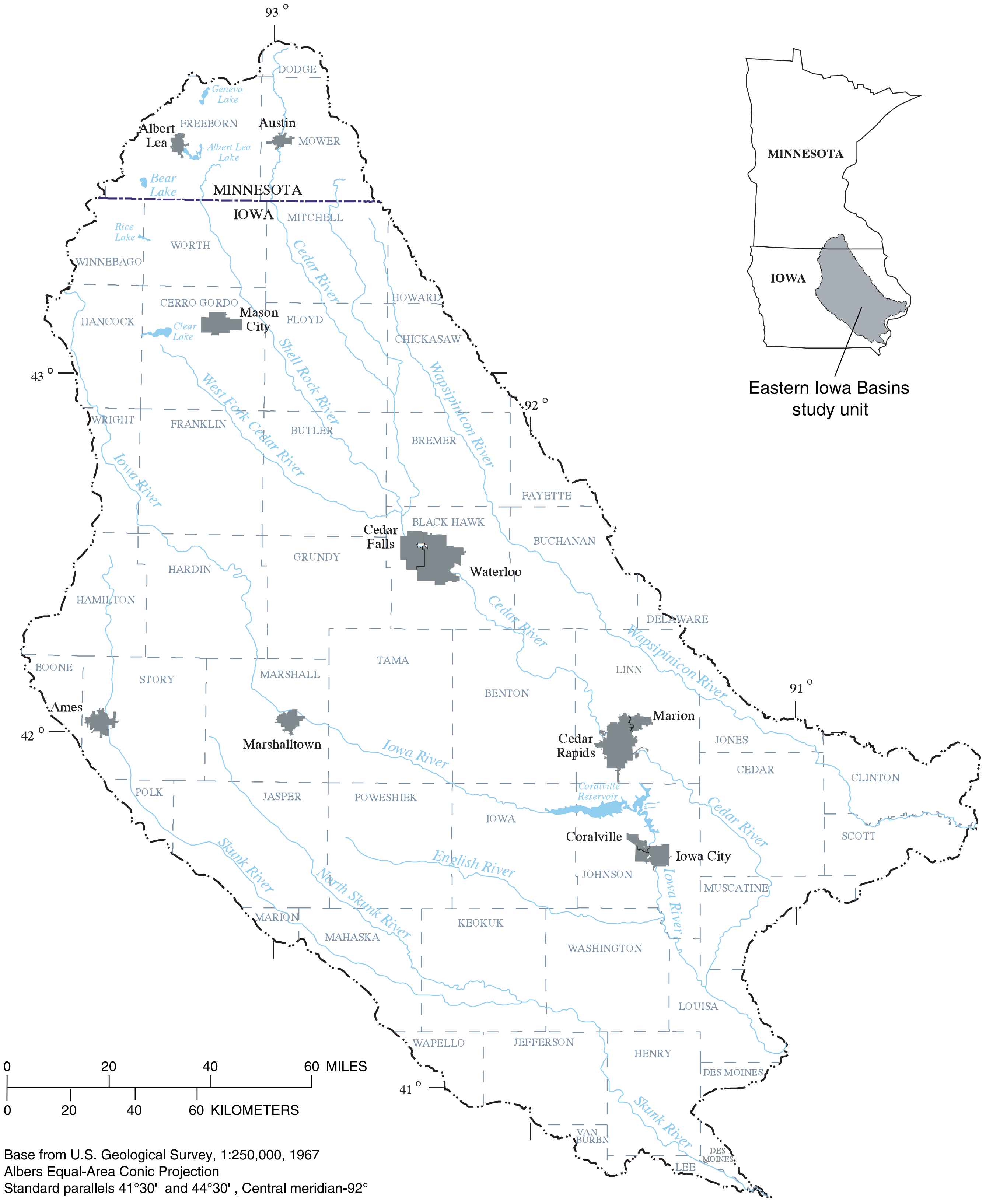
# DESCRIPTION OF STUDY AREA

The Silurian-Devonian and Upper Carbonate aquifers underlie most of the study unit and supply about 37 percent of ground-water use (E.E. Fischer and A.D. Arntson, U.S. Geological Survey, written commun., 1998). The study area consists of the eastern portion of the study unit where the Silurian-Devonian and Upper Carbonate aquifers and the overlying confining units of the Devonian-age Lime Creek Formation and Yellow Spring Group form the bedrock surface (fig. 2). The study area includes the most intensively used (ground-water supply) part of the Silurian-Devonian and Upper Carbonate aquifers and encompasses an area of about 12,400 mi$^2$.

Agriculture is the dominant land use/land cover and is present in 92.2 percent of the study area (fig. 3). Forested land cover accounts for 4.6 percent of the study area, urban 2.3 percent, water 0.4 percent, wetland 0.3 percent, and barren 0.2 percent.

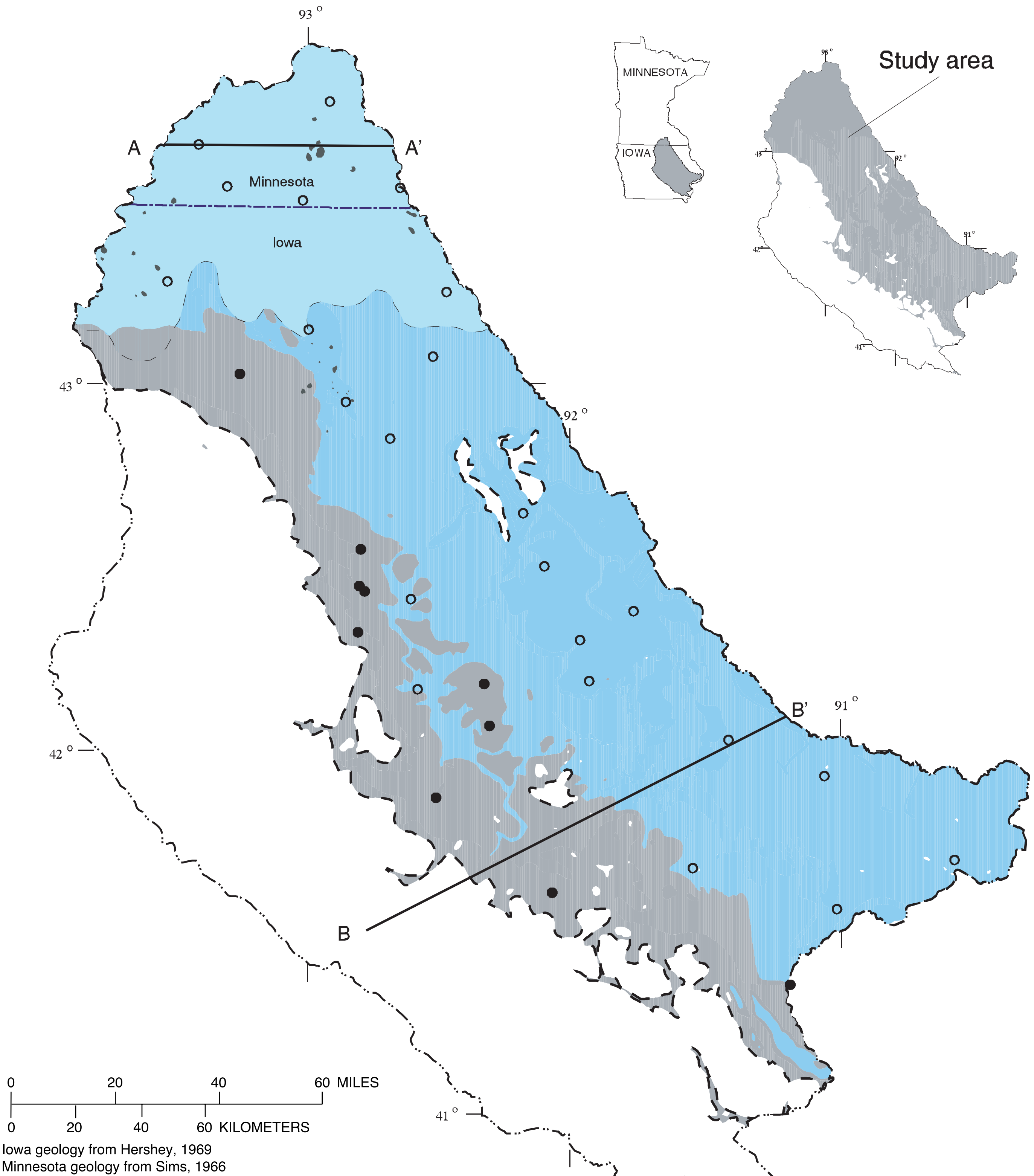
The Silurian-Devonian aquifer underlies the central and southern parts of the study area and consists of 200–400 ft of limestone, dolomite, sandstone, shale, and evaporite deposits (table 1) of shallow marine origin. These units gently dip to the southwest (fig. 4, hydrogeologic section B-B') beneath regionally confining Devonian-age shales of the Lime Creek Formation and Yellow Spring Group in the western part of the study area. Shales of the Devonian-age Wapsipinicon Formation produce locally confined conditions within the aquifer in the east-central part of the study area. The aquifer forms the bedrock surface in the eastern part of the study area where it is overlain by unconsolidated Quaternary-age deposits (sand, gravel, silt, and clay) and is unconfined except in areas where overlying fine-grained deposits produce locally confined conditions. The Silurian-Devonian aquifer is underlain by a confining unit consisting of the Ordovician-age Maquoketa Shale.

The Upper Carbonate aquifer underlies the northern part of the study area and consists of 250 to 600 ft of Ordovician- and Devonian-age limestone, dolomite, dolomitic limestone, and shale (table 1; fig. 4, hydrogeologic section A-A') of shallow marine origin. The aquifer is overlain by unconsolidated Quaternary- and Cretaceous-age deposits (sand, gravel, and clay) and is unconfined except in areas where overlying fine-grained deposits produce locally confined conditions. The Upper Carbonate aquifer is underlain by a confining unit consisting of the Ordovician-age Decorah Shale, Platteville Formation, and Glenwood Shale.



Base from U.S. Geological Survey, 1:250,000, 1967
Albers Equal-Area Conic Projection
Standard parallels 41°30' and 44°30' , Central meridian-92°

**Figure 1**. Location and extent of Eastern Iowa Basins study unit.



Iowa geology from Hershey, 1969
Minnesota geology from Sims, 1966

Base from U.S. Geological Survey, 1:250,000, 1967
Albers Equal-Area Conic Projection
Standard parallels 41° 30' and 44° 30', Central meridian-92°

**Figure 2.** Uppermost bedrock units in the study area and location of sampling sites and hydrogeologic sections.

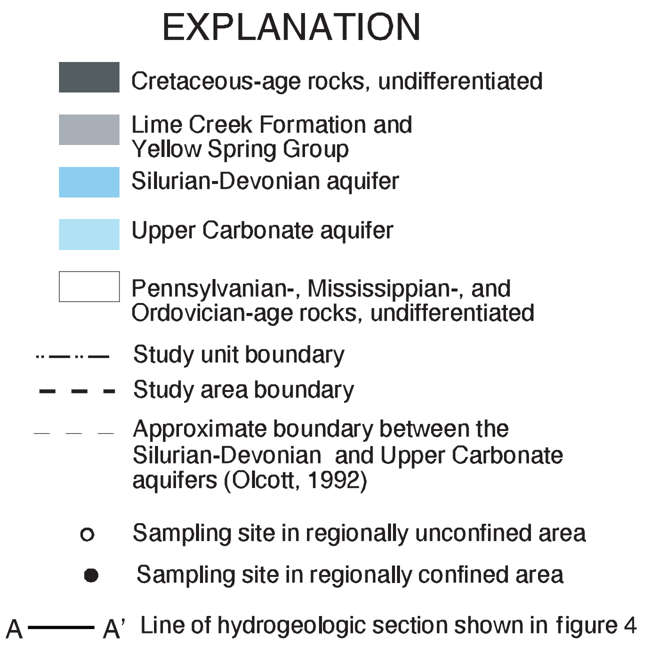


**Figure 2.** Uppermost bedrock units in the study area and location of sampling sites and hydrogeologic sections —Continued.

The location of the boundary between the Silurian-Devonian and Upper Carbonate aquifers in northern Iowa has been approximated by Olcott (1992) and described as a facies change in the Maquoketa Shale from dolomite in southern Minnesota to shale in northern Iowa that limits the southern extent of permeable Ordovician-age units of the Upper Carbonate aquifer. In the same region, the northward absence of permeable Silurian-age units limits the northern extent of the Silurian-Devonian aquifer (Horick, 1984). Permeable Devonian-age units are common to both aquifers and are present throughout most of the study area.

Recharge to the Silurian-Devonian and Upper Carbonate aquifers is primarily from precipitation that infiltrates through overlying Quaternary deposits in unconfined areas (Farrell and others, 1975; Horick, 1984). Water also enters the aquifers directly through sinkholes and losing stream reaches in karst areas (Horick, 1984; Ruhl and Wolf, 1984).

Regional ground-water movement in the Silurian-Devonian and Upper Carbonate aquifers is generally to the south and southeast where it discharges to major rivers and provides base flow during dry periods (Farrell and others, 1975; Horick, 1984). The movement and storage of ground water in the carbonate rocks of the Silurian-Devonian and Upper Carbonate aquifers take place primarily in secondary openings, such as joints, fractures, and bedding planes, that in many areas have been enlarged by solution to form karst (Farrell and others, 1975; Horick, 1984). Karst features are common in the north-central part of the study area, where the bedrock aquifers are overlain by a thin mantle of Quaternary deposits (Delin and Woodward, 1984; Horick, 1984). Porous reef facies in Silurian and Devonian rocks may locally contribute to primary porosity (Horick, 1984).

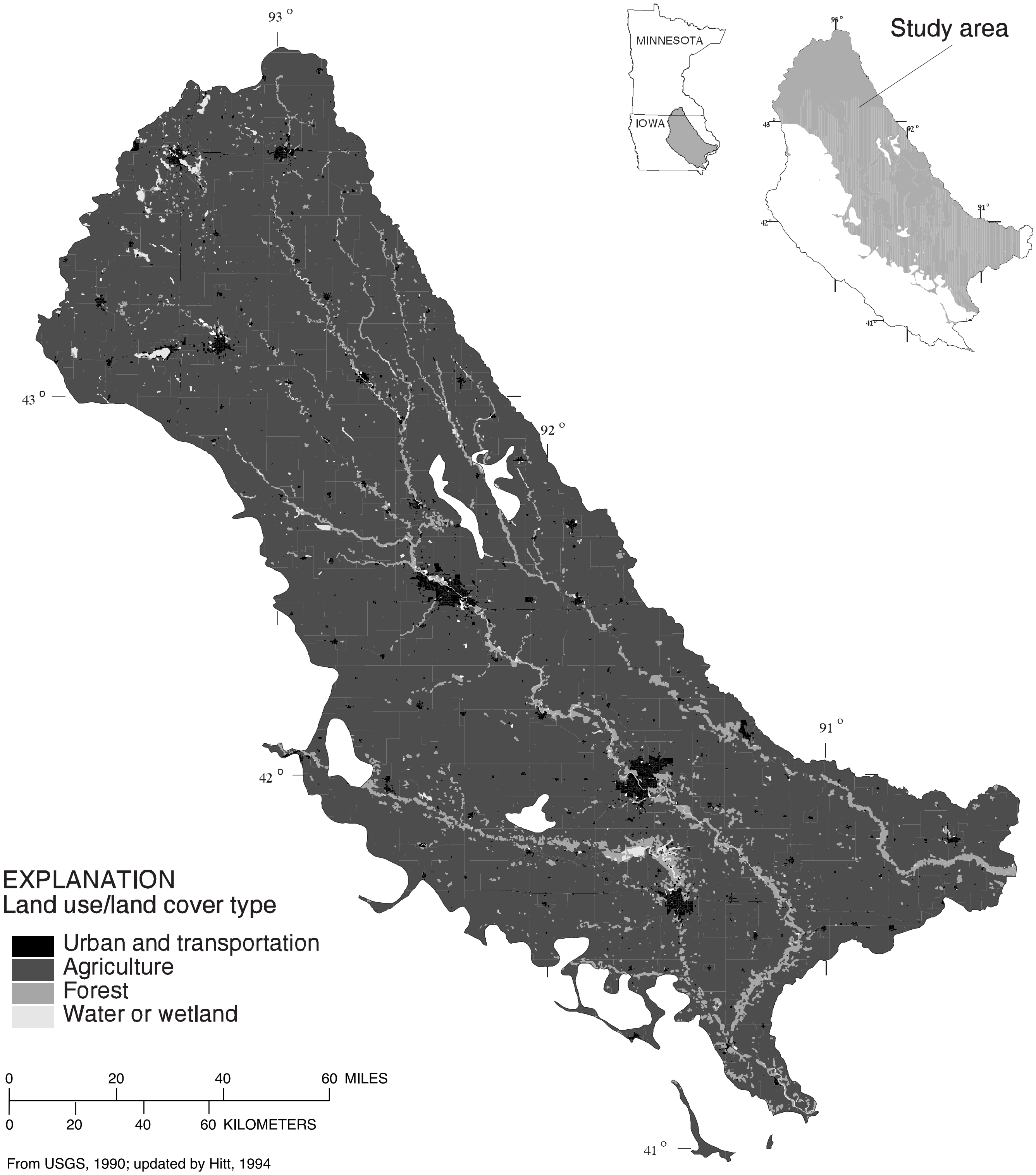
Detailed descriptions of the hydrogeology of the Silurian-Devonian and Upper Carbonate aquifers are given by Farrell and others (1975), Wahl and others (1978), Horick (1984), Ruhl and Wolf (1984), Delin and Woodward (1984), and Olcott (1992).

## STUDY DESIGN AND METHODS

This study was designed to provide a broad assessment of the ground-water quality of the eastern part of the Silurian-Devonian and Upper Carbonate aquifers in the Eastern Iowa Basins study unit. Ground-water samples were collected from domestic wells that were randomly selected within the study area.

### Well Selection

Potential sampling locations in the study area were identified using a stratified random selection process (Scott, 1990). Field reconnaissance within a 1-mile radius of each potential location was conducted to determine if a suitable well could be found. Well selection criteria were as follows: well was for domestic use and was completed in the Silurian-Devonian or Upper Carbonate aquifers; permission to sample the well could be obtained from the landowner; well depth was known; well was equipped with a submersible pump; and a sample could be obtained before water entered a pressure tank or other treatment system. Information about the well was obtained from well owner interviews and driller’s logs. If a suitable well could not be found at the primary location, a search was initiated at the closest alternate location. Alternate locations were identified using the same stratified random selection process (Scott, 1990) and well selection criteria used for primary locations.



From USGS, 1990; updated by Hitt, 1994

Base from U.S. Geological Survey, 1:250,000, 1967
Albers Equal-Area Conic Projection
Standard parallels 41°30' and 44°30', Central meridian-92°

**Figure 3**. Land use and land cover in the study area.

**Table 1.** Hydrogeologic units in the study area

| System | Stratigraphic unit | Principal lithology | Hydrogeologic unit |
|---|---|---|---|
| **Northern part of study area (modified from Ruhl and Wolf, 1984)** | | | |
| Quaternary | Glacial and alluvial deposits | Sand, gravel, silt, and clay | Surficial aquifer |
| Cretaceous | Dakota Formation | Sand | Isolated, water-bearing units |
| Devonian | Cedar Valley Limestone | Limestone, dolomite, dolomitic limestone, and shale | Upper Carbonate aquifer |
| Ordovician | Maquoketa Shale | | |
| | Dubuque Formation | | |
| | Galena Dolomite | | |
| | Decorah Shale | Shale, dolomitic limestone, and limestone | Confining unit |
| | Platteville Formation | | |
| | Glenwood Shale | | |
| **Central and southern part of study area (modified from Horick, 1984)** | | | |
| Quaternary | Glacial and alluvial deposits | Sand, gravel, silt, and clay | Surficial aquifer |
| Devonian | Yellow Spring Group | Shale | Confining unit |
| | Lime Creek Group | Dolomite and shale | Confining unit |
| | Shell Rock Formation | Limestone | |
| | Cedar Valley Limestone | Limestone, dolomite, some gypsum | Silurian-Devonian aquifer |
| | Wapsipinicon Formation | Dolomite, limestone, some shale, sandstone, and gypsum | Confining unit |
| Silurian | Gower Formation | Dolomite and limestone | |
| | Scotch Grove Formation | | |
| | Hopkington Formation | | |
| | Blanding Formation | | |
| | Tete des Mortes Formation | Dolomite | |

Thirty-three domestic wells were selected for sampling. Wells were typically located in rural agricultural areas and occasionally in residential areas in small towns. Well depths ranged from 32 to 700 ft. Ten wells were completed in regionally confined parts of the aquifers, and 23 wells were completed in regionally unconfined parts of the aquifers (fig. 2).

## Sample Collection

Ground-water samples were collected from 33 wells during June–July of 1996. Sample collection followed NAWQA protocols (Koterba and others, 1995). Prior to sample collection, wells were purged of at least three well-casing volumes using the well’s submersible pump. Pumping continued until field measurements of water temperature, pH, specific conductance, and dissolved oxygen stabilized, at which time water samples were collected for the analysis of major ions, nutrients, pesticides and pesticide metabolites, VOCs, tritium, radon-222, and environmental isotopes. Static and pumping water levels were also recorded for each well.

Major ion, nutrient, and alkalinity samples were filtered using 0.45-micron cartridge filters. Pesticide

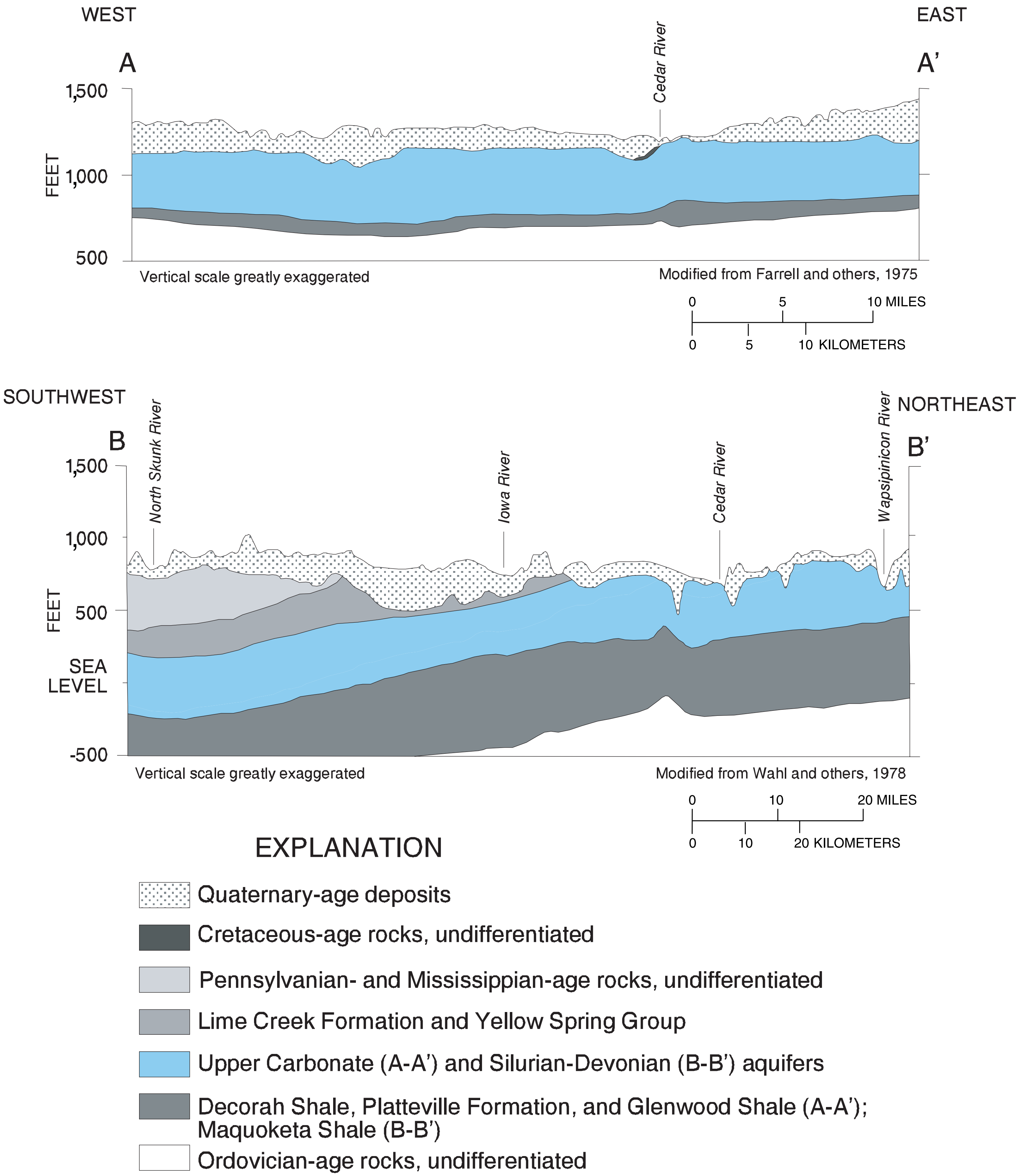


**Figure 4.** Generalized hydrogeologic sections through the study area.

samples were filtered using 0.7-micron baked glass-fiber filters. VOC, tritium, radon-222, and environmental isotope samples were not filtered. Major ion and VOC samples were acidified prior to shipping. Samples were chilled and shipped (overnight delivery) to USGS analytical laboratories. All sampling and filtering equipment was decontaminated after each use (Koterba and others, 1995).

## Water-Quality Analysis

Samples collected for this study were analyzed at the USGS National Water-Quality Laboratory (NWQL) in Arvada, Colorado. Selected pesticides and pesticide metabolites were analyzed at the USGS Organic Geochemistry Research Laboratory (OGRL) in Lawrence, Kansas. Tritium samples were analyzed at the USGS Isotope Tracers Project Laboratory in Menlo Park, California. Environmental-isotope samples were analyzed at the USGS National Research Program Laboratory in Reston, Virginia. The analytical methods used in this study are summarized in table 2.

Analyte detections were evaluated in the context of minimum reporting levels (MRLs) and method detection limits (MDLs) established by NWQL. The MRL is the minimum concentration of an analyte that can be reliably measured and reported by the laboratory using a given analytical method. MRLs are commonly reported with analytical results for major ions, nutrients, radiochemicals, and VOCs. The MDL is the minimum concentration of a substance that can be identified, measured, and reported with 99 percent confidence that the analyte concentration is greater than zero. MDLs are generally smaller and more well defined statistically than MRLs and are commonly reported with analytical results for pesticides and pesticide metabolites (Zaugg and others, 1995). MRLs and MDLs provide information about relative analytical precision and detection sensitivity but do not constitute low concentration reporting limits for conclusively identified analytes (Zaugg and others, 1995). Concentration values below the lowest calibration standard are reported as estimated by NWQL. Estimated values indicate analyte detection; however, the reported concentration value is questionable. Lowest calibration standards are generally larger than MRLs and MDLs. Water-quality constituents and associated MRLs and MDLs are listed in the appendix of this report.

Quality-control samples were collected during the study to document the potential effects of field and laboratory methods on analytical results. Quality-control samples consisted of field blanks, equipment blanks, trip blanks, replicates (sequential samples), and laboratory surrogate recoveries. Three field blanks were analyzed for pesticides and pesticide

**Table 2.** Laboratory analytical methods

[UV, ultra-violet; NWQL, National Water Quality Laboratory; OGRL, Organic Geochemistry Research Laboratory; GC/MS, gas chromatography/mass spectrometry; HPLC, high-performance liquid chromatography]

| Analytes | Analysis method | Reference |
|---|---|---|
| Major ions and nutrients | Various methods | Fishman and Friedman (1989) |
| Dissolved organic carbon | UV-promoted persulfate oxidation and infrared spectrometry | Brenton and Arnett (1993) |
| Pesticides (NWQL) | Extraction on C-18 cartridge and analyzed by GC/MS | Zaugg and others (1995) |
| Pesticides and metabolites (OGRL) | Extraction on C-18 cartridge and analyzed by GC/MS<br>and<br>Extraction on Carbopak-B cartridge and analyzed by HPLC | Thurman and others (1990)<br>Ferrer and others (1997) |
| Volatile organic compounds | Purge and trap GC/MS | Rose and Schroeder (1995) |
| Tritium | Electrolytic enrichment and liquid scintillation | Ostlund and Dorsey (1977) |
| Radon-222 | Liquid scintillation | American Society for Testing and Materials (1996) |
| Deuterium/hydrogen ratio | Hydrogen equilibrium | Coplen and others (1991) |
| Oxygen-18/oxygen-16 ratio | Carbon dioxide equilibrium | Epstein and Mayeda (1953) |

metabolites; five for VOCs; and two for major ions and nutrients. One VOC equipment blank and two VOC trip blanks were used to investigate potential VOC contamination from sampling equipment and during sample shipment. Three replicate samples were analyzed for major ions, nutrients, VOCs, pesticides and pesticide metabolites, radon-222, tritium, and environmental isotopes; and one replicate sample was analyzed for major ions, nutrients, VOCs, and pesticides. Laboratory surrogate recoveries were performed on selected VOCs and pesticides for all ground-water samples. The results of quality-control sampling are presented in Akers and others (1999).

Field blanks showed that for most constituents, chemical contaminants were not being introduced as a result of sample collection and equipment decontamination procedures. However, several major ions, nutrients, VOCs, and metolachlor were present in field blanks at concentrations greater than the MRL or MDL for the constituent (table 3). Calcium, magnesium, and sodium were detected in field blanks at lower concentrations than those measured in ground-water samples. Silica, iron, ammonia, and orthophosphorus were detected in field blanks at concentrations similar to those measured in several ground-water samples. As a result, concentrations of silica, iron, ammonia, and orthophosphorus that approach field-blank concentration values should be considered questionable due to uncertainties concerning the extent to which contamination may affect ground-water sample results. The presence of detectable concentrations of several major ions and nutrients in field blanks may be the result of their presence in the blank water used during this study.

Acetone and methylethylketone were detected in VOC field blanks but were not detected in ground-water samples. Xylene and 1,2,4-trimethylbenzene were detected in field blanks at concentrations that were similar or higher than those measured in ground-water samples. Equipment blanks and trip blanks for VOCs showed that samples were not being contaminated by sampling equipment or during holding and transport. Concentrations of VOCs that approach blank concentration values should be considered questionable. Metolachlor was detected in a field blank at a lower concentration than those measured in ground-water samples; the contaminant source is not known.

Replicate samples showed an acceptable level of precision in field and laboratory procedures for most constituents. However, several major ions, nutrients, and VOCs had relative percent differences (RPDs) between environmental and replicate samples of more than 10 percent (table 4). For many constituents (ammonia, nitrite plus nitrate, phosphorus, orthophosphoros, and bromide), small concentration differences (0.01 mg/L to 0.03 mg/L) resulted in large RPDs because environmental and replicate sample concentrations also were small. The cause of large RPDs for

**Table 3.** Constituents detected in field blanks

[MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; mg/L, milligrams per liter; µg/L, micrograms per liter]

| Constituent | Blanks/ detections | MRL or MDL | Range of concentrations equal to or exceeding MRL or MDL |
|---|---|---|---|
| Calcium | 2/2 | 0.02 mg/L | 0.18 - 1.2 |
| Magnesium | 2/2 | 0.01 mg/L | 0.02 - 0.05 |
| Sodium | 2/2 | 0.20 mg/L | 0.30 - 2.1 |
| Silica | 2/2 | 0.01 mg/L | 0.54 - 12 |
| Iron | 2/2 | 3.0 µg/L | 3.0 - 30 |
| Ammonia, as N | 2/1 | 0.015 mg/L | 0.02 |
| Orthophosphorus, as P | 2/1 | 0.01 mg/L | 0.01 |
| Acetone | 5/3 | 5.0 µg/L | 5.3 - 9.7 |
| Ketone, methylethyl- | 5/3 | 5.0 µg/L | 18.5 - 46.9 |
| Benzene, 1,2,4-trimethyl- | 5/1 | 0.05 µg/L | 0.14 |
| Xylene | 5/2 | 0.05 µg/L | 0.13 |
| Benzene | 5/2 | 0.05 µg/L | 0.05 - 0.12 |
| Metolachlor | 6/1 | 0.002 µg/L | 0.004 |

**Table 4.** Constituents with relative percent differences greater than 10 percent in replicate samples

[RPD, relative percent difference; mg/L, milligrams per liter; >, greater than]

| Constituent | Replicates/ RPDs>10 percent | Average concentration (environmental plus duplicate sample) (mg/L) | Concentration difference (mg/L) | RPD (percent) |
|---|---|---|---|---|
| Ammonia, as N | 4/1 | 0.075 | 0.01 | 13 |
| Nitrite plus nitrate, as N | 4/1 | 0.085 | 0.01 | 12 |
| Phosphorus, as P | 4/2 | 0.035 and 0.055 | 0.01 and 0.03 | 29 and 55 |
| Orthophosphorus, as P | 4/1 | 0.045 | 0.01 | 22 |
| Potassium | 4/1 | 0.65 | 0.1 | 15 |
| Fluoride | 4/1 | 0.25 | 0.1 | 40 |
| Bromide | 4/1 | 0.055 | 0.03 | 55 |

potassium and fluoride is not known. Changes in ground-water quality during environmental and replicate sample collection can affect replicate precision.

Laboratory surrogate recoveries were performed by NWQL to determine the precision and accuracy of analyte recovery in the sample matrix and to evaluate the effectiveness of the analytical methods for selected analytes. Recoveries for selected VOCs (ethane and benzene) ranged from 78 to 118 percent; recoveries for selected pesticides (diazinon, terbuthylazine, and HCH alpha) ranged from 74 to 125 percent. These results indicate that matrix effects were minor, and the analytical methods were effective.

## Statistical Analysis

Water-quality data were graphically represented using box plots to show the 10th, 25th, 50th (median), 75th, and 90th percentiles and concentration values outside the 10th and 90th percentiles. Box plots also were used to illustrate differences between groups of data, for example atrazine concentrations in old water and recently recharged water.

The Wilcoxon rank sum and Kruskal-Wallis nonparametric statistical tests (Ott, 1993, p. 279, 792) were used to evaluate the statistical significance of concentration differences between groups of data. Values were generated by the tests to describe the probability that observed differences between groups occurred by chance. A probability (p) value of 0.05 indicates a 95-percent confidence that observed differences are not the result of chance occurrence. Differences between groups with probability values of 0.05 or less were considered significant.

# GROUND-WATER QUALITY

The U.S. Environmental Protection Agency (USEPA) has established drinking-water regulations for some of the constituents analyzed for this study (U.S. Environmental Protection Agency, 1996). USEPA regulations include maximum contaminant levels (MCL), which are health-based, maximum permissible levels of contaminants that are enforceable for public water-supply systems, and secondary maximum contaminant levels (SMCL), which are nonenforceable and relate to constituents that can affect the aesthetic quality of drinking water. USEPA regulations do not apply to domestic supplies but are used as guidelines to evaluate water quality.

## Analytical Results

The analytical results for ground-water samples collected during this study are presented in Akers and others (1999). A statistical summary of these data is given in the appendix of this report.

Ground water from wells in the study area was commonly of a calcium bicarbonate type (fig. 5). A calcium sulfate type water was present in samples from several wells in the regionally confined part of the Silurian-Devonian aquifer. Large sulfate concentrations (greater than 500 mg/L) also were reported by Horick (1984) in ground water from this area. Magnesium commonly accounted for 20 to 40 percent of the total cations. Sodium commonly accounted for less than 30 percent of the total cations but was the dominant cation in two samples. Concentrations of sulfate exceeded the USEPA MCL (500 mg/L) in 15 percent

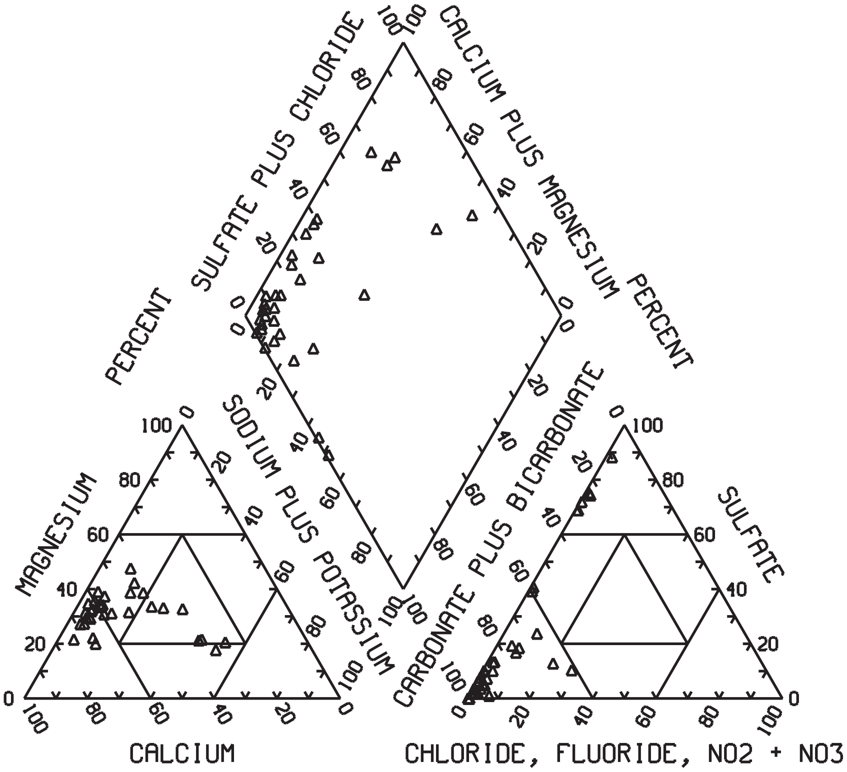


**Figure 5.** Major-ion composition of ground water from the Silurian-Devonian and Upper Carbonate aquifers in the study area.

of samples. USEPA SMCLs were exceeded in 70 percent of samples for iron (300 µg/L), 33 percent for manganese (0.05 mg/L), 24 percent for dissolved solids (500 mg/L), and 9 percent for fluoride (2.0 mg/L).

Nutrients were commonly detected in ground water. Ammonia was the most commonly detected nutrient and was present at concentrations above the MRL (0.015 mg/L as N) in all samples. Orthophosphorus and phosphorus were detected in 73 percent and 55 percent of samples, respectively, in concentrations at or near their MRL (0.01 mg/L). Nitrite plus nitrate was detected in 42 percent of samples and exceeded the MCL (10 mg/L as N) in 6 percent of samples. Nitrite concentrations were at or below the MRL (0.01 mg/L as N) in 97 percent of samples and were detected at a maximum concentration of 0.03 mg/L; therefore, nitrite plus nitrate will be referred to as nitrate in this report.

Atrazine and metolachlor were the only pesticides detected above their MDLs (0.001 µg/L and 0.002 µg/L, respectively) and were present in 18 percent and 12 percent of samples, respectively. Atrazine concentrations were below the MCL (3.0 µg/L); there is no MCL for metolochlor. Alachlor ethanesulfonic acid was the most commonly detected pesticide metabolite and was present at concentrations above the MDL (0.20 µg/L) in 16 percent of samples; deethylatrazine was present at concentrations above the MDL (0.05 µg/L) in 9 percent of samples. Less frequently detected metabolites include metolachlor ethanesulfonic acid, deisopropylatrazine, metolachlor oxanilic acid, alachlor oxanilic acid, and cyanazine-amide. There are currently no USEPA drinking water regulations for pesticide metabolites. Seven samples contained detectable concentrations of at least two pesticides or metabolites; four of these samples contained at least four pesticides or metabolites.

Benzene, ethylbenzene, carbon disulfide, O-ethyltoluene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, and m/p xylene were the only VOCs detected above their MRL and were present in 3 percent of samples. Concentrations of benzene, 1,2,4-trimethylbenzene, and xylene should be considered questionable due to their presence in at least one field blank at similar concentrations. None of the VOC concentrations exceeded USEPA MCLs.

Tritium was present at concentrations above the MRL (1.0 pCi/L) in 42 percent of samples. Small amounts of tritium are produced in the upper atmosphere and introduced into ground water through precipitation recharge. Elevated amounts of tritium began entering the atmosphere in the 1950’s as a result of above-ground nuclear testing. Plummer and others (1993) estimate that ground water derived from precipitation prior to above-ground testing would have a maximum decayed tritium concentration in the 1990’s of 0.6 to 2.6 pCi/L. Based on this criterion, 70 percent of samples represent ground water that was most likely recharged prior to the 1950’s (older water); 30 percent of samples represent ground water that was most likely recharged after the 1950’s (recent recharge).

Radon-222 was present at concentrations above the MRL (24 pCi/L) in all samples. Concentrations exceeded the USEPA previously proposed MCL (300 pCi/L) in 47 percent of samples. Currently, there is no USEPA regulation for radon-222 in drinking water. Environmental isotope analyses were not interpreted in this report. A statistical summary of environmental isotope analyses is given in the appendix of this report.

## Comparison of Data With Other Studies

Ground-water-quality data collected during this study were compared to two other data sets collected during previous studies from wells completed in the Silurian-Devonian and Upper Carbonate aquifers within the same area. Domestic supply wells were sampled in 1988–89 as part of the State-Wide Rural Well-Water Survey (SWRL) (Kross and others, 1990). Municipal supply wells have been sampled annually since 1982 as part of the Iowa Ground-Water Monitoring Network (GWM) (Detroy, 1985; Schaap and Linhart, 1998). Water-quality data from 101 SWRL wells and 118 GWM wells were used for comparison with data from the 33 wells from this study. A statistical comparison of constituents common to all three data sets is given in table 5.

Statistical comparison of the three data sets indicates that for many constituents, statistically significant differences were observed (table 5). Well depths were significantly greater, and specific-conductance values significantly higher in the NAWQA and GWM studies (Wilcoxon rank sum test, p=0.0001 and 0.0251, respectively) than in the SWRL study. Values of pH were significantly lower (p=0.0001) in the NAWQA and SWRL studies than in the GWM study. Chloride concentrations were significantly higher (p=0.0494) in the GWM study than in the NAWQA study. Fluoride concentrations were significantly higher in the NAWQA study than in the GWM (p=0.0312) or SWRL (p=0.0001) studies, whereas magnesium concentrations were significantly higher in the SWRL study than in the NAWQA (p=0.0315) or GWM (p=0.0001) studies. Sodium concentrations were significantly higher in the SWRL study than in the GWM study. Ammonia concentrations were higher (p=0.0002) in the NAWQA and SWRL studies than in the GWM study.

Significantly higher specific conductance values from the NAWQA and GWM studies may be the result of longer ground-water residence times due to significantly greater well depths than the SWRL wells. Significantly higher ammonia concentrations from the NAWQA and SWRL studies may be due to the presence of land-use settings (rural, agricultural) with the potential for nutrient application and subsequent infiltration. The municipal wells sampled for the GWM study are commonly located in nonagricultural settings and often lie within wellhead protection areas. The reasons for the significant differences in pH, chloride, fluoride, magnesium, and sodium are not known.

Due to the small number of detections, a statistical comparison of pesticide and metabolite data for the three data sets could not be performed. However, a comparison based on the number of detections (above the largest MDL of the three data sets for each constituent) indicated that pesticides were rarely (less than 10 percent) detected in the Silurian-Devonian and Upper Carbonate aquifers. Deethylatrazine was detected (MDL=0.1 µg/L) in 6 percent of NAWQA samples, 2 percent of SWRL samples, and

**Table 5.** Comparison of NAWQA, SWRL, and GWM water-quality data for the Silurian-Devonian aquifer in the Eastern Iowa Basins study unit

[NAWQA, National Water-Quality Assessment program; SWRL, Iowa State-wide Rural Well-water Survey; GWM, Iowa Ground-Water Monitoring program; *, statistical comparison not conducted; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; >, greater than; <, less than]

| Measurement or constituent | NAWQA (1996) 33 wells | SWRL (1988–89) 101 wells | GWM (1982–96) 118 wells | Significant difference (Wilcoxon p<0.05) |
|---|---|---|---|---|
| | Median | Median | Median | |
| **FIELD MEASUREMENTS** | | | | |
| Well depth (feet) | 225 | 146 | 230 | NAWQA and GWM > SWRL |
| Specific conductance (µS/cm) | 589 | 528 | 572 | NAWQA and GWM > SWRL |
| pH (standard units) | 7.2 | 7.2 | 7.4 | GWM > NAWQA and SWRL |
| **MAJOR IONS, dissolved (mg/L)** | | | | |
| Calcium | 75 | 74.1 | 73.5 | None |
| Chloride | 2.3 | 3.4 | 4.7 | GWM > NAWQA |
| Fluoride | 0.5 | <0.1 | 0.3 | NAWQA > GWM > SWRL |
| Magnesium | 25 | 31.8 | 24 | SWRL > GWM and NAWQA |
| Potassium | 2.1 | 1.8 | 1.6 | None |
| Sodium | 8.6 | 13.6 | 8.3 | SWRL > GWM |
| Sulfate | 24 | 22.6 | 30.5 | None |
| **NUTRIENTS, dissolved (mg/L)** | | | | |
| Ammonia, as N | 0.6 | 0.3 | <0.1 | NAWQA and SWRL > GWM |
| Nitrite plus nitrate, as N | <0.1 | <0.1 | <0.1 | None |
| **PESTICIDES and PESTICIDE METABOLITES, dissolved (µg/L)** | | | | |
| Alachlor | <0.2 | <0.2 | <0.2 | * |
| Atrazine | <0.2 | <0.2 | <0.2 | * |
| Atrazine, deethyl- | <0.1 | <0.1 | <0.1 | * |
| Atrazine, deisopropyl- | <0.1 | <0.1 | <0.1 | * |
| Cyanazine | <0.1 | <0.1 | <0.1 | * |
| Metolachlor | <0.1 | <0.1 | <0.1 | * |
| Metribuzin | <0.1 | <0.1 | <0.1 | * |

none of the GWM samples. Deisopropylatrazine was detected (MDL=0.1 µg/L) in 6 percent of NAWQA samples, 4 percent of SWRL samples, and none of GWM samples. Atrazine was detected (MDL= 0.2 µg/L) in 4 percent of GWM samples, 3 percent of NAWQA samples, and 2 percent of SWRL samples. Metolachlor and cyanazine were detected (MDL= 0.1 µg/L) in 12 percent and 3 percent of GWM samples, respectively, and in none of the NAWQA or SWRL samples. Alachlor was detected (MDL= 0.2 µg/L) in 1 percent of SWRL samples, 2 percent of GWM samples and in none of the NAWQA samples. Metribuzin was detected (MDL=0.1 µg/L) in 1 percent of GWM samples and in none of the NAWQA or SWRL samples.

## Factors Affecting Ground-Water Quality

The physical properties and lithologic composition of geologic materials can affect ground-water quality. The rate at which ground water moves through geologic materials is determined in part by the material’s hydraulic conductivity. Smaller hydraulic conductivities and long flow paths to aquifers beneath confining units increase the residence time (age) of ground water and allow for more complete dissolution of soluble minerals and higher dissolved-solids concentrations. Dominant ions commonly reflect the mineral composition of geologic materials contacted by the ground water. Geochemical environments can influence constituent speciation, and human activities may affect ground-water quality if anthropogenic chemicals and nutrients infiltrate the subsurface.

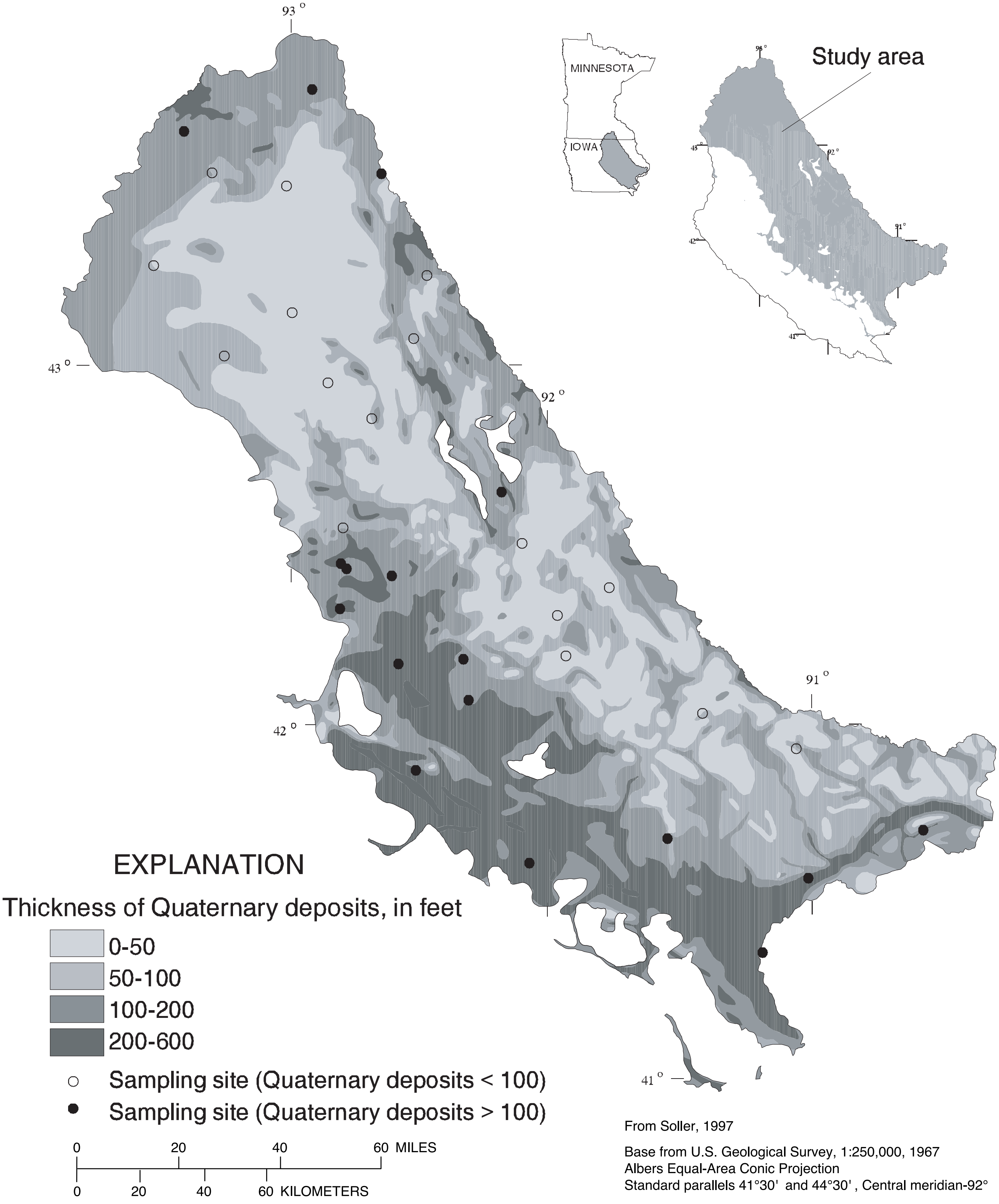
Limestone and dolomite are the dominant lithologies in the Silurian-Devonian and Upper Carbonate aquifers. Calcium, magnesium, and bicarbonate were commonly the dominant ions in ground-water samples from the aquifers (fig. 5), and their presence may be the result of the solution of carbonate minerals (calcite and dolomite) in the aquifer material. Calcium and sulfate were the dominant ions in three ground-water samples, and their presence suggests the dissolution of an evaporite mineral such as gypsum. Hershey (1969) noted the presence of gypsum in the Devonian-age Cedar Valley Limestone and Wapsipinicon Formation within the study area.

The Devonian-age Lime Creek Formation and Yellow Spring Group regionally confine the Silurian-Devonian aquifer in the western part of the study area. Unconsolidated Quaternary-age deposits, which commonly contain low permeability glacial deposits, cover most of the study area (fig. 6). The Iowa Department of Natural Resources evaluated the effects of glacial deposits on aquifer vulnerability (Hoyer and Hallberg, 1991) and suggested that 100 ft or more of glacial material can reduce the potential for contamination of underlying bedrock aquifers. A comparison of water quality from relatively well protected areas (where the aquifer is overlain by a bedrock confining unit or more than 100 feet of Quaternary-age deposits) and relatively poorly protected areas (where the aquifer is not overlain by a bedrock confining unit or is overlain by less than 100 feet of Quaternary-age deposits) of the Silurian-Devonian and Upper Carbonate aquifers in the study area was performed. Tritium-based ground-water ages were significantly older (p=0.024) in relatively well protected areas of the aquifers than in relatively poorly protected areas (fig. 7). Dissolved-solids concentrations were significantly higher (p=0.011) in relatively well protected areas of the aquifers than in relatively poorly protected areas (fig. 7).

Nitrogen- and phosphorus-based fertilizers are applied at land surface throughout the study area and are important potential sources of nutrients in ground water. Ammonia concentrations in the Silurian-Devonian and Upper Carbonate aquifers were significantly higher ($p<0.001$) in relatively well protected areas and in samples from wells that produced older water (p=0.001; fig. 8). Nitrate concentrations were significantly higher (p=0.004) in relatively poorly protected areas and in samples from wells that produced recently recharged water (p=0.046; fig. 8). Nitrogen speciation is influenced by the geochemical environment. Ammonia concentrations were higher in ground water with dissolved-oxygen concentrations of 0.5 mg/L or less (fig. 9), allowing for the anaerobic reduction of nitrate to ammonia. Nitrate concentrations were highest in ground water with dissolved-oxygen concentrations in excess of 0.5 mg/L. Statistically significant relations between relative aquifer protection and concentrations of orthophosphorus and phosphorus were not observed.

Pesticide usage in agricultural and urban settings is common throughout the study area. With time, pesticides degrade to form a series of metabolites. As pesticides and their metabolites are leached from land surface, they may enter ground water. Pesticide and metabolite concentrations in the Silurian-Devonian and Upper Carbonate aquifers were significantly higher (p=0.001 to 0.032) in samples from wells that produced recently recharged water than from wells that produced older water (fig. 10). Alachlor ESA and deethylatrazine were not detected in any samples from wells that produced older water. Atrazine and metolachlor had only one detection each in samples from wells that produced older water. Atrazine, metolachlor, and deethylatrazine were not detected in any samples from relatively well protected areas of the aquifers, and alachlor ESA was detected in only one sample from relatively well protected areas (fig. 11). Atrazine and metolachlor concentrations were significantly higher (p=0.004 and 0.023, respectively) in relatively poorly protected areas of the aquifers. The effect of relative aquifer protection was not statistically significant for alachlor ESA and deethylatrazine (p=0.057 and 0.116, respectively).

Radon-222 is a naturally occurring gas produced by the radioactive decay of uranium. Radon is radioactive (half-life of 3.8 days) and water soluble (Hem, 1985). Radon-222 concentrations in the Silurian-Devonian and Upper Carbonate aquifers were significantly higher in samples from wells that produced recently recharged water than from wells that produced older water (p=0.023; fig. 12). This relation suggests that uranium-bearing glacial deposits (Schumann, 1993) may be a source of radon-222 in the underlying Silurian-Devonian and Upper Carbonate aquifers. A statistically significant relation between relative aquifer protection and concentrations of radon-222 was not observed.



From Soller, 1997

Base from U.S. Geological Survey, 1:250,000, 1967
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Standard parallels 41°30' and 44°30', Central meridian-92°

**Figure 6.** Distribution and thickness of Quaternary deposits and location of sampling sites in the study area.

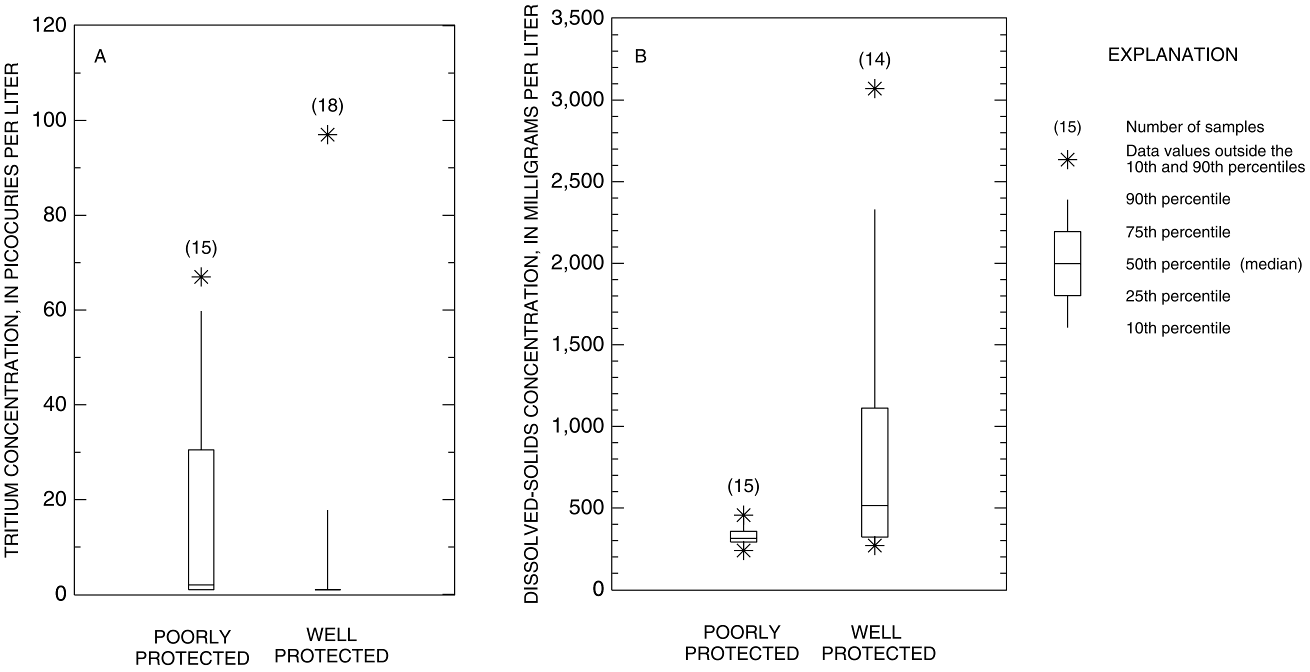

**Figure 7.** Relation between relative aquifer protection and (A) tritium concentration, and (B) dissolved-solids concentration.

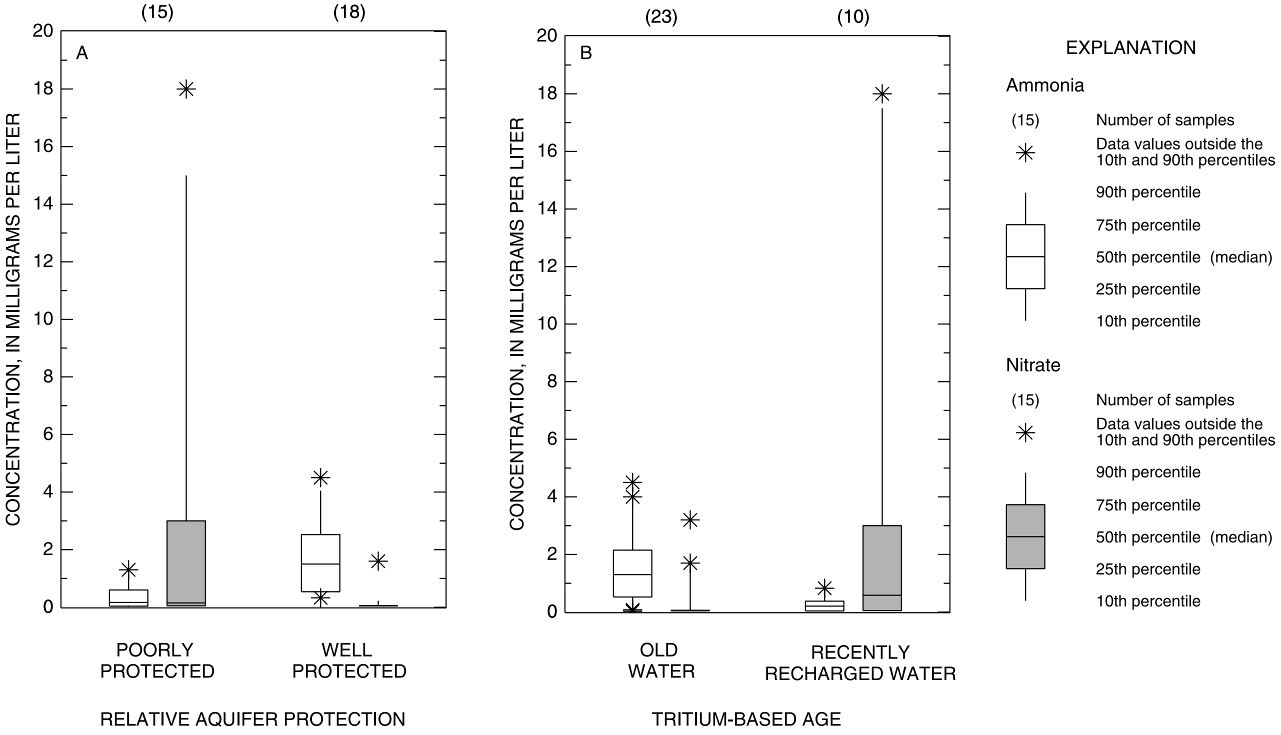

**Figure 8.** Relation between (A) relative aquifer protection and ammonia and nitrate concentrations, and (B) tritium-based ground-water age and ammonia and nitrate concentrations.

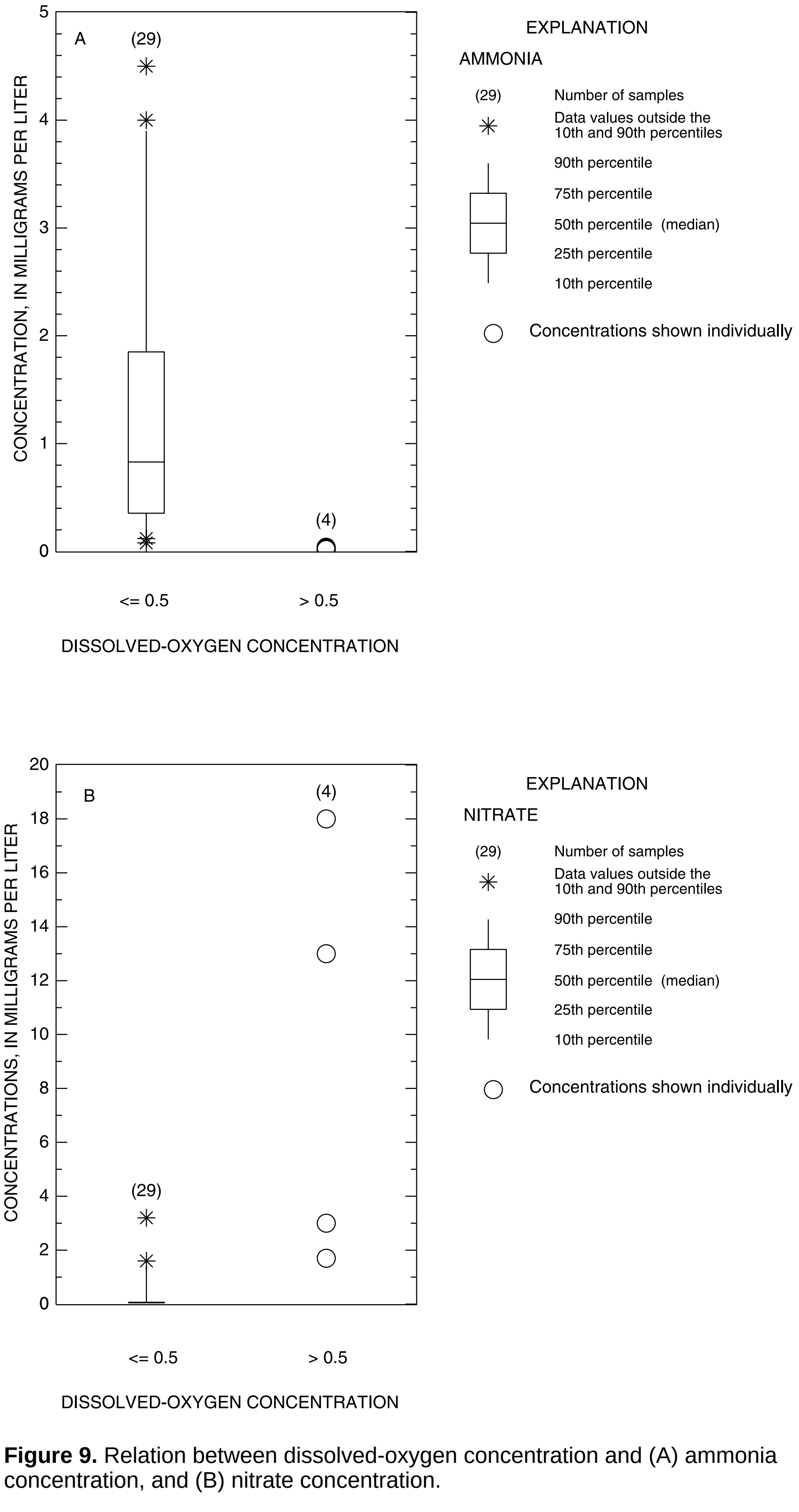

**Figure 9.** Relation between dissolved-oxygen concentration and (A) ammonia concentration, and (B) nitrate concentration.

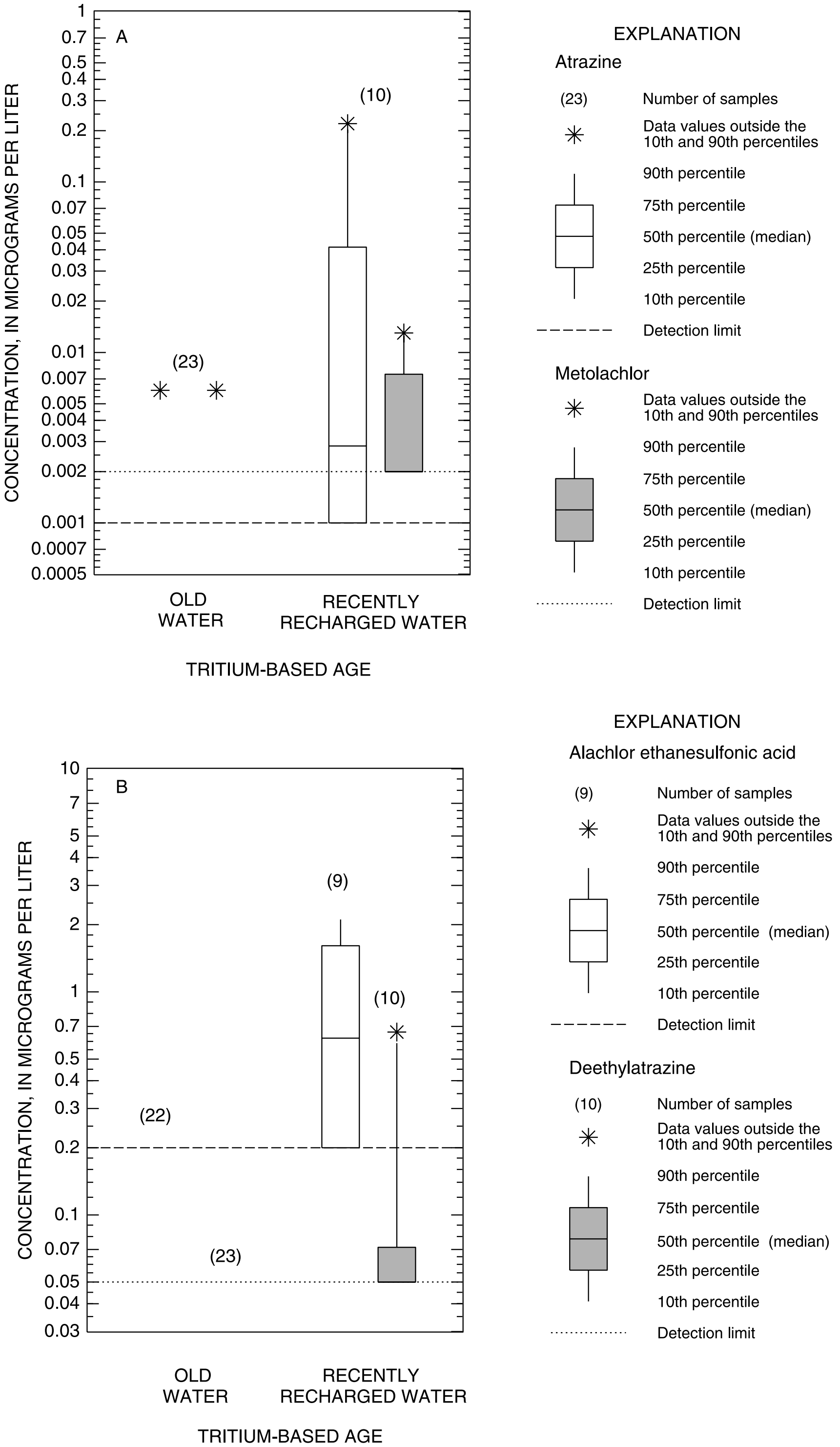

**Figure 10.** Relation between tritium-based ground-water age and (A) atrazine and metolachlor concentrations, and (B) alachlor ethanesulfonic acid and deethylatrazine concentrations.

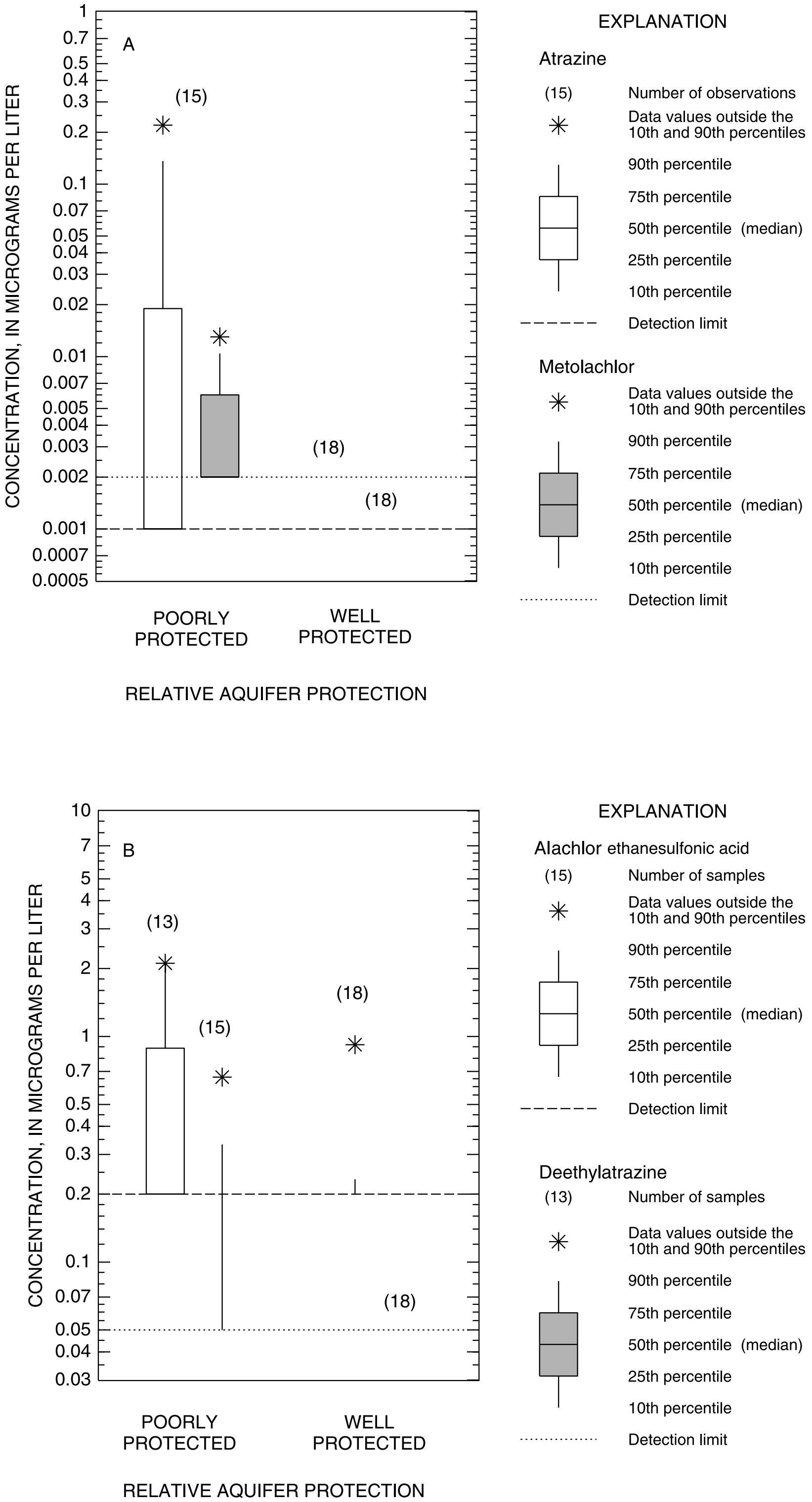

**Figure 11.** Relation between relative aquifer protection and (A) atrazine and metolachlor concentrations, and (B) alachlor ethanesulfonic acid and deethylatrazine concentrations.

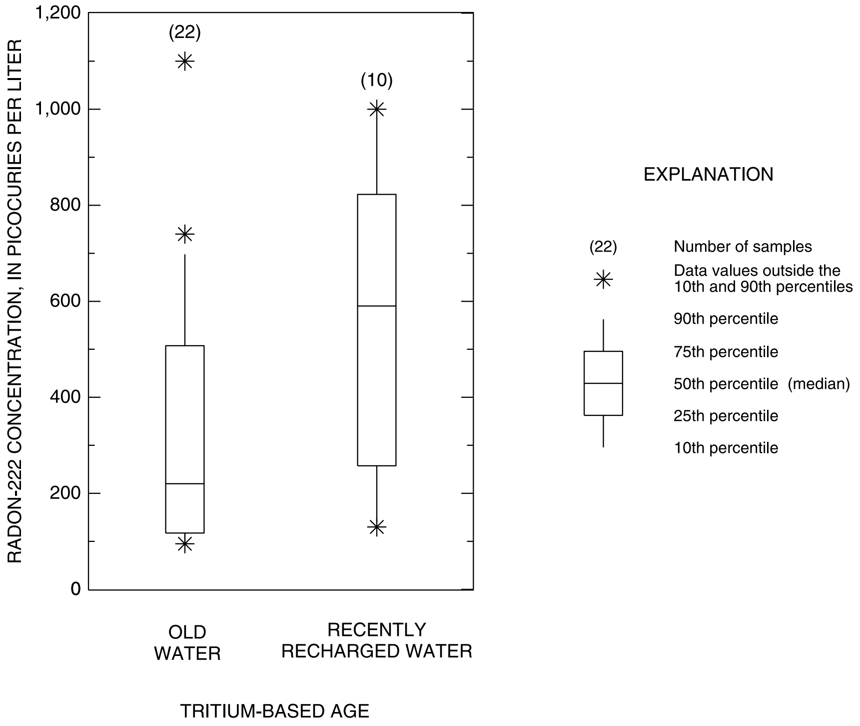

**Figure 12**. Relation between tritium-based ground-water age and radon-222 concentration.

## SUMMARY

The Eastern Iowa Basins study unit encompasses an area of about 19,500 mi$^2$ in eastern Iowa and southern Minnesota and is one of 59 study units in the NAWQA Program. Ground-water samples were collected from 33 domestic wells completed in the eastern part of the Silurian-Devonian and Upper Carbonate aquifers in the Eastern Iowa Basins study unit during June–July 1996 to assess the water quality of the most intensively used (ground-water supply) part of the aquifers in the study area. Ground-water samples were analyzed for major ions, nutrients, pesticides and pesticide metabolites, VOC’s, tritium, radon, and environmental isotopes.

Calcium, magnesium, and bicarbonate were the dominant ions in most samples and were likely derived from the solution of carbonate minerals (calcite and dolomite) present in the aquifer materials. The dominance of sulfate in samples from several wells suggests the solution of evaporite minerals. Ammonia and orthophosphorus were the most commonly detected nutrients. Nitrate was detected in about half of the samples and exceeded the USEPA MCL (10 mg/L, as N) in 6 percent of samples. Atrazine and metolachlor were the only pesticides detected and were present in 18 percent and 12 percent of samples, respectively. Alachlor ethanesulfonic acid and deethylatrazine were the most commonly detected pesticide metabolites and were present in 16 percent and 9 percent of samples, respectively. Radon-222 was detected in all samples, and 47 percent had concentrations in excess of the USEPA previously proposed MCL (300 pCi/L). Radon-222 concentrations were significantly higher in wells that produced recently recharged water. This relation suggests that uranium-bearing glacial deposits may be a source of radon-222 in the underlying aquifers.

The presence of regional confining units and thick overlying Quaternary-age deposits have an effect on water quality in the Silurian-Devonian and Upper Carbonate aquifers in the study area. A comparison of water quality from relatively well protected areas (where the aquifers are overlain by a bedrock confining unit or more than 100 feet of Quaternary-age deposits) and relatively poorly protected areas (where the aquifers are not overlain by a bedrock confining unit or are overlain by less than 100 feet of Quaternary-age deposits) of the Silurian-Devonian and Upper Carbonate aquifers in the study area was performed. Tritium-based ground-water ages were significantly older, and dissolved-solids concentrations were significantly higher in relatively well protected areas of the aquifers. Ammonia concentrations were significantly higher in relatively well protected areas and in samples from wells that produced older water. Higher ammonia concentrations also were observed in ground water with dissolved-oxygen concentrations of 0.5 mg/L or less, allowing for the anaerobic reduction of nitrate to ammonia. Nitrate concentrations were significantly higher in relatively poorly protected areas and in samples from wells that produced recently recharged water. Pesticide and metabolite concentrations were significantly higher in samples from wells that produced recently recharged water. Atrazine, metolachlor, and deethylatrazine were not detected in any samples from relatively well protected areas of the aquifers. Alachlor ethanesulfonic acid was detected in only one sample from a relatively well protected area. Atrazine and metolachlor concentrations were significantly higher in relatively poorly protected areas of the aquifers.

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# APPENDIX

**Appendix:** Statistical summary of selected ground-water quality data from wells in the eastern part of the Silurian-Devonian and Upper Carbonate aquifers

[MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; $^oC$, degrees Celsius; <, less than; pCi/L, picocuries per liter; µg/L, micrograms per liter]

| Constituent | Samples/ detec- tions | MRL or MDL | Maximum value | Minimum value | 75th percentile | Median | 25th percentile |
|---|---|---|---|---|---|---|---|
| **FIELD MEASUREMENTS AND PHYSICAL CHARACTERISTICS** | | | | | | | |
| Well depth (feet below land surface) | 33/na | na | 700 | 32 | 320 | 225 | 155 |
| Water level (feet below land surface) | 33/na | na | 224 | 12 | 77 | 59 | 31 |
| Dissolved oxygen (mg/L) | 33/na | na | 7.8 | 0.0 | 0.10 | 0.10 | 0.10 |
| pH (standard units) | 33/na | na | 7.5 | 6.8 | 7.3 | 7.2 | 7.0 |
| Specific conductance (µS/cm at 25$^oC$) | 33/na | na | 3,810 | 395 | 774 | 589 | 521 |
| Water temperature ($^oC$) | 33/na | na | 17.7 | 9.3 | 13.5 | 12.1 | 10.9 |
| **MAJOR IONS, dissolved (mg/L, except as indicated)** | | | | | | | |
| Alkalinity (mg/L as $CaCO_3$) | 33/na | na | 448 | 148 | 320 | 275 | 231 |
| Bicarbonate (mg/L as $HCO_3$) | 33/na | na | 547 | 181 | 390 | 336 | 282 |
| Bromide | 33/30 | 0.01 | 0.15 | <0.01 | 0.06 | 0.04 | 0.02 |
| Calcium | 33/33 | 0.02 | 230 | 42 | 100 | 75 | 67 |
| Chloride | 33/33 | 0.10 | 30 | 0.10 | 5.8 | 2.3 | 0.5 |
| Fluoride | 33/32 | 0.10 | 2.3 | <0.10 | 0.80 | 0.50 | 0.30 |
| Iron (µg/L) | 33/31 | 3.0 | 4,900 | <3.0 | 1,400 | 630 | 280 |
| Magnesium | 33/33 | 0.01 | 120 | 13 | 32 | 25 | 21 |
| Manganese | 33/32 | 0.001 | 0.74 | <0.001 | 0.068 | 0.021 | 0.011 |
| Potassium | 33/33 | 0.10 | 24 | 0.5 | 4.3 | 2.1 | 1.5 |
| Silica | 33/33 | 0.01 | 31 | 7 | 14 | 12 | 9.1 |
| Sodium | 33/33 | 0.20 | 530 | 3.4 | 36 | 8.6 | 6.9 |
| Sulfate | 33/29 | 0.10 | 2,000 | <0.10 | 66 | 24 | 8.6 |
| Dissolved solids | 29/29 | 1.0 | 3,070 | 240 | 456 | 336 | 304 |
| **NUTRIENTS, dissolved (mg/L)** | | | | | | | |
| Ammonia, as N | 33/33 | 0.015 | 4.5 | 0.02 | 1.5 | 0.6 | 0.19 |
| Ammonia plus organic, as N | 33/26 | 0.2 | 7.3 | <0.2 | 2.0 | 0.6 | 0.3 |
| Nitrite, as N | 33/6 | 0.01 | 0.03 | <0.01 | <0.01 | <0.01 | <0.01 |
| Nitrite plus nitrate, as N | 33/14 | 0.05 | 18 | <0.05 | 0.15 | 0.05 | <0.05 |
| Orthophosphorus, as P | 33/24 | 0.01 | 0.16 | <0.01 | 0.04 | 0.02 | <0.01 |
| Phosphorus, as P | 33/18 | 0.01 | 0.51 | <0.01 | 0.04 | 0.02 | <0.01 |
| **RADIOCHEMICALS and ENVIRONMENTAL ISOTOPES** | | | | | | | |
| Radon-222 (pCi/L) | 32/32 | 24 | 1,100 | 95 | 595 | 290 | 155 |
| Tritium (pCi/L) | 33/14 | 1.0 | 97 | <1.0 | 9.0 | <1.0 | <1.0 |
| Oxygen-18/Oxygen-16 (per mil) | 33/na | na | -6.99 | -9.23 | -7.31 | -8.03 | -8.53 |
| Deuterium/Protium (per mil) | 33/na | na | -43.4 | -62.7 | -47.8 | -52.8 | -57 |
| **PESTICIDES and PESTICIDE METABOLITES, dissolved (µg/L)** | | | | | | | |
| Acetochlor | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Acetochlor ESA | 31/0 | 0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| Acetochlor oxanilic acid | 31/0 | 0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| Alachlor | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Alachlor ESA | 31/5 | 0.2 | 2.11 | <0.2 | <0.2 | <0.2 | <0.2 |
| Alachlor oxanilic acid | 31/1 | 0.2 | 0.62 | <0.2 | <0.2 | <0.2 | <0.2 |
| Atrazine | 33/6 | 0.001 | 0.22 | <0.001 | <0.001 | <0.001 | <0.001 |
| Atrazine, deethyl- | 33/3 | 0.05 | 0.66 | <0.05 | <0.05 | <0.05 | <0.05 |

**Appendix:** Statistical summary of selected ground-water quality data from wells in the eastern part of the Silurian-Devonian and Upper Carbonate aquifers—Continued

[MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; $^{o}$C, degrees Celsius; <, less than; pCi/L, picocuries per liter; µg/L, micrograms per liter]

| Constituent | Samples/ detec- tions | MRL or MDL | Maximum value | Minimum value | 75th percentile | Median | 25th percentile |
|---|---|---|---|---|---|---|---|
| **PESTICIDES and PESTICIDE METABOLITES, dissolved (µg/L)—Continued** | | | | | | | |
| Atrazine, deisopropyl- | 33/2 | 0.05 | 0.36 | <0.05 | <0.05 | <0.05 | <0.05 |
| Atrazine, hydroxy- | 31/0 | 0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| Azinphos, methyl- | 33/0 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Benfluralin | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Butylate | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Carbaryl | 33/0 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Carbofuran | 33/0 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Chlorpyrifos | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Cyanazine | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Cyanazine-amide | 33/1 | 0.05 | 0.19 | <0.05 | <0.05 | <0.05 | <0.05 |
| DCPA | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| DDE, p,p’- | 33/0 | 0.006 | <0.006 | <0.006 | <0.006 | <0.006 | <0.006 |
| Diazinon | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Dieldrin | 33/0 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Diethylaniline, 2,6- | 33/0 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Disulfoton | 33/0 | 0.017 | <0.017 | <0.017 | <0.017 | <0.017 | <0.017 |
| EPTC | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Ethalfluralin | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Ethoprop | 33/0 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Fonofos | 33/0 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| HCH, alpha- | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Lindane | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Linuron | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Malathion | 33/0 | 0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Metolachlor | 33/4 | 0.002 | 0.013 | <0.002 | <0.002 | <0.002 | <0.002 |
| Metolachlor ESA | 31/2 | 0.20 | 4.36 | <0.2 | <0.2 | <0.2 | <0.2 |
| Metolachlor oxanilic acid | 31/1 | 0.02 | 0.86 | <0.2 | <0.2 | <0.2 | <0.2 |
| Metribuzin | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Molinate | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Napropamide | 33/0 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Parathion | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Parathion, methyl- | 33/0 | 0.006 | <0.006 | <0.006 | <0.006 | <0.006 | <0.006 |
| Pebulate | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Pendimethalin | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Permethrin, cis- | 33/0 | 0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Phorate | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Prometon | 33/0 | 0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| Pronamide | 33/0 | 0.003 | <0.003 | <0.003 | <0.003 | <0.003 | <0.003 |
| Propachlor | 33/0 | 0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 |
| Propanil | 33/0 | 0.004 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 |
| Propargite | 33/0 | 0.013 | <0.013 | <0.013 | <0.013 | <0.013 | <0.013 |
| Simazine | 33/0 | 0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |

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[MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; <, less than; pCi/L, picocuries per liter; µg/L, micrograms per liter]

| Constituent | Samples/ detec- tions | MRL or MDL | Maximum value | Minimum value | 75th percentile | Median | 25th percentile |
|---|---|---|---|---|---|---|---|
| **PESTICIDES and PESTICIDE METABOLITES, dissolved (µg/L)—Continued** | | | | | | | |
| Tebuthiuron | 33/0 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Terbacil | 33/0 | 0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 |
| Terbufos | 33/0 | 0.013 | <0.013 | <0.013 | <0.013 | <0.013 | <0.013 |
| Thiobencarb | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| Triallate | 33/0 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Trifluralin | 33/0 | 0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| **VOLATILE ORGANIC COMPOUNDS, total (µg/L)** | | | | | | | |
| Acetate, vinyl- | 33/0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Acetone | 33/0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Acrolein | 33/0 | 2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 |
| Acrylonitrile | 33/0 | 2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 |
| Acrylonitrile, methyl- | 33/0 | 2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 |
| Benzene | 33/1 | 0.05 | 0.13 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, 1,2,3-trichloro- | 33/0 | 0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| Benzene, 1,2,4-trichloro- | 33/0 | 0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| Benzene, 1,2,3-trimethyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, 1,2,4-trimethyl- | 33/1 | 0.05 | 0.210 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, O-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, 1,3,5-trimethyl- | 33/1 | 0.05 | 0.07 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, 1,3-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, 1,4-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, isopropyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, bromo- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, chloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, ethyl- | 33/1 | 0.05 | 0.07 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, n-butyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, n-propyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, sec-butyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Benzene, tert-butyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Bromoform | 33/0 | 0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Butene, trans-1,4-dichloro-2- | 33/0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Carbon disulfide | 33/1 | 0.05 | 0.30 | <0.05 | <0.05 | <0.05 | <0.05 |
| Carbon tetrachloride | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ethane, 1,1,1,2-tetrachloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ethane, 1,1,1-trichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ethane, 1,1,2,2-tetrachloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ethane, 1,1,2-trichloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ethane, 1,1-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ethane, 1,2-dibromo- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ethane, 1,2-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ethane, chloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ethane, hexachloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |

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[MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; $^{o}$C, degrees Celsius; <, less than; pCi/L, picocuries per liter; µg/L, micrograms per liter]

| Constituent | Samples/ detec- tions | MRL or MDL | Maximum value | Minimum value | 75th percentile | Median | 25th percentile |
|---|---|---|---|---|---|---|---|
| **VOLATILE ORGANIC COMPOUNDS, total (µg/L)—Continued** | | | | | | | |
| Ethene, bromo- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ethene, cis-1,2-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ethene, trans-1,2-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ether, diisopropyl- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ether, ethyl- | 33/0 | 0.10 | <0.10 | <0.10 | <,0.10 | <0.10 | <0.10 |
| Ether, tert-butyl ethyl- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ether, tert-pentyl methyl- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ethyl methacrylate | 33/0 | 1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Ethylene, 1,1-dichloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Ethylene, trichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Freon-113 | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Furan, tetrahydro- | 33/0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Hexachlorobutadiene | 33/0 | 0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Hexanone, 2- | 33/0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Iodine, methyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Isodurene | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ketone, methyl ethyl- | 33/0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Ketone, methyl iso-butlyl- | 33/0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| Methacrylate, methyl- | 33/0 | 1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |
| Methane, bromochloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Methane, dibromo- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Methane, dibromochloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Methane, dichlorobromo- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Methane, dichlorodifluoro- | 33/0 | 0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Methane, trichlorofluoro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Methyl acrylate | 33/0 | 2.0 | <2.0 | <2.0 | <2.0 | <2.0 | <2.0 |
| Methyl bromide | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Methyl chloride | 33/0 | 0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Methyl tert-butyl ether | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Naphthalene | 33/0 | 0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Prehnitene | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Propane, 1,2,3-trichloro- | 33/0 | 0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Propane, dibromochloro- | 33/0 | 0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Propane, 1,2-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Propane, 1,3-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Propane, 2,2-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Propene, 1,1-dichloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Propene, 3-chloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Propene, cis-1,3-dichloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Propene, trans-1,3-dichloro- | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Styrene | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Toluene, o-chloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |

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| Constituent | Samples/ detec- tions | MRL or MDL | Maximum value | Minimum value | 75th percentile | Median | 25th percentile |
|---|---|---|---|---|---|---|---|
| **VOLATILE ORGANIC COMPOUNDS, total (µg/L)—Continued** | | | | | | | |
| Toluene, o-ethyl | 33/1 | 0.05 | 0.10 | <0.05 | <0.05 | <0.05 | <0.05 |
| Toluene, p-chloro- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Toluene, P-isopropyl- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Vinyl chloride | 33/0 | 0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Xylene, m/p- | 33/1 | 0.05 | 0.17 | <0.05 | <0.05 | <0.05 | <0.05 |
| Xylene, o- | 33/0 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |