

EFFECTS OF LAND USE AND HYDROGEOLOGY ON THE WATER QUALITY OF ALLUVIAL AQUIFERS IN EASTERN IOWA AND SOUTHERN MINNESOTA, 1997

Water-Resources Investigations Report 99-4246



Effects of Land Use and Hydrogeology on the Water Quality of Alluvial Aquifers in Eastern Iowa and Southern Minnesota, 1997

By Mark E. Savoca, Eric M. Sadorf, S. Mike Linhart, and Kymm K.B. Akers

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 99-4246

Iowa City, Iowa
2000

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

For additional information write to:

District Chief
U.S. Geological Survey
P.O. Box 1230
Iowa City, Iowa 52244

Copies of this report can be purchased
from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

CONTENTS

Abstract.....	1
Introduction.....	2
Purpose and Scope.....	2
Description of Study Area.....	5
Acknowledgments.....	5
Study Design and Methods.....	5
Site Selection.....	5
Well Installation.....	5
Land-Use Classification.....	7
Sample Collection.....	7
Water-Quality Analysis.....	8
Statistical Analysis.....	11
Effects of Land Use and Hydrogeology on Water Quality.....	12
Common Ions.....	13
Nutrients.....	13
Radiochemicals.....	16
Pesticides and Metabolites.....	19
Volatile Organic Compounds.....	23
Summary and Conclusions.....	25
References.....	26
Appendix.....	31

FIGURES

1–3. Maps showing:	
1. Location and extent of Eastern Iowa Basins study unit.....	3
2. Distribution of alluvial deposits and location of sampling sites.....	4
3. Land use and land cover in the study unit.....	6
4–6. Boxplots showing:	
4. Relation between land use and well depth, depth to water, and depth to top of sample interval.....	12
5. Relation between land use and tritium concentration.....	13
6. Relation between land use and cumulative clay thickness.....	13
7. Piper diagram showing major-ion composition of ground water from alluvial aquifers in the study unit.....	14
8–13. Boxplots showing:	
8. Relation between land use and dissolved-solids, sodium, and chloride concentrations.....	15
9. Relation between land use and ammonia, nitrate, and dissolved-oxygen concentrations.....	16
10. Relation between dissolved-oxygen concentration and ammonia and nitrate concentrations in samples from (A) agricultural areas, and (B) urban areas.....	17
11. Relation between nitrate concentration and well depth, depth below water table to top of sample interval, and cumulative clay thickness above the sample interval in samples from (A) agricultural areas, and (B) urban areas.....	17
12. Relation between land use and organic carbon and dissolved organic carbon concentrations.....	18
13. Relation between nitrate concentration and organic carbon and dissolved organic carbon concentrations in samples from (A) agricultural, and (B) urban areas.....	18
14–16. Graphs showing:	
14. Relation between radon-222 concentration and cumulative clay thickness above the sample interval.....	19
15. Frequency of detection of pesticides in samples from agricultural and urban areas.....	20
16. Frequency of detection of pesticide metabolites in samples from agricultural and urban areas.....	21
17. Boxplot showing relation between land use and total pesticide (parent compounds) and total metabolite concentrations.....	22

18–21. Graphs showing:

- 18. Relation between atrazine, deethylatrazine, and deisopropylatrazine concentrations and well depth in samples from agricultural areas 22
- 19. Relation between atrazine, deethylatrazine, and deisopropylatrazine concentrations and depth below water table to top of sample interval in samples from agricultural areas 23
- 20. Relation between atrazine concentration and cumulative clay thickness above the sample interval in samples from urban areas..... 23
- 21. Frequency of detection of volatile organic compounds in samples from urban areas 24

TABLES

- 1. Statistical summary of percent land use within 1,640 feet of agricultural and urban land-use monitoring wells..... 8
- 2. Laboratory analytical methods 9
- 3. Constituents detected in equipment and field blanks 10
- 4. Constituents with relative percent differences greater than 10 percent in replicate samples..... 11

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 degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

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.

Effects of Land Use and Hydrogeology on the Water Quality of Alluvial Aquifers in Eastern Iowa and Southern Minnesota, 1997

By Mark E. Savoca, Eric M. Sadorf, S. Mike Linhart, and Kymm K.B. Akers

Abstract

Ground-water samples were collected from monitoring wells at 31 agricultural and 30 urban sites in the Eastern Iowa Basins study unit during June–August 1997 to evaluate the effects of land use and hydrogeology on the water quality of alluvial aquifers. Ground-water samples were analyzed for common ions, nutrients, dissolved organic carbon, tritium, radon-222, pesticides and pesticide metabolites, volatile organic compounds, and environmental isotopes.

Calcium, magnesium, and bicarbonate were the dominant ions in most samples and were likely derived from solution of carbonate minerals (calcite and dolomite) present in alluvial detrital deposits. Chloride and nitrate were dominant anions in samples from several wells. Sodium and chloride concentrations were significantly higher in samples from urban areas, where roads are more numerous and road salts may be more frequently applied, than in agricultural areas. Nitrate was detected in 94 percent of samples from agricultural areas and 77 percent of samples from urban areas. Nitrate concentrations were significantly higher in agricultural areas than in urban areas and exceeded the U.S. Environmental Protection Agency maximum contaminant level for drinking water (10 milligrams per liter as N) in 39 percent of samples from agricultural areas. Nitrate concentrations in samples from urban areas did not exceed the maximum contaminant level. Greater use of fertilizers in agricultural areas most likely contributes to higher nitrate concentrations in samples from those areas.

Tritium-based ages indicate ground water was most likely recharged after the 1950's at all but one sampling site. Agricultural and urban land-use areas have remained relatively stable in the study area since the 1950's; therefore, the effects of current land use should be reflected in ground water sampled during this study. Radon-222 was detected in all samples and exceeded the U.S. Environmental Protection Agency's previously proposed maximum contaminant level for drinking water (300 picocuries per liter) in 71 percent of samples.

Pesticides were detected in 84 percent of samples from agricultural areas and 70 percent from urban areas. Atrazine and metolachlor were the most frequently detected pesticides in samples from agricultural areas; atrazine and prometon were the most frequently detected pesticides in samples from urban areas. None of the pesticide concentrations exceeded U.S. Environmental Protection Agency maximum contaminant levels or lifetime health advisories for drinking water. Pesticide metabolites were detected in 94 percent of samples from agricultural areas and 53 percent from urban areas. Metolachlor ethane sulfonic acid and deethylatrazine were the most frequently detected metabolites in samples from agricultural areas; metolachlor ethane sulfonic acid and alachlor ethane sulfonic acid were the most frequently detected metabolites in samples from urban areas.

Total metabolite concentrations were significantly higher in samples from agricultural areas than in samples from urban areas. Total pesticide concentrations (parent compounds) tended to be

higher in samples from agricultural areas; however, this difference was not statistically significant. Metabolites constituted the major portion of the total residue concentration in the alluvial aquifer.

Volatile organic compounds were detected in 40 percent of samples from urban areas and 10 percent from agricultural areas. Methyl tert-butyl ether was the most commonly detected volatile organic compound and was present in 23 percent of samples from urban areas. Elevated concentrations (greater than 30 micrograms per liter) of methyl tert-butyl ether and BTEX compounds (benzene, toluene, ethylbenzene, and xylene) in two samples from urban areas suggest the possible presence of point-source gasoline leaks or spills.

Factors other than land use may contribute to observed differences in water quality between and within agricultural and urban areas. Nitrate, atrazine, deethylatrazine, and deisopropylatrazine concentrations were significantly higher in shallow wells with sample intervals nearer the water table and in wells with thinner cumulative clay thickness above the sample intervals. These relations suggest that longer flow paths allow for greater residence time and increase opportunities for sorption, degradation, and dispersion, which may contribute to decreases in nutrient and pesticide concentrations with depth. Nitrogen speciation was influenced by redox conditions. Nitrate concentrations were significantly higher in ground water with dissolved-oxygen concentrations in excess of 0.5 milligram per liter. Ammonia concentrations were higher in ground water with dissolved-oxygen concentrations of 0.5 milligram per liter or less; however, this relation was not statistically significant. The amount of available organic matter may limit denitrification rates. Elevated nitrate concentrations (greater than 2.0 mg/L) were significantly related to lower dissolved organic carbon concentrations in water samples from both agricultural and urban areas. A similar relation between nitrate concentrations (in water) and organic carbon concentrations (in aquifer material) also was observed but was not statistically significant.

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 mi² in eastern Iowa and southern Minnesota (fig. 1) and is one of 59 study units in the NAWQA Program.

Land-use studies are an important component of the NAWQA Program and are designed to assess the concentration and distribution of water-quality constituents in recently recharged ground water associated with the most significant land use and hydrogeologic settings within a study unit. Land-use studies provide information to better understand the natural and human factors in each setting that affect ground-water quality (Gilliom and others, 1995). The focus of the land-use study in the Eastern Iowa Basins study unit is agricultural and urban land uses and alluvial aquifers. Agriculture is the dominant land use in the study unit. Urban areas, although not extensive, represent important potential source areas of contaminants associated with residential, commercial, and industrial activities. Alluvial aquifers are present throughout much of the study unit and constitute a major ground-water supply that is susceptible to contamination from land-use activities.

Purpose and Scope

This report presents the results of a study to evaluate the effects of land use and hydrogeology on the water quality of alluvial aquifers in the Eastern Iowa Basins study unit. Shallow ground-water monitoring wells were completed in alluvial aquifers at 31 agricultural and 30 urban sites (fig. 2). Ground-water samples were collected from these wells during June–August 1997 and analyzed to determine the concentrations of common ions, nutrients, dissolved organic carbon (DOC), tritium, radon-222, pesticides and pesticide metabolites, volatile organic compounds (VOCs), and environmental isotopes. Field measurements of temperature, specific conductance, pH, dissolved oxygen, alkalinity, and turbidity also were obtained. Samples of

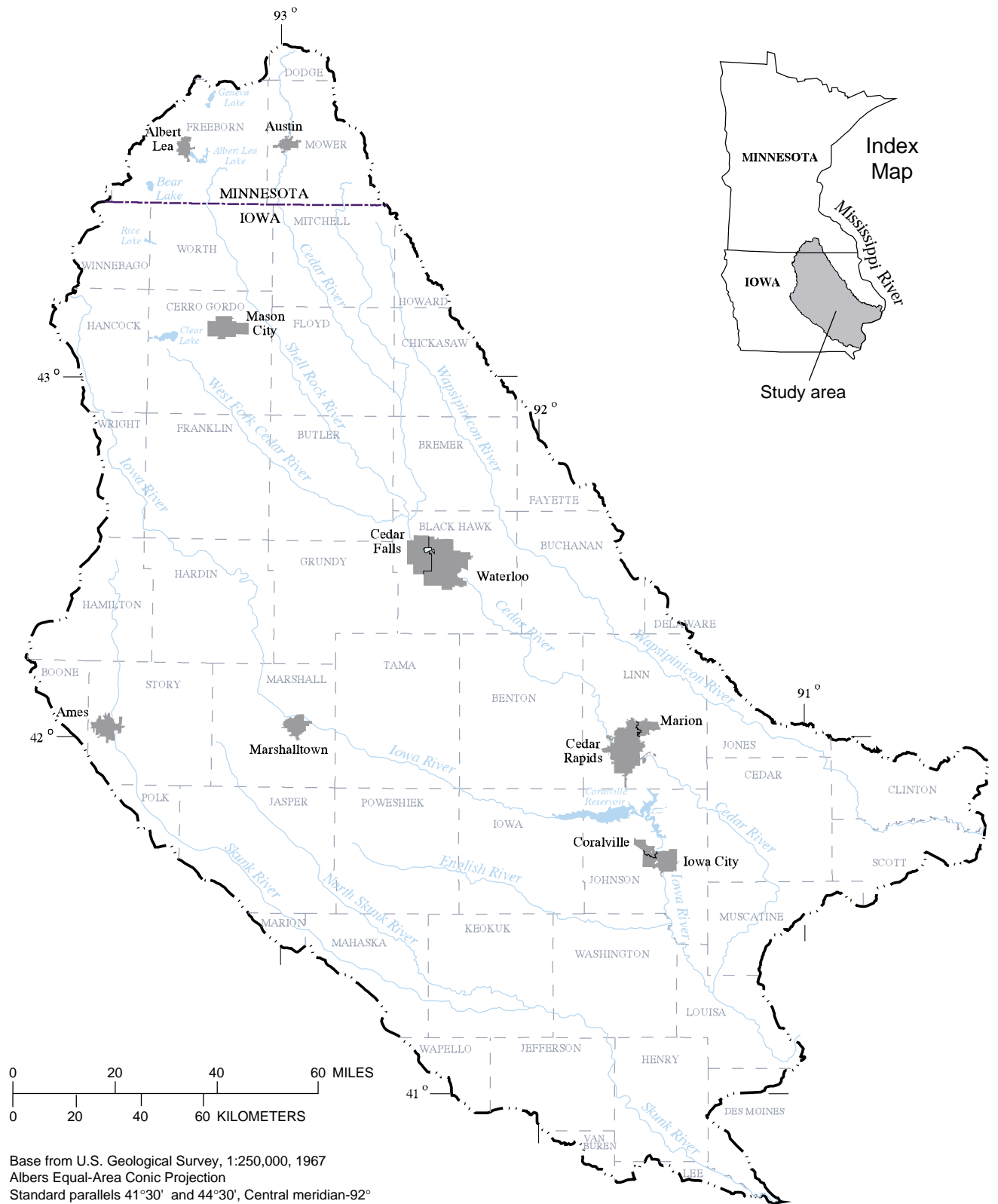


Figure 1. Location and extent of Eastern Iowa Basins study unit.

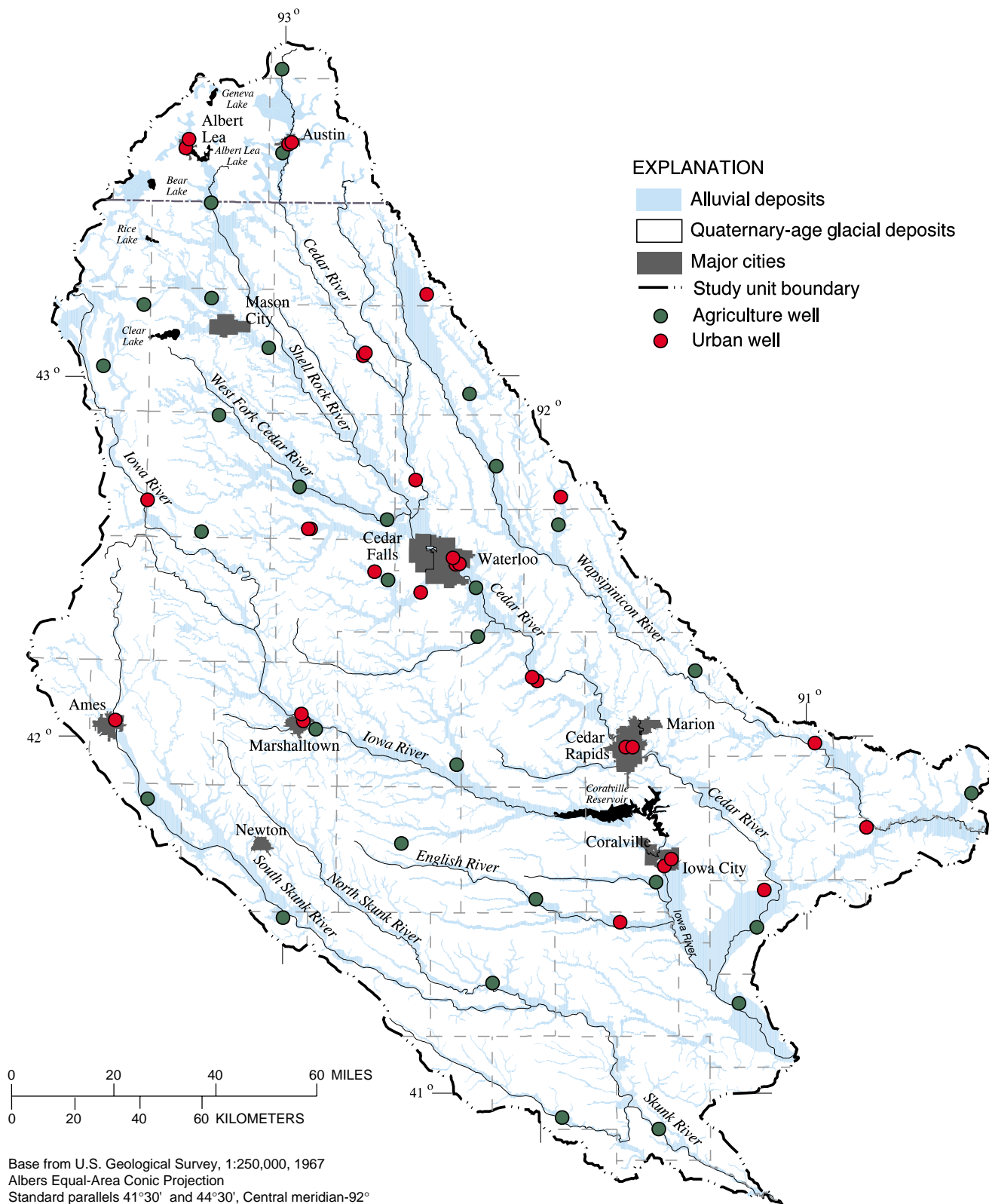


Figure 2. Distribution of alluvial deposits and location of sampling sites.

alluvial material obtained during well drilling were analyzed for particle size and organic carbon content. Land use in the vicinity of each well was characterized and quantified. The relations between shallow ground-water quality and land use and hydrogeology are discussed.

Description of Study Area

The study unit includes the Wapsipinicon, Cedar, Iowa, and Skunk River Basins (fig. 1), all of which are tributary to the Mississippi River. Surficial alluvial deposits are restricted to Holocene-age river valleys (fig. 2) and commonly consist of 30 to 100 ft of unconsolidated sands and gravels interbedded with less permeable silts and clays (Steinhilber and Horick, 1970; Wahl and others, 1978; Hoyer and Hallberg, 1991; Olcott, 1992). Depth to the water table in these alluvial aquifers typically is 5 to 20 ft. Recharge to alluvial aquifers is primarily from precipitation that infiltrates through overlying unsaturated surficial materials. Water also enters the aquifers along losing stream reaches. Ground water in alluvial aquifers discharges to gaining stream reaches, providing base flow (Anderson, 1983; Olcott, 1992). Underlying or laterally adjacent bedrock aquifers may either receive or contribute ground water to alluvial aquifers (Olcott, 1992).

Surficial alluvial aquifers and Quaternary-age buried-channel and glacial-outwash deposits supply about 44 percent of the ground water used in the study unit (E.E. Fisher and A.D. Arntson, U.S. Geological Survey, written commun., 1998). The presence of permeable sands and gravels, shallow depths to the water table, and the absence of overlying confining units make alluvial aquifers in the study unit susceptible to contamination from land-use activities (Hoyer and Hallberg, 1991).

Agriculture is the dominant land use and is present across 92.8 percent of the study unit (fig. 3). Forest land occurs across 4.5 percent of the study area, urban 2.0 percent, water 0.3 percent, wetland 0.2 percent, and barren 0.2 percent. Agriculture and urban land use are present across 84 and 2.6 percent (respectively) of alluvial deposits in the study unit.

Acknowledgments

The authors thank the private landowners and city and county governments in the Eastern Iowa Basins study unit that allowed the USGS to install and sample monitoring wells on private and public property. Ron Kuzniar's (USGS) guidance and participation during well installation is greatly appreciated. Former USGS employee Jennifer Tobias and current USGS employees Ron Kuzniar and Joel Galloway collected much of the data presented in this report.

STUDY DESIGN AND METHODS

This study was designed to evaluate the effects of agricultural and urban land use and hydrogeology on the water quality of alluvial aquifers in the Eastern Iowa Basins study unit. Ground-water samples were collected from shallow monitoring wells installed by the USGS at randomly selected sites within the land-use and hydrogeologic settings of interest.

Site Selection

Potential well locations in the study unit were identified using a stratified random selection process (Scott, 1990) and geographic information system land-use coverages. Field reconnaissance within a 1-mi radius of each potential location was conducted to determine if a suitable well site could be found. Site-selection criteria were: the presence of selected land use and hydrogeologic setting; no known point source of contamination in vicinity of site; the site was accessible to a drill rig; and permission to drill and sample the well could be obtained from the landowner or city/county government. If a suitable site could not be found at a primary location, a search was initiated at the closest alternative location.

Well Installation

Ground-water monitoring wells were completed in alluvial aquifers at 31 agricultural and 30 urban land-use sites using procedures described by Lapham and others (1995). Boreholes were drilled using 4.25-inch inside-diameter continuous-flight hollow-stem augers. The augers were left in place during well construction to prevent borehole collapse. Wells were constructed of 2-inch outside-diameter flush-threaded

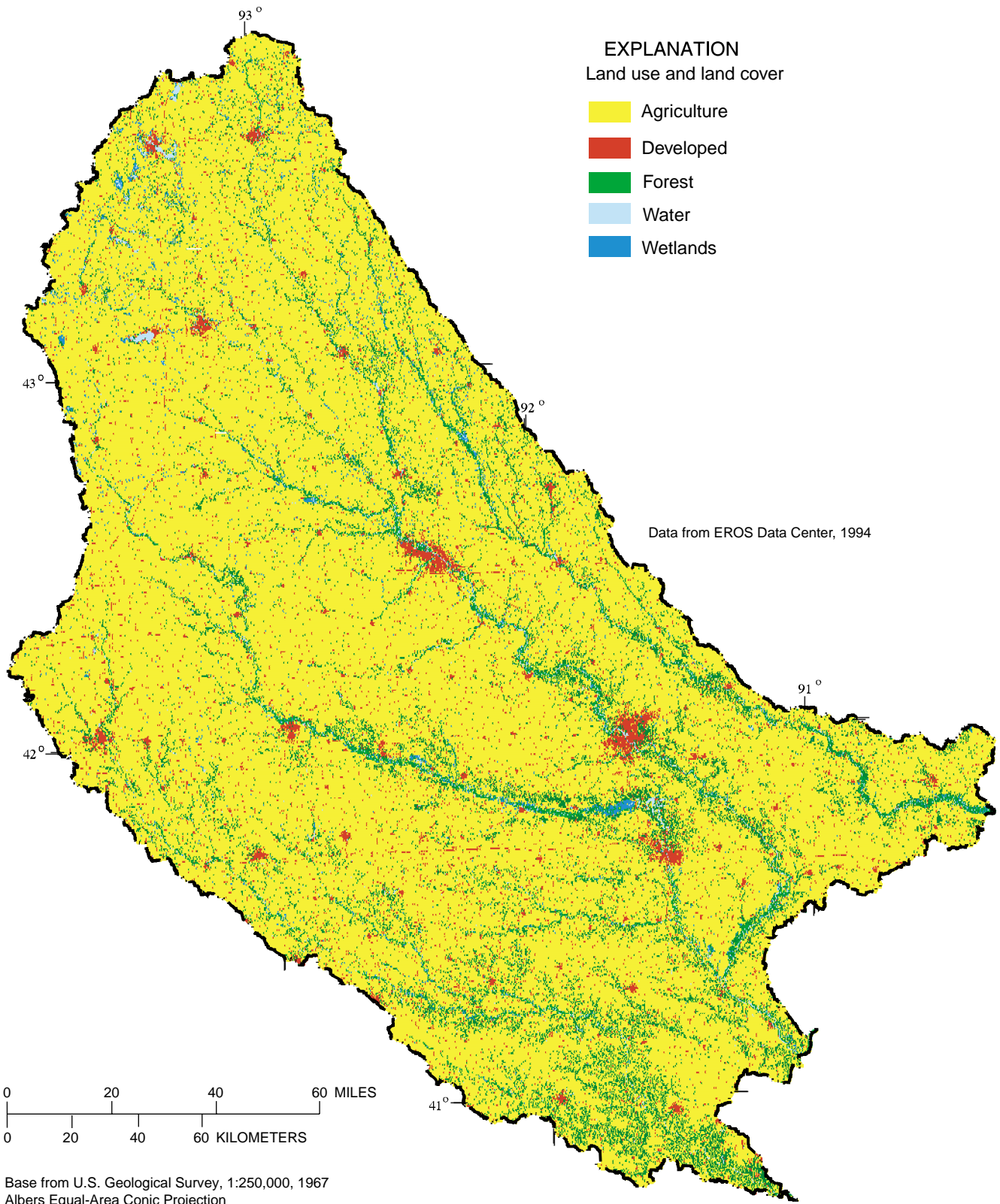


Figure 3. Land use and land cover in the study unit.

polyvinyl-chloride (PVC) pipe and 5 ft of 0.02-inch slotted PVC screen at the base of each well. Well depths ranged from 10 to 37.5 ft below land surface. The depth below the water table to the top of the well screens ranged from 0 to 16 ft. Alluvial material was allowed to fill the annular space around the screen during removal of the augers to form a natural filter pack extending about 2 ft above the top of the screen. An artificial sand-filter pack was emplaced around the screen in wells having fine-grained material adjacent to the screened interval. A bentonite annular seal was placed above the filter pack, and the remainder of the borehole was backfilled with native material to within a few feet of land surface. A lockable, protective steel casing set in a cement pad was installed at land surface to protect the well casing and prevent infiltration of surface water down the borehole. Wells were developed after completion (mechanical surge and pump), and the augers and associated drilling equipment were cleaned between well sites.

Samples of alluvial material obtained during well drilling were analyzed for particle size and organic carbon content. A thickness-weighted average organic carbon content was computed for each well, and cumulative clay thickness above the water-sample interval was estimated from drillers' logs. Lithologies classified as clay, for this analysis, include clay, silty clay, and clayey silt.

Land-Use Classification

A comparison between land use and ground-water quality requires knowledge of land use within the recharge area of the monitoring well. Information on the rate and direction of ground-water flow can be used to determine the size and shape of the recharge area. However, this information was not readily available for the well sites used in this study. Several studies have observed significant correlations between ground-water quality in surficial aquifers and land use within circular areas of probable recharge around wells (Eckhardt and others, 1989; Barringer and others, 1990; Ferrari and Ator, 1995; Ator and Ferrari, 1997; Kolpin, 1997).

Land use was classified within a 1,640-ft-radius buffer around each well in the study unit using procedures described by Koterba (1998), which included field observations and the use of high-resolution aerial photography. The delineation of specific land uses (for example, row crop, residential, commercial) within agricultural and urban well buffers permits a

comparison between the occurrence of specific land uses and ground-water quality. The land-use classification system used in this study is based on the work of Anderson and others (1976).

Row crops (corn and soybeans) were the dominant land use around wells in agricultural areas and had a median value of 90 percent of the buffer area. Residential areas were the dominant land use around wells in urban settings and had a median value of 44 percent of the buffer area. Urban areas in the study unit typically are small and usually are surrounded by agricultural cropland. Urban well buffers commonly contained a greater variety of land uses than wells in agricultural settings. A statistical summary of land use is given in table 1.

Sample Collection

Ground-water samples were collected from 61 wells in agricultural or urban settings during June–August of 1997. Sample collection followed NAWQA protocols (Koterba and others, 1995). Prior to sample collection, wells were purged of at least three well-casing volumes using a 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 common ions, nutrients, DOC, tritium, radon-222, pesticides and pesticide metabolites, VOCs, and environmental isotopes. Static and pumping water levels also were recorded for each well.

Nutrient, alkalinity, and selected common ion samples were filtered using 0.45-micron pore-size cellulose-fiber cartridge filters. Pesticide samples were filtered using 0.7-micron pore-size baked glass-fiber filters. DOC samples were filtered using 0.45-micron pore-size silver membrane filters. VOC, tritium, radon-222, and environmental-isotope samples were not filtered. VOC and selected common ion samples were acidified prior to shipping. Samples were chilled and shipped by overnight delivery to USGS analytical laboratories. All sampling and filtering equipment was cleaned after each use (Koterba and others, 1995).

The analytical results for ground-water samples collected during this study are presented in Akers and others (2000). A statistical summary of selected ground-water-quality data is given in the appendix of this report.

Table 1. Statistical summary of percent land use within 1,640 feet of agricultural and urban land-use monitoring wells

[All values in percent. Row crop, corn and soybeans; Ag infrastructure, farm residence, buildings, and related development; Livestock, cattle, pigs, and horses; Residential, single- and multi-family housing, and mobile homes; Commercial, stores, shopping centers, and malls; Municipal facility, schools, hospitals, and cemeteries; Right-of-way, highways, airports, railroads, and utilities, with associated grounds and structures; Industrial, manufacturing and development; Vacant, abandoned and barren commercial and residential property; Waste management, landfills, recycling centers, and sewage-treatment facilities]

Land use	Agricultural areas			Urban areas		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Row crop	20	90	100	0.0	2	49
Ag infrastructure	0.0	2	25	0.0	0.0	12
Fallow and grass	0.0	0.0	55	0.0	0.0	9
Livestock	0.0	0.0	16	0.0	0.0	15
Residential	0.0	0.0	4	1.0	44	93
Commercial	0.0	0.0	0.0	0.0	14	62
Municipal facility	0.0	0.0	1	0.0	0.1	20
Right-of-way	0.0	0.0	0.0	0.0	0.0	55
Park	0.0	0.0	0.0	0.0	0.0	45
Industrial	0.0	0.0	0.0	0.0	0.0	43
Vacant	0.0	0.0	0.0	0.0	0.0	4
Waste management	0.0	0.0	0.0	0.0	0.0	10
Water and wetland	0.0	0.0	14	0.0	0.0	22
Forest	0.0	0.0	23	0.0	0.0	32

Water-Quality Analysis

Most 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. NWQL pesticide data and OGRL pesticide metabolite data are used in this report. Tritium samples were analyzed at the USGS Isotope Tracers Project Laboratory in Menlo Park, California. Environmental-isotope samples were analyzed at the 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 lower 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 generally are higher than MRLs and MDLs. Water-quality constituents and associated MRLs and MDLs are listed in the appendix of this report.

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). The USEPA regulations include Maximum Contaminant Levels (MCL), which are health-based, maximum

permissible levels of contaminants that are enforceable for public water-supply systems; Secondary Maximum Contaminant Levels (SMCL), which are nonenforceable and relate to constituents that can affect the esthetic quality of drinking water; and lifetime health advisories (HAL), which define the maximum concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects over a lifetime of exposure and include a margin of safety. USEPA regulations are used in this report as guidelines to evaluate water quality.

Quality-control samples were collected during the study to evaluate the potential effects of field and laboratory methods on analytical results. Quality-control samples consisted of equipment blanks, field blanks, replicates (sequential samples), and laboratory surrogate and field spike recoveries. One equipment blank was analyzed for pesticides and two equipment blanks were analyzed for VOCs. Three field blanks were analyzed for common ions, nutrients, and pesticides and pesticide metabolites; four field blanks for VOCs; and two field blanks for DOC. Three replicate samples were analyzed for common ions, nutrients, DOC, pesticides and pesticide metabolites, VOCs, tritium, radon-222, and environmental isotopes. Laboratory surrogate recoveries were performed on selected VOCs and pesticides for all ground-water

samples. One field-spiked sample was analyzed for pesticides and VOCs. The results of quality-control sampling are presented in Akers and others (2000).

Equipment blanks showed that for most pesticides and VOCs, sampling equipment did not introduce contaminants into the ground-water samples. However, toluene and carbon disulfide were present in equipment blanks at concentrations greater than the MRL (table 3).

Field blanks showed that for most constituents, sampling and laboratory procedures did not introduce contaminants into the ground-water samples. However, several constituents were detected in blank samples at concentrations greater than the corresponding MRL (table 3). Calcium, magnesium, silica, sulfate, and manganese were detected in field blanks at substantially lower concentrations than those measured in ground-water samples. Fluoride, bromide, ammonia, and DOC were detected in field blanks at concentrations similar to those measured in some ground-water samples. As a result, concentrations of fluoride, bromide, ammonia, and DOC that approach field-blank concentration values should be used with caution due to uncertainties concerning the extent to which contamination may affect ground-water sample results. Field-blank concentrations of VOCs listed in table 3 were higher than some of the concentrations

Table 2. Laboratory analytical methods

[UV, ultraviolet; 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)
Organic carbon	Induction furnace and modified Van Slyke	Wershaw and others (1987)
Pesticides (NWQL schedule 2010)	Extraction on C-18 cartridge and analyzed by GC/MS	Zaugg and others (1995)
Pesticides (NWQL schedule 2050)	Extraction on Carbopak-B cartridge and analyzed by HPLC	Werner and others (1996)
Pesticides and metabolites (OGRL)	Extraction on C-18 cartridge and analyzed by GC/MS and Extraction on Carbopak-B cartridge and analyzed by HPLC	Zimmerman and Thurman (1999) 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)

Table 3. Constituents detected in equipment and field blanks

[MRL, minimum reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent	Blanks/detections	MRL (mg/L, except as indicated)	Range of concentrations equal to or exceeding MRL (mg/L, except as indicated)
Equipment blanks			
Toluene (µg/L)	2/2	0.038	0.070–0.080
Carbon disulfide (µg/L)	2/2	0.080	0.50–1.45
Field blanks			
Calcium	3/3	0.02	0.093–0.152
Magnesium	3/2	0.01	0.012–0.014
Silica	3/3	0.01	0.032–0.058
Sulfate	3/1	0.10	0.113
Fluoride	3/1	0.10	0.111
Manganese	3/1	1.0	1.166
Bromide	3/1	0.01	0.017
Ammonia, as N	3/1	0.015	0.02
DOC	2/2	0.10	0.70–3.80
Toluene (µg/L)	4/3	0.038	0.04–0.809
Benzene (µg/L)	4/2	0.032	0.05–0.09
Ethylbenzene (µg/L)	4/1	0.030	0.05
Tetrachloroethene (µg/L)	4/1	0.038	0.07
Carbon disulfide (µg/L)	4/1	0.080	0.07
1,2,4-Trimethylbenzene (µg/L)	4/1	0.056	0.07
Acetone (µg/L)	4/3	4.90	5.0–10.0
m- and p-Xylene (µg/L)	4/1	0.064	0.10
Bromodichloromethane (µg/L)	4/1	0.048	0.07
Chloroform (µg/L)	4/1	0.052	0.344

measured in ground-water samples. The analysis of VOC results in this report is limited to ground-water sample concentrations that are greater than field-blank VOC concentrations. The presence of several major ions, nutrients, and VOCs in field blanks may be the result of their presence in the blank water used during this study.

Replicate samples showed an acceptable level of precision in field and laboratory procedures for most constituents. However, several constituents had relative percent differences (RPDs) of more than 10 percent between concentrations in environmental and replicate samples (table 4). For many constituents (bromide, ammonia, nitrite, phosphorus, orthophosphorus, butylate, bentazon, and toluene), small concentration differences resulted in large RPDs because environmental and replicate sample concentrations also were small. The cause of large RPDs for iron, nitrite plus nitrate, DOC, and carbon disulfide is

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

Laboratory surrogate and field-spike recoveries were used 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. Acceptable recoveries typically range from 80 to 120 percent for pesticides and 70 to 130 percent for VOCs. Laboratory surrogate recoveries for selected pesticides (HCH alpha and BDMC) ranged from 67 to 129 percent; recoveries for selected VOCs (ethane, toluene, and benzene) ranged from 88 to 133 percent. These results indicate that matrix effects were minor and the analytical methods were effective. Laboratory surrogate recoveries for diazinon ranged from 56 to 152 and indicate possible matrix effects or analytical method inefficiency. Field-spike recoveries, given in the appendix of this report, for NWQL schedule 2010 pesticides ranged from 36 to

128 percent, and recoveries for schedule 2050 pesticides ranged from 0 to 133 percent. Field-spike recoveries for pesticides (schedules 2010 and 2050) that were detected in ground-water samples ranged from 66 to 128 percent. Field-spike recoveries for selected VOCs ranged from 48 to 99 percent and included 9 of 38 VOCs detected in ground-water samples.

Statistical Analysis

Water-quality data were graphically represented using boxplots to show the 10th, 25th, 50th (median), 75th, and 90th percentiles, and concentration values outside the 10th and 90th percentiles. Boxplots also were used to illustrate differences between groups of data—for example, nitrate concentrations in samples from agricultural and urban areas.

Frequency-of-detection plots were used to show the percentage of samples with detectable concentrations of analytes. An inverse relation between MDLs and the frequency of pesticide and metabolite detections has been documented (Kolpin and others, 1998a; Barbash and Resek, 1996), and it has been suggested that analyte data might be adjusted to a common detection limit to compensate for this effect. The selection of common detection limits for pesticides and metabolites detected in this study, 0.01 and 0.2 µg/L, respectively, resulted in the loss of several

previously detected analytes but did not alter the ranking of most frequently detected analytes. Therefore, unadjusted data were used in frequency-of-detection plots in this report.

Wilcoxon rank sum and Kruskal-Wallis nonparametric statistical tests (Ott, 1993, p. 279, 792) were used to evaluate the statistical significance of 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. Spearman's rank order correlation nonparametric statistical test (Ott, 1993, p. 465) was used to measure the monotonic relation (*rho*) between two continuous variables—for example, atrazine concentration and well depth. The magnitude of *rho* ($-1 \leq \rho \leq 1$) determines the strength of the relation.

Due to the small number of detections, statistical comparisons of most pesticides, pesticide metabolites, and VOC's with land use and other potential factors affecting water quality were not performed. However, statistical comparisons were performed using summed (total) concentrations per sample—for example, the relation between total pesticide concentration per sample and land use.

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

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

Constituent	Replicates/ RPDs>10 percent	Average concentration (environmental plus duplicate sample) (mg/L, except as indicated)	Concentration difference (mg/L, except as indicated)	RPD (percent)
Iron (µg/L)	3/2	28.5 and 62.0	10.0 and 49.1	16 and 172
Bromide	3/1	0.038	0.004	11
Ammonia, as N	3/1	0.016	0.002	13
Nitrite, as N	3/1	0.012	0.002	17
Nitrite plus nitrate, as N	3/1	0.808	1.50	186
Phosphorus, as P	3/1	0.019	0.017	90
Orthophosphorus, as P	3/1	0.0255	0.005	20
DOC	3/1	2.20	0.40	18
Bentazon (µg/L)	3/1	0.055	0.01	18
Butylate (µg/L)	3/1	0.00225	0.0003	13
Carbon disulfide (µg/L)	3/1	0.1325	0.145	109
Toluene (µg/L)	3/1	0.099	0.042	42

EFFECTS OF LAND USE AND HYDROGEOLOGY ON WATER QUALITY

Ground-water quality can be affected by human activities and natural (physical, chemical, and microbial) processes. Anthropogenic activities may affect ground-water quality if associated chemicals and nutrients infiltrate the subsurface, and the occurrence of specific suites of contaminants may relate to specific land-use types (Eckhardt and others, 1989; Burkart and Kolpin, 1993; Squillace and others, 1995; Kolpin, 1997). Predominant ions commonly reflect the mineral composition of geologic materials contacted by the ground water. The presence of clay and other materials of low hydraulic conductivity may provide aquifers with some protection from the infiltration of some contaminants, and the presence of fine-grained

materials with large specific grain-surface areas facilitate sorption. Geochemical environments can influence constituent speciation, and microbially mediated processes have the potential to alter or degrade a variety of constituents.

Differences in selected hydrogeologic factors, common to agricultural and urban land-use sampling sites, were evaluated to better understand the significance of land use on water quality. Well depth and depth to water were significantly greater ($p < 0.001$) at urban sampling sites than at agricultural sites (fig. 4) and may contribute to observed differences in water quality between the land-use settings. Depth below the water table to the top of the sampling interval, tritium concentration (and tritium-based ground-water age), and cumulative clay thickness above the sampling interval were not significantly different ($p = 0.829$, 0.530, and 0.981, respectively) between agricultural

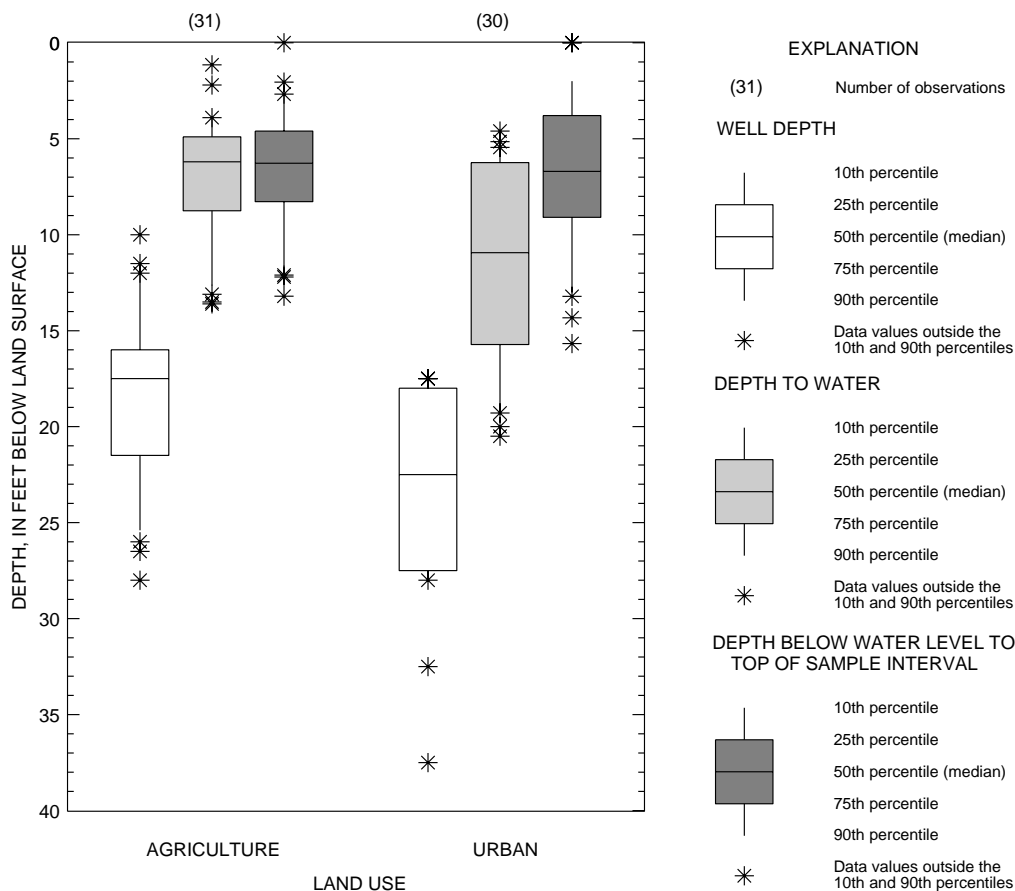


Figure 4. Relation between land use and well depth, depth to water, and depth to top of sample interval.

and urban sites (figs. 4, 5, and 6) and most likely do not contribute to observed differences in water quality between the land-use settings. It was assumed that cumulative clay thickness at the well location was representative of cumulative clay thickness upgradient from the well in the recharge area.

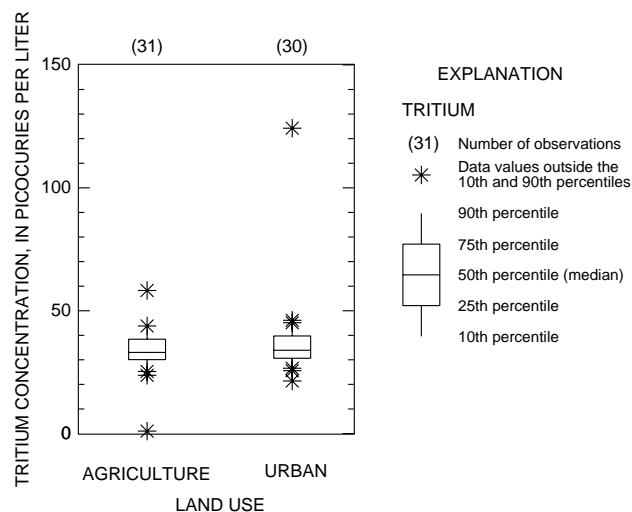


Figure 5. Relation between land use and tritium concentration.

Common Ions

Ground water from alluvial aquifers in the study area was commonly of a calcium bicarbonate type (fig. 7). Chloride and nitrate were the predominant anions in samples from several wells. Magnesium commonly accounted for 20 to 40 percent of the total cations; sodium accounted for less than 30 percent. Road salts are used throughout the study unit during winter, especially in urban areas where roads are more numerous and road salts may be more frequently applied than in agricultural areas. Dissolved-solids, sodium, and chloride concentrations were significantly higher ($p < 0.001$) in samples from urban areas than from agricultural areas (fig. 8). Sodium concentrations in samples from urban sites were positively correlated ($p = 0.046$, $\rho = 0.37$) with percentage of land use classified as commercial (retail stores and services), where road density and maintenance are high; chloride concentrations were negatively correlated ($p = 0.01$, $\rho = -0.46$) with percentage of land use classified as row crops (corn and soybeans).

Limestone and dolomite are common bedrock lithologies throughout the study unit (Hershey, 1969) and are likely sources of erosional material incorporated in alluvial deposits. Large concentrations of calcium, magnesium, and bicarbonate ions in groundwater samples from the alluvial aquifer probably are the result of solution of carbonate minerals (calcite and dolomite) present in the alluvial deposits. Clay weathering and cation exchange also could contribute significant concentrations of calcium, magnesium, and bicarbonate to ground water as precipitation percolates through the unsaturated zone. The USEPA SMCLs were exceeded in 46 percent of samples for manganese ($50 \mu\text{g/L}$), 23 percent for dissolved solids (500 mg/L), 16 percent for iron ($300 \mu\text{g/L}$), and 2 percent for chloride (250 mg/L) and sulfate (250 mg/L).

Nutrients

Sources of nutrients to ground water include precipitation, the decay of organic matter, and microbial fixation. Anthropogenic sources of nutrients such as chemical fertilizers, septic tank effluent, and manure from feedlots may increase nutrient concentrations in ground water. Nitrate concentrations greater than 2 to 3 mg/L are generally attributed to anthropogenic sources (Madison and Brunett, 1985; Hallberg, 1989; Mueller and others, 1995). The physical properties of soil and aquifer materials can affect the rate of

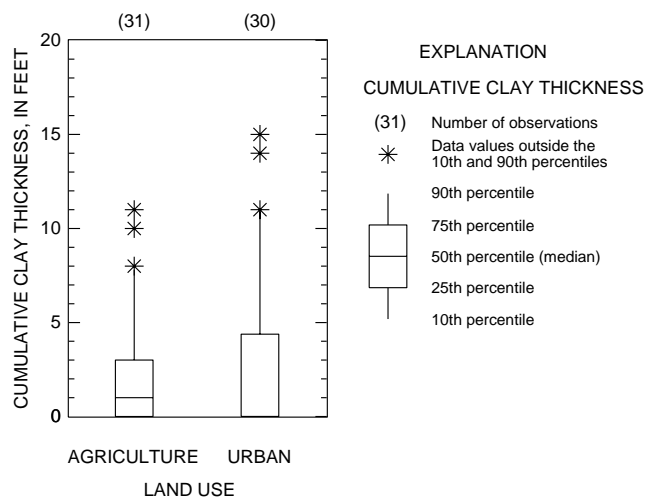


Figure 6. Relation between land use and cumulative clay thickness.

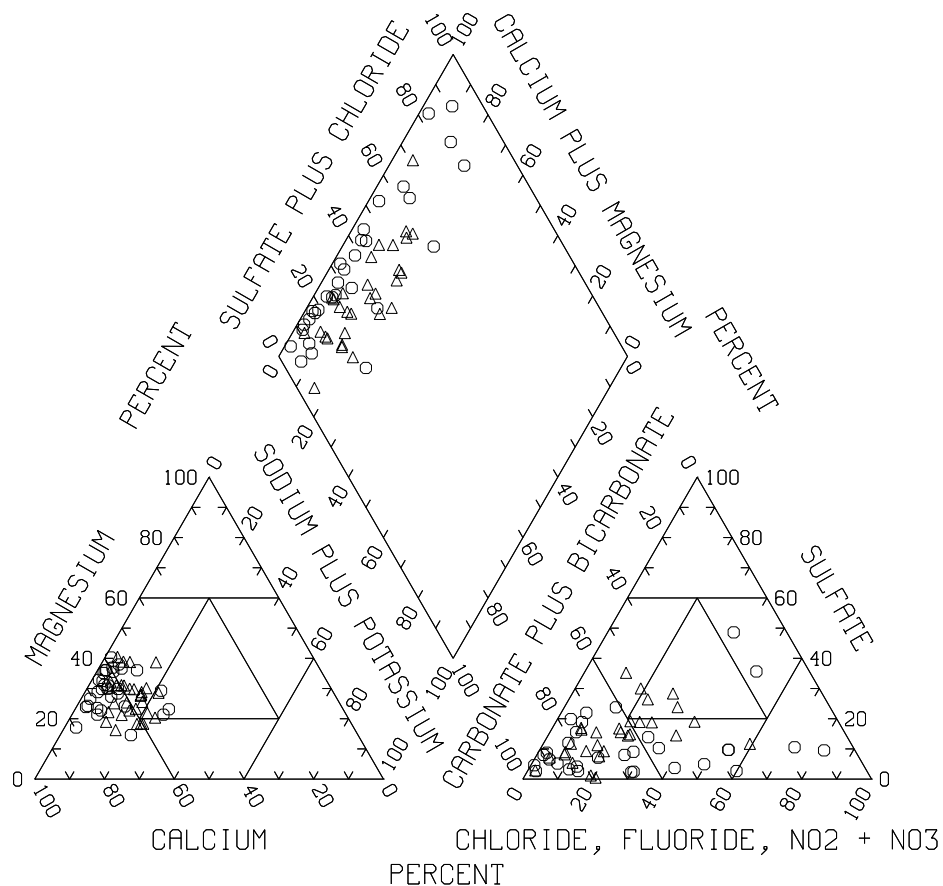


Figure 7. Major-ion composition of ground water from alluvial aquifers in the study unit.

downward movement of water and nitrate. The presence of fine-grained materials of low hydraulic conductivity, such as clays, can reduce ground-water infiltration rates and limit the amount of nitrate at depth (Mueller and others, 1995; Hinkle, 1997; Tesoriero and Voss, 1997).

Nitrite plus nitrate was detected in 94 percent of samples from agricultural areas and 77 percent of samples from urban areas. Nitrite concentrations were at or below the MRL (0.01 mg/L as N) in 92 percent of samples and were detected at a maximum concentration of 0.99 mg/L; therefore, nitrite plus nitrate will be referred to as nitrate in this report. Nitrate exceeded the USEPA MCL for drinking water (10 mg/L as N) in 39 percent of samples from agricultural areas. Other studies of shallow aquifers in the Midwest (Buchmiller and Squillace, 1988; Hallberg, 1989; Kross and others, 1990; Blevins and others, 1996; Schapp and Linhart, 1998) indicate nitrate exceeds its MCL in 10 to 40 percent of samples. Nitrate did not exceed the

MCL in samples from urban areas. Ammonia was detected in 36 percent of samples from agricultural areas and 70 percent of samples from urban areas.

Orthophosphate was the most commonly detected nutrient and was present in 94 percent of samples from agricultural areas and 87 percent of samples from urban areas. Phosphorus was present in 71 percent of samples from agricultural areas and 60 percent of samples from urban areas. Orthophosphate and phosphorus are readily sorbed to sediments and are not very mobile (Hem, 1985; Kolpin and others, 1994), resulting in detection concentrations at or near the MRL (0.01 mg/L).

Nitrate concentrations were affected by a combination of factors, including land use, dissolved-oxygen concentrations, and hydrogeology. Nitrate concentrations were significantly higher ($p=0.008$) in agricultural areas than in urban areas, and ammonia concentrations were significantly higher ($p=0.008$) in urban areas than in agricultural areas (fig. 9). Greater

use of fertilizers in agricultural areas most likely contributes to higher nitrate concentrations in those areas. Dissolved-oxygen concentrations tended to be higher in agricultural areas (fig. 9), and although this difference was not statistically significant ($p=0.058$), it may explain the higher ammonia concentrations associated with more reducing conditions in the urban areas. Nitrogen speciation within agricultural and urban areas was influenced by redox conditions (fig. 10). Nitrate concentrations were significantly higher in ground water with dissolved-oxygen concentrations greater than 0.5 mg/L in both agricultural and urban areas ($p=0.039$ and 0.042, respectively). Ammonia concentrations were higher in ground water with dissolved-oxygen concentrations of 0.5 mg/L or less; however, this relation was not statistically significant in either agricultural or urban areas ($p=0.094$ and 0.089, respectively).

Elevated nitrate concentrations (greater than 2.0 mg/L) in samples from agricultural areas (fig. 11) were significantly related to wells with sample intervals nearer the water table ($p=0.001$) and wells with

thinner cumulative clay thickness above sampling intervals ($p=0.010$). The relation between elevated nitrate concentrations, well depth, and depth to water was not significant ($p=0.149$ and 0.205, respectively).

Elevated nitrate concentrations (greater than 2.0 mg/L) in samples from urban areas (fig. 11) were significantly related to shallower wells ($p=0.022$) and wells with sample intervals nearer the water table ($p=0.023$). The relation between elevated nitrate concentrations, cumulative clay thickness above sample intervals, and depth to water was not significant ($p=0.281$ and 0.494, respectively). Significantly greater ($p<0.001$) well depths at urban sampling sites may contribute to observed differences in nitrate concentrations with land use.

The observed differences in nitrate concentrations in urban and agricultural areas also were likely affected by differing organic carbon content in soils and ground water. Organic carbon (aquifer material) and dissolved organic carbon concentrations (groundwater sample) were significantly higher ($p=0.021$ and 0.008, respectively) in urban areas than in agricultural

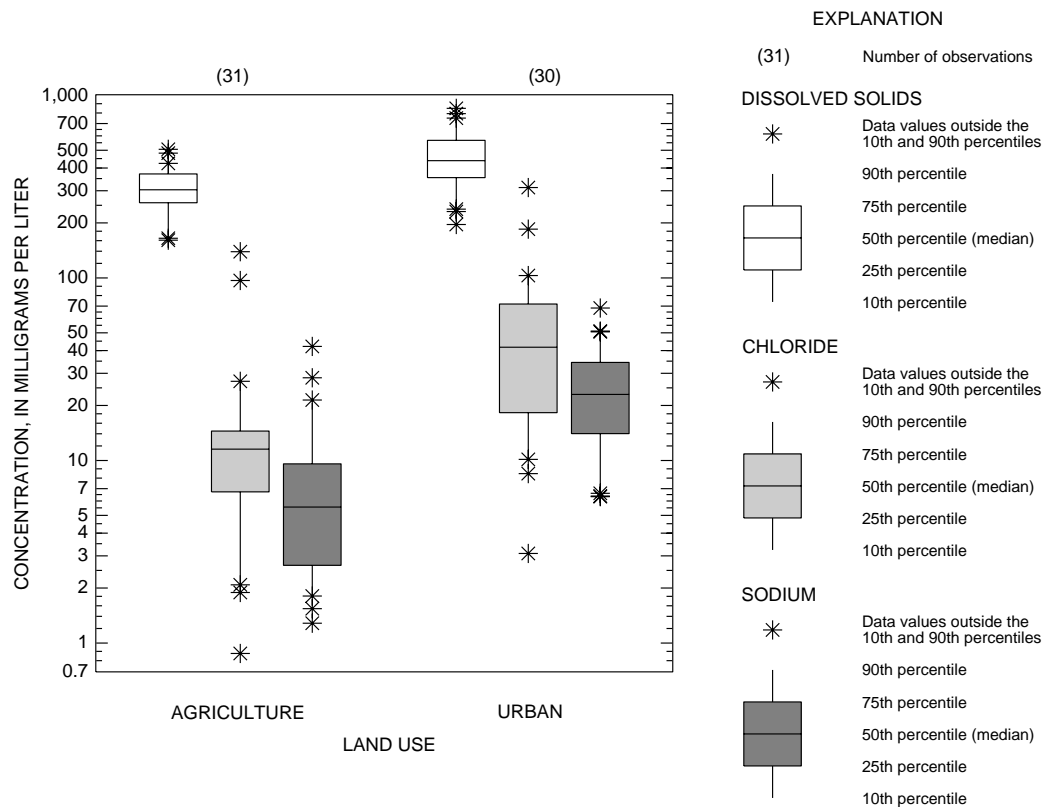


Figure 8. Relation between land use and dissolved-solids, sodium, and chloride concentrations.

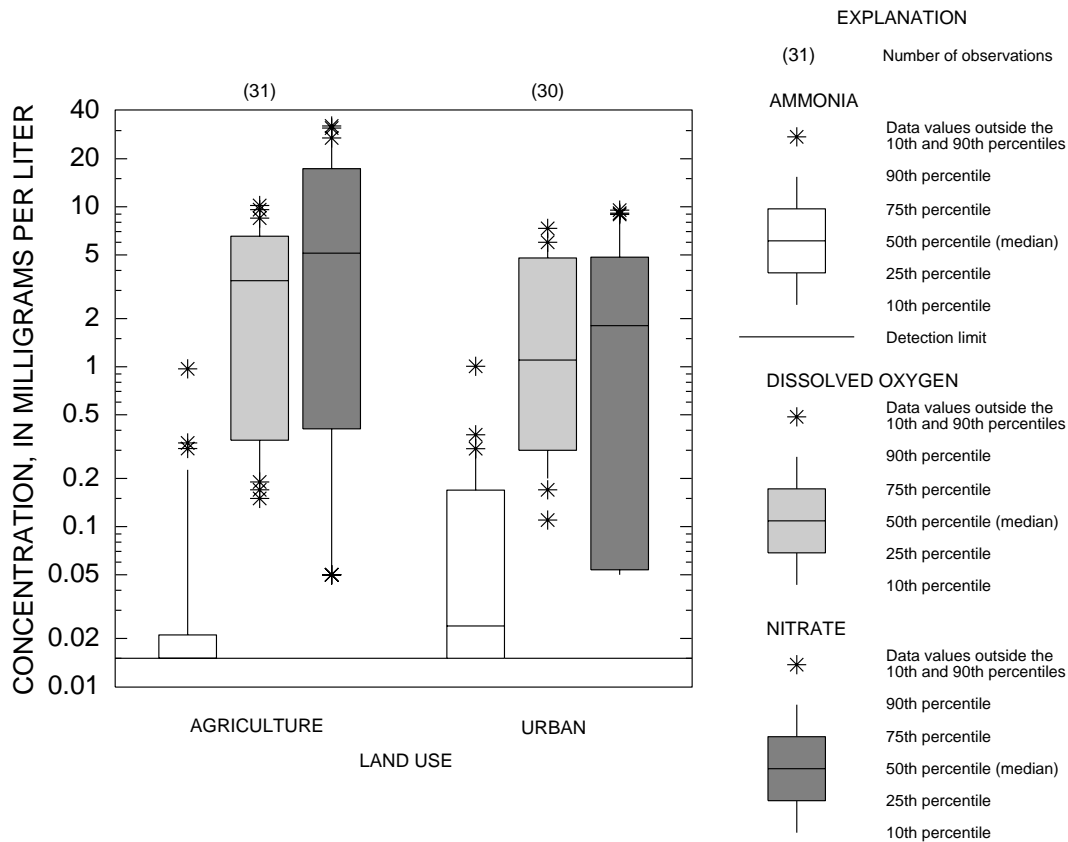


Figure 9. Relation between land use and ammonia, nitrate, and dissolved-oxygen concentrations.

areas (fig. 12). Microbial denitrification requires the presence of reduced electron-donating substrates (organic matter) and terminal electron acceptors (nitrogen oxides) (Chapelle, 1993; Hallberg and Keeney, 1993). The amount of available organic matter may limit denitrification rates (Starr and Gillham, 1993). Elevated nitrate concentrations (greater than 2.0 mg/L) were significantly related to lower dissolved organic carbon concentrations in water samples from both agricultural and urban areas ($p=0.031$ and 0.014 , respectively; fig. 13). A similar relation between nitrate concentrations (in water) and organic carbon concentrations (in aquifer material) also was observed but was not statistically significant in either agricultural or urban areas ($p=0.063$ and 0.756 , respectively). These results suggest that, in addition to lower nitrogen inputs, lower nitrate concentrations from urban areas may be due in part to the greater availability of organic material at urban sampling sites, resulting in higher denitrification rates and the conversion of greater

amounts of nitrate to more reduced nitrogen species than at agricultural sites. The potential for higher denitrification rates at urban sampling sites is supported by the presence of lower dissolved-oxygen concentrations and higher ammonia concentrations (fig. 10), indicating reducing conditions at these sites. Higher ammonia concentrations also may reflect the partial microbial reduction of nitrate to ammonia, which is common for many bacteria (Chapelle, 1993).

Radiochemicals

Tritium concentrations found in the alluvial aquifers indicate that shallow ground water in the aquifers has been recharged in the last 30 years. Tritium was present at concentrations above the 1.0-pCi/L MRL in 98 percent of samples. Tritium is a radioactive isotope of hydrogen with a half-life of about 12.3 years (Hem, 1985). Small amounts

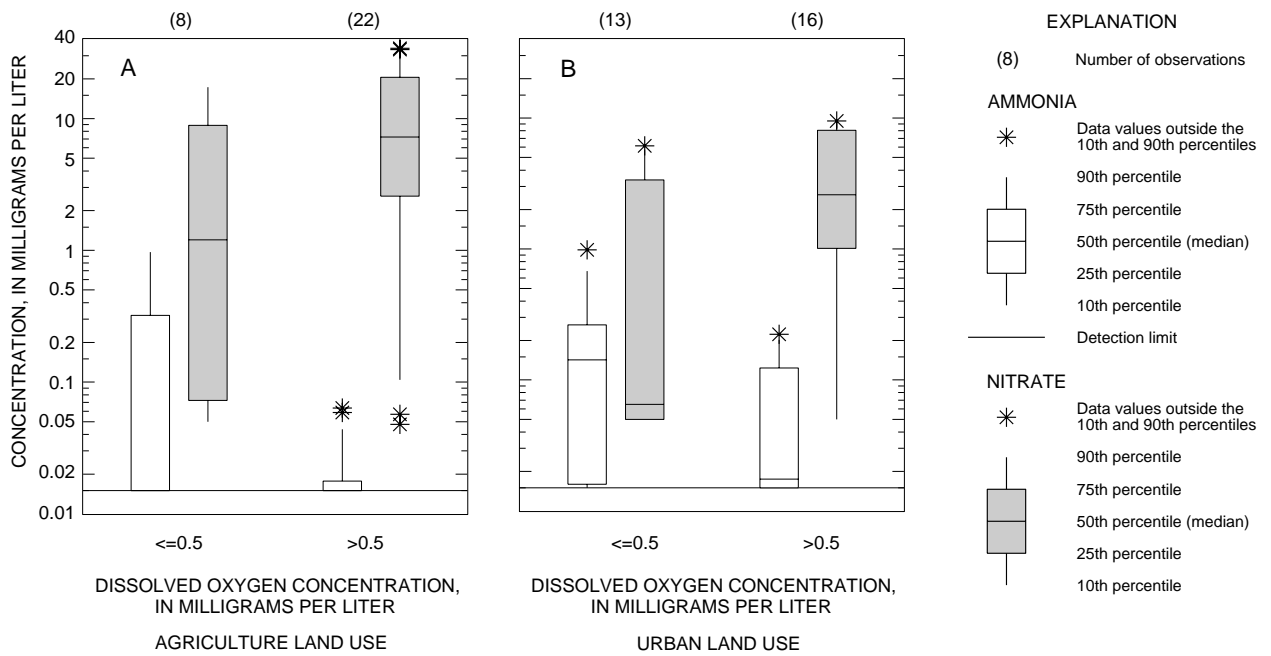


Figure 10. Relation between dissolved-oxygen concentration and ammonia and nitrate concentrations in samples from (A) agricultural areas, and (B) urban areas.

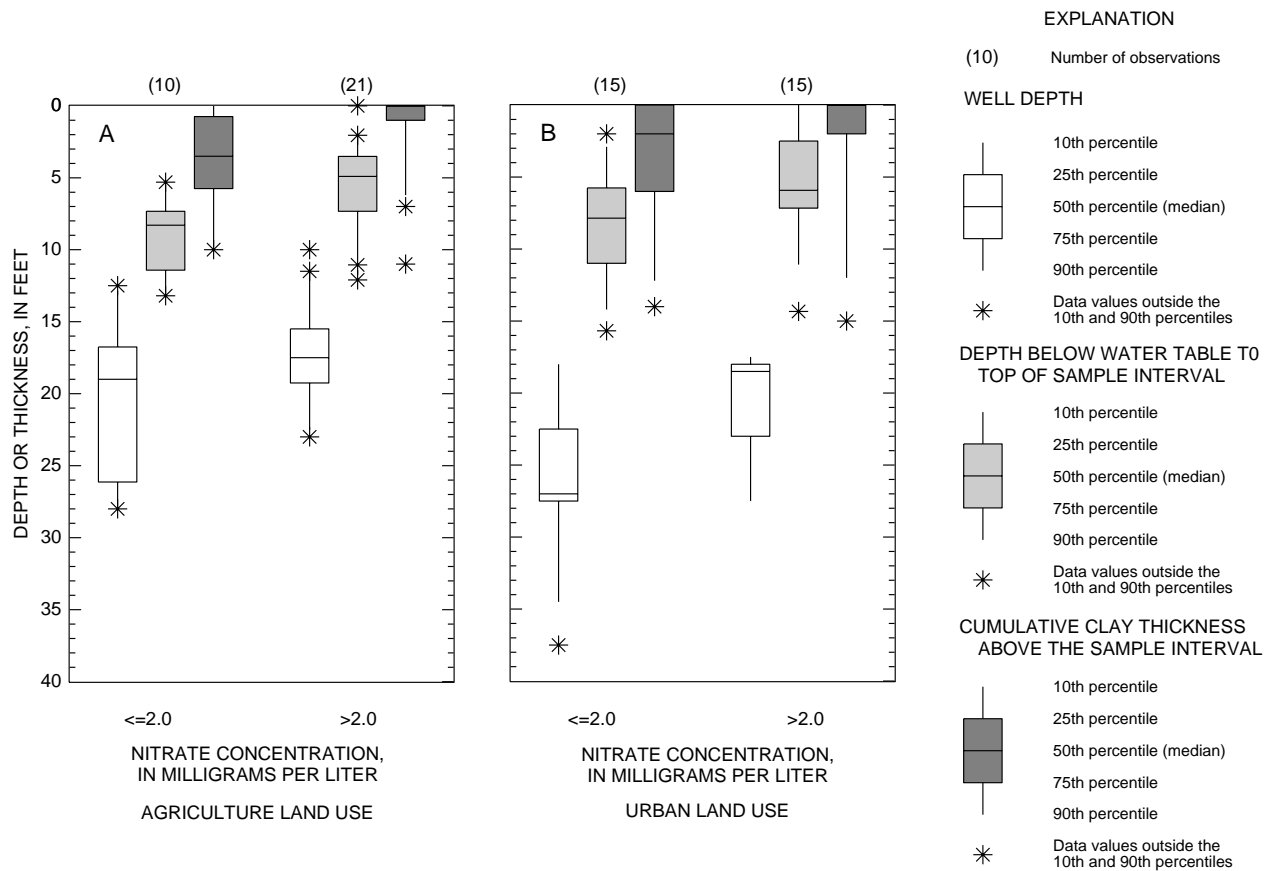


Figure 11. Relation between nitrate concentration and well depth, depth below water table to top of sample interval, and cumulative clay thickness above the sample interval in samples from (A) agricultural areas, and (B) urban areas.

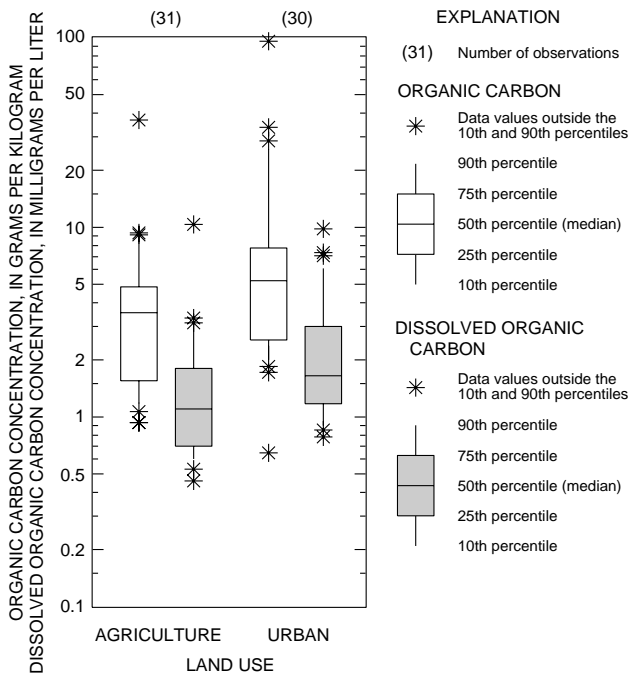


Figure 12. Relation between land use and organic carbon and dissolved organic carbon concentrations.

of tritium are produced naturally 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, 98 percent of samples represent ground water that most likely was recharged after the 1950's; 2 percent of samples represent ground water that most likely was recharged prior to the 1950's. The comparison between land use and ground-water quality requires that land use at the time of precipitation recharge was similar to the current land use characterized at the well site. Agricultural and urban areas have remained relatively stable in the study unit for many decades (U.S. Geological Survey, 1990; Hitt, 1994). The presence of ground water that most likely recharged after the 1950's at all but one sampling site increases the

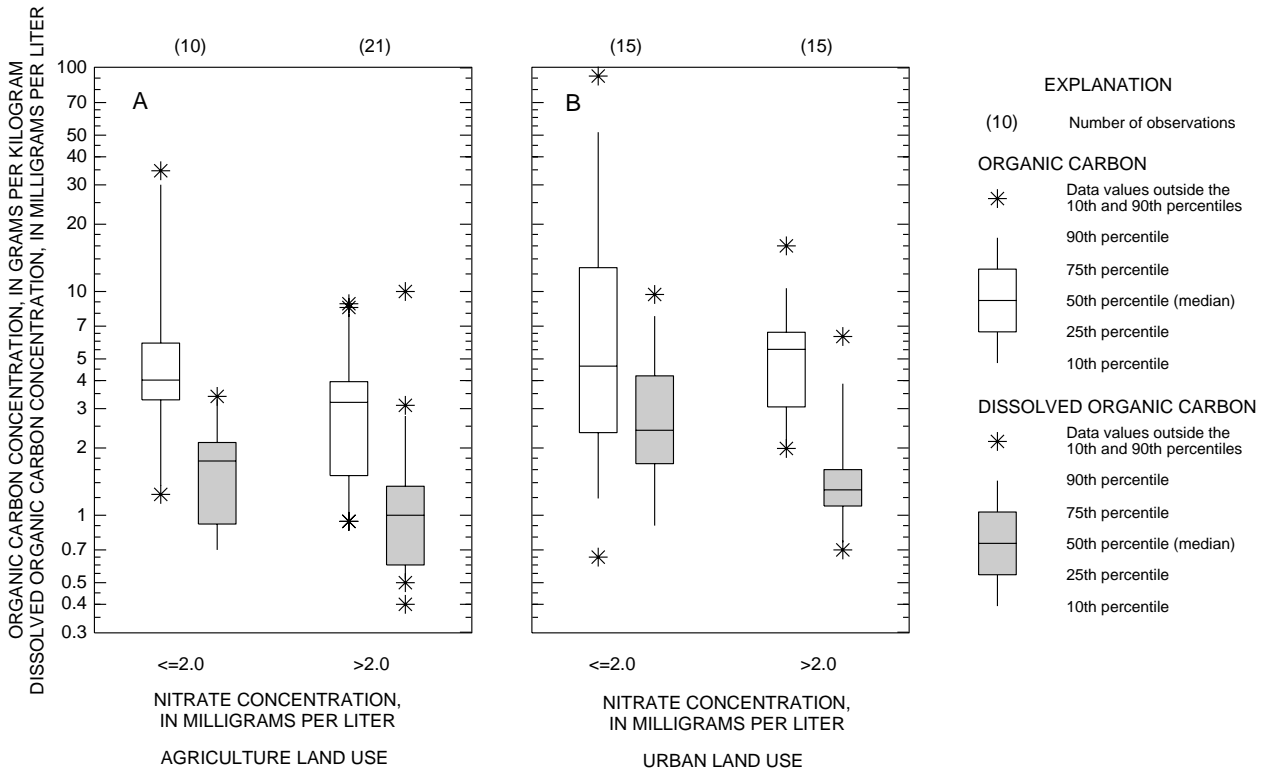


Figure 13. Relation between nitrate concentration and organic carbon and dissolved organic carbon concentrations in samples from (A) agricultural, and (B) urban areas.

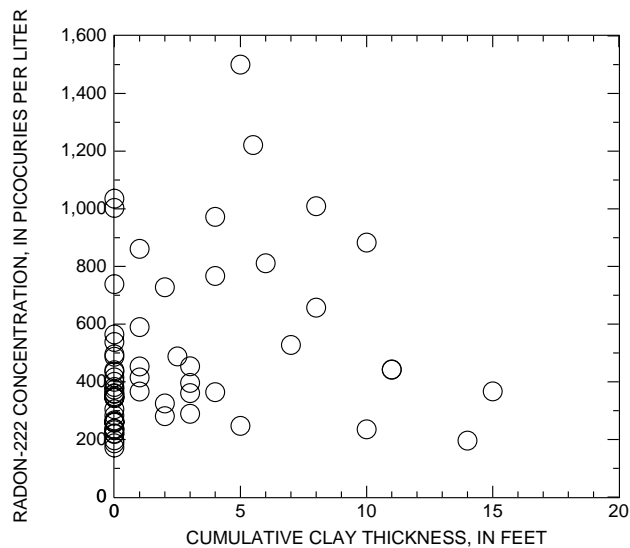


Figure 14. Relation between radon-222 concentration and cumulative clay thickness above the sample interval.

likelihood that the effects of current land use are reflected in ground water sampled during this study. As noted earlier, tritium concentrations (and tritium-based ground-water ages) were not significantly different ($p=0.530$) between agricultural and urban samples (fig. 5).

Radon-222 is a naturally occurring gas produced by the decay of uranium and is radioactive (half-life of 3.8 days) and water soluble (Hem, 1985). Radon-222 was present at concentrations above the MRL (24 pCi/L) in all samples. Concentrations exceeded the USEPA previously proposed drinking-water MCL (300 pCi/L) in 71 percent of samples. Currently, there is no USEPA regulation for radon-222 in drinking water. Radon-222 concentrations were not significantly different ($p=0.589$) between agricultural and urban samples. Schumann (1993) suggests that clays derived from uranium-bearing glacial deposits might be a source of radon-222 in the Upper Midwest. However, the relation between radon-222 concentrations and cumulative clay thickness above the sample interval from agricultural and urban areas (fig. 14) was not statistically significant.

Environmental-isotope analyses were not interpreted in this report. A statistical summary of environmental-isotope analyses is given in the appendix of this report.

Pesticides and Metabolites

Synthetic organic pesticides are widely used in agricultural and nonagricultural areas (Rao and Alley, 1993; Barbash and Resek, 1996) to control unwanted vegetation and insects. Widespread use has led to the detection of pesticides and their metabolites in shallow ground-water aquifers throughout the United States (Barbash and Resek, 1996; Kolpin and others, 1998a). Following application, pesticides may be leached directly to ground water or enter the atmosphere through volatilization or attached to dust particles. The subsequent transport and redeposition of airborne pesticides can significantly affect water quality far from application sites (Majewski and Capel, 1995; Goolsby and others, 1997; Majewski and others, 1998).

Pesticides were detected in 84 percent of samples from agricultural areas and 70 percent from urban areas. A total of 10 pesticides were detected in samples from agricultural areas (fig. 15); 13 pesticides were detected in urban areas. Atrazine and metolachlor were the most commonly detected pesticides in samples from agricultural areas; atrazine and prometon were the most commonly detected pesticides in samples from urban areas. None of the pesticide concentrations exceeded USEPA drinking-water MCLs or HALs. Pesticides have generally not exceeded MCLs or HALs in other studies of shallow aquifers in the midwest (Kolpin and others, 1998b; Schapp and Linhart, 1998).

Some pesticides may be degraded in the subsurface by biotic and abiotic processes that result in the removal of functional groups and occasional cleavage of the pesticide's recalcitrant central ring structure (Dhileepan and Schnoor, 1992; McMahan and others, 1992; Chapelle, 1993; Aga and others, 1996; Alvey and Crowley, 1996; Field and Thurman, 1996; Kalkhoff and others, 1998). Microbial degradation may result in the complete mineralization of pesticides to carbon dioxide, water, and other simple products (Rao and Alley, 1993; Alvey and Crowley, 1995). Research suggests that microbial activity and pesticide degradation rates decrease with increasing depth in response to decreasing organic carbon and dissolved-oxygen concentrations, lower temperatures, and smaller microbial populations that may lack the metabolic diversity necessary for pesticide degradation (Lavy and others, 1973; Pothuluri and others, 1990; Dhileepan and Schnoor, 1992; McMahan and others, 1992; Johnson and Lavy, 1994).

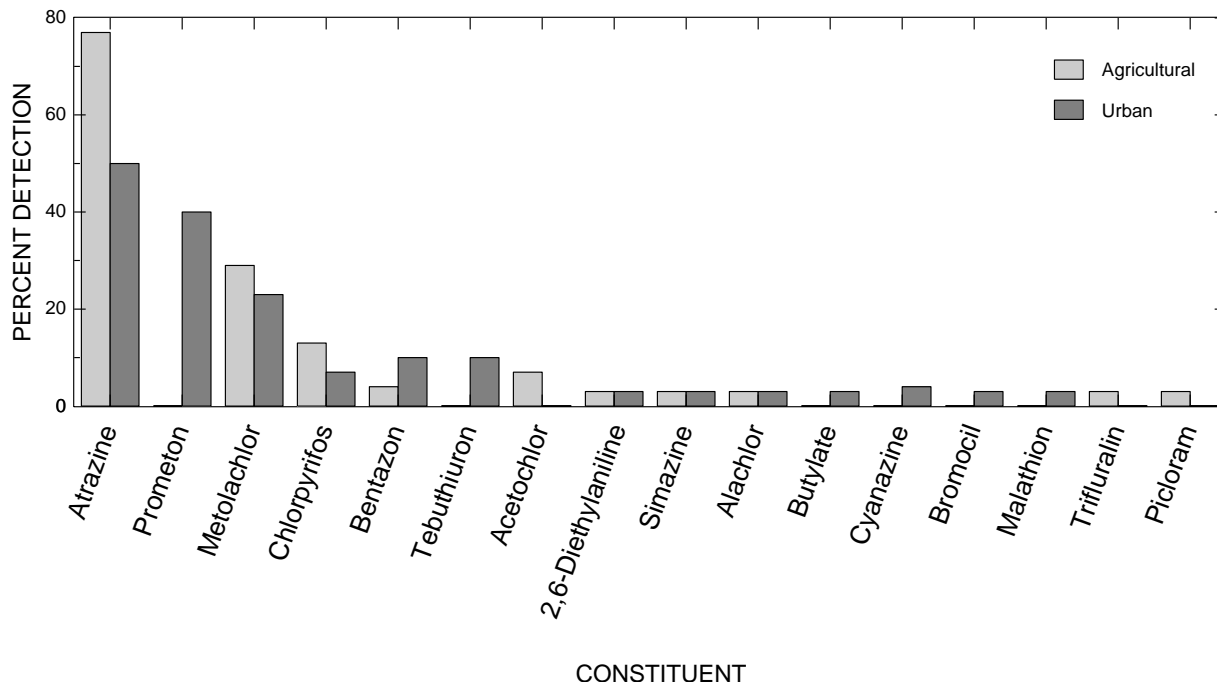


Figure 15. Frequency of detection of pesticides in samples from agricultural and urban areas.

Pesticide metabolites were detected in 94 percent of samples from agricultural areas and 53 percent of samples from urban areas. All 10 of the pesticide metabolites analyzed for were detected in samples from agricultural areas (fig. 16); 8 of the metabolites were detected in samples from urban areas. Metolachlor ESA and deethylatrazine were the most commonly detected metabolites in samples from agricultural areas; metolachlor ESA and alachlor ESA were the most commonly detected metabolites in samples from urban areas. There are currently no USEPA drinking-water regulations for pesticide metabolites.

The presence of corn herbicides (such as atrazine, metolachlor, and alachlor) and their metabolites in samples from urban areas was unexpected. However, many urban areas in the study unit consist of smaller towns surrounded by row crops (corn and soybean), which, in some cases, occupied a portion of the 1,640-ft land-use buffer around urban land-use wells (table 1). It is likely that local ground-water flow from cropland areas could account for the presence of corn herbicides and metabolites in the ground water of adjacent urban areas. The presence of corn herbicides in precipitation (Nations and Hallberg, 1992) also could provide a source to urban ground water.

Total metabolite concentrations were significantly higher ($p < 0.001$) for samples from agricultural areas than for urban areas (fig. 17). Total pesticide concentrations (parent compounds) tended to be higher in samples from agricultural areas; however, this difference was not statistically significant ($p = 0.279$). Metabolites constituted the major portion of the total residue concentration in the alluvial aquifer. Total metabolite concentrations were significantly higher ($p < 0.001$) than total pesticide concentrations (parent compounds) in samples from agricultural areas (fig. 17). Total metabolite concentrations tended to be higher than total pesticide concentrations (parent compounds) in samples from urban areas; however, this difference was not statistically significant ($p = 0.273$). Previous investigations in the Midwestern United States have indicated that pesticide metabolites frequently are present in concentrations exceeding those of the parent compounds (Kolpin and others, 1997; Kalkhoff and others, 1998; Kolpin and others, 1998b).

Longer ground-water flow paths allow for greater residence time and increase opportunities for sorption, degradation, and dispersion, which may contribute to decreases in pesticide concentration with depth. Atrazine, deethylatrazine, and

deisopropylatrazine concentrations in samples from agricultural areas were negatively correlated with well depth ($p=0.022$, $\rho=-0.41$; $p=0.018$, $\rho=-0.42$; and $p=0.016$, $\rho=-0.43$, respectively) (fig. 18) and depth below the water table to the top of the sample interval ($p=0.018$, $\rho=-0.42$; $p<0.001$, $\rho=-0.65$; and $p=0.004$, $\rho=-0.50$, respectively) (fig. 19). Deethylatrazine concentrations in samples from urban areas also were negatively correlated with well depth ($p=0.049$, $\rho=-0.36$). Metolachlor concentrations in samples from agricultural areas were negatively correlated with well depth ($p=0.035$, $\rho=-0.38$) and showed a weak negative correlation with depth below the water table to the top of the sampling interval ($p=0.06$, $\rho=-0.34$). Previous studies have related higher pesticide concentrations to shallow well depths and wells with sample intervals nearer the water table (Kross and others, 1990; Kalkhoff and others, 1992; Koterba and others, 1993). Statistically significant relations between pesticide and metabolite concentrations and depth to water were not observed; however, weak negative correlations were present between deethylatrazine and deisopropylatrazine concentrations and depth to water ($p=0.063$, $\rho=-0.34$; and $p=0.10$, $\rho=-0.31$, respectively) in samples from agricultural areas.

Pesticide mobility and fate in the subsurface are influenced by sorption and degradation processes. The effectiveness of these processes is determined, in part, by the physical and chemical properties of the pesticide, such as organic-carbon and mineral-surface sorption coefficients, aqueous solubility, and soil dissipation half-life (Rao and Alley, 1993). Sorption of pesticides onto clays and solid-phase organic material can slow their movement in the subsurface (Hance, 1988; Barbash and Resek, 1996; Kolpin and others, 1998a). However, pesticide mobility may be increased as a result of sorption onto dissolved organic material (Madhun and others, 1986; Pennington and others, 1991; Barbash and Resek, 1996). Dissolved organic material also may compete with pesticides for available sorption sites on clay and solid-phase organic material (Lee and others, 1990; Celis and others, 1998), resulting in increased pesticide mobility.

Atrazine concentrations in samples from urban areas were negatively correlated with cumulative clay thickness above the sample interval ($p=0.023$, $\rho=-0.41$; fig. 20). Prometon concentrations showed a weak negative correlation with cumulative clay thickness above the sample interval ($p=0.077$, $\rho=-0.33$). Weak negative correlations also were observed between deethylatrazine and

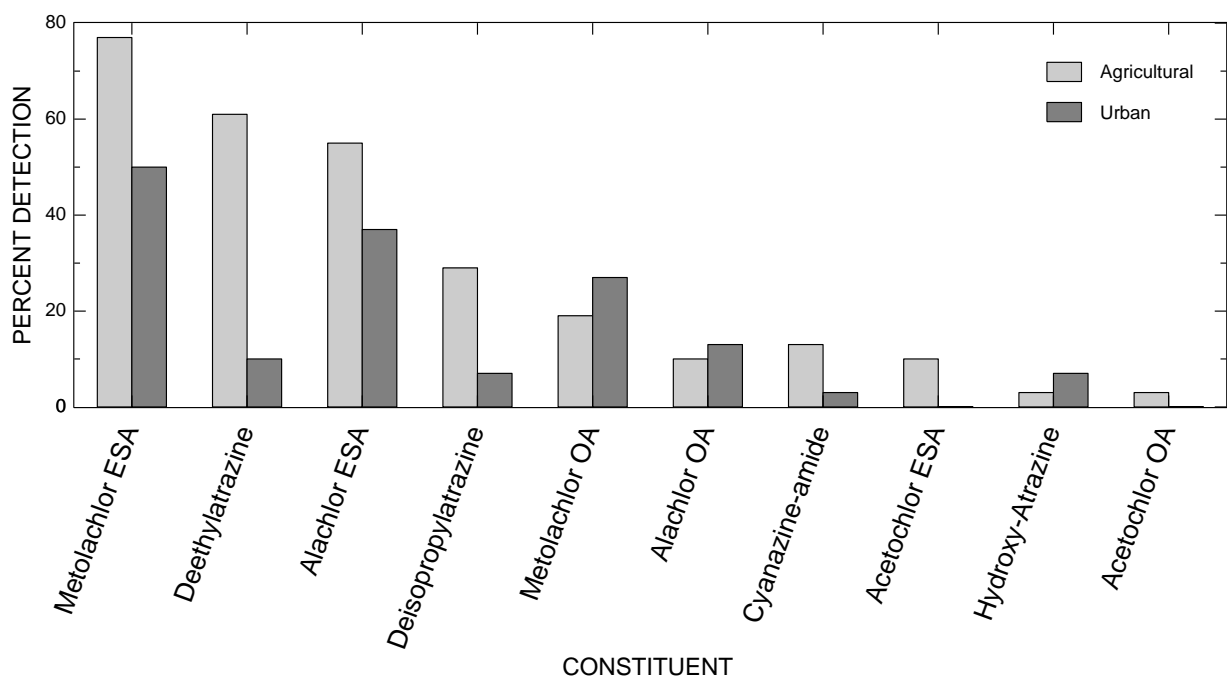


Figure 16. Frequency of detection of pesticide metabolites in samples from agricultural and urban areas.

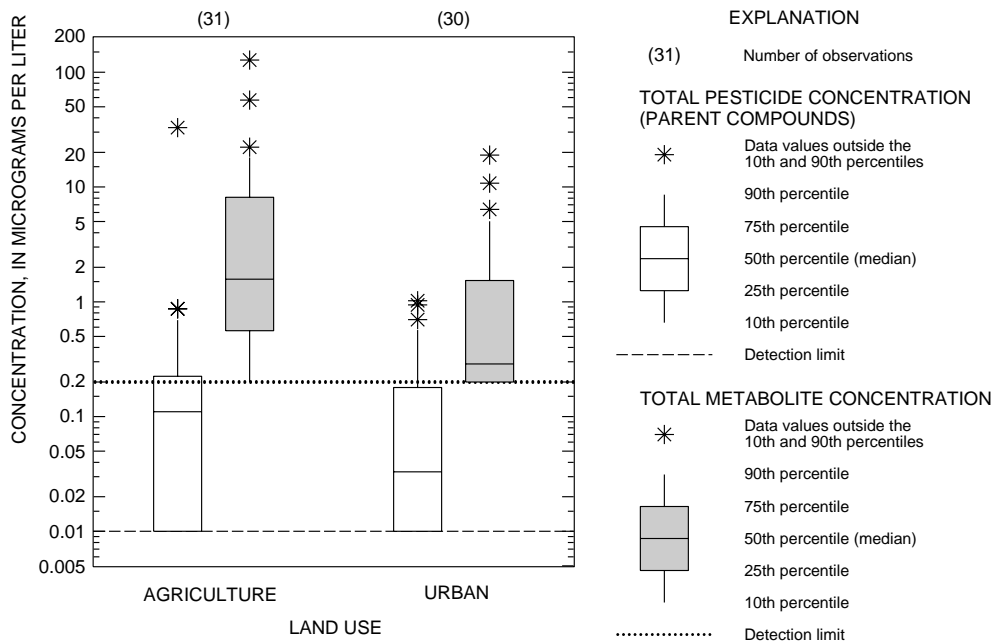


Figure 17. Relation between land use and total pesticide (parent compounds) and total metabolite concentrations.

deisopropylatrazine concentrations and cumulative clay thickness above the sample interval ($p=0.052$, $\rho=-0.35$ and $p=0.098$, $\rho=-0.30$, respectively) in samples from urban areas.

Statistically significant relations between pesticide and metabolite concentrations and organic carbon, and dissolved organic carbon concentrations were not observed. However, a weak negative correlation between atrazine concentrations and organic carbon content ($p=0.067$, $\rho=-0.34$) and a weak positive correlation between alachlor ESA and dissolved organic carbon concentrations ($p=0.078$, $\rho=0.33$) were present in samples from urban areas.

Microbial deethylation of atrazine results in the formation of the metabolite deethylatrazine. The deethylatrazine to atrazine ratio (DAR) has been used as an indicator of atrazine residence time in the unsaturated zone and of the probable source (point or nonpoint) of atrazine in ground water (Adams and Thurman, 1991; Thurman and others, 1992). DAR values greater than 0.3 have been attributed to longer residence times in the unsaturated zone and nonpoint sources of atrazine in ground water (Kolpin and others, 1994). DAR values were calculated for 58 percent of samples (those with detections of both analytes) from agricultural areas and ranged from 0.37 to 14.8, with a median value of 1.85. These

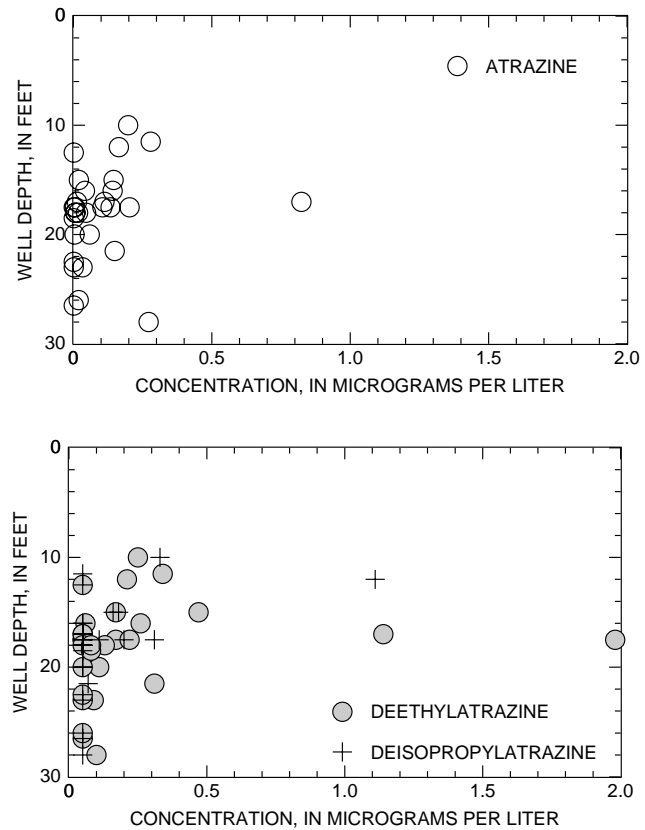


Figure 18. Relation between atrazine, deethylatrazine, and deisopropylatrazine concentrations and well depth in samples from agricultural areas.

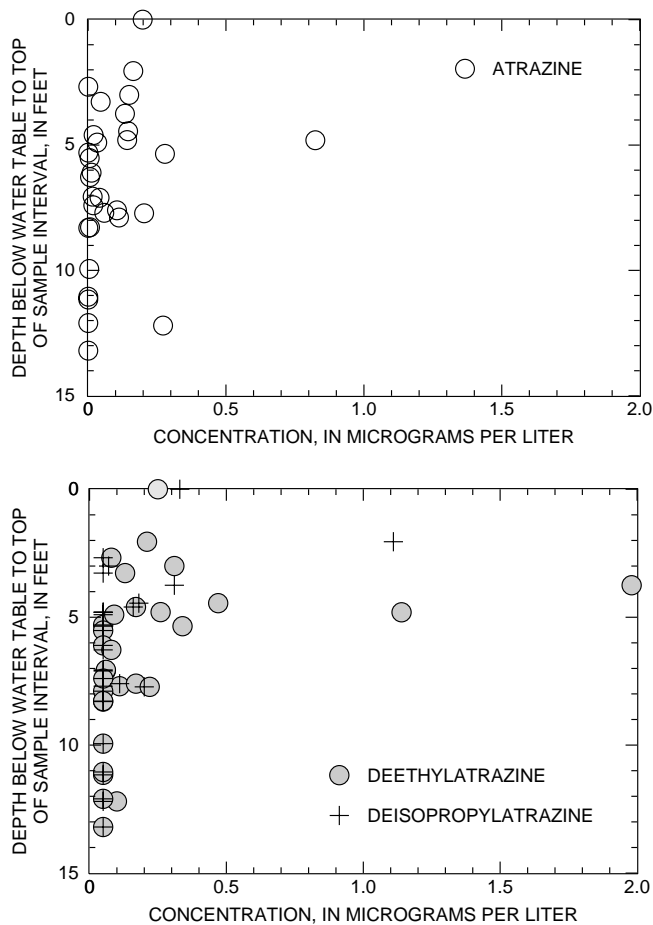


Figure 19. Relation between atrazine, deethylatrazine, and deisopropylatrazine concentrations and depth below water table to top of sample interval in samples from agricultural areas.

results suggest that the atrazine detected in samples from these wells moved slowly through the unsaturated zone and was derived from nonpoint sources. DAR values could not be interpreted in samples from urban areas due to the small number of detections (10 percent) of both analytes.

Volatile Organic Compounds

Volatile organic compounds are associated with a variety of manufacturing processes and are present in many commodities, including gasoline, paints, solvents, dry-cleaning agents, pharmaceuticals, and liquid formulations of some pesticides (Verschuieren, 1983; Wang and others, 1995). Widespread use has led to the detection of VOCs in ground water throughout the United States (Westrick, 1990; Mackay and Smith,

1993). VOCs can enter ground water directly from near-surface leaks and spills or through atmospheric deposition following volatilization (Mackay and Smith, 1993; Squillace and others, 1995; Pankow and others, 1997). VOCs comprise a diverse group of compounds that exhibit a wide range of physical and chemical properties (molecular weight, vapor pressure, aqueous solubility, and organic carbon and sediment sorption coefficients). These properties influence partitioning, sorption, advection-dispersion, and degradation processes and affect VOC mobility and fate in the subsurface (Verschuieren, 1983; Gillham and Rao, 1990; Chapelle, 1993).

VOCs were detected in 40 percent of samples from urban areas and 10 percent from agricultural areas. Thirty-seven VOCs were detected in samples from urban areas (fig. 21); 3 VOCs (1,2,4-trimethylbenzene, methylene chloride, and carbon disulfide) were detected in agricultural areas. The VOCs detected during this study are used as fuel oxygenates, gasoline hydrocarbons, solvents, organic synthesizers, fumigants, and refrigerants. Methyl tert-butyl ether (MTBE), a fuel oxygenate, was the most frequently detected VOC and was present in 23 percent of samples from urban areas but was not detected in samples from agricultural areas. Trichloroethene and cis-1,2-dichloroethene were the most frequently detected solvents and were present in 13 percent of samples from urban areas. 1,2,4-trimethylbenzene, chloroform, o-ethyltoluene, and methyl iodide were the most frequently detected VOCs used in organic synthesis and were present in 7 percent

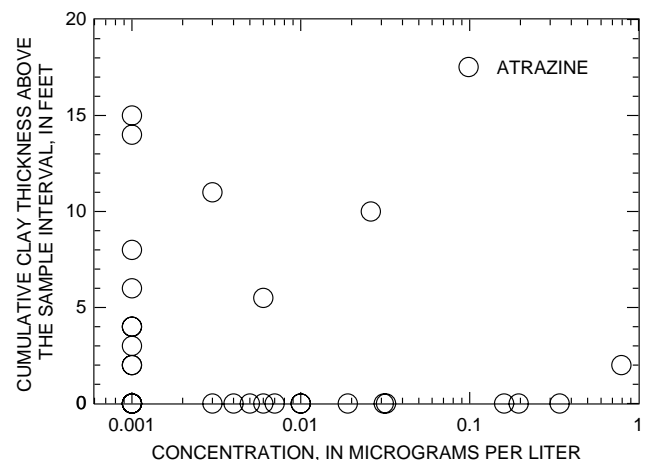


Figure 20. Relation between atrazine concentration and cumulative clay thickness above the sample interval in samples from urban areas.

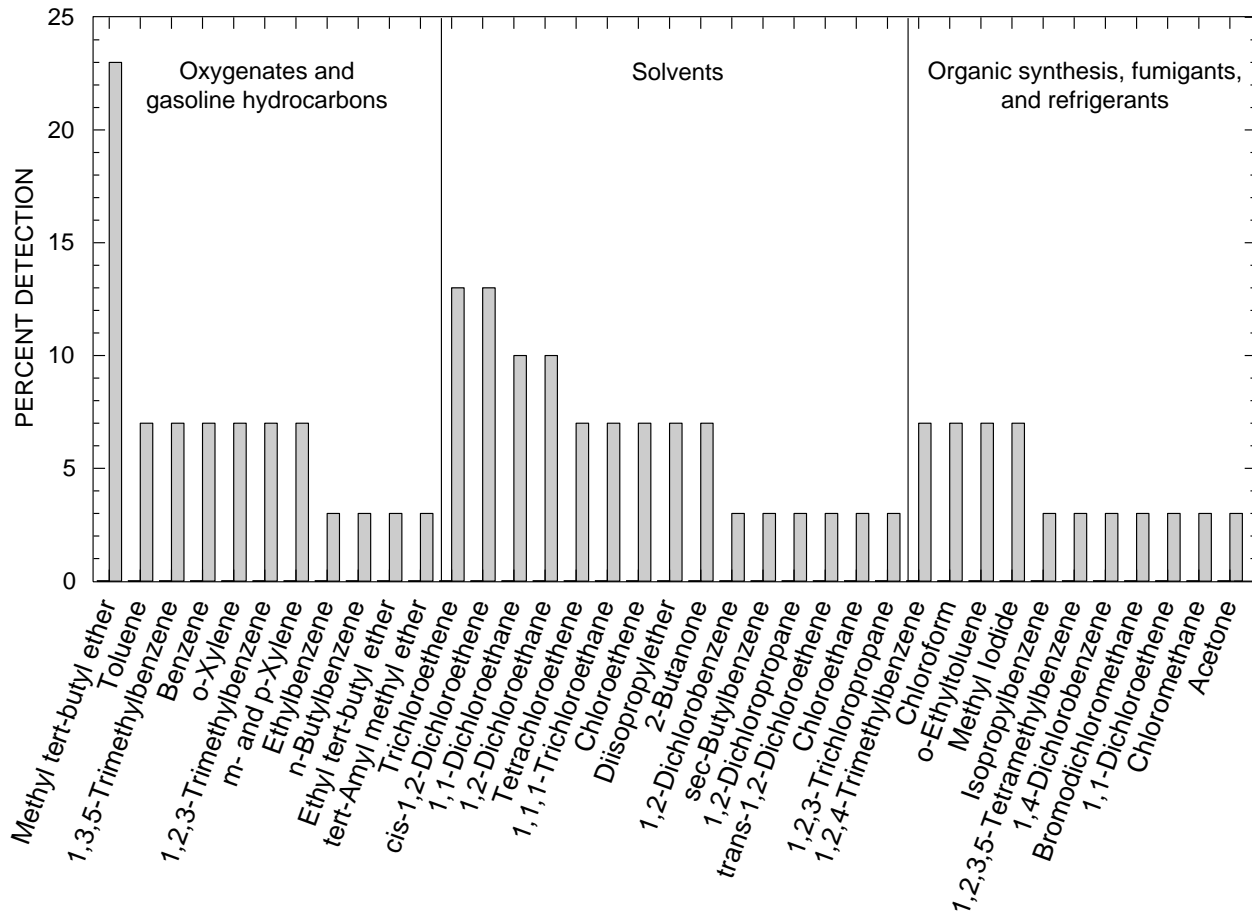


Figure 21. Frequency of detection of volatile organic compounds in samples from urban areas.

of samples from urban areas. 1,2,4-trimethylbenzene was detected in 3 percent of samples from agricultural areas. The USEPA has tentatively classified MTBE as a possible human carcinogen and has issued a draft HAL of 20 to 200 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 1996). MTBE concentrations exceeded 20 $\mu\text{g/L}$ in 7 percent of samples from urban areas. USEPA drinking-water MCLs were exceeded in 7 percent of urban samples for benzene (5.0 $\mu\text{g/L}$) and 3 percent of samples for 1,2-dichloroethane (5.0 $\mu\text{g/L}$) and chloroethene (2.0 $\mu\text{g/L}$).

MTBE has been widely used to increase gasoline octane levels since 1979 (Garrett and others, 1986) and as a fuel oxygenate since 1988 (Begley and Rotman, 1993). Widespread use has led to frequent detection of MTBE in ground water from urban areas throughout the United States (Squillace and others, 1995); however, it was not detected during a recent study of urban ground-water quality in an area of the

Upper Midwest where oxygenated gasoline use is required during winter months (Andrews and others, 1998).

MTBE concentrations in samples from urban sites were positively correlated ($p=0.017$, $\rho=0.43$) with percentage of land use classified as commercial (retail stores and services) where gas stations and automotive-repair shops are likely to be present. Statistically significant relations between MTBE concentrations and factors other than land use, such as well depth, cumulative clay thickness, and organic matter concentration, were not observed. Elevated concentrations (greater than 30 $\mu\text{g/L}$) of MTBE and BTEX compounds (benzene, toluene, ethylbenzene, and xylene) in two samples from urban areas suggest the possible presence of point-source gasoline leaks or spills (Squillace and others, 1996). Insufficient numbers of detections prevented a statistical analysis of the remainder of detected VOCs.

SUMMARY AND CONCLUSIONS

The Eastern Iowa Basins study unit encompasses an area of about 19,500 mi² in eastern Iowa and southern Minnesota and is one of 59 study units in the USGS NAWQA Program. Ground-water samples were collected from monitoring wells at 31 agricultural and 30 urban sites in the Eastern Iowa Basins study unit during June–August 1997 to evaluate the effects of hydrogeology and agricultural and urban land use on the water quality of alluvial aquifers. Ground-water samples were analyzed for common ions, nutrients, DOC, tritium, radon-222, pesticides and pesticide metabolites, VOCs, and environmental isotopes.

Land use and hydrogeology affect the water quality of alluvial aquifers in the study area. Calcium, magnesium, and bicarbonate were the dominant ions in most samples and were likely derived from solution of carbonate minerals (calcite and dolomite) present in alluvial detrital deposits. Chloride and nitrate were dominant anions in samples from several wells. Road salts are used throughout the study unit during winter, especially in urban areas where roads are more numerous and road salts may be more frequently applied than in agricultural areas. Sodium and chloride concentrations were significantly higher in samples from urban areas than from agricultural areas. Sodium concentrations in samples from urban sites were positively correlated with percentage of land use classified as commercial (retail stores and services); chloride concentrations were negatively correlated with percentage of land use classified as row crops (corn and soybeans). Nitrate was detected in 94 percent of samples from agricultural areas and 77 percent of samples from urban areas. Nitrate concentrations were significantly higher in agricultural areas than in urban areas and exceeded the USEPA MCL for drinking water (10 mg/L as N) in 39 percent of samples from agricultural areas. Nitrate concentrations in samples from urban areas did not exceed the MCL. Chemical fertilizer and livestock manure applications to cropland in agricultural areas most likely contribute to higher nitrate concentrations in samples from those areas.

Tritium-based ages indicate ground water was most likely recharged after the 1950's at all but one sampling site. Agricultural and urban areas have remained relatively stable in the study unit for many decades, and the presence of ground water that was most likely recharged after the 1950's increases the likelihood that the effects of current land use are reflected in ground water sampled during this study.

Tritium-based ground-water ages were not significantly different between agricultural and urban samples. Radon-222 was detected in all samples and exceeded the USEPA previously proposed MCL for drinking water (300 pCi/L) in 71 percent of samples.

Pesticides were detected in 84 percent of samples from agricultural areas and 70 percent from urban areas. Atrazine and metolachlor were the most frequently detected pesticides in samples from agricultural areas; atrazine and prometone were the most frequently detected pesticides in samples from urban areas. None of the pesticide concentrations exceeded USEPA MCLs or HALs for drinking water. Pesticide metabolites were detected in 94 percent of samples from agricultural areas and 53 percent from urban areas. Metolachlor ESA and deethylatrazine were the most frequently detected metabolites in samples from agricultural areas; metolachlor ESA and alachlor ESA were the most frequently detected metabolites in samples from urban areas. There are currently no USEPA drinking-water regulations for pesticide metabolites.

Total metabolite concentrations were significantly higher in samples from agricultural areas than in samples from urban areas. Total pesticide concentrations (parent compounds) tended to be higher in samples from agricultural areas; however, this difference was not statistically significant. Metabolites constituted the major portion of the total residue concentration in the alluvial aquifer. Total metabolite concentrations were significantly higher than total pesticide concentrations (parent compounds) in samples from agricultural areas. Total metabolite concentrations tended to be higher than total pesticide concentrations (parent compounds) in samples from urban areas; however, this difference was not statistically significant.

Volatile organic compounds were detected in 40 percent of samples from urban areas and 10 percent from agricultural areas. MTBE was the most frequently detected VOC and was present in 23 percent of samples from urban areas. Elevated concentrations (greater than 30 µg/L) of MTBE and BTEX compounds in two samples from urban areas suggest the possible presence of point-source gasoline leaks or spills. MTBE concentrations in samples from urban sites were positively correlated with percent of land use classified as commercial, where gas stations and automotive-repair shops are likely to be present. MTBE was not detected in samples from agricultural areas.

Factors other than land use may contribute to observed differences in water quality between and within agricultural and urban areas. Nitrate, atrazine, deethylatrazine, and deisopropylatrazine concentrations were significantly higher in shallow wells with sample intervals nearer the water table and in wells with thinner cumulative clay thickness above the sample intervals. These relations suggest that longer flow paths allow for greater residence time and increase opportunities for sorption, degradation, and dispersion, which may contribute to decreases in nutrient and pesticide concentrations with depth. Nitrogen speciation was influenced by redox conditions. Nitrate concentrations were significantly higher in ground water with dissolved-oxygen concentrations in excess of 0.5 mg/L. Ammonia concentrations were higher in ground water with dissolved-oxygen concentrations of 0.5 mg/L or less, however, this relation was not statistically significant. Microbial denitrification requires the presence of reduced electron-donating substrates (organic matter) and terminal electron acceptors (nitrogen oxides). The amount of available organic matter may limit denitrification rates. Elevated nitrate concentrations (greater than 2.0 mg/L) were significantly related to lower dissolved organic carbon concentrations in water samples from both agricultural and urban areas. A similar relation between nitrate concentrations (in water) and organic carbon concentrations (in aquifer material) also was observed but was not statistically significant.

REFERENCES

- Adams, C.D., and Thurman, E.M., 1991, Formation and transport of deethylatrazine in the soil and vadose zone: *Journal of Environmental Quality*, v. 20, no. 3, p. 540–547.
- Aga, D.S., Thurman, E.M., Yockel, M.E., Zimmerman, L.R., and Williams, T.D., 1996, Identification of a new sulfonic acid metabolite of metolachlor in soil: *Environmental Science and Technology*, v. 30, no. 2, p. 592–597.
- Akers, K.K.B., Montgomery, D.L., Christiansen, D., Savoca, M.E., Schnoebelen, D.J., Becher, K.D., and Sadorf, E.M., 2000, Water-quality assessment of the Eastern Iowa Basins—Hydrologic data, October 1996 through September 1998: U.S. Geological Survey Open-File Report 00–67, 300 p.
- Alvey, S., and Crowley, D.E., 1995, Influence of organic amendments on biodegradation of atrazine as a nitrogen source: *Journal of Environmental Quality*, v. 24, no. 6, p. 1156–1162.
- Alvey, S., and Crowley, D.E., 1996, Survival and activity of an atrazine-mineralizing bacterial consortium in rhizosphere soil: *Environmental Science and Technology*, v. 30, no. 5, 1596–1603.
- American Society for Testing Materials, 1996, Annual book of ASTM standards, section 11, Water and environmental technology: v. 11.02.
- Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 8 p.
- Anderson, W.I., 1983, *Geology of Iowa—Over two billion years of change*: Ames, Iowa State University Press, 268 p.
- Andrews, W.J., Fong, A.L., Harrod, L., and Dittes, M.E., 1998, Water-quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin—Ground-water quality in an urban part of the Twin Cities metropolitan area, Minnesota, 1996: U.S. Geological Survey Water-Resources Investigations Report 97–4248, 54 p.
- Ator, S.W., and Ferrari, M.J., 1997, Nitrate and selected pesticides in ground water of the Mid-Atlantic region: U.S. Geological Survey Water-Resources Investigations Report 97–4139, 8 p.
- Barbash, J.E., and Resek, E.A., 1996, *Pesticides in ground water—Distribution, trends, and governing factors*: Chelsea, Michigan, Ann Arbor Press, 588 p.
- Barringer, T., Dunn, D., Battaglin, W., and Vowinkel, E., 1990, Problems and methods involved in relating land use to ground-water quality: American Water Resources Association, *Water Resources Bulletin*, v. 26, no. 1, p. 1–9.
- Begley, R., and Rotman, D., 1993, Health complaints fuel federal concern over MTBE: *Chemical Week*, v. 152, no. 10, p. 7.
- Blevins, D.W., Wilkison, D.H., Kelly, B.P., and Silva, S.R., 1996, Movement of nitrate fertilizer to glacial till and runoff from a claypan soil: *Journal of Environmental Quality*, v. 25, no. 3, p. 584–593.
- Brenton, R.W., and Arnett, T.L., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of dissolved organic carbon by UV-promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92–480, 12 p.

- Buchmiller, R.C., and Squillace, P.J., 1988, Ground-water quality—Iowa, *in* U.S. Geological Survey National Water Summary 1986: U.S. Geological Survey Water-Supply Paper 2325, p. 251–258.
- Burkart, M.R., and Kolpin, D.W., 1993, Hydrologic and land-use factors associated with herbicides and nitrate in near-surface aquifers: *Journal of Environmental Quality*, v. 22, no. 4, p. 646–656.
- Celis, R., Barriuso, E., and Houot, S., 1998, Sorption and desorption of atrazine by sludge-amended soil—Dissolved organic matter effects: *Journal of Environmental Quality*, v. 27, no. 6, p. 1348–1356.
- Chapelle, F.H., 1993, *Ground-water microbiology and geochemistry*: New York, John Wiley & Sons, Inc., 424 p.
- Coplen, T.B., Wildman, J.D., and Chen, J., 1991, Improvements in the gaseous hydrogen-water equilibrium technique for hydrogen isotope ratio analysis: *Analytical Chemistry*, v. 63, p. 910–912.
- Dhileepan, R.N., and Schnoor, J.L., 1992, Effect of two electron acceptors on atrazine mineralization rates in soil: *Environmental Science and Technology*, v. 26, no. 11, p. 2298–2230.
- Eckhardt, D.A., Flipse, Jr., W.J., and Oaksford, E.T., 1989, Relation between land use and ground-water quality in the upper glacial aquifer in Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 86–4142, 35 p.
- Epstein, S., and Mayeda, T., 1953, Variation of O-18 content of water from natural sources: *Geochimica et Cosmochimica Acta*, v. 4, p. 213–224.
- Ferrari, M.J., and Ator, S.W., 1995, Nitrate in ground water in the Great Valley Carbonate Subunit of the Potomac River Basin: U.S. Geological Survey Water-Resources Investigations Report 95–4099, 6 p.
- Ferrer, I., Thurman, E.M., and Barcelo, D., 1997, Identification of new ionic chloroacetanilide-herbicide metabolites in surface and ground water by HPLC/MS using negative ion detection: *Analytical Chemistry* v. 69, p. 4547–4553.
- Field, J.A., and Thurman, E.M., 1996, Glutathione conjugation and contaminant transformation: *Environmental Science and Technology*, v. 30, no. 5, p. 1413–1418.
- Fishman, M.J., and Friedman, L.C., eds., 1989, *Methods for determination of inorganic substances in water and fluvial sediments*: U.S. Geological Survey Techniques for Water-Resources Investigations, book 5, chap. A1, 545 p.
- Garrett, P., Moreau, M., and Lowry, J.D., 1986, MTBE as a ground water contaminant, *in* Proceedings of petroleum hydrocarbons and organic chemicals in ground water—Prevention, detection and restoration, November 12–14, 1986: Houston, Texas, National Water Well Association and American Petroleum Institute, p. 227–238.
- Gillham, R.W., and Rao, P.S., 1990, Transport, distribution, and fate of volatile organic compounds in groundwater, *in* Ram, N.M., Christman, R.F., and Cantor, K.P., eds., *Significance and treatment of volatile organic compounds in water supplies*: Chelsea, Michigan, Lewis Publishers, p. 141–181.
- Gilliom, R.J., Alley, W.A., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.
- Goolsby, D.A., Thurman, E.M., Pomes, M.L., Meyer, M.T., and Battaglin, W.A., 1997, Herbicides and their metabolites in rainfall—Origin, transport, and depositional patterns across the Midwestern and Northeastern United States, 1990–91: *Environmental Science and Technology*, v. 31, no. 5, p. 1325–1333.
- Hallberg, G.R., 1989, Nitrate in ground water in the United States, *in* Follett, R.F., ed., *Nitrogen management and ground-water protection*: New York, Elsevier Science Publishing Co., p. 35–74.
- Hallberg, G.R., and Keeney, D.R., 1993, Nitrate, *in* Alley, W.M., ed., *Regional ground-water quality*: New York, Van Nostrand Reinhold, p. 297–322.
- Hance, R.J., 1998, Adsorption and bioavailability, *in* Grover, R., ed., *Environmental chemistry of herbicides*, v. I: Boca Raton, Florida, CRC Press, Inc., p. 1–19.
- Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 264 p.
- Hershey, H.G., 1969, *Geologic map of Iowa*: Iowa Geological Survey, 1 sheet.
- Hinkle, S.R., 1997, Quality of shallow ground water in alluvial aquifers of the Willamette Basin, Oregon, 1993–95: U.S. Geological Survey Water-Resources Investigations Report 97–4082–B, 48 p.
- Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a national water-quality assessment program: U.S. Geological Survey Circular 1021, 42 p.
- Hitt, K.J., 1994, Refining 1970's land-use data with 1990 population data to indicate new residential development: U.S. Geological Survey Water-Resources Investigations Report 94–4250, 15 p.
- Hoyer, B.E., and Hallberg, G.R., 1991, Groundwater vulnerability regions of Iowa: Energy and Geological Resources Division, Geological Survey Bureau, Iowa Department of Natural Resources, Special Map Series II.

- Johnson, W.G., and Lavy, T.L., 1994, In-situ dissipation of benomyl, carbofuran, thiobencarb, and triclopyr at three soil depths: *Journal of Environmental Quality*, v. 23, no. 3, p. 556–562.
- Kalkhoff, S.J., Detroy, M.G., Cherryholmes, K.L., and Kuzniar, R.L., 1992, Herbicide and nitrate variation in alluvium underlying a corn field at a site in Iowa County, Iowa: *Water Resources Bulletin*, v. 28, no. 6, p. 1001–1011.
- Kalkhoff, S.J., Kolpin, D.W., Thurman, E.M., Ferrer, I., and Barcelo, D., 1998, Degradation of chloroacetanilide herbicides—The prevalence of sulfonic and oxanilic acid metabolites in Iowa groundwaters and surface waters: *Environmental Science and Technology*, v. 32, no. 11, p. 1738–1740.
- Kolpin, D.W., 1997, Agricultural chemicals in groundwater of the midwestern United States—Relations to land use: *Journal of Environmental Quality*, v. 26, no. 4, p. 1025–1037.
- Kolpin, D.W., Burkart, M.R., and Thurman, E.M., 1994, Herbicides and nitrate in near-surface aquifers in the Midcontinental United States, 1991: U.S. Geological Survey Water-Supply Paper 2413, 34 p.
- Kolpin, D.W., Barbash, J.E., and Gilliom, R.J., 1998a, Occurrence of pesticides in shallow groundwater of the United States—Initial results from the National Water-Quality Assessment Program: *Environmental Science and Technology*, v. 32, no. 5, p. 558–566.
- Kolpin, D.W., Stamer, J.K., Goolsby, D.A., and Thurman, E.M., 1998b, Herbicides in groundwater of the Midwest—A regional study of shallow aquifers, 1991–94: U.S. Geological Survey Fact Sheet FS-076–98.
- Kolpin, D.W., Kalkhoff, S.J., Goolsby, D.A., Sneek-Fahrer, D.A., and Thurman, E.M., 1997, Occurrence of selected herbicides and herbicide degradation products in Iowa's groundwater, 1995: *Ground Water*, v. 35, no. 4, p. 679–688.
- Koterba, M.T., 1998, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment program—Collection, documentation, and compilation of required site, well, subsurface, and landscape data for wells: U.S. Geological Survey Water-Resources Investigations Report 98–4107, 91 p.
- Koterba, M.T., Banks, W.S.L., and Shedlock, R.J., 1993, Pesticides in shallow groundwater in the Delmarva Peninsula: *Journal of Environmental Quality*, v. 22, no. 3, p. 500–518.
- Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment program—Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95–399, 113 p.
- Kross, B.C., Hallberg, G.R., Bruner, D.R., Libra, R.D., Rex, K.D., Weih, L.M.B., Vermace, M.E., Burmeister, L.F., Hall, N.H., Cherryholmes, K.L., Johnson, J.K., Selim, M.I., Nations, B.K., Seigley, L.S., Quade, D.J., Dudler, A.G., Sesker, K.D., Culp, M.A., Lynch, C.F., Nicholson, H.F., and Hughes, J.P., 1990, The Iowa state-wide rural well-water survey water-quality data—Initial analysis: Iowa Department of Natural Resources Technical Information Series 19, 142 p.
- Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment program—Selection, installation, and documentation of wells, and collection of related data: U.S. Geological Survey Open-File Report 95–398, 69 p.
- Lavy, T.L., Roeth, F.W., and Fenster, C.R., 1973, Degradation of 2,4-D and atrazine at three soil depths in the field: *Journal of Environmental Quality*, v. 2, no. 1, p. 132–137.
- Lee, D.Y., Farmer, W.J., and Aochi, Y., 1990, Sorption of noproamide on clay and soil in the presence of dissolved organic matter: *Journal of Environmental Quality*, v. 19, no. 3, p. 567–573.
- Mackay, D.M., and Smith, L.A., 1993, Organic contaminants, in Alley, W.M., ed., *Regional groundwater quality*: New York, Van Nostrand Reinhold, p. 323–343.
- Madhun, Y.A., Young, J.L., and Freed, V.H., 1986, Binding of herbicides by water-soluble organic materials from soil: *Journal of Environmental Quality*, v. 15, no. 1, p. 64–68.
- Madison, R.J., and Brunett, J.O., 1985, Overview of the occurrence of nitrate in ground water of the United States, in U.S. Geological Survey National Water Summary 1984: U.S. Geological Survey Water-Supply Paper 2275, p. 93–105.
- Majewski, M.J., and Capel, P.D., 1995, Pesticides in the atmosphere—Distribution, trends, and governing factors: Chelsea, Michigan, Ann Arbor Press, 214 p.
- Majewski, M.J., Foreman, W.T., Goolsby, D.A., and Nakagaki, N., 1998, Airborne pesticides along the Mississippi River: *Environmental Science and Technology*, v. 32, no. 23, p. 3689–3698.
- McMahon, P.B., Chapelle, F.H., and Jagucki, M.L., 1992, Atrazine mineralization potential of alluvial-aquifer sediments under aerobic conditions: *Environmental Science and Technology*, v. 26, no. 8, p. 1556–1559.
- Mueller, D.K., Hamilton, P.A., Helsel, D.R., Hitt, K.J., and Ruddy, B.C., 1995, Nutrients in ground water and surface water of the United States—An analysis of data through 1992: U.S. Geological Survey Water-Resources Investigations Report 95–4031, 74 p.

- Nations, B.K., and Hallberg, G.R., 1992, Pesticides in Iowa precipitation: *Journal of Environmental Quality*, v. 21, no. 3, p. 486–492.
- Olcott, P.G., 1992, Ground water atlas of the United States—Segment 9, Iowa, Michigan, Minnesota, Wisconsin: U.S. Geological Survey Hydrologic Investigations Atlas 730–J, 31 p.
- Ostlund, H.G., and Dorsey, H.G., 1977, Rapid electrolytic enrichment of hydrogen gas proportional counting of tritium: *Proceedings of International Conference on Low Radioactivity Measurement and Applications, High Tatras, Czechoslovakia, October, 1975*, 6 p.
- Ott, R.L., 1993, *An introduction to statistical methods and data analysis*: Belmont, California, Duxbury Press, Wadsworth Publishing Company, 1051 p.
- Pankow, J.F., Thomson, N.R., Johnson, R.L., Baehr, A.L., and Zogorski, J.S., 1997, The urban atmosphere as a non-point source for the transport of MTBE and other volatile organic compounds (VOCs) to shallow groundwater: *Environmental Science and Technology*, v. 31, no. 10, p. 2821–2828.
- Pennington, K.L., Harper, S., and Koskinen, W.C., 1991, Interactions of herbicides with water-soluble soil organic matter: *Weed Science*, v. 39, p. 667–672.
- Plummer, L.N., Michel, R.L., Thurman, E.M., and Glynn, P.D., 1993, Environmental tracers for age dating young ground water, *in* Alley, W.M., ed., *Regional ground-water quality*: New York, Van Nostrand Reinhold, p. 255–294.
- Pothuluri, J.V., Moorman, T.B., Obenhuber, D.C., and Wauchope, R.D., 1990, Aerobic and anaerobic degradation of alachlor in samples from a surface-to-groundwater profile: *Journal of Environmental Quality*, v. 19, no. 3, p. 525–530.
- Rao, P.S., and Alley, W.M., 1993, Pesticides, *in* Alley, W.M., ed., *Regional ground-water quality*: New York, Van Nostrand Reinhold, p. 345–382.
- Rose, D.L., and Schroeder, M.P., 1995, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of volatile organic compounds in water by purge and trap capillary gas chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 94–708, 26 p.
- Schapp, B.D., and Linhart, S.M., 1998, Quality of ground water used for selected municipal water supplies in Iowa, 1982–96 water years: U.S. Geological Survey Open-File Report 98–3, 67 p.
- Schumann, R.R., 1993, Geologic radon potential of the glaciated Upper Midwest—*Proceedings of the 1992 International Symposium on Radon and Radon Reduction Technology*, v. 2, Symposium Oral Papers, Technical Sessions VII–XII: Research Triangle Park, N.C., U.S. Environmental Protection Agency Report EPA–600/R–93/083b, p. 8–33—8–49.
- Scott, J.C., 1990, Computerized stratified random site-selection approaches for design of a ground-water-quality sampling network: U.S. Geological Survey Water-Resources Investigations Report 90–4101, 109 p.
- Squillace, P.J., Zogorski, J.S., Wilber, W.G., and Price, C.V., 1995, A preliminary assessment of the occurrence and possible sources of MTBE in ground water of the United States, 1993–94: U.S. Geological Survey Open-File Report 95–456, 16 p.
- Squillace, P.J., Pankow, J.F., Korte, N.E., and Zogorski, J.S., 1996, Environmental behavior and fate of methyl tert-butyl ether (MTBE): U.S. Geological Survey Fact Sheet FS–203–96, 6 p. (revised February 1998).
- Starr, R.C., and Gillham, R.W., 1993, Denitrification and organic carbon availability in two aquifers: *Ground Water*, v. 31, no. 6, p. 934–946.
- Steinilber, W.L., and Horick, P.J., 1970, Ground-water resources of Iowa, *in* Horick, P.J., ed., *Water resources of Iowa*: Iowa City, University Printing Service, p. 29–49.
- Tesoriero, A.J., and Voss, F.D., 1997, Predicting the probability of elevated nitrate concentrations in the Puget Sound Basin—Implications for aquifer susceptibility and vulnerability: *Ground Water*, v. 35, no. 6, p. 1029–1039.
- Thurman, E.M., Goolsby, D.A., Meyer, M.T., Mills, M.S., Pomes, M.L., and Kolpin, D.W., 1992, A reconnaissance study of herbicides and their metabolites in surface water of the midwestern United States using immunoassay gas chromatography/mass spectrometry: *Environmental Science and Technology*, v. 26, no. 12, p. 2240–2247.
- U.S. Environmental Protection Agency, 1996, *Drinking water regulations and health advisories*: Office of Water 4304 [unpaginated].
- U.S. Geological Survey, 1990, Land use and land cover digital data from 1:250,000- and 1:100,000-scale maps: U.S. Geological Survey Data User Guide 4, 25 p.
- Verschueren, K., 1983, *Handbook of environmental data on organic chemicals*: New York, Van Nostrand Reinhold, 1310 p.
- Wahl, K.D., Ludvigson, G.A., Ryan, G.L., and Steinkampf, W.C., 1978, *Water resources of east-central Iowa*: Iowa Geological Survey Water Atlas 6, 91 p.
- Wang, W., Liszewski, M., Buchmiller, R., and Cherryholmes, K., 1995, Occurrence of active and inactive herbicide ingredients at selected sites in Iowa: *Water, Air and Soil Pollution*, v. 83, p. 21–35.

- Werner, S.L., Burkhardt, M.R., and DeRusseau, S.N., 1996, Methods of analysis by the National Water Quality Laboratory—Determination of pesticides in water by carbopak-B solid-phase extraction and high-performance liquid chromatography: U.S. Geological Survey Open-File Report 96-261, 42 p.
- Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., eds., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 80 p.
- Westrick, J.J., 1990, National surveys of volatile organic compounds in ground and surface waters, *in* Ram, N.M., Christman, R.F., and Cantor, K.P., eds., Significance and treatment of volatile organic compounds in water supplies: Chelsea, Michigan, Lewis Publishers, p. 103-138.
- Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the National Water Quality Laboratory—Determination of pesticides in water by C-18 solid-phase extraction and capillary column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95-181, 60 p.
- Zimmerman, L.R., and Thurman, E.M., 1999, Method of analysis by the U.S. Geological Survey Organic Geochemistry Research Group—Determination of triazine and chloroacetanilide herbicides in water by solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 98-634, 21 p.

APPENDIX

Table A1. Statistical summary of selected ground-water quality data from land-use wells in the Eastern Iowa Basins study unit

[Ag, agricultural land use area; Ur, urban land use area; MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter; $^{\circ}\text{C}$, degrees Celsius; <, less than; pCi/L, picocuries per liter; $\mu\text{g}/\text{L}$, micrograms per liter; NWQL, U.S. Geological Survey National Water Quality Laboratory]

Constituent or property	Samples/detections Ag wells	Samples/detections Ur wells	MRL or MDL	Maximum/median Ag wells	Maximum/median Ur wells	Spike recovery (percent)
Field measurements and physical characteristics						
Well depth (feet below land surface)	31 / na	30 / na	na	28.0 / 17.5	37.5 / 22.5	na
Water level (feet below land surface)	31 / na	30 / na	na	13.6 / 6.2	20.5 / 10.9	na
Dissolved oxygen (mg/L)	30 / na	29 / na	na	10.2 / 3.5	7.34 / 1.1	na
pH (standard units)	31 / 31	30 / 30	na	7.50 / 6.94	7.15 / 6.79	na
Specific conductance ($\mu\text{S}/\text{cm}$ at 25°C)	31 / 31	30 / 30	na	810 / 512	1,490 / 791	na
Water temperature ($^{\circ}\text{C}$)	31 / na	30 / na	na	21.5 / 11.2	26.0 / 13.7	na
Common ions, dissolved (mg/L, except as indicated)						
Alkalinity (mg/L as CaCO_3)	31 / na	30 / na	1.0	460 / 168	431 / 267	na
Bicarbonate (mg/L as HCO_3)	31 / na	30 / na	na	556 / 206	526 / 326	na
Bromide	30 / 27	30 / 30	0.01	0.094 / 0.039	0.407 / 0.076	na
Calcium	31 / 31	30 / 30	0.02	110 / 68	187 / 96	na
Chloride	31 / 31	30 / 30	0.10	139 / 12	312 / 42	na
Fluoride	31 / 21	30 / 25	0.10	0.35 / 0.16	0.57 / 0.19	na
Iron ($\mu\text{g}/\text{L}$)	31 / 11	30 / 22	3.0	3,520 / <3.0	5,760 / 24	na
Magnesium	31 / 31	30 / 30	0.01	37 / 19	67 / 27	na
Manganese ($\mu\text{g}/\text{L}$)	31 / 22	30 / 23	1.0	1,600 / 8.8	2,210 / 174	na
Potassium	31 / 31	30 / 30	0.10	5.4 / 0.7	21 / 2.7	na
Silica	31 / 31	30 / 30	0.01	30 / 19	39 / 18	na
Sodium	31 / 31	30 / 30	0.20	42 / 5.6	68 / 23	na
Sulfate	31 / 31	30 / 30	0.10	70 / 22	255 / 45	na
Dissolved solids	31 / 31	30 / 30	1.0	506 / 304	849 / 439	na
Nutrients and organics, dissolved (mg/L)						
Ammonia, as N	31 / 11	30 / 21	0.015	0.97 / <0.015	1.01 / 0.024	na
Ammonia plus organic, as N	31 / 5	30 / 8	0.2	1.25 / <0.2	1.59 / <0.2	na
Nitrite, as N	31 / 5	30 / 8	0.01	0.99 / <0.01	0.149 / <0.01	na
Nitrite plus nitrate, as N	31 / 29	30 / 23	0.05	32.1 / 5.13	9.54 / 1.83	na
Orthophosphate, as P	31 / 29	30 / 26	0.01	0.148 / 0.033	0.117 / 0.023	na
Phosphorus, as P	31 / 22	30 / 18	0.01	0.163 / 0.033	0.108 / 0.015	na
Organic carbon	31 / 31	30 / 30	0.10	10.0 / 1.10	9.70 / 1.65	na
Radiochemicals and environmental isotopes						
Radon-222 (pCi/L)	31 / 31	30 / 30	24	1,500 / 396	1221 / 378	na
Trtium (pCi/L)	31 / 30	30 / 30	1.0	58.2 / 33.0	124 / 33.9	na
Oxygen-18/Oxygen-16 (per mil)	31 / na	30 / na	na	-6.72 / -8.15	-7.07 / -8.39	na
Deuterium/Protium (per mil)	31 / na	30 / na	na	-41.8 / -52.2	-45.7 / -55.1	na
Pesticides (NWQL schedule 2010) and pesticide metabolites, dissolved ($\mu\text{g}/\text{L}$)						
Acetochlor	31 / 2	30 / 0	0.002	0.031 / <0.002	<0.002 / <0.002	104
Acetochlor ESA	31 / 3	30 / 0	0.20	1.42 / <0.20	<0.20 / <0.20	na
Acetochlor oxanilic acid	31 / 1	30 / 0	0.20	0.63 / <0.20	<0.20 / <0.20	na
Alachlor	31 / 1	30 / 1	0.002	0.003 / <0.002	0.082 / <0.002	104
Alachlor ESA	31 / 17	30 / 11	0.20	35.06 / 0.31	1.89 / <0.20	na
Alachlor oxanilic acid	31 / 3	30 / 4	0.20	0.63 / <0.20	5.40 / <0.20	na

Table A1. Statistical summary of selected ground-water quality data from land-use wells in the Eastern Iowa Basins study unit—Continued

[Ag, agricultural land use area; Ur, urban land use area; MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; μ S/cm, microsiemens per centimeter; °C, degrees Celsius; <, less than; pCi/L, picocuries per liter; μ g/L, micrograms per liter; NWQL, U.S. Geological Survey National Water Quality Laboratory]

Constituent or property	Samples/detections Ag wells	Samples/detections Ur wells	MRL or MDL	Maximum/median Ag wells	Maximum/median Ur wells	Spike recovery (percent)
Pesticides (NWQL schedule 2010) and pesticide metabolites, dissolved (μg/L)—Continued						
Atrazine	31 / 24	30 / 15	0.001	0.824 / 0.033	0.792 / 0.004	107
Atrazine, deethyl-	31 / 19	30 / 3	0.05	1.98 / 0.22	0.23 / <0.05	na
Atrazine, deisopropyl-	31 / 9	30 / 2	0.05	1.11 / <0.05	0.29 / <0.05	na
Atrazine, hydroxy-	31 / 1	30 / 2	0.20	0.38 / <0.20	2.12 / <0.20	na
Azinphos, methyl-	31 / 0	30 / 0	0.001	<0.001 / <0.001	<0.001 / <0.001	96
Benfluralin	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	85
Butylate	31 / 0	30 / 1	0.002	<0.002 / <0.002	0.0024 / <0.002	97
Chlorpyrifos	31 / 4	30 / 2	0.004	0.021 / <0.004	0.005 / <0.004	96
Cyanazine	31 / 0	29 / 1	0.004	<0.004 / <0.004	0.007 / <0.004	128
Cyanazine-amide	31 / 4	30 / 1	0.05	0.21 / <0.05	0.08 / <0.05	na
DCPA	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	108
DDE, p,p'-	31 / 0	30 / 0	0.006	<0.006 / <0.006	<0.006 / <0.006	67
Diazinon	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	106
Dieldrin	31 / 0	30 / 0	0.001	<0.001 / <0.001	<0.001 / <0.001	87
Diethylaniline, 2,6-	31 / 1	30 / 1	0.003	0.044 / <0.003	0.031 / <0.003	105
Disulfoton	31 / 0	30 / 0	0.017	<0.017 / <0.017	<0.017 / <0.017	92
EPTC	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	105
Ethalfuralin	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	84
Ethoprop	31 / 0	30 / 0	0.003	<0.003 / <0.003	<0.003 / <0.003	111
Fonofos	31 / 0	30 / 0	0.003	<0.003 / <0.003	<0.003 / <0.003	90
HCH, alpha-	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	97
Lindane	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	86
Linuron	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	109
Malathion	31 / 0	30 / 1	0.005	<0.005 / <0.005	0.010 / <0.005	99
Metolachlor	31 / 9	30 / 7	0.002	32.8 / <0.002	0.556 / <0.002	105
Metolachlor ESA	31 / 24	30 / 15	0.20	63.67 / 0.56	12.36 / 0.22	na
Metolachlor oxanilic acid	31 / 6	30 / 8	0.20	13.39 / <0.02	3.60 / <0.20	na
Metribuzin	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	104
Molinate	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	113
Napropamide	31 / 0	30 / 0	0.003	<0.003 / <0.003	<0.003 / <0.003	89
Parathion	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	97
Parathion, methyl-	31 / 0	30 / 0	0.006	<0.006 / <0.006	<0.006 / <0.006	108
Pebulate	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	98
Pendimethalin	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	92
Permethrin, cis-	31 / 0	30 / 0	0.005	<0.005 / <0.005	<0.005 / <0.005	36
Phorate	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	92
Prometon	31 / 0	30 / 12	0.018	<0.018 / <0.018	0.356 / <0.018	107
Pronamide	31 / 0	30 / 0	0.003	<0.003 / <0.003	<0.003 / <0.003	100
Propachlor	31 / 0	30 / 0	0.007	<0.007 / <0.007	<0.007 / <0.007	105
Propanil	31 / 0	30 / 0	0.004	<0.004 / <0.004	<0.004 / <0.004	122

Table A1. Statistical summary of selected ground-water quality data from land-use wells in the Eastern Iowa Basins study unit—Continued

[Ag, agricultural land use area; Ur, urban land use area; MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na; not applicable; mg/L, milligrams per liter; μ S/cm, microsiemens per centimeter; °C, degrees Celsius; <, less than; pCi/L, picocuries per liter; μ g/L, micrograms per liter; NWQL, U.S. Geological Survey National Water Quality Laboratory]

Constituent or property	Samples/detections Ag wells	Samples/detections Ur wells	MRL or MDL	Maximum/median Ag wells	Maximum/median Ur wells	Spike recovery (percent)
Pesticides (NWQL schedule 2010) and pesticide metabolites, dissolved (μg/L)—Continued						
Propargite	31 / 0	30 / 0	0.013	<0.013 / <0.013	<0.013 / <0.013	92
Simazine	31 / 1	30 / 1	0.005	0.011 / <0.005	0.011 / <0.005	107
Tebuthiuron	31 / 0	30 / 3	0.01	<0.01 / <0.01	0.10 / <0.01	114
Terbacil	31 / 0	30 / 0	0.007	<0.007 / <0.007	<0.007 / <0.007	58
Terbufos	31 / 0	30 / 0	0.013	<0.013 / <0.013	<0.013 / <0.013	87
Thiobencarb	31 / 0	30 / 0	0.002	<0.002 / <0.002	<0.002 / <0.002	103
Triallate	31 / 0	30 / 0	0.001	<0.001 / <0.001	<0.001 / <0.001	101
Trifluralin	31 / 1	30 / 0	0.002	0.004 / <0.002	<0.002 / <0.002	93
Pesticides (NWQL schedule 2050), dissolved (μg/L)						
2,4,5-T	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	68
2,4-D	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	64
2,4-DB	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	55
Acifluorfen	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	76
Aldicarb	31 / 0	30 / 0	0.016	<0.016 / <0.016	<0.016 / <0.016	31
Aldicarb sulfone	31 / 0	30 / 0	0.016	<0.016 / <0.016	<0.016 / <0.016	19
Aldicarb sulfoxide	31 / 0	30 / 0	0.021	<0.021 / <0.021	<0.021 / <0.021	52
Bentazon	29 / 1	30 / 3	0.014	0.110 / <0.014	0.150 / <0.014	66
Bromacil	31 / 0	30 / 1	0.035	<0.035 / <0.035	0.120 / <0.035	69
Bromoxynil	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	67
Carbaryl	31 / 0	30 / 0	0.008	<0.008 / <0.008	<0.008 / <0.008	74
Carbofuran	31 / 0	30 / 0	0.028	<0.028 / <0.028	<0.028 / <0.028	71
Carbofuran, 3-hydroxy-	31 / 0	30 / 0	0.014	<0.014 / <0.014	<0.014 / <0.014	70
Chloramben	31 / 0	30 / 0	0.011	<0.011 / <0.011	<0.011 / <0.011	na
Chlorothalonil	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	45
Clopyralid	31 / 0	30 / 0	0.05	<0.05 / <0.05	<0.05 / <0.05	32
Dacthal, mono-acid-	30 / 0	30 / 0	0.017	<0.017 / <0.017	<0.017 / <0.017	133
Dicamba	30 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	71
Dichlobenil	31 / 0	30 / 0	0.020	<0.020 / <0.020	<0.020 / <0.020	42
Dichlorprop	31 / 0	30 / 0	0.032	<0.032 / <0.032	<0.032 / <0.032	66
Dinoseb	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	67
Diuron	31 / 0	30 / 0	0.020	<0.020 / <0.020	<0.020 / <0.020	72
DNOC	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	49
Esfenvalerate	31 / 0	30 / 0	0.019	<0.019 / <0.019	<0.019 / <0.019	22
Fenuron	31 / 0	30 / 0	0.013	<0.013 / <0.013	<0.013 / <0.013	71
Fluometuron	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	78
Linuron	31 / 0	30 / 0	0.018	<0.018 / <0.018	<0.018 / <0.018	71
MCPA	31 / 0	30 / 0	0.05	<0.05 / <0.05	<0.05 / <0.05	85
MCPB	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	54
Methiocarb	31 / 0	30 / 0	0.026	<0.026 / <0.026	<0.026 / <0.026	69
Methomyl	31 / 0	30 / 0	0.017	<0.017 / <0.017	<0.017 / <0.017	75

Table A1. Statistical summary of selected ground-water quality data from land-use wells in the Eastern Iowa Basins study unit—Continued

[Ag, agricultural land use area; Ur, urban land use area; MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na; not applicable; mg/L, milligrams per liter; μ S/cm, microsiemens per centimeter; °C, degrees Celsius; <, less than; pCi/L, picocuries per liter; μ g/L, micrograms per liter; NWQL, U.S. Geological Survey National Water Quality Laboratory]

Constituent or property	Samples/detections Ag wells	Samples/detections Ur wells	MRL or MDL	Maximum/median Ag wells	Maximum/median Ur wells	Spike recovery (percent)
Pesticides (NWQL schedule 2050), dissolved (μg/L)—Continued						
1-Naphthol	31 / 0	30 / 0	0.007	<0.007 / <0.007	<0.007 / <0.007	0
Neburon	31 / 0	30 / 0	0.015	<0.015 / <0.015	<0.015 / <0.015	68
Norflurazon	31 / 0	30 / 0	0.024	<0.024 / <0.024	<0.024 / <0.024	72
Oryzalin	31 / 0	30 / 0	0.019	<0.019 / <0.019	<0.019 / <0.019	54
Oxamyl	31 / 0	30 / 0	0.018	<0.018 / <0.018	<0.018 / <0.018	63
Picloram	31 / 1	30 / 0	0.05	0.83 / <0.05	<0.05 / <0.05	124
Propham	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	84
Propoxur	31 / 0	30 / 0	0.035	<0.035 / <0.035	<0.035 / <0.035	94
Silvex	31 / 0	30 / 0	0.021	<0.021 / <0.021	<0.021 / <0.021	65
Triclopyr	31 / 0	30 / 0	0.05	<0.05 / <0.05	<0.05 / <0.05	69
Volatile organic compounds, total (μg/L)						
1,1,1,2-Tetrachloroethane	31 / 0	30 / 0	0.044	<0.044 / <0.044	<0.044 / <0.044	na
1,1,1-Trichloroethane	31 / 0	30 / 2	0.032	<0.032 / <0.032	0.134 / <0.032	93
1,1,2,2-Tetrachloroethane	31 / 0	30 / 0	0.132	<0.132 / <0.132	<0.132 / <0.132	na
1,1,2-Trichloroethane	31 / 0	30 / 0	0.064	<0.064 / <0.064	<0.064 / <0.064	na
1,1,2-Trichloro-1,2,2-trifluoroethane	31 / 0	30 / 0	0.032	<0.032 / <0.032	<0.032 / <0.032	na
1,1-Dichloroethane	31 / 0	30 / 3	0.066	<0.066 / <0.066	0.364 / <0.066	na
1,1-Dichloroethene	31 / 0	30 / 1	0.044	<0.044 / <0.044	0.256 / <0.044	78
1,1-Dichloropropene	31 / 0	30 / 0	0.026	<0.026 / <0.026	<0.026 / <0.026	na
1,2,3,4-Tetramethylbenzene	31 / 0	30 / 0	0.23	<0.23 / <0.23	<0.23 / <0.23	na
1,2,3,5-Tetramethylbenzene	31 / 0	30 / 1	0.24	<0.24 / <0.24	15 / <0.24	na
1,2,3-Trichlorobenzene	31 / 0	30 / 0	0.266	<0.266 / <0.266	<0.266 / <0.266	na
1,2,3-Trichloropropane	31 / 0	30 / 1	0.070	<0.070 / <0.070	0.207 / <0.070	na
1,2,3-Trimethylbenzene	31 / 0	30 / 2	0.124	<0.124 / <0.124	0.242 / <0.124	na
1,2,4-Trichlorobenzene	31 / 0	30 / 0	0.188	<0.188 / <0.188	<0.188 / <0.188	na
1,2,4-Trimethylbenzene	31 / 1	30 / 2	0.056	0.193 / <0.056	4.49 / <0.056	na
1,2-Dibromo-3-chloropropane	31 / 0	30 / 0	0.214	<0.214 / <0.214	<0.214 / <0.214	na
1,2-Dibromoethane	31 / 0	30 / 0	0.036	<0.036 / <0.036	<0.036 / <0.036	na
1,2-Dichlorobenzene	31 / 0	30 / 1	0.048	<0.048 / <0.048	0.749 / <0.048	na
1,2-Dichloroethane	31 / 0	30 / 3	0.134	<0.134 / <0.134	33.4 / <0.134	95
cis-1,2-Dichloroethene	31 / 0	30 / 4	0.038	<0.038 / <0.038	58.8 / <0.038	na
trans-1,2-Dichloroethene	31 / 0	30 / 1	0.032	<0.032 / <0.032	3.87 / <0.032	na
1,2-Dichloropropane	31 / 0	30 / 1	0.068	<0.068 / <0.068	0.416 / <0.068	na
cis-1,3-Dichloropropene	31 / 0	30 / 0	0.092	<0.092 / <0.092	<0.092 / <0.092	na
1,3,5-Trimethylbenzene	31 / 0	30 / 2	0.044	<0.044 / <0.044	9.48 / <0.044	na
1,3-Dichlorobenzene	31 / 0	30 / 0	0.054	<0.054 / <0.054	<0.054 / <0.054	na
1,3-Dichloropropane	31 / 0	30 / 0	0.116	<0.116 / <0.116	<0.116 / <0.116	na
trans-1,3-Dichloropropene	31 / 0	30 / 0	0.134	<0.134 / <0.134	<0.134 / <0.134	na
1,4-Dichlorobenzene	31 / 0	30 / 1	0.050	<0.050 / <0.050	0.166 / <0.050	83
trans-1,4-Dichloro-2-butene	31 / 0	30 / 0	0.692	<0.629 / <0.629	<0.629 / <0.629	na

Table A1. Statistical summary of selected ground-water quality data from land-use wells in the Eastern Iowa Basins study unit—Continued

[Ag, agricultural land use area; Ur, urban land use area; MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; μ S/cm, microsiemens per centimeter; °C, degrees Celsius; <, less than; pCi/L, picocuries per liter; μ g/L, micrograms per liter; NWQL, U.S. Geological Survey National Water Quality Laboratory]

Constituent or property	Samples/detections Ag wells	Samples/detections Ur wells	MRL or MDL	Maximum/median Ag wells	Maximum/median Ur wells	Spike recovery (percent)
Volatile organic compounds, total (μg/L)—Continued						
2,2-Dichloropropane	31 / 0	30 / 0	0.078	<0.078 / <0.078	<0.078 / <0.078	na
2-Butanone	31 / 0	30 / 2	1.65	<1.65 / <1.65	47.4 / <1.65	na
2-Chlorotoluene	31 / 0	30 / 0	0.042	<0.042 / <0.042	<0.042 / <0.042	na
2-Hexanone	31 / 0	30 / 0	0.746	<0.746 / <0.746	<0.746 / <0.746	na
3-Chloropropene	31 / 0	30 / 0	0.196	<0.196 / <0.196	<0.196 / <0.196	na
4-Chlorotoluene	31 / 0	30 / 0	0.056	<0.056 / <0.056	<0.056 / <0.056	na
1-Isopropyl-4-methylbenzene	31 / 0	30 / 0	0.110	<0.110 / <0.110	<0.110 / <0.110	na
4-Methyl-2-pentanone	31 / 0	30 / 0	0.374	<0.374 / <0.374	<0.374 / <0.374	na
Acetone	31 / 0	30 / 1	4.9	<4.9 / <4.9	20.0 / <4.9	na
Acrolein	31 / 0	30 / 0	1.432	<1.432 / <1.432	<1.432 / <1.432	na
Acrylonitrile	31 / 0	30 / 0	1.226	<1.226 / <1.226	<1.226 / <1.226	na
tert-Amyl methyl ether	31 / 0	30 / 1	0.112	<0.112 / <0.112	0.158 / <0.112	na
Benzene	31 / 0	30 / 2	0.032	<0.032 / <0.032	230 / <0.032	na
Bromobenzene	31 / 0	30 / 0	0.036	<0.036 / <0.036	<0.036 / <0.036	na
n-Butylbenzene	31 / 0	30 / 1	0.186	<0.186 / <0.186	0.555 / <0.186	na
sec-Butylbenzene	31 / 0	30 / 1	0.048	<0.048 / <0.048	0.080 / <0.048	na
tert-Butylbenzene	31 / 0	30 / 0	0.096	<0.096 / <0.096	<0.096 / <0.096	na
Bromochloromethane	31 / 0	30 / 0	0.044	<0.044 / <0.044	<0.044 / <0.044	na
Bromodichloromethane	31 / 0	30 / 1	0.048	<0.048 / <0.048	0.611 / <0.048	99
Bromoform	31 / 0	30 / 0	0.104	<0.104 / <0.104	<0.104 / <0.104	81
Bromomethane	31 / 0	30 / 0	0.148	<0.148 / <0.148	<0.148 / <0.148	na
Bromoethene	31 / 0	30 / 0	0.100	<0.100 / <0.100	<0.100 / <0.100	na
Carbon disulfide	31 / 1	30 / 0	0.080	0.769 / <0.080	<0.080 / <0.080	na
Chlorobenzene	31 / 0	30 / 0	0.028	<0.028 / <0.028	<0.028 / <0.028	na
Chloroethane	31 / 0	31 / 1	0.120	<0.120 / <0.120	1.00 / <0.120	na
Chloroethene	31 / 0	30 / 2	0.112	<0.112 / <0.112	8.13 / <0.112	48
Chloroform	31 / 0	30 / 2	0.052	<0.052 / <0.052	15.8 / <0.052	na
Chloromethane	31 / 0	30 / 1	0.254	<0.254 / <0.254	0.400 / <0.254	na
Dibromochloromethane	31 / 0	30 / 0	0.182	<0.182 / <0.182	<0.182 / <0.182	92
Dibromomethane	31 / 0	30 / 0	0.05	<0.05 / <0.05	<0.05 / <0.05	na
Dichlorodifluoromethane	31 / 0	30 / 0	0.096	<0.096 / <0.096	<0.096 / <0.096	na
Dichloromethane	31 / 1	30 / 0	0.382	25.8 / <0.382	<0.382 / <0.382	na
Diethyl ether	31 / 0	30 / 0	0.170	<0.170 / <0.170	<0.170 / <0.170	na
Diisopropyl ether	31 / 0	30 / 2	0.098	<0.098 / <0.098	2.50 / <0.098	na
Ethyl methacrylate	31 / 0	30 / 0	0.278	<0.278 / <0.278	<0.278 / <0.278	na
Ethyl tert-butyl ether	31 / 0	30 / 1	0.054	<0.054 / <0.054	0.188 / <0.054	na
Ethylbenzene	31 / 0	30 / 1	0.030	<0.030 / <0.030	3.58 / <0.030	94
Hexachlorobutadiene	31 / 0	30 / 0	0.142	<0.142 / <0.142	<0.142 / <0.142	na

Table A1. Statistical summary of selected ground-water quality data from land-use wells in the Eastern Iowa Basins study unit—Continued

[Ag, agricultural land use area; Ur, urban land use area; MRL, minimum reporting level; MDL, method detection limit for pesticides and pesticide metabolites; na, not applicable; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter; $^{\circ}\text{C}$, degrees Celsius; <, less than; pCi/L, picocuries per liter; $\mu\text{g}/\text{L}$, micrograms per liter; NWQL, U.S. Geological Survey National Water Quality Laboratory]

Constituent or property	Samples/detections Ag wells	Samples/detections Ur wells	MRL or MDL	Maximum/median Ag wells	Maximum/median Ur wells	Spike recovery (percent)
Volatile organic compounds, total ($\mu\text{g}/\text{L}$)—Continued						
Hexachloroethane	31 / 0	30 / 0	0.362	<0.362 / <0.362	<0.362 / <0.362	na
Isopropylbenzene	31 / 0	30 / 1	0.032	<0.032 / <0.032	0.371 / <0.032	na
Methyl acrylate	31 / 0	30 / 0	0.612	<0.612 / <0.612	<0.612 / <0.612	na
Methyl acrylonitrile	31 / 0	30 / 0	0.57	<0.57 / <0.57	<0.57 / <0.57	na
Methyl iodide	31 / 0	30 / 2	0.076	<0.076 / <0.076	0.60 / <0.076	na
Methyl methacrylate	31 / 0	30 / 0	0.350	<0.350 / <0.350	<0.350 / <0.350	na
Methyl tert-butyl ether	31 / 0	30 / 7	0.112	<0.112 / <0.112	100 / <0.112	86
Naphthalene	31 / 0	30 / 0	0.25	<0.25 / <0.25	<0.25 / <0.25	na
n-Propylbenzene	31 / 0	30 / 0	0.042	<0.042 / <0.042	<0.042 / <0.042	na
Styrene	31 / 0	30 / 0	0.042	<0.042 / <0.042	<0.042 / <0.042	na
Tetrachloroethene	31 / 0	30 / 2	0.038	<0.038 / <0.038	2.78 / <0.038	93
Tetrachloromethane	31 / 0	30 / 0	0.088	<0.088 / <0.088	<0.088 / <0.088	91
Tetrahydrofuran	31 / 0	30 / 0	1.148	<1.148 / <1.148	<1.148 / <1.148	na
Toluene	31 / 0	30 / 2	0.038	<0.038 / <0.038	12.1 / <0.038	na
o-Ethyl toluene	31 / 0	30 / 2	0.100	<0.100 / <0.100	<0.100 / <0.100	na
Trichloroethene	31 / 0	30 / 4	0.038	<0.038 / <0.038	0.946 / <0.038	95
Trichlorofluoromethane	31 / 0	30 / 0	0.092	<0.092 / <0.092	<0.092 / <0.092	na
m- and p-Xylene	31 / 0	30 / 2	0.064	<0.064 / <0.064	12.1 / <0.064	na
o-Xylene	31 / 0	30 / 2	0.064	<0.064 / <0.064	2.13 / <0.064	na

