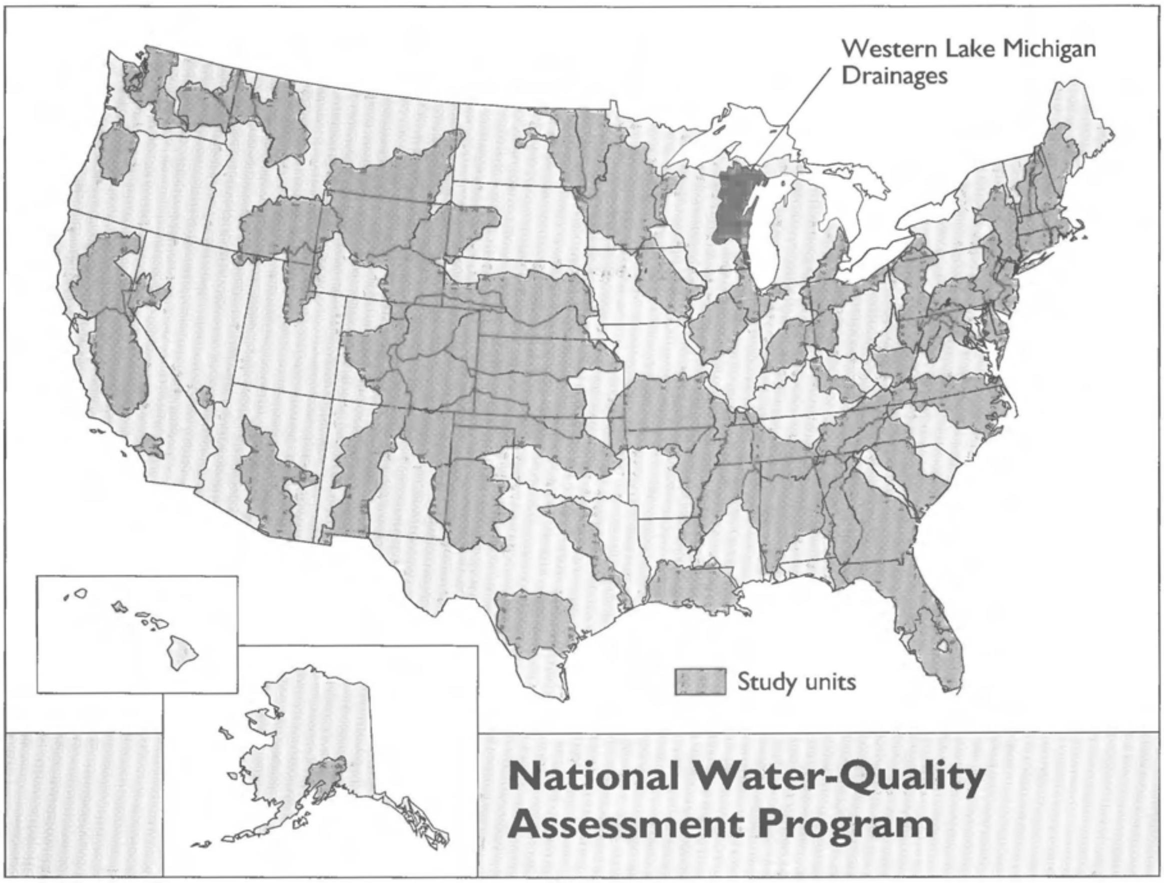
U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96-4292

Effects of Land Use and Geohydrology on the Quality of Shallow Ground Water in Two Agricultural Areas in the Western Lake Michigan Drainages, Wisconsin



National Water-Quality Assessment Program

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

EFFECTS OF LAND USE AND GEOHYDROLOGY ON THE QUALITY OF SHALLOW GROUND WATER IN TWO AGRICULTURAL AREAS IN THE WESTERN LAKE MICHIGAN DRAINAGES, WISCONSIN

By David A. Saad

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Madison, Wisconsin
1997

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FOREWORD

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

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

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

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

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

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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

Multiply	By	To Obtain
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
pound (lb)	453,600	milligram
gallon (gal)	3.79	liter
pounds per acre (lb/acre)	1.12	kilograms per hectare

Temperature, in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = [1.8(°C)] + 32.$$

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 and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L), micrograms per liter (µg/L), or picograms per kilogram (pg/kg). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. One thousand micrograms per liter is equivalent to one milligram per liter. Picograms per kilogram is a unit expressing the concentration of chemical constituents in solution as weight (picograms) of solute per unit mass (kilogram) of water.

Radioactivity is expressed in picocuries per liter (pCi/L). A picocurie is the amount of radioactivity that yields 2.22 radioactive disintegrations per minute.

MISCELLANEOUS ABBREVIATIONS

DOC	Dissolved organic carbon
CFCs	Chlorofluorocarbons
ES	Enforcement Standard
GIS	Geographic information system
K	Hydraulic conductivity
MDL	Laboratory Method Detection Limit
MCL	Maximum Contaminant Level
NAWQA	National Water-Quality Assessment
as N	as quantified as measured nitrogen
as P	as quantified as measured phosphorus
PAL	Preventive Action Limit
PMCL	Proposed Maximum Contaminant Level
RHU	Relatively Homogeneous Unit
SMCL	Secondary Maximum Contaminant Level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOCs	Volatile organic compounds

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Effects of Land Use and Geohydrology on the Quality of Shallow Ground Water in Two Agricultural Areas in the Western Lake Michigan Drainages, Wisconsin

By David A. Saad

Abstract

Water-quality and geohydrologic data were collected between September, 1993 and September 1994, from 56 wells and 2 springs, in two agricultural areas in the Western Lake Michigan Drainages study unit of the National-Water Quality Assessment Program. These data were used to study the effects of land use and geohydrology on shallow ground-water quality. Water samples from each well and spring were analyzed for major ions, nutrients, dissolved organic carbon, pesticides, volatile organic compounds, oxygen and hydrogen isotopes, and uranium; measurements of temperature, pH, specific conductance, and dissolved oxygen were made in the field. Ground-water samples were also analyzed for tritium or chlorofluorocarbons, or both, to estimate the recharge date of the ground water. Slug tests were performed on most of the wells to estimate the hydraulic conductivity of the surficial deposits in the vicinity of the well.

The two areas chosen for study had similar agricultural land uses but different geohydrologic characteristics. Sampled monitor wells and springs were located down gradient from farm fields having similar crop rotation patterns, mainly corn and alfalfa. Area 1 is characterized by sand and clay surficial deposits overlying carbonate bedrock, and area 2 is characterized by sand and gravel surficial deposits overlying sandstone or crystalline bedrock. The depth to water was significantly deeper and the hydraulic conductivity of the surficial deposits was significantly higher in area 2.

Water-quality analyses indicate that agricultural land use has affected the ground-water quality of both of the study areas, however, Wisconsin ground-water-quality enforcement standards were exceeded in only 22 percent (13 of 58) of samples for dissolved nitrate and 2 percent (1 of 58) of samples for dissolved atrazine plus deethyl atrazine. There was a significant difference between the two areas in the concentrations of dissolved nitrate and atrazine plus deethyl atrazine in the shallow ground water. Although the amount of nitrogen fertilizer and manure applied to the land surface was similar or slightly higher in area 2, as compared to area 1, and atrazine application rates may have been slightly higher in area 1, area 2 had significantly higher concentrations of both dissolved nitrate and atrazine plus deethyl atrazine in shallow ground water. The areal difference in nitrate and atrazine concentrations was likely due to the relatively higher permeability and lower organic matter content of the surficial deposits in area 2. The more permeable surficial deposits in area 2 allowed nitrate and atrazine (and its metabolites) to readily move from the land surface to ground water. Additionally, the lower organic matter content in area 2 helped to maintain higher dissolved oxygen concentrations in recharging water and throughout the saturated zone, thus reducing the possibility of denitrification or assimilative uptake.

Estimated recharge dates showed that historic patterns of atrazine plus deethyl atrazine concentrations in ground water mimic historic patterns of atrazine use on corn. Concentrations in ground water that recharged prior to the early 1960s, when atrazine started to become widely used on corn in Wisconsin, were very low or not detectable. As atrazine use on corn steadily increased from the late 1960s to the late 1970s and early 1980s, detectable concentrations of atrazine plus deethyl atrazine in ground water became more common. The recharge dates of some of the

highest measured concentrations of atrazine plus deethyl atrazine in ground water from both study areas correspond to the period of highest atrazine use on corn in the State.

INTRODUCTION

Background

The Western Lake Michigan Drainages study unit of the National Water-Quality Assessment (NAWQA) Program encompasses an area of about 19,900 mi^2 in eastern Wisconsin and central Upper Michigan (fig. 1). Collection and analysis of ground-water data in the study unit began in 1993. The NAWQA design for examining ground-water quality includes flowpath studies, land-use studies, and study-unit surveys (Gilliom and others, 1995). Flowpath studies are designed to be small in scale, typically covering an area of several square miles or smaller, and are designed to examine ground-water quality along inferred flowpaths and interactions of ground water and surface water. Land-use studies are designed to examine natural and human factors that affect shallow ground-water quality in an area characterized by a specific land use, and typically cover an area ranging from several hundred to several thousand square miles. Study-unit surveys are designed to provide a broad assessment of water-quality conditions in the major aquifers or defined hydrogeologic settings in a study unit. and typically cover an area ranging from several thousand to tens of thousands of square miles.

This report describes the results of two NAWQA land-use studies that are the first of several planned for the Western Lake Michigan Drainages. The information obtained from these studies may be used locally for assessing the quality of shallow ground water in the land-use study areas. This information may also be useful for understanding the differences in water quality between land-use study areas within a NAWQA study unit or between NAWQA study units on a regional or national scale. Additionally, these studies will provide baseline data for evaluating long-term trends in the quality of shallow ground water in areas where it may be affected by land-use practices.

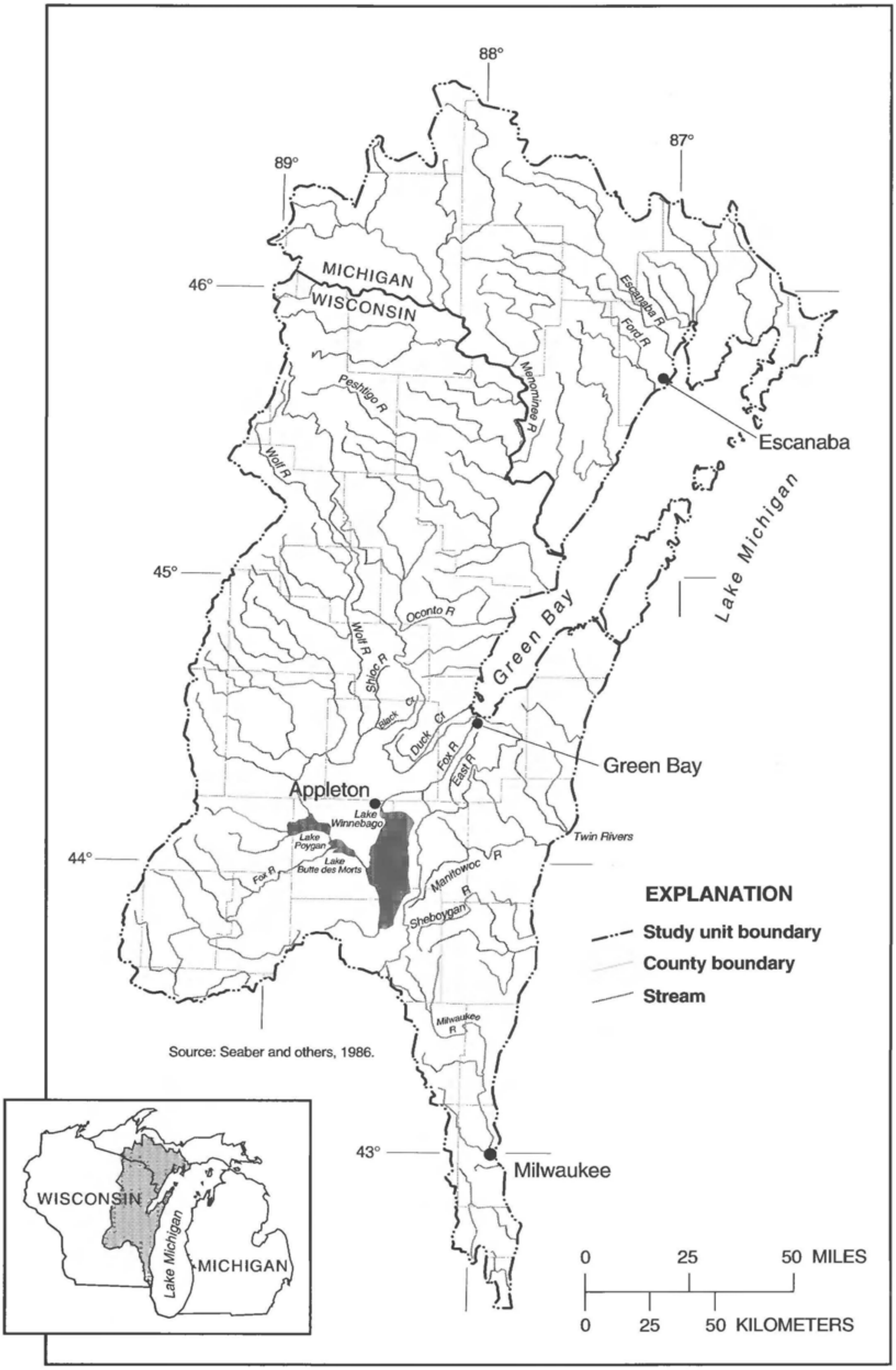
Purpose and Scope

This report describes land use and geohydrologic effects (mainly differences in texture of surficial deposits) on the quality of shallow ground water in two agricultural areas in the Western Lake Michigan Drainages NAWQA study unit (fig. 2). Land use, including nutrient and pesticide applications rates, is described using historical land use and land cover and application-rate information, and the results of a questionnaire sent to land owners who participated in the land-use studies. Geohydrologic information is based on available reports and maps, as well as information, such as lithology and hydraulic conductivity, that was obtained from 56 monitor wells installed in the two study areas. Ground-water-quality samples were collected between September, 1993 and September, 1994, from the 56 monitor wells and two springs (fig. 3). The source of the sampled ground water is described using hydrogen and oxygen isotopes, and the age of the sampled water was estimated from tritium and chlorofluorocarbons (CFCs). The water-quality description includes major ions, nutrients, dissolved organic carbon (DOC), 85 pesticides and soil metabolites, 60 volatile organics compounds (VOCs), and uranium, as well as field measurements of temperature, pH, specific conductance, and dissolved oxygen.

Description of Study Areas

The two agricultural areas described in this report are located in the southeastern (area 1) and western (area 2) parts of the Western Lake Michigan Drainages NAWQA study unit (fig. 2). This NAWQA study unit was subdivided into 28 relatively homogeneous units (RHUs) based on three environmental factors: land use, texture of surficial deposits, and bedrock type (Robertson and Saad, 1995). Three of the RHUs were chosen to represent the two land-use study areas (fig. 2).

Area 1 covers approximately 1,370 mi^2 and comprises all of RHU 3. Area 1 includes parts of Calumet, Columbia, Fond du Lac, Green Lake, Manitowoc, Ozaukee, Sheboygan, Washington, and Winnebago Counties, in southeastern Wisconsin. Agriculture is the main land use and sand and clay surficial deposits are underlain by carbonate bedrock in this area. The topography of area 1 is characterized by plains and rolling hills and land-surface elevations range from about 780 to 1,180



Source: Seaber and others, 1986.

Figure 1. Western Lake Michigan Drainages study unit of the National Water-Quality Assessment Program.

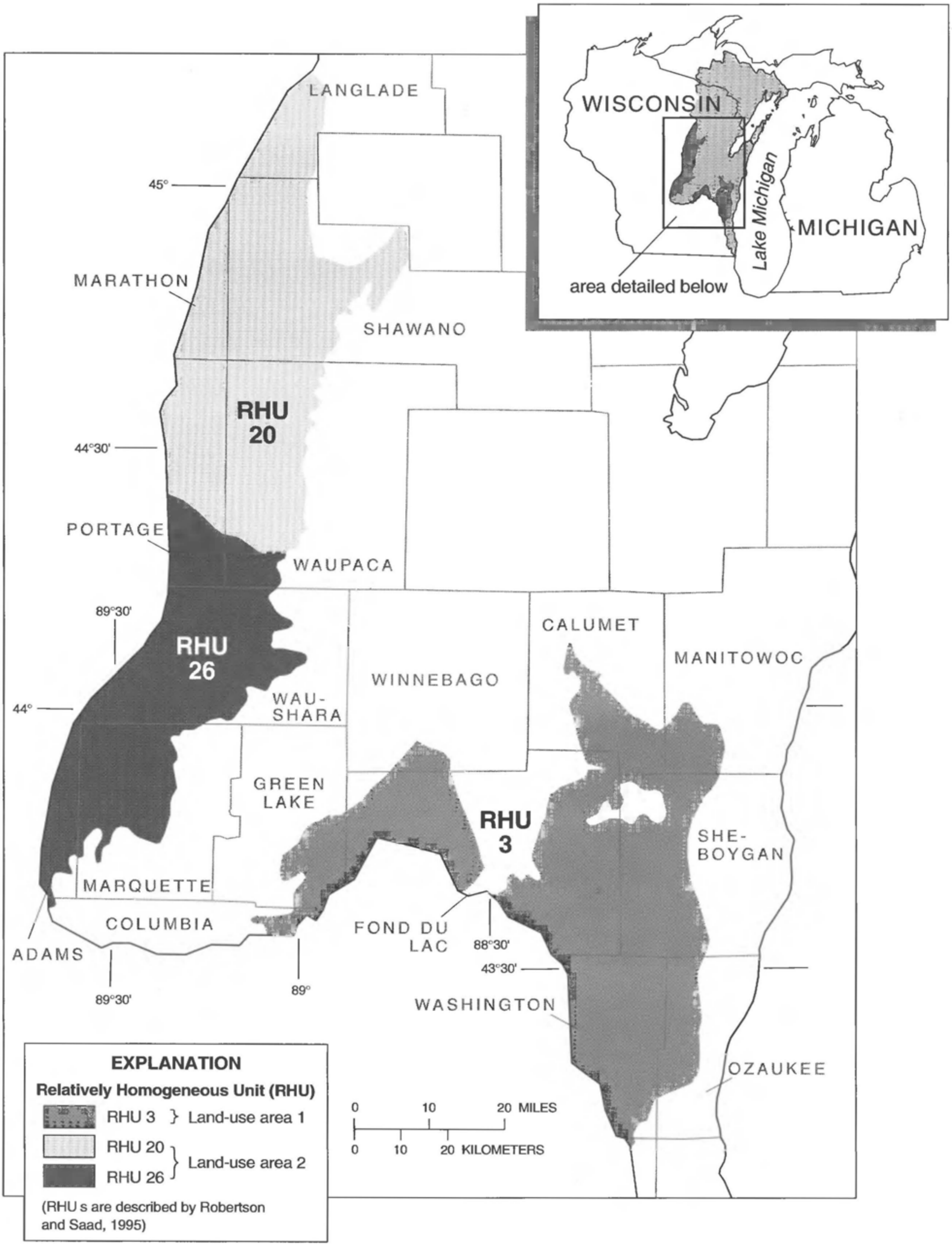


Figure 2. Location of land-use study areas and Relatively Homogeneous Units (RHUs) in the Western Lake Michigan Drainages.

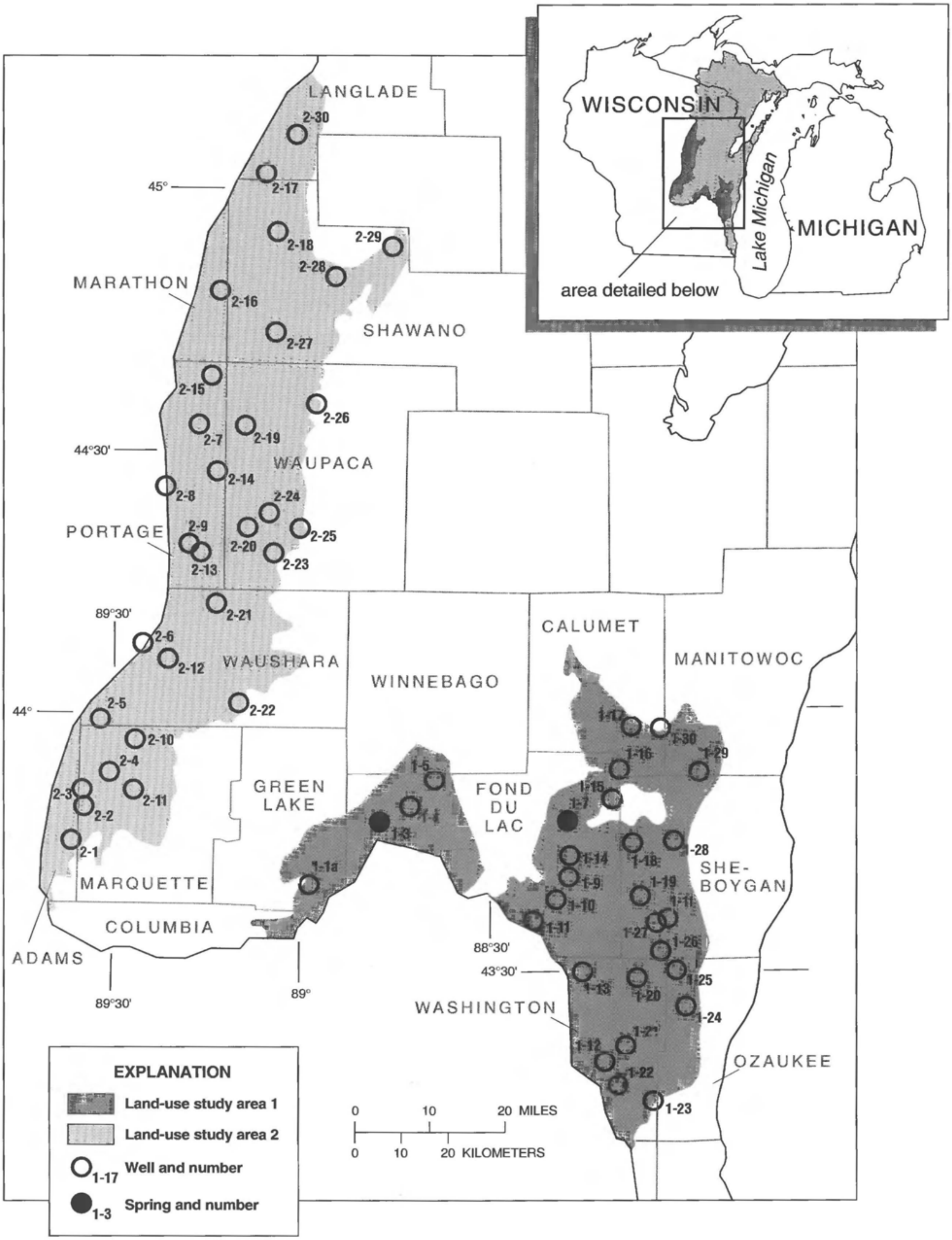


Figure 3. Location of sampled wells and springs in the study areas.

ft above mean sea level. Depth to the water table was generally 5 to 15 ft based on measured water levels.

Area 2 covers approximately 1,690 mi^2 and is composed of two RHUs, RHUs 20 and 26. The two areas were combined to create a single study area closer to the size of area 1 and includes parts of Adams, Langlade, Marathon, Marquette, Portage, Shawano, Waupaca, and Waushara Counties, in central Wisconsin. Agriculture and forest were the main land uses and sand and gravel surficial deposits are underlain by sandstone or crystalline bedrock in this area. Plains and morainal ridges characterize the topography of this area, where land-surface elevations range from about 820 to 1,580 ft above mean sea level. Based on measured water levels, depth to the water table was generally 10 to 35 ft.

Land Use

Detailed land use and land-cover information, which will be referred to as land use, for the two study areas (fig. 4) was obtained from high-altitude aerial photographs collected by the USGS between 1971 and 1981 (Feagus and others, 1983). Land use was interpreted manually from the photographs on the basis of the land-use classification system of Anderson and others (1976). Agricultural land use covers the largest percentage of both areas; 80 percent in area 1, and 48 percent in area 2. In area 1, agricultural land use is primarily cropland associated with dairy farming. In area 2, cropland associated with dairy farming and vegetable production are the main types of agriculture. Agricultural land use in area 2 also includes some christmas tree farming which is suited to the well-drained soils there. In area 1, other land uses include forest (10 percent), wetland (6 percent), urban (3 percent) and water (1 percent). In area 2, forest is the second largest land use (41 percent), followed by wetland (9 percent), water (1 percent), and urban (1 percent).

Although the effects of agricultural land use on shallow ground water is a major focus, this report does not attempt to evaluate the effects of varying percentages or different kinds of agricultural land use in the two study areas. Despite the large difference in percentage of agricultural land use between the two areas, the actual sampling sites were chosen so that the land use immediately upgradient from the sites were as similar as possible in the two study areas. This allowed different geohydrologic factors, and their effects on shallow ground-water quality, to be evaluated. The process of site selection and a detailed comparison of land uses in the study areas is discussed later in this report.

Geohydrology

In both areas, most ground water moves along relatively short flow paths, through local flow systems, that are generally less than 6 miles from recharge areas to discharge areas (Young and Batten, 1980), such as streams, lakes, wetlands, or pumped wells. The local flow systems include shallow ground water, which in this report refers to ground water at or near the water table. The water table in both study areas, based on measured water levels, was generally less than 35 ft below land surface and was typically within the surficial deposits.

In area 1, surficial deposits are largely till and have been described as sandy [(Richmond and Fullerton, 1983), (fig. 5)]. However, analysis of drill cuttings from monitoring wells installed for this study showed that the unconsolidated deposits in the area also often included large amounts of clay and clayey sand. The surficial deposits in area 1 are up to several hundred feet thick in the eastern part of the study area (Newport, 1962), but are typically less then 100 ft thick in the west (Olcott, 1968). In area 1, the surficial deposits are often too thin or impermeable, or both, to be used as an aquifer, therefore, most of the ground water used in this area is supplied by bedrock aquifers. Immediately underlying the surficial deposits in this area is carbonate bedrock of Ordovician and Silurian age.

In area 2, the surficial deposits are remnants of glacial outwash and ice-contact deposits, and are generally described as sand or sand and gravel [(Richmond and Fullerton, 1983), (fig. 5)]. The deposits are generally 75 to 200 ft thick (Olcott, 1968) and, where they are saturated, they are the primary source of ground water used in the study area. Bedrock in area 2 typically does not produce adequate amounts of water. In the northern half of this study area (RHU 20 in fig. 2), surficial deposits are underlain by relatively impermeable Precambrian-aged igneous and metamorphic crystalline rocks. In the southern half of area 2 (RHU 26 in fig. 2), surficial deposits are immediately underlain by Cambrian-aged sandstone, which can be a good aquifer, but is relatively thin in much of this study area.

Recharge to the water table in both areas is mainly from precipitation and direct infiltration. The major recharge period for both areas is during late winter and spring during snowmelt; rain can produce a

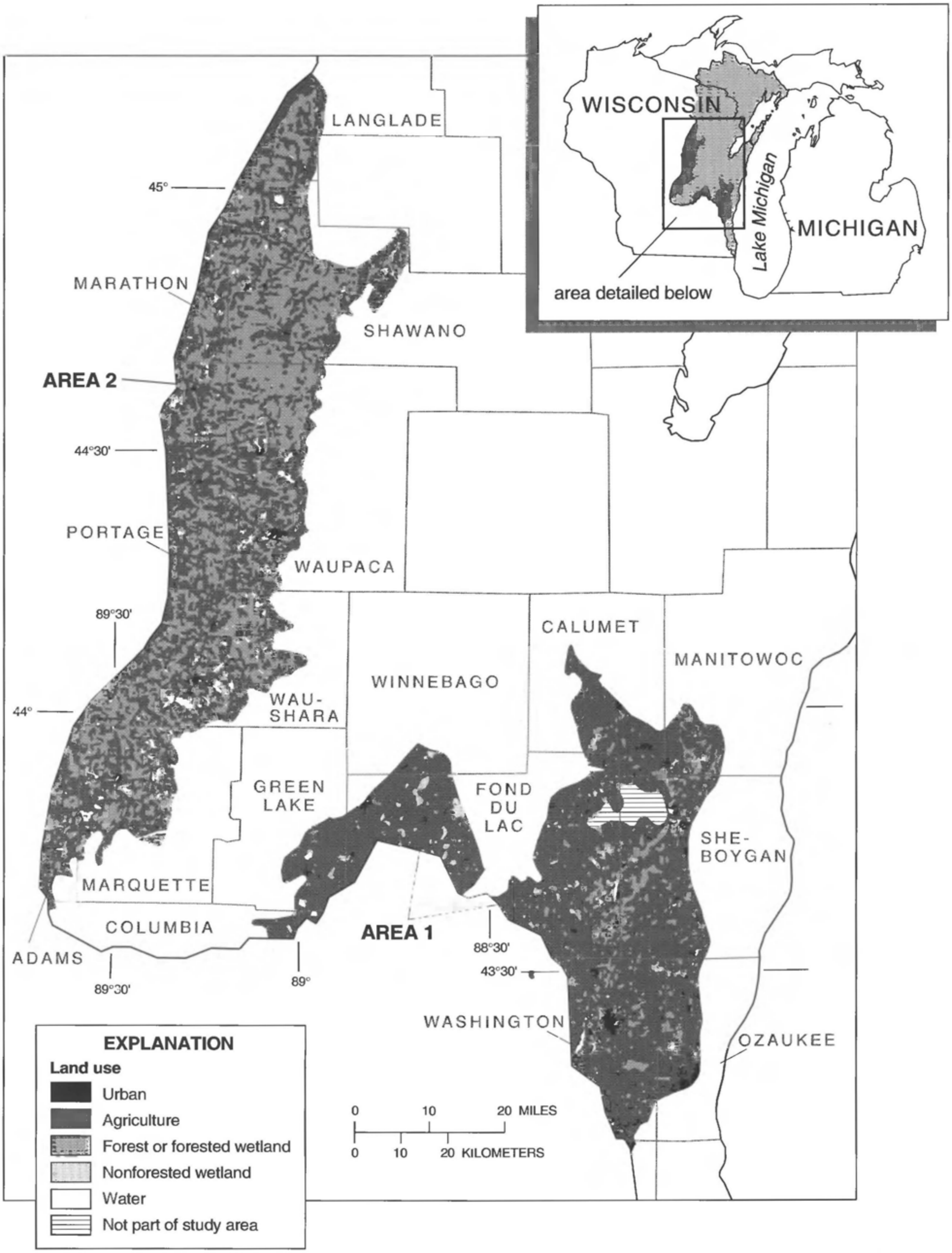


Figure 4. Distribution of land-use and land-cover categories in the study areas (from Feagus and others, 1983).

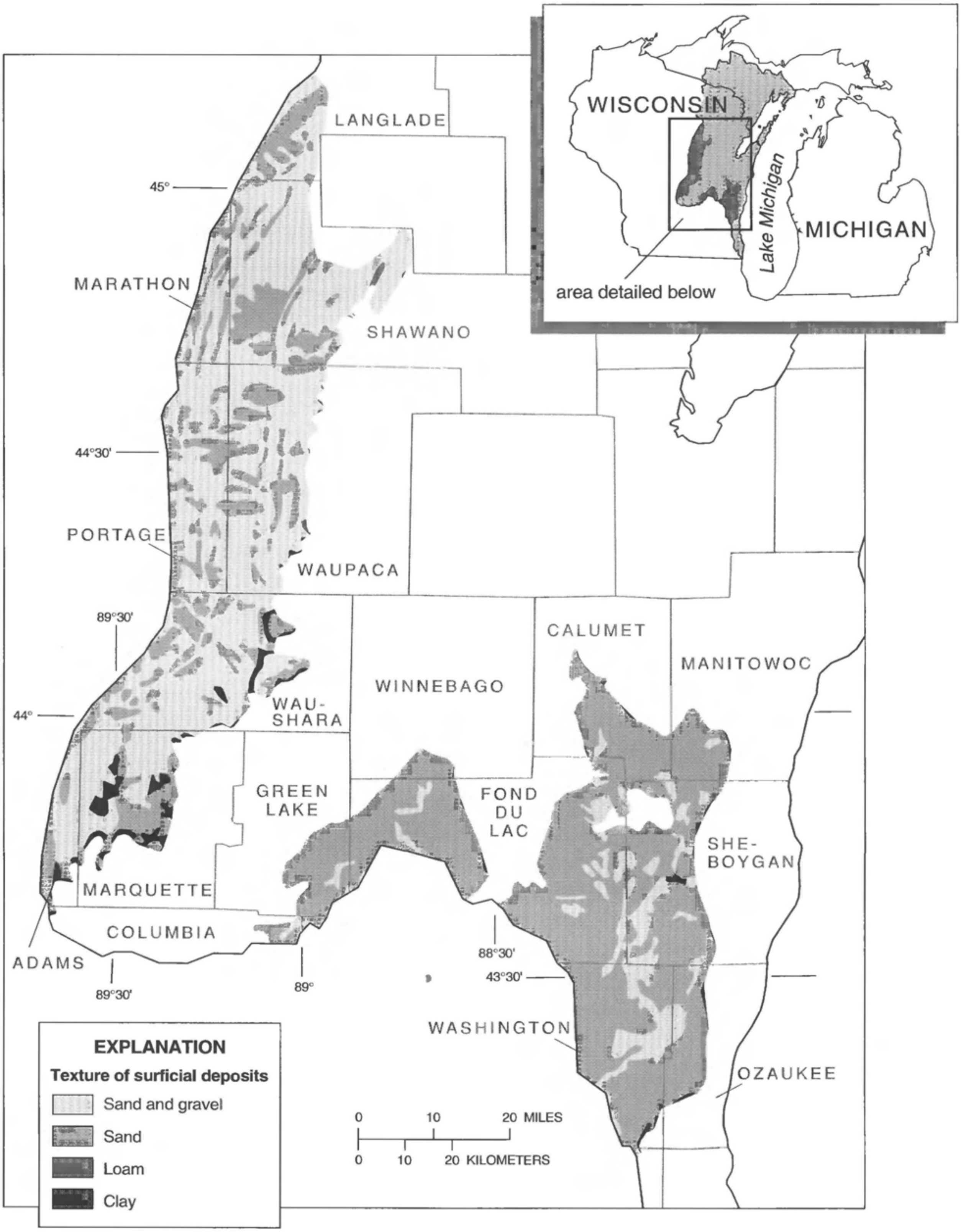


Figure 5. Texture of surficial deposits in the study areas (from Richmond and Fullerton, 1983).

minor recharge during fall (Berkstresser, 1964; Summers, 1965; Olcott, 1968; Skinner and Borman, 1973; Batten, 1987). Very little, if any, recharge reaches the water table during the summer growing season due to evapotranspiration (Berkstresser, 1964; Summers, 1965). Estimates of ground-water recharge in and around area 1 generally range from 1 to 10 in. per year, depending on the permeability of surficial deposits (Gonthier, 1975; Young and Batten, 1980; Conlon, 1995). Near area 2, where surficial deposits are coarse and relatively permeable, estimates of recharge generally range from 8 to 14 in. per year (Holt, 1965; Summers, 1965; Batten, 1987).

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The author wishes to thank the private landowners in the Western Lake Michigan Drainages study unit who allowed the USGS to install and sample wells on their property. The author also wishes to thank Gene Sorensen, Director of Public Works for the city of Waupaca, Wisconsin, for access to the city's monitoring wells, one of which was sampled for the study in area 2.

STUDY DESIGN AND METHODS

The land-use studies were designed to determine the effects of geohydrologic factors on the concentration and distribution of water-quality constituents in shallow ground water in two agricultural areas. Sampling sites were chosen using a stratified-random process. Most of the sampled wells were installed specifically for these studies in order to control sampling location and depth.

Site Selection Process

Thirty sampling sites in each area were chosen using a geographic information system (GIS)-based, stratified-random-selection computer program (Scott, 1990). Each study area was divided into 30 cells. Each cell contained equal amounts of agricultural land for that study area. A sampling site and several alternative sites were then randomly chosen in an agricultural part of each cell. The sampling sites were plotted on maps using the computer-generated latitude and longitude, and then the sites were located in the field. The nearest suitable drilling site, within approximately a 2-mile radius of the computer-generated site, was selected. If the first computer-selected site was not suitable, then one of the alternative sites within the cell was used. The chosen site had to meet several criteria before a well could be installed. The criteria included:

1. The selected site must have been immediately downgradient from fields used to grow corn and/or alfalfa. If point sources of contamination for nutrients, pesticides, or VOCs, were noticeable in the vicinity, the site was not selected,
2. The site must have been accessible to a drill rig,
3. The landowner must have given permission to the USGS to install and sample a well.

In area 2, site location and installation of 30 wells was easily accomplished. In area 1, 30 sites were found, but only 26 wells were sampled. Of the remaining four sites, two wells were not installed because the water table was at or below bedrock and two wells were installed but could not be sampled because the wells were dry at the time of sampling. At two of these sites nearby springs were sampled instead.

Installation, Development, and Description of Wells and Springs

All wells, except well 2-23, were installed by the USGS using protocols and procedures described by Lapham and others (1995). Holes were drilled into the first water-bearing zone using hollow-stem augers, and wells were constructed of 2-in. PVC screens and casings. Screens were generally 5 ft in length with 0.01-in. slots. Casing joints were flush threaded and joined without glue. The annular space around the screen was filled with clean, coarse, quartz sand to approximately 2 ft above the top of the screen. A bentonite seal was placed above the sandpack, and then the hole was backfilled with native material to the land surface. A cement seal was added around the casing at the land surface to prevent water from moving down the borehole. Well 2-23 was installed by the city of Waupaca, Wisconsin to monitor water quality near one of the city's public-supply wells. It was drilled using hollow-stem augers and constructed similar to the USGS-installed wells. The only differences in construction were a larger screen slot size, 0.03 in., and backfilling with bentonite instead of native materials.

Wells were developed with either a bailer or a submersible pump prior to sampling. Wells were developed until the water appeared relatively clear or until no further improvement in water clarity was apparent. Bailers were used on wells that were expected to produce small amounts of water, and the bailers were surged in and out of the water in an attempt to remove fine particles from the screened interval. Some wells never developed clear water, and were sampled at a low discharge rate to minimize disturbance in the well bore.

The wells ranged in depth from 11 to 58 ft in area 1 and from 10 to 128 ft in area 2 (table 1). Water levels were generally 5 to 15 ft below land surface in area 1, including one well with a water level approximately 1.5 ft above land surface. In area 2, water levels were generally 10 to 35, but was as much as 103 ft below land surface. The median and range of depth to the top of the screened interval below the measured water level was similar for both areas. The median was about 12 ft and the range was 0 to 54 ft in area 1. In area 2, the median was about 14 ft and the range was 0 to 49 ft.

The two springs sampled in area 1 are perennial and relatively small; both discharges were estimated to be less than 1 cubic foot per second. The crops within approximately a 1-mile radius of the spring, as noted during reconnaissance and sampling, were mostly corn and alfalfa.

Sample Collection

Water from wells and springs was sampled according to USGS ground-water sampling protocols (Koterba and others, 1995) using stainless steel, positive-displacement pumps with Teflon[1] discharge lines. Most wells were purged of at least three casing volumes and until field measurements of temperature, pH, specific conductance, and dissolved oxygen, taken at 5-minute intervals, stabilized. Water from springs was sampled by inserting a length of PVC casing in the submerged spring outlets and then sampling from the casing in the same manner as a well. Water samples were collected from springs when field measurements stabilized. In area 1, wells 1-5, 1-9, 1-11, and 1-13, recovered very slowly. These wells were purged dry, allowed to recover to above the top of the screen, purged dry again, and then allowed to recover enough to sample. Field measurements from these wells were recorded just prior to sample collection.

Water from wells and springs was sampled for major ions, nutrients, DOC, 85 pesticides and soil metabolites, 60 VOCs, oxygen and hydrogen isotopes, and uranium. Field measurements of temperature, pH, specific conductance, and dissolved oxygen were also collected. In addition, samples for tritium or CFCs, or both, were collected at all sites to estimate the recharge date of the ground water. CFCs were collected using equipment and procedures developed by Busenberg and Plummer (1992). Constituents (excluding CFCs) analyzed in ground-water samples, the number of samples in which each constituent was detected, and method detection limits (MDL) are in appendix 1. CFC information is in tables 1 and 2.

Water-Quality Analysis

Samples collected for these studies were analyzed by the USGS for inorganic and organic constituents using methods described in table 3. Field measurements of temperature, pH, specific conductance, and dissolved oxygen, were collected using a Hydrolab H20 which was calibrated daily.

Quality control included submitting blank, replicate, and spiked samples for analysis with ground-water samples. Quality-control samples include: (1) four field blanks for major ions, nutrients, DOC, pesticides, and VOCs, (2) four VOC trip blanks, (3) four replicate samples for major ions, nutrients, and DOC, (4) one replicate for pesticides, VOCs, uranium, deuterium/hydrogen ratio, $^{18}O/^{16}O$ ratio, and tritium, (5) four field-spiked pesticide samples, (6) four field-spiked VOC samples, and (7) one laboratory-spiked VOC sample. Additionally, recoveries for four pesticide surrogates and three VOC surrogates, which were added to all ground-water samples in the field, were evaluated.

Field blanks showed that field and laboratory protocols and recommended procedures did not contaminate ground-water samples for most constituents. However, several major ions and DOC were detected in field blanks from both study areas. Most of these detections were at lower concentrations than were present in ground-water samples. Constituents that were found at relatively high concentrations in field blanks (more than 2 percent of the lowest measured ground-water concentration) include DOC, which ranged from <0.1

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[1] Use of trade names is for identification purposes only and does not constitute an endorsement by the USGS.

to 1 mg/L (milligrams per liter); dissolved iron, which ranged from <3 to 8 µg/L (micrograms per liter); silica, which ranged from 0.03 to 2.4 mg/L; and sodium, which ranged from <0.2 to 0.6 mg/L. Only DOC and dissolved iron had blank concentrations that were above many of the concentrations measured in ground-water samples. For this reason, low concentrations of DOC and dissolved iron (in field blanks and ground-water samples) may be artifacts of field (sample-collection, processing, and shipping) or laboratory (processing and analysis) methods. Concentrations in ground-water samples were not adjusted for the measured blank concentrations.

Methyl chloride was detected in all four field blanks as wells as in most ground-water samples, and it is believed to have resulted from the preservation of the water sample with concentrated hydrochloric acid. Methylene chloride was detected at a low concentration (0.3 µg/L) in one field blank and toluene was detected at a low concentrations (0.3 and 0.5 µg/L) in two trip blanks. Methylene chloride was not detected in ground-water samples and toluene was only detected in samples associated with potential contamination from the PVC used to construct the wells. Toluene was detected in 15 of 58 ground-water samples and benzene was detected in 2 of 58 ground-water samples. These two VOCs were detected in samples from wells constructed of PVC that was cleaned by the manufacturer with a solution containing toluene and benzene. Where benzene, methyl chloride, and toluene were detected in ground-water samples, it is believed to be from sample contamination. For this reason these VOCs will not be discussed further in this report.

Analysis of replicate samples indicated that field and laboratory procedures had minimal effects on water-quality measurement variability. For area 1, measured concentrations from replicate samples were with 10 percent (calculated as the difference between the two measurements divided by the average of the two measurements) for all constituents except dissolved ammonium, dissolved orthophosphate, and dissolved fluoride. For area 2, they were within 10 percent for all constituents except dissolved ammonium, dissolved bromide, dissolved organic carbon, and dissolved potassium. In each case, where the percent difference was greater than 10 percent, the measured concentrations were near the detection limit for that constituent and the absolute range of the measured values were small.

Field-spiked samples, surrogate analysis, and one lab-spiked sample were used to determine the recovery of pesticide and VOC analytes in different ground-water matrices. Acceptable recovery ranges for pesticides are typically from 80 to 120 percent and for VOCs the acceptable range is about 70 to 130 percent. Recoveries of pesticides for four field spikes, for many of the analytes from schedules 2001 and 2010, ranged from 16 to 210 percent, and 0 to 132 percent for many of the analytes from schedules 2050 and 2051. The average recovery for the four field spikes ranged from 70 to 86 percent for the schedule 2001/2010 analytes, and from 42 to 55 percent for the schedule 2050/2051 analytes. Three of the four pesticide field-spiked samples were extracted in the field (schedules 2010 and 2051). The lab-extracted field spike (schedules 2001 and 2050) had the lowest average recovery (70 percent) for the schedule 2001/2010 analytes and the second highest average recovery (51 percent) for the schedule 2050/2051 analytes. All pesticide samples collected in 1993 were lab extracted, and those collected in 1994 were field extracted. Recoveries from field spikes, for pesticides that were also detected in ground-water samples, ranged from 16 to 107 percent. All pesticides or metabolites that were detected in ground-water samples were included as analytes in the schedule 2001/2010 pesticide-spike mixture. The average percent recoveries for those 12 pesticides or metabolites in the four field-spiked samples were as follows: 2,6'-diethylaniline (86 percent); atrazine (89 percent); deethyl atrazine (37 percent); carbofuran (61 percent); cyanazine (87 percent); DCPA (96 percent); p,p'-DDE (66 percent); metolachlor (97 percent); prometon (76 percent); simazine (85 percent); tebuthiuron (69 percent); and triallate (84 percent). The average recoveries for four pesticide surrogates (BDMC, diazinon-d_{10}, alpha HCH-d_6, and terbuthylazine) ranged from 49 to 98 percent for ground-water samples from area 1, and from 86 to 92 percent for samples from area 2. Four VOC field spikes had recoveries that ranged from 39 to 85 percent, and averaged between 51 and 63 percent recovery. Only one VOC, dichlorobromomethane, was detected in ground-water samples and also included in the field-spike mixture. Dichlorobromomethane averaged 59 percent recovery in the four VOC field-spiked samples. The average recoveries for three VOC surrogates (1-bromo-4-fluorobenzene, 1,2-dichloroethane-d_4, and toluene-d_8) ranged from 95 to 98 percent for ground-water samples from area 2. Surrogate recoveries were not reported for samples from area 1. One

Table 1. Location and characteristics of land-use study wells and springs

[deg, degree; min.minutes; sec, second; yyyy, year; mm, month; dd, day; na, not applicable; --, no data; SAND, sand; SDGL, sand and gravel; SGVC, sand, gravel, and clay; SDCL, sand and clay; CLAY, clay; >, younger than; <, older than]

Well number (study area)	USGS site identification number	Latitude and longitude (deg min sec)	Elevation, in feet above mean sea level	Well construction date (yyyymmdd)	Well depth, in feet below land surface	Water level, in feet below land surface[1]	Depth to top of screened interval, in feet below land surface	Length of screened interval, in feet	Lithology of surficial deposits[2]	Hydraulic conductivity (K), in feet per day[3]	CFC-based ground-water recharge date (corrected for lag time)[4]	Tritium-based ground-water recharge date
Well 1-1f (area 1)	433720088014901	43 37 20 88 01 49	970	19931129	44	15.43	34	10	SGVC	0.03	<1959.5	>1955
Well 1-1a (area 1)	434101088585501	43 41 01 88 58 55	915	19940719	47	36.60	42	5	SGVC	.2	1983.5	--
Spring 1-3 (area 1)	434818088474201	43 48 18 88 47 42	940	na	na	na	na	na	na	na	1988.0	--
Well 1-4 (area 1)	435000088425401	43 50 00 88 42 54	885	19930524	27	6.77	22	5	SGVC	1.3	--	>1955
Well 1-5 (area 1)	435302088390201	43 53 02 88 39 02	903	19931026	21	10.45	16	5	CLAY	.45	--	>1955
Spring 1-7 (area 1)	434834088174601	43 48 34 88 17 46	945	na	na	na	na	na	na	na	1982.5	--
Well 1-9 (area 1)	434206088173301	43 42 06 88 17 33	1,130	19931027	24	5.85	19	5	SDCL	.05	--	<1955
Well 1-10 (area 1)	433932088193501	43 39 32 88 19 35	1,030	19930924	23.5	15.43	18.5	5	SGVC	.44	1987.0	--
Well 1-11 (area 1)	433705088230701	43 37 05 88 23 07	1,010	19930923	23	10.81	18	5	SGVC	.05	--	>1955
Well 1-12 (area 1)	432053088114301	43 20 53 88 11 43	990	19930812	43	2.99	38	5	SDCL	.33	--	<1955
Well 1-13 (area 1)	433114088152001	43 31 14 88 15 20	1,045	19940106	15	9.20	10	5	SGVC	--	--	>1955
Well 1-14 (area 1)	434437088172501	43 44 37 88 17 25	1,055	19931028	24	12.24	19	5	SDCL	1.6	1983.5	--
Well 1-15 (area 1)	435101088104101	43 51 01 88 10 41	1,011	19931028	22	13.79	17	5	SDGL	54	1984.5	--
Well 1-16 (area 1)	435426088092601	43 54 26 88 09 26	1,010	19930527	22	5.10	17	5	SGVC	.06	--	>1955
Well 1-17 (area 1)	435923088073901	43 59 23 88 07 39	910	19930526	11	6.57	6	5	SGVC	9.2	--	>1955
Well 1-18 (area 1)	434603088072401	43 46 03 88 07 24	1,035	19930525	53	20.20	48	5	SAND	.68	--	<1955
Well 1-19 (area 1)	433959088061001	43 39 59 88 06 10	1,080	19931202	32	14.43	27	5	SGVC	.15	1975.0	--
Well 1-20 (area 1)	433031088063801	43 30 31 88 06 38	965	19940718	33	18.50	28	5	SDCL	.03	--	>1955
Well 1-21 (area 1)	432242088082401	43 22 42 88 08 24	940	19930813	58	-1.60	53	5	CLAY	1.2	--	<1955
Well 1-22 (area 1)	431812088094001	43 18 12 88 09 40	871	19930817	34	17.41	29	5	SGVC	.07	--	<1955

Table 1. Location and characteristics of land-use study wells and springs—Continued

Well number (study area)	USGS site identification number	Latitude and longitude (deg min sec)	Elevation, in feet above mean sea level	Well construction date (yyyymmdd)	Well depth, in feet below land surface	Water level, in feet below land surface[1]	Depth to top of screened interval, in feet below land surface	Length of screened interval, in feet	Lithology of surficial deposits[2]	Hydraulic conductivity (K), in feet per day[3]	CFC-based ground-water recharge date (corrected for lag time)[4]	Tritium-based ground-water recharge date
Well 1-23 (area 1)	431623088041001	43 16 23 88 04 10	905	19930816	24	13.96	19	5	SDCL	0.17	--	>1955
Well 1-24 (area 1)	432717087585601	43 27 17 87 58 56	870	19940718	38	35.90	33	5	SDCL	9.5	1980.5	--
Well 1-25 (area 1)	433126088002301	43 31 26 88 00 23	870	19930818	42	18.60	37	5	SGVC	.03	--	>1955
Well 1-26 (area 1)	433336088025901	43 33 36 88 02 59	805	19930817	28	1.71	23	5	SDCL	.55	--	<1955
Well 1-27 (area 1)	433653088033601	43 36 53 88 03 36	852	19930923	36	3.06	31	5	SDCL	21	1948.0	--
Well 1-28 (area 1)	434619088005401	43 46 19 88 00 54	915	19930526	43	16.30	38	5	SDCL	.68	--	>1955
Well 1-29 (area 1)	435411087565001	43 54 11 87 56 50	860	19930528	28	5.20	23	5	SGVC	2.7	--	>1955
Well 1-30 (area 1)	435910088025701	43 59 10 88 02 57	830	19930527	43.5	1.01	38.5	5	CLAY	.06	--	<1955
Well 2-1 (area 2)	434551089365001	43 45 51 89 36 50	915	19940719	54	33.75	49	5	SAND	27	1975.5	>1955
Well 2-2 (area 2)	434944089345001	43 49 44 89 34 50	959	19940720	73	36.39	68	5	SAND	95	1980.5	>1955
Well 2-3 (area 2)	435140089351301	43 51 40 89 35 13	942	19940720	23	6.20	18	5	SAND	83	1979.5	>1955
Well 2-4 (area 2)	435339089305001	43 53 39 89 30 50	897	19940720	44	18.40	39	5	SDCL	22	1981.0	>1955
Well 2-5 (area 2)	435946089323001	43 59 46 89 32 30	1,000	19940721	39	18.61	34	5	SAND	67	1994.5	>1955
Well 2-6 (area 2)	440827089255001	44 08 27 89 25 50	1,154	19940825	94	74.06	89	5	SAND	12	1983.0	>1955
Well 2-7 (area 2)	443342089171601	44 33 42 89 17 16	1,142	19940817	68	45.82	63	5	SDGL	89	1987.0	>1955
Well 2-8 (area 2)	442631089222901	44 26 31 89 22 29	1,135	19940818	59	23.50	54	5	SAND	53	1977.0	>1955
Well 2-9 (area 2)	441958089183601	44 19 58 89 18 36	1,128	19940823	81	60.84	76	5	SAND	140	1993.0	>1955
Well 2-10 (area 2)	435729089265401	43 57 29 89 26 54	910	19940721	84	29.97	79	5	SDGL	14	1991.0	>1955
Well 2-11 (area 2)	435142089270101	43 51 42 89 27 01	849	19940721	32	10.46	27	5	SDGL	.56	<1981.5	>1955

Table 1. Location and characteristics of land-use study wells and springs—Continued

Well number (study area)	USGS site identification number	Latitude and longitude (deg min sec)	Elevation, in feet above mean sea level	Well construction date (yyyymmdd)	Well depth, in feet below land surface	Water level, in feet below land surface[1]	Depth to top of screened interval, in feet below land surface	Length of screened interval, in feet	Lithology of surficial deposits[2]	Hydraulic conductivity (K), in feet per day[3]	CFC-based ground-water recharge date (corrected for lag time)[4]	Tritium-based ground-water recharge date
Well 2-12 (area 2)	440643089214501	44 06 43 89 21 45	1,091	19940831	128	103.25	123	5	SAND	--	1979.5	>1955
Well 2-13 (area 2)	441900089164501	44 19 00 89 16 45	1,080	19940824	62	59.48	57	5	SAND	160	1994.5	>1955
Well 2-14 (area 2)	442819089141301	44 28 19 89 14 13	1,080	19940817	94	70.14	89	5	SDGL	--	1972.0	>1955
Well 2-15 (area 2)	443921089152001	44 39 21 89 15 20	1,149	19940816	33	16.60	28	5	SDGL	85	1966.5	>1955
Well 2-16 (area 2)	444910089140401	44 49 10 89 14 04	1,215	19940714	23.5	9.69	18.5	5	SDCL	45	1984.0	>1955
Well 2-17 (area 2)	450242089065401	45 02 42 89 06 54	1,400	19940713	39	18.25	34	5	SAND	.34	1991.5	>1955
Well 2-18 (area 2)	445556089045701	44 55 56 89 04 57	1,235	19940713	10	5.97	5	5	SDGL	51	1973.5	>1955
Well 2-19 (area 2)	443339089095001	44 33 39 89 09 50	978	19940817	19	2.79	14	5	SDGL	25	1986.0	>1955
Well 2-20 (area 2)	442151089091301	44 21 51 89 09 13	931	19940822	43	20.45	38	5	SAND	--	1989.5	>1955
Well 2-21 (area 2)	441304089141101	44 13 04 89 14 11	1,010	19940824	62	53.92	57	5	SDGL	130	1982.5	>1955
Well 2-22 (area 2)	440149089102401	44 01 49 89 10 24	851	19940826	41	21.69	36	5	SDGL	31	1994.5	>1955
Well 2-23 (area 2)	441858089045901	44 18 58 89 04 59	842	19940316	22	18.41	17	5	SDGL	.67	--	<1955
Well 2-24 (area 2)	442333089055201	44 23 33 89 05 52	915	19940822	29	10.92	24	5	SAND	29	1985.5	>1955
Well 2-25 (area 2)	442154089005301	44 21 54 89 00 53	848	19940819	39	20.39	34	5	SDGL	.82	1988.0	>1955
Well 2-26 (area 2)	443610088582201	44 36 10 88 58 22	870	19940816	29.5	18.82	24.5	5	SAND	1.1	1980.0	>1955
Well 2-27 (area 2)	444423089050201	44 44 23 89 05 02	1,052	19940714	29	11.38	24	5	SGVC	.4	1986.0	>1955
Well 2-28 (area 2)	445052088552801	44 50 52 88 55 28	1,030	19940815	28	12.26	23	5	SDGL	25	1967.5	>1955
Well 2-29 (area 2)	445421088461801	44 54 21 88 46 18	998	19940714	22	10.47	17	5	SGVC	2	1990.0	>1955
Well 2-30 (area 2)	450709089020301	45 07 09 89 02 03	1,455	19940711	45	33.48	40	5	SAND	13	1988.5	>1955

[1] Date of water-level measurement is same as sample date show in appendix 2.

[2] Generalized description of surficial deposits in vicinity of sampled monitor well, based on drill cuttings.

[3] Based on slug tests analyzed by the Bouwer and Rice (1989) method.

[4] CFC data and lag times used to calculate recahrge dates are show in table 2. Recharge dates corrected for lag time are rounded to the nearest 0.5 years.

Table 2. Concentrations of dissolved CFC-11, CFC-12, and CFC-113 in ground-water samples, uncorrected recharge dates, and lag times of sampled wells in land-use study areas 1 and 2

[--, no data; °C, degrees Celsius; BP, barometric pressure; mm, millimeters of mercury; mn, month; dd, day; yy, year; CFC, chlorofluorocarbon; pg/kg, picogram per kilogram; pptv, parts per trillion; contam, contaminated]

Well number	Recharge[1]		Sample		Concentration in solution, in pg/kg			Calculated atmospheric partial pressure, in pptv			CFC recharge dates[2] (uncorrected for lag time)			Lag time[3]
	Temp (°C)	BP (mm)	Date (mn/dd/yy)	Time	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	
1-1f	7.5	733.4	06/16/94	1535	63.9	61.8	634.5	19.8	85.2	466.0	1963.0	1966.5	contam	0
				1540	33.6	30.0	24.5	10.4	41.4	18.0	1960.0	1961.0	1976.5	
				1600	18.1	23.0	10.1	5.6	31.7	7.4	1956.5	**(1959.5)**	1970.0	
1-1a	7.5	734.9	08/04/94	1125	594.3	312.1	454.5	184.0	429.4	333.1	1981.5	1987.0	contam	1.2
				1135	569.2	256.1	439.1	176.2	352.2	321.8	1980.5	**1982.5**	contam	
				1140	568.1	262.5	448.5	175.9	361.1	328.7	1980.5	1983.0	contam	
Spring 1-3	7.5	734.2	08/03/94	1545	622.1	334.7	55.4	192.8	460.8	40.6	1982.5	**1988.0**	1984.0	0
				1555	625.0	336.1	46.8	193.7	462.7	34.3	1982.5	1988.5	1983.0	
				1600	621.8	328.4	51.1	192.7	452.2	37.5	1982.5	1988.0	1983.5	
1-4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Spring 1-7	7.5	734.1	08/04/94	1515	256.3	252.4	36.2	79.4	347.6	26.6	1972.0	**1982.5**	1980.5	0
				1525	253.6	254.2	40.7	78.6	350.1	29.9	1972.0	1982.5	1981.5	
				1530	254.9	257.2	30.0	79.0	354.1	22.0	1972.0	1982.5	1978.5	
1-9	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-10	7.5	731.8	07/12/94	1205	650.3	313.6	221.5	202.2	433.2	163.0	1983.5	**1987.0**	contam	0
				1215	665.3	317.6	115.8	206.9	438.7	85.2	1984.0	1987.0	1993.0	
				1220	667.1	330.2	151.7	207.4	456.1	111.7	1984.5	1988.0	contam	
1-11	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-12	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-13	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-14	7.5	731.1	07/12/94	1715	451.5	252.5	44.4	140.5	349.1	32.7	1976.5	1982.5	1982.5	0
				1725	463.9	167.0	62.7	144.4	369.1	46.2	1977.0	**1983.5**	1985.0	
				1730	460.4	270.8	53.8	143.3	374.5	39.6	1977.0	1984.0	1984.0	
1-15	7.5	728.6	07/14/94	1115	633.7	276.6	609.	197.9	383.8	45.0	1983.0	**1984.5**	1985.0	0
				1125	629.6	274.4	49.3	196.6	380.6	36.5	1983.0	1984.5	1983.5	
				1130	625.2	276.9	52.1	195.2	384.1	38.5	1983.0	1984.5	1984.0	
1-16	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-17	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-18	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-19	7.5	730.4	08/02/94	1430	92.7	171.4	30.9	28.9	237.2	22.8	1965.5	1975.5	1979.0	0
				1445	85.7	159.3	33.0	26.7	220.5	24.3	1965.0	**1975.0**	1980.0	
				1450	86.6	139.1	26.9	27.0	192.6	19.8	1965.0	1973.5	1977.5	
1-20	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 2. Concentrations of dissolved CFC-11, CFC-12, and CFC-113 in ground-water samples, uncorrected recharge dates, and lag times of sampled wells in land-use study areas 1 and 2—Continued

Well number	Recharge[1]		Sample		Concentration in solution, in pg/kg			Calculated atmospheric partial pressure, in pptv			CFC recharge dates[2] (uncorrected for lag time)			Lag time[3]
	Temp (°C)	BP (mm)	Date (mn/dd/yy)	Time	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	
1-21	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-22	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-24	7.5	736.1	08/01/94	1620	405.4	218.5	28.7	125.3	300.1	21.0	1975.5	**1979.5**	1978.0	1.2
				1635	402.7	234.2	25.2	124.5	321.6	18.5	1975.5	1981.0	1976.5	
				1645	405.1	217.2	25.3	125.2	298.3	18.5	1975.5	1979.5	1976.5	
1-25	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-26	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-27	7.5	736.6	07/11/94	1630	035	3.7	18.4	0.2	5.1	13.5	1947.5	1948.5	1973.5	0
				1635	035	3.5	13.4	0.1	4.7	9.8	1947.5	**1948.0**	1971.5	
1-28	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-29	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-30	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-1	7.5	734.9	10/04/94	1230	362.8	153.4	19.6	112.3	210.9	14.4	1974.5	**1974.5**	1974.0	1.1
				1250	371.1	163.8	18.2	114.9	225.3	13.3	1974.5	1975.0	1973.5	
				1300	360.2	159.9	19.4	111.5	220.0	14.2	1974.5	1974.5	1974.0	
2-2	7.5	733.7	10/04/94	1505	511.7	218.4	24.2	158.7	301.0	17.7	1978.5	**1979.5**	1976.0	1.2
				1515	524.2	228.2	32.3	162.6	314.4	23.7	1979.0	1980.5	1979.5	
				1520	514.3	221.2	29.8	159.5	304.8	21.9	1978.5	1979.5	1978.5	
2-3	7.5	734.2	10/04/94	1645	485.9	217.3	71.4	150.6	299.3	52.4	1977.5	**1979.5**	1986.0	0
				1700	494.2	220.2	73.0	153.2	303.2	53.5	1978.0	1979.5	1986.0	
				1715	477.0	207.9	71.0	147.8	286.2	52.1	1977.5	1978.0	1986.0	
2-4	7.5	735.4	10/04/94	1025	431.7	231.7	33.7	142.8	318.5	24.7	1976.5	**1981.0**	1980.0	0
				1035	469.9	243.4	35.1	145.4	334.6	25.7	1977.0	1981.5	1980.5	
				1040	471.1	231.6	30.3	145.7	318.4	22.2	1977.0	1981.0	1978.5	
2-5	7.5	732.6	10/05/94	1235	762.5	402.2	98.2	236.8	554.9	72.2	1987.0	**1994.5**	1989.0	0
				1245	755.3	371.8	105.0	234.6	513.1	77.2	1986.5	1992.0	1989.0	
				1250	789.3	415.7	118.1	245.1	573.6	86.8	1987.5	1994.5	1994.5	
2-6	7.5	728.5	10/06/94	0900	607.6	261.8	51.4	189.8	363.3	38.0	1982.5	**1983.0**	1984.0	0
				0910	608.3	268.5	51.9	190.0	372.6	38.4	1982.5	1984.0	1984.0	
				0925	596.0	251.4	48.9	186.1	348.9	36.1	1982.0	1982.5	1983.5	
2-7	7.5	728.8	10/13/94	1655	679.8	311.9	50.9	212.2	432.6	37.6	1984.5	**1987.0**	1984.0	0
				1715	760.3	321.3	82.0	237.4	445.7	60.6	1987.0	1987.5	1987.0	
				1720	703.6	309.6	58.1	219.6	429.4	42.9	1985.5	1987.0	1984.5	

Table 2. Concentrations of dissolved CFC-11, CFC-12, and CFC-113 in ground-water samples, uncorrected recharge dates, and lag times of sampled wells in land-use study areas 1 and 2—Continued

Well number	Recharge[1]		Sample		Concentration in solution, in pg/kg			Calculated atmospheric partial pressure, in pptv			CFC recharge dates[2] (uncorrected for lag time)			Lag time[3]
	Temp (°C)	BP (mm)	Date (mn/dd/yy)	Time	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	
2-8	7.5	729	10/24/94	1230	424.8	198.8	47.3	132.6	275.6	35.0	1976.0	1977.5	1983.0	0
				1250	411.9	192.8	44.2	128.6	267.4	32.7	1975.5	**1977.0**	1982.5	
				1310	411.0	187.7	42.4	128.3	260.3	31.3	1975.5	1977.0	1982.0	
2-9	7.5	729.2	10/14/94	1130	637.0	269.2	56.7	198.8	373.2	41.9	1983.0	**1984.0**	1984.5	8.8
				1150	642.6	274.1	59.5	200.5	379.9	44.0	1983.5	1984.0	1984.5	
				1155	641.5	266.1	55.5	200.2	368.9	41.0	1983.5	1983.5	1984.5	
2-10	7.5	731.8	10/05/94	1510	726.1	296.7	65.8	225.7	409.9	48.4	1986.0	**1986.0**	1985.5	4.8
				1525	620.0	343.6	77.5	192.8	474.6	57.1	1982.5	1989.0	1986.5	
				1530	631.3	291.8	86.4	196.3	403.1	63.6	1983.0	1985.5	1987.5	
2-11	7.5	736.7	10/05/94	0820	167.8	236.4	23.5	51.8	324.4	17.2	1969.0	1981.0	1976.0	2.6
				0835	136.7	224.8	17.3	42.2	308.5	12.6	1967.5	1980.0	1973.0	
				0845	120.4	215.9	16.3	37.2	296.2	11.9	1967.0	**(1979.0)**	1972.5	
2-12	7.5	730.2	10/06/94	1145	541.8	504.5	35.9	168.8	698.5	26.5	**1979.5**	contam	1980.5	0
				1210	539.1	505.1	34.1	168.0	699.4	25.2	1979.5	contam	1980.0	
				1215	533.9	483.2	35.2	166.4	669.0	25.9	1979.5	contam	1980.5	
2-13	7.5	730.4	10/14/94	0855	788.8	404.3	127.7	245.7	559.5	94.2	1987.5	**1994.5**	contam	0[4]
				0910	779.3	427.9	131.8	242.7	592.2	97.2	1987.5	1994.5	contam	
2-14	7.5	730.4	10/24/94	1625	136.7	251.6	9.4	42.6	348.2	6.9	**1967.5**	1982.5	1970.0	4.5
				1635	130.2	194.8	9.3	40.6	269.5	6.9	1967.5	1977.5	1970.0	
				1650	144.8	177.5	8.8	45.1	245.6	6.5	1968.0	1976.0	1969.5	
2-15	7.5	728.6	10/13/94	1510	4.7	94.8	17.5	1.5	131.6	12.9	1952.0	1970.0	1973.5	0
				1520	2.9	43.8	--	0.9	60.7	--	1951.0	1964.0	--	
				1525	2.7	59.1	3.9	0.9	82.1	2.9	1950.5	**1966.5**	1967.5	
2-16	7.5	726.8	10/11/94	1320	277.9	265.6	65.4	87.0	369.5	48.5	1972.5	1983.5	1985.5	0
				1350	291.1	319.3	36.7	91.1	444.1	27.2	1973.0	1987.5	1980.5	
				1355	282.3	269.7	31.0	88.4	375.2	23.1	1972.5	**1984.0**	1979.0	
2-17	7.5	721.9	10/12/94	1235	616.7	350.3	84.2	194.4	490.5	62.8	1982.5	1990.0	1987.5	0
				1245	627.5	378.2	69.8	197.8	529.6	52.1	1983.0	1994.0	1986.0	
				1300	642.9	364.2	69.8	202.6	510.0	52.1	1983.5	**1991.5**	1986.0	
2-18	7.5	726.3	10/11/94	1645	120.0	112.9	27.1	37.6	157.1	20.1	1967.0	1971.5	1977.5	0
				1705	160.5	140.1	34.6	50.3	195.0	25.6	1968.5	**1973.5**	1980.5	
				1720	178.5	142.1	34.1	55.9	197.8	25.3	1969.5	1973.5	1980.0	
2-19	7.5	733.2	10/25/94	1340	433.8	254.1	40.6	134.6	350.3	29.8	1976.0	1982.5	1981.5	4.3
				1355	449.3	237.2	45.5	139.4	327.1	33.4	1976.5	1981.0	1982.5	
				1400	438.9	240.4	42.1	136.2	331.5	30.9	1976.5	**1981.5**	1982.0	
2-20	7.5	734.5	10/26/94	0905	631.7	348.1	73.7	195.7	479.1	54.0	1983.0	**1989.5**	1986.0	0
				0915	635.9	373.1	71.4	197.0	513.5	52.4	1983.0	1992.0	1986.0	
				0920	606.1	343.5	67.3	187.8	472.8	49.4	1982.0	1989.0	1985.5	

Table 2. Concentrations of dissolved CFC-11, CFC-12, and CFC-113 in ground-water samples, uncorrected recharge dates, and lag times of sampled wells in land-use study areas 1 and 2—Continued

Well number	Recharge[1]		Sample		Concentration in solution, in pg/kg			Calculated atmospheric partial pressure, in pptv			CFC recharge dates[2] (uncorrected for lag time)			Lag time[3]
	Temp (°C)	BP (mm)	Date (mn/dd/yy)	Time	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	
2-21	7.5	732.3	10/26/94	1105	547.2	1,047.3	51.4	170.0	1,445.7	37.8	**1980.0**	contam	1984.0	2.6
				1120	549.3	1,047.9	51.3	170.7	1,446.5	37.8	1980.0	contam	1984.0	
				1130	547.1	1,065.9	52.0	107.0	1,471.3	38.2	1980.0	contam	1984.0	
2-22	7.5	736.6	10/05/94	1715	730.6	432.2	108.3	225.7	593.2	79.2	1986.0	**1994.5**	1990.0	0
				1725	719.4	417.8	95.3	222.2	573.3	69.7	1985.5	1994.5	1988.5	
				1730	711.7	418.7	93.9	219.8	574.5	68.6	1985.5	1994.5	1998.5	
2-23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-24	7.5	734.9	10/25/94	1850	672.2	307.6	61.4	208.1	423.2	45.0	1984.5	1986.5	1985.0	0
				1905	648.1	273.9	54.1	200.6	376.7	39.7	1983.5	1984.0	1984.0	
				1915	648.1	293.6	53.1	200.7	403.8	39.1	1983.5	**1985.5**	1984.0	
2-25	7.5	736.7	10/25/94	0920	475.4	332.8	40.8	146.8	456.7	29.8	1977.0	**1988.0**	1981.5	0
				0930	491.8	327.5	44.6	151.9	449.4	32.6	1978.0	1987.5	1982.5	
				0935	487.9	336.0	44.3	150.7	461.1	32.4	1977.5	1988.0	1982.5	
2-26	7.5	736.1	10/25/94	1105	555.4	529.8	83.4.	171.7	727.5	61.0	**1980.0**	contam	1987.5	0
				1125	571.0	442.1	41.8	176.5	607.1	30.6	1980.5	contam	1981.5	
				1135	555.9	405.1	74.9	171.8	556.4	54.8	1980.0	1994.5	1986.5	
2-27	7.5	731.2	10/13/94	1235	299.1	342.3	48.5	93.1	473.2	35.7	1973.0	1989.0	1983.0	0
				1250	328.6	300.2	64.4	102.2	415.1	47.4	1973.5	**1986.0**	1985.0	
				1300	329.3	299.4	53.5	102.5	414.0	39.4	1973.5	1986.0	1984.0	
2-28	7.5	731.8	10/12/94	1710	17.2	139.0	5.8	5.3	192.0	4.3	1956.0	1973.5	1968.0	0
				1720	16.0	71.4	7.9	5.0	98.6	5.8	1956.0	**1967.5**	1968.0	
2-29	7.5	732.7	10/12/94	1530	488.7	353.8	93.4	151.8	488.2	68.7	1978.0	**1990.0**	1988.5	0
				1540	473.2	399.3	89.3	146.9	551.0	65.7	1977.0	1994.5	1988.0	
2-30	7.5	720.5	10/12/94	0915	647.7	320.8	74.6	204.5	450.1	55.8	1984.0	**1987.5**	1986.5	1.0
				0940	650.6	316.3	77.1	205.5	443.7	57.6	1984.0	1987.5	1987.0	
				1000	619.2	367.5	61.2	195.5	515.6	45.8	1983.0	1992.0	1985.0	

[1] The recharge temperature and barometric pressure used influence the calculated CFC recharge dates. Higher temperatures and pressures yield younger CFC ages. Temperature was estimated from mean annual air temperature and barometric pressure was determined based on elevations from table 1.

[2] Corrected recharge dates are shown in table 1. Recharge dates in bold were assigned as the uncorrected recharge date for that site. Recharge dates in parenthesis indicate that concentrations were decreasing and they are censored with a "<" in table 1 to indicate that the actual recharge date may be older than the assigned recharge date. A sample identified as contaminated (contam) indicates that it could not be dated because the calculated CFC partial pressures were greater than the CFC concentrations in the atmosphere in 1994.

[3] The lag time represents the time, in years, that it takes for CFCs to move through the unsaturated zone to the water table. The lag time is added to the assigned recharge date for a site to correct for water that recharged through an unsaturated zone greater than 30 feet thick. Lag time was calculated for the CFC used to assign the recharge date and only for wells with an unsaturated zone greater than 30 feet thick, based on measured water levels shown in table 1. Values of lag time for wells with unsaturated zone less than 30 feet were set to zero. Recharge dates corrected for lag time are shown in table 1.

[4] The unsaturated zone is greater than 30 feet thick at this well, however, a lag time was not calculated because the assigned recharge date was identified as "modern."

Table 3. Laboratory analysis methods for inorganic and organic constituents

Constituent or category	Analysis method	Reference
Inorganics[1]	Various methods	Fishman and Friedman (1989)
Deuterium/hydrogen ratio	Hydrogen equilibrium technique	Coplen and others (1991)
$^{18}O/^{16}O$ ratio	Carbon dioxide equilibrium technique	Epstein and Mayeda (1953)
Uranium	Laser phosphorescence	ASTM (1991)
Tritium	Electrolytic enrichment with gas counting	Östlund and Dorsey (1977)
DOC	UV-promoted persulfate oxidation and infrared spectrometry	Brenton and Arnett (1993)
Pesticides [USGS NWQL schedule 2001 (lab extracted) and 2010 (field extracted)]	Solid-phase extraction (SPE) on a C-18 cartridge and analysis using gas chromatograph/mass spectrometry	Zaugg and others (1995)
Pesticides [USGS NWQL schedule 2050 (lab extracted) and 2051 (field extracted)]	SPE on a Carbopak-B cartridge and analysis using high performance liquid chromatography with UV detection	Werner and others (1996)
Volatile Organic Compounds (VOCs)	Purge and trap capillary gas chromatography/mass spectrometry	Rose and Schroeder (1995)
Chlorofluorocarbons (CFCs)	Purge-and trap gas chromatography with an electron capture detector	Busenberg and Plummer (1992)

[1] Not including stable and radioisotopes.

VOC lab spike had recoveries that ranged from 58 to 104 percent, and averaged 82 percent.

In general, schedule 2001/2010 pesticide-spike recoveries were fairly good while recoveries for schedule 2050/2051 pesticides were often quite poor. All of the pesticides detected in ground-water samples were from schedules 2001 or 2010. VOC spike recoveries were generally below the acceptable range. Measured concentrations of pesticides and VOCs in ground-water samples were not adjusted to reflect the recoveries determined from the spiked samples.

Statistical Analysis

Water-quality and geohydrologic data are displayed using boxplots, which demonstrate the differences between groups of data, such as concentrations of dissolved nitrate in samples from the two study areas. Boxplots in this report illustrate the 10th, 25th, 50th (median), 75th, and 90th percentiles of the data, as well as values outside of the 10th and 90th percentiles. In order to determine whether any apparent differences shown by the boxplots were statistically significant, the nonparametric Wilcoxon-Mann-Whitney rank sum test (Iman and Conover, 1983, p. 281) was performed using the computer program SAS (SAS, 1989). The null hypothesis, that the mean rank of the groups are equal, was used. Estimated values were treated as actual data and values below the detection limit (less than values) were set to a value lower than the lowest measured value above the detection limit (Helsel and Hirsch, 1992, p. 367) so that they could be included in nonparametric statistical analyses.

Contingency tables and a nonparametric test for independence (Iman and Conover, 1983, p. 296) were used to measure the statistical association between factors that could be grouped into categories, such as ground-water age (with the categories of "old" and "modern") and land-use study area (with the categories of "area 1" and "area 2"). Percentages of all possible combinations of categories were calculated and a nonparametric test for independence was performed using the computer program SAS to determine if the null hypothesis, that the two categories were independent of each other, were true.

The alpha value used in this report is 0.05. The probability (or p-value) that observed difference occurs by chance is described in the text or shown on each graph. If the p-value is smaller than or equal to the alpha value, then the null hypothesis is rejected.

Nutrient and pesticide data from springs were not included in statistical comparisons between areas 1 and 2. It has been shown that ground water discharging from a spring has more potential to be affected by contaminants, such as nutrients and pesticides, applied at the land surface than water withdrawn from wells (Adamski and Pugh, 1996; Barbash and Resek, 1996).

Hydraulic Conductivity, X-Ray Diffraction, and Age-Dating Analysis

Hydraulic conductivity (K) values for the surficial deposits in the vicinity of the screened intervals for most of the installed monitoring wells were estimated from slug tests. Slug test data were analyzed using the Bouwer and Rice method (Bouwer, 1989). Because the thickness of the aquifer being tested was not always known, it was assumed to be equal to the thickness of the saturated zone penetrated by the well. This assumption can result in a slight overestimation of K when the top of the well screen is near the water table and a slight underestimation of K when the top of the screen is far below the water table (Brown and others, 1995). Estimates of K for the two study areas are included in table 1.

The mineralogy of surficial deposits was determined for two cores collected near well 1-1f, in area 1. X-ray diffraction analyses were performed on approximately 10 samples taken from each core. The analyses were done by the University of Wisconsin-Milwaukee, Center for Great Lakes Studies, using an automated step-scan x-ray diffractometer with a copper tube and a graphite monochromator.

Ground-water recharge dates were determined using tritium and CFCs. Starting in the mid-1950s nuclear weapons testing increased the amount of tritium in the atmosphere and in precipitation, which increased the amount of tritium in recharge to ground water. Tritium has a half-life of 12.43 years and can be used as an indicator of recently recharged ground water (Egboka and others, 1983; Knott and Olympio, 1986; Robertson and Cherry, 1989). Tritium-based ground-water recharge dates were determined in the study areas by matching the measured tritium concentrations in a ground-water sample to a decay-corrected tritium input curve for precipitation. The determined ground-water recharge dates assume that all of the sampled water comes from precipitation and the dates refer to when the sampled water first entered the subsurface. A tritium input curve was developed for precipitation near Madison, Wisconsin, by Bradbury (1991), and was assumed to be representative of that for the two study areas. Using this input curve, ground-water samples from the study areas were described as "modern" or "old." For this report, modern refers to water that entered the subsurface after about 1955 (identified as ">1955" in table 1) and old refers to water that entered the subsurface before about 1955 (identified as "<1955" in table 1). Using Bradbury's input curve, the cut off point between modern and old water corresponds to about 16 picocuries per liter (pCi/L) or 5 tritium units (where 1 tritium unit = 3.193 pCi/L).

CFC-based ground-water recharge dates were determined by using measured ground-water concentrations of CFCs (CFC-11, CFC-12, and CFC-113) to calculate the CFC concentrations in the unsaturated zone air when the water was recharged, and subsequently matching the concentrations in the unsaturated zone air to historical concentrations of CFCs in the atmosphere. The temperature and atmospheric pressure in the unsaturated zone are used to determine the CFC concentrations in the unsaturated zone air that was required to produce the measured concentrations in ground water. This information was not known but it was estimated based on the mean annual air temperature and elevation at the sampled location and by assuming that the sampled water was recharged nearby (table 2).

The CFC-based ground-water recharge dates refer to when the sampled water first became isolated from the atmosphere, which is assumed to occur at the water table in both areas. This age-dating method also assumes that the CFCs dissolved in recharging water that is moving through the unsaturated zone are in equilibrium with CFCs in the unsaturated zone air, and that CFC concentrations in the unsaturated zone air are similar to those in the atmosphere. These assumptions are reasonable if recharge occurs by relatively slow infiltration and if the unsaturated zone materials are somewhat permeable and relatively thin (less than 30 ft thick). At most of the sampling locations the surficial deposits that make up the unsaturated zone are somewhat permeable, however, at several locations the unsaturated zone was more than 30 ft thick. At these sites, ground water that was recharged through a thick unsaturated zone may have a CFC-based recharge date that makes it appear older than it is.

CFCs move into the unsaturated zone by advection and diffusion; at depths greater than a few meters, diffusion is the dominant process (Cook and Solomon, 1995), and CFCs can take years to move deep into the unsaturated zone. As a result, concentrations in the unsaturated zone air below a few meters represent past, and lower, atmospheric concentrations. Recharging water moves faster than CFCs through the unsaturated zone, and, if the unsaturated zone is thick, it reaches equilibrium with CFCs in the unsaturated zone air that are at lower concentrations than in the atmosphere. This can cause CFC-based recharge dates to appear older than they are. The CFC travel time, or "lag time," through the unsaturated zone was calculated for wells that have an unsaturated zone greater than 30 ft by using methods described by Cook and Solomon (1995), and then the lag time was added to the CFC-based recharge date of the water sample to give a "corrected" CFC recharge date. For example, based on measured water levels, the unsaturated zone at well 2-9 is about 103 ft thick, and this results in a lag time of 8.8 years for CFC-12. If 8.8 years is added to the uncorrected CFC-12-based recharge date of 1984 (table 2), then the "corrected" recharge date is about 1993 (table 1). The assumptions used to determine lag time include a volumetric soil water content of 15 percent, soil porosity of 35 percent, soil temperature of 10 degrees Celsius, and no effective recharge. Recharge rates up to 12 inches per year have minimal effects on the lag time (Cook and Solomon, 1995).

Concentrations of CFCs measured in ground-water samples and uncorrected CFC-based recharge dates, which are based on analysis of three sequential samples collected at each well or spring, are shown in chronological order of collection in table 2. Recharge dates based on CFC-12 were considered the most reliable because it is the most conservative of the CFCs that were measured (Cook and others, 1995).

Recharge dates were assigned to each well based mainly on CFC-12 results. However, if a set of samples appeared to be contaminated with CFC-12, that is if measured concentrations were above current atmospheric concentrations, then the CFC-11 recharge date was used instead. There were no instances where one sample appeared to be contaminated with CFC-12 and CFC-11. Where CFC-11 was used, samples did not appear to be degraded with respect to CFC-11, and the CFC-11 recharge dates generally agreed with the corresponding CFC-113 recharge dates. If there were a range of CFC recharge dates for a well, then the middle value was used unless a chronologically increasing or decreasing trend in CFC concentrations was apparent for CFC-11, CFC-12, and CFC-113. An increasing trend in concentrations could indicate that younger water, which contains higher CFC concentrations, was drawn into the screened interval during the purging and sampling process. A decreasing trend could indicate that the well was not completely purged of the water that was in the well prior to sampling. In either case, the actual recharge date would be older than the oldest date determined from the samples analyzed. None of the sample sets showed an increasing trend, however, 2 samples sets, from wells 1-1f and 2-11, showed slight decreasing trends. The oldest recharge date, based on CFC-12, for samples showing a decreasing trend was assigned as the recharge date for that well. The corrected recharge date was censored with a "<" to show that the water may actually be older than indicated (table 1).

EFFECTS OF LAND USE AND GEOHYDROLOGIC FACTORS ON THE OCCURRENCE OF INORGANIC AND ORGANIC CHEMICALS

Since agriculture was the largest percent of land use in both areas and sampling sites were chosen to be downgradient from fields used to grow corn and alfalfa, it was expected that agricultural practices would cause concentrations of nutrients and pesticides to be elevated in ground water in both areas. However, it was also expected that geohydrologic factors would control the magnitude of the agricultural effects. Comparisons of land use and geohydrologic factors with water quality in the study areas will be discussed in the following sections of this report.

Land Use Comparison

The land use in the two areas were similar but there was no certainty that the application rates of nutrients and pesticides in the areas would be identical. Application rates for nutrients (fertilizer and manure) were only available on a statewide basis for Wisconsin, and the rates were generally not usable for smaller scales. There are, however, recommended nitrogen application rates for corn in Wisconsin based on soil type (Bundy and others, 1992). "Soils" in this report refers to unconsolidated deposits within 6 ft of the land surface. Nitrogen application rates ranging from 80 to 200 pounds of N per acre per year (lb/acre/yr) are recommended for areas that have soils described as sands or loamy sands, such as those in much of area 2. The recommended rates increase with decreasing soil organic-matter content and where soils are irrigated. Most of the sampled wells were located away from irrigated fields in area 2, therefore, the nonirrigated application rates range from 80 to 120 lb/acre/yr. The soils in area 2 are generally described as well drained to excessively drained with low to medium organic-matter content (Otter and Fiala, 1978; Gundlach and others, 1982; Otter, 1984; Mitchell, 1986; Otter and others, 1989). More fertilizer and manure is typically applied on land with well-drained soils, such as those

Table 4. Historical application rates for atrazine, alachlor, cyanazine, and metolachlor used on corn and percentages of acres planted in corn that were treated with the pesticide in the vicinity of land-use study areas 1 and 2 (WASS, 1979, 1986 and 1991)
[--, no data]

Year	Crop reporting district[1]	Atrazine		Alachlor		Cyanazine		Metolachlor	
		Application rate[2]	Percentage of acres treated[3]	Application rate[2]	Percentage of acres treated[3]	Application rate[2]	Percentage of acres treated[3]	Application rate[2]	Percentage of acres treated[3]
1978	east central	1.60	76	1.90	32	1.70	13	--	--
	southeast	1.50	63	2.00	46	1.70	25	--	--
	central	1.30	89	1.70	36	1.40	5	--	--
	northeast	1.30	89	1.60	17	1.10	8	--	--
1985	east central	1.97	70	1.83	29	1.69	35	2.47	15
	southeast	1.56	60	2.35	38	1.63	36	1.85	29
	central	1.62	84	1.73	34	1.66	14	2.22	9
	northeast	1.22	76	1.38	30	1.46	27	1.90	17
1990	east central	1.59	39	1.47	16	1.67	15	1.90	18
	southeast	1.64	32	1.70	23	1.56	29	--	--
	central	1.29	65	1.66	23	1.33	12	1.95	8
	northeast	1.44	40	1.51	14	1.28	31	1.45	11

[1] The east central and southeast crop reporting districts (unshaded) represent applications rates near land-use study area 1 and the central and northeast crop reporting districts (shaded) represent application rates near land-use study area 2.

[2] Application rates in pounds of active ingredient per acre per year.

[3] Indicates percentage of acres planted in corn that were treated with that pesticide.

in area 2, because of the low organic-matter content and low moisture capacity (Spalding and Exner, 1993). Nitrogen application rates ranging from 80 to 180 lb/acre/yr, again depending on the amount of soil organic matter, for soils other than sands or loamy sand, such as those in much of area 1, are recommended. The soils in area 1 are generally described as poor to well drained with a medium to high organic-matter content (Parker and others, 1970; Schmude, 1971; Link, 1973; Engel and others, 1978). In general, the recommended application rates are similar in the two areas. However, slightly more fertilizer and manure may have been applied in area 2 because of the well-drained soils with lower organic matter content.

Pesticide application rates, which were based on the number of acres treated and pounds of active ingredient applied, were available on a regional scale for the state from the Wisconsin Agricultural Statistics Service (WASS). Numerous pesticides have been used in the State, and four of the most commonly used on corn have been atrazine, alachlor, cyanazine, and metolachlor (WASS, 1979, 1986 and 1991). Historical pesticide application rates of these four pesticides, in area 1, much of which is included in the east central and southeast WASS crop reporting districts, have been slightly higher than rates in area 2, much of which is included in the central and northeast WASS crop reporting districts (table 3). Application rates generally increased from 1978 to 1985 for these pesticides, whereas the rates generally decreased from 1985 to 1990.

Atrazine, which is one of the most widely used pesticides in Wisconsin, has been a restricted use pesticide nationally since 1990, which means that it may be purchased and used only by a certified applicator. However, in 1991, the State of Wisconsin limited its use even further by restricting atrazine application rates (Wisconsin Department of Natural Resources, 1992) because it was being detected in drinking water from ground-water wells. Atrazine use was prohibited in some areas of the State, but in most areas the amount that could be used was limited and allowable rates were based on soil texture. Atrazine application rates allowed in Wisconsin in 1995 were 0.75 lb/acre/yr on fields where more than 25 percent of soils are described as coarse; this includes sands, loamy sands, and sandy loam, that are typical of area 2. Allowable rates on soils described as medium, which includes loam, silt, and clay among others, which is more typical of soils in area 1, ranged from 1.0 to 1.5 lb/acre/yr, depending on whether atrazine was used the previous year. Based on the regional estimates of pesticide application rates and recent restrictions on atrazine, applications of the most commonly used pesticides were, and probably will continue to be, slightly higher in area 1 than in area 2.

In order to better understand the recent and historical fertilizer and manure application rates in the study areas, as well as to obtain information about pesticide use and crop rotation patterns, a list of 11 questions was sent to the participating landowners who were farmers or who rented land to farmers. These questions referred only to owned or rented fields that were within 100 yards of the installed monitoring well. A copy of the questionnaire is shown in appendix 3.

Forty-seven questionnaires (22 in area 1, 25 in area 2) were sent out, and 18 (7 from area 1, 10 from area 2, and 1 unidentified) were returned. Responses to the questions varied in detail, and did not fully account for land use and application rates in the entire contributing area to all wells; however, some useful information was obtained.

Question 1 requested information about crop rotation patterns for fields near the installed monitoring well, and the question was answered in detail by all respondents. The crop rotation patterns typically consisted of a 5-to-7-year rotation of corn and alfalfa (2 to 3 years of corn followed by 3 to 4 years of alfalfa). In area 1, one of the corn years was occasionally replaced by a year of barley, oats, or wheat. In area 2, one of the corn years was occasionally replaced or a year was sometimes added with crops of barley, oats, peas, potatoes, rye, or sweet corn.

Questions 2 through 7 inquired about fertilizer and manure application rates. Most respondents answered questions 2 and 3, which inquired about fertilizer application rates in 1994 and 1993, respectively, and questions 5 and 6, which inquired about manure application rates during the same years. However, few answered questions 4 and 7, which inquired about what typical fertilizer and manure application rates were if 1994 and 1993 were non-typical years. This may indicate that 1994 and 1993 were typical years for application rates or that the questions were not understood by the respondents. All responses were converted to pounds of nitrogen (N) per acre per year. Responses to questions 2 and 3 ranged from 0 to 280 lb/acre/yr in area 1 and from 0 to 300 lb/acre/yr in area 2. Responses to questions 5 and 6 ranged from 0 to 160 lb/acre/yr in area 1 and from 0 to 90 lb/acre/yr in area 2. In general, fertilizer and manure application rates in the two areas appeared to be similar based on these survey results.

Questions 8 and 9 inquired about what pesticides were used on the nearby fields in 1994 and 1993, respectively. Question 10 inquired about pesticide application rates in 1994 and 1993, and question 11 inquired as to what pesticides were used prior to 1993. In general, information about actual pesticide application rates was limited, but all respondents did indicate what pesticides had been used recently (1993 and 1994) and historically (prior to 1993). Based on answers to questions 8, 9, and 11, 20 different pesticides, including 14 in area 1 and 15 in area 2, were noted to have been used recently or historically on fields near the monitoring wells. Nine of the 20 pesticides were used in both areas. In area 1, some of the most commonly used pesticides (used by at least 30 percent of respondents in each area) historically have been alachlor, atrazine, and cyanazine, whereas recently some of the most common include atrazine, cyanazine, and dicamba. Historically, in area 2, some of the most commonly used pesticides also included alachlor, atrazine, and cyanazine, although recently they only included atrazine and cyanazine. The list of less commonly used pesticides is generally similar between study areas and between those used historically and recently. This pesticide use summary is only a generalization and it does not necessarily represent the most used pesticides in either area, but it does show that the pesticides used in both areas have been similar.

In general, agricultural practices near the sampling locations appeared to be similar in both areas. The crops grown in the fields near the monitoring wells were similar based on observations during reconnaissance and drilling and based on results of the landowner survey. The fertilizer and manure application rates appear to have been similar or slightly higher in area 2, based on results from the survey and recommended rates for corn in Wisconsin. The most commonly used pesticides appear to have been similar in the two areas, based on results of the survey. Historical and recent pesticide application rates, based on regional use data and the atrazine restrictions, were probably slightly higher in area 1.

Geohydrologic Comparison

Many of the chemicals applied at the land surface in agricultural areas can leach to ground water, but the amount that leaches and the amount of time that it takes to reach the ground water can vary depending on geohydrologic factors such as the amount of recharge, the depth to water, and the permeability of surficial deposits (Hamilton and Helsel, 1995; Barbash and Resek, 1996). Irrigation can increase chemical leaching to ground water, however, most of the sampling locations were located away from irrigated fields.

Data from 58 samples in the two study areas, for deuterium/hydrogen ratio and $^{18}O/^{16}O$ ratio (appendix 2c), plot very close to the meteoric water line (Drever, 1988, p. 371). This indicates that all of the sampled ground water originated from precipitation. The amount of precipitation was generally similar in the two areas, and it is normally about 31 inches per year (Owenby and Ezell, 1992). However, the surficial deposits are generally more permeable in area 2 than in area 1, which results in greater recharge to ground water in area 2. Estimates of K for the screened part of the aquifer were determined from slug tests performed on 52 wells in the two areas (table 1). The results of the slug tests reflect the different types of surficial deposits in the two areas (fig. 6). Hydraulic conductivity was significantly lower (p-value < 0.001) in area 1, where the median was 0.44 ft/d, than in area 2, where the median was 27 ft/d).

Slug tests only provide estimates of K for the screened part of the aquifer, but the tests can be used to infer the permeability of the overlying surficial deposits if drill cuttings indicate that similar materials exist throughout the length of the hole. In area 2, the surficial deposits were generally uniform throughout the length of the hole. In area 1, surficial deposits were often in alternating layers of sand and clay. Therefore, the permeability of the screened interval may be very different from that of the overlying materials. During drilling and well installation in area 1, the screened interval was positioned in the more permeable deposits if possible and this may have biased K towards larger values.

Recharge dates were estimated at all locations using tritium or chlorofluorocarbons (CFCs), or both. Tritium was collected at 19 of 28 sites in area 1 and at all 30 sites in area 2 to provide a rough estimate of the ground-water recharge date. Based on the tritium results, samples were identified as either "modern" water, which was recharged after about 1955, or "old" water, which was recharged before about 1955. Seven of the 19 samples from area 1 were of old water compared to 1 of 30 from area 2 (table 1). The "age" of a sample actually represents an intermediate age of the water being drawn into a well or discharging at a spring outlet. Mixing of "old" and "modern" water was evident in several wells where the ground-water age was identified as old, yet atrazine, which was not widely used in Wisconsin until the early 1960s, was detected at low concentrations in the ground-water samples.

Chlorofluorocarbons were collected at 10 of 28 sites in area 1 and at 29 of 30 sites in area 2, and provided a more quantitative recharge date than did the analyses for tritium (table 1). CFC-based ground-water ages were generally younger in area 2 than in area 1 (fig. 7), however, the apparent difference was not statistically significant (p-value = 0.103). Combining the results of tritium- and CFC-based recharge dates provides additional evidence that there is a difference in ground-water ages in the study areas. In area 1, 29 percent (8 of 28) of wells or springs produced "old" water. In area 2, only 3 percent (1 of 30) of wells produced "old" water. A nonparametric test for independence using a contingency table showed that the age of the water (using the categories of "old" and "modern") was dependent on whether the samples were from area 1 or area 2 (p-value = 0.008). This means that "old" water makes up a significantly higher percent of the samples from area 1 than from area 2.

Other factors, such as depth to the water table and depth of sampling location below the water table, can also affect the age of sampled water. A deeper water table and a sampling location at depths well below the water table generally results in a longer residence time and older ground water. The distribution of sample depths below the water table was similar between the two areas, however, area 2, which has a significantly deeper water table (fig. 8), appears to have younger ground-water. Although water has generally traveled a greater vertical distance to the sampled location in area 2, the more permeable surficial deposits allow the water to get there faster. This information about geologic materials, their hydraulic properties, and the age of sampled water is important for interpreting ground-water-quality data in relation to land use.

Ground-Water Quality Comparison

The quality of the shallow ground water in the two study areas is affected by both natural and anthropogenic factors. Natural processes, such as dissolution and oxidation or reduction of geological materials,

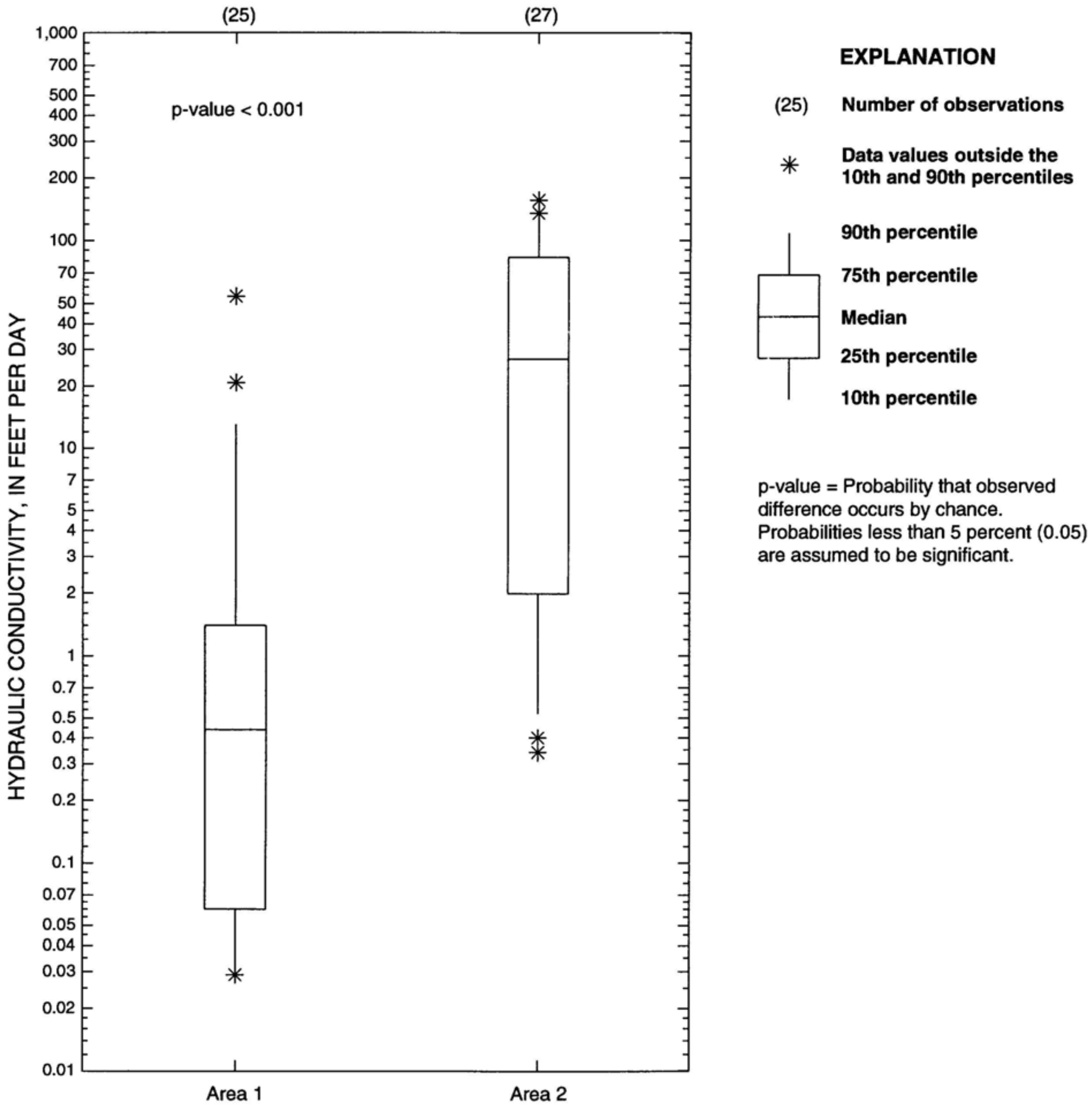


Figure 6. Boxplots of hydraulic conductivity estimates for the study areas.

account for most of the dominant major ions in ground water. Anthropogenic factors, such as applications of fertilizer, manure, and pesticides, probably account for the elevated concentrations of nutrients and the presence of trace concentrations of pesticides in many of the ground-water samples. Measurements of water-quality constituents that were detected in ground-water samples from the land-use study areas are shown in appendix 2. The water-quality from the two springs sampled in area 1 was similar to that of the wells in area 1. They are included in the discussion in this section, except where statistical comparisons of nutrients and pesticides between study areas were made.

Total dissolved solids concentrations were significantly higher ($p\text{-value} < 0.001$) in area 1 than in area 2 (fig. 9). Calcium, magnesium, and bicarbonate, were

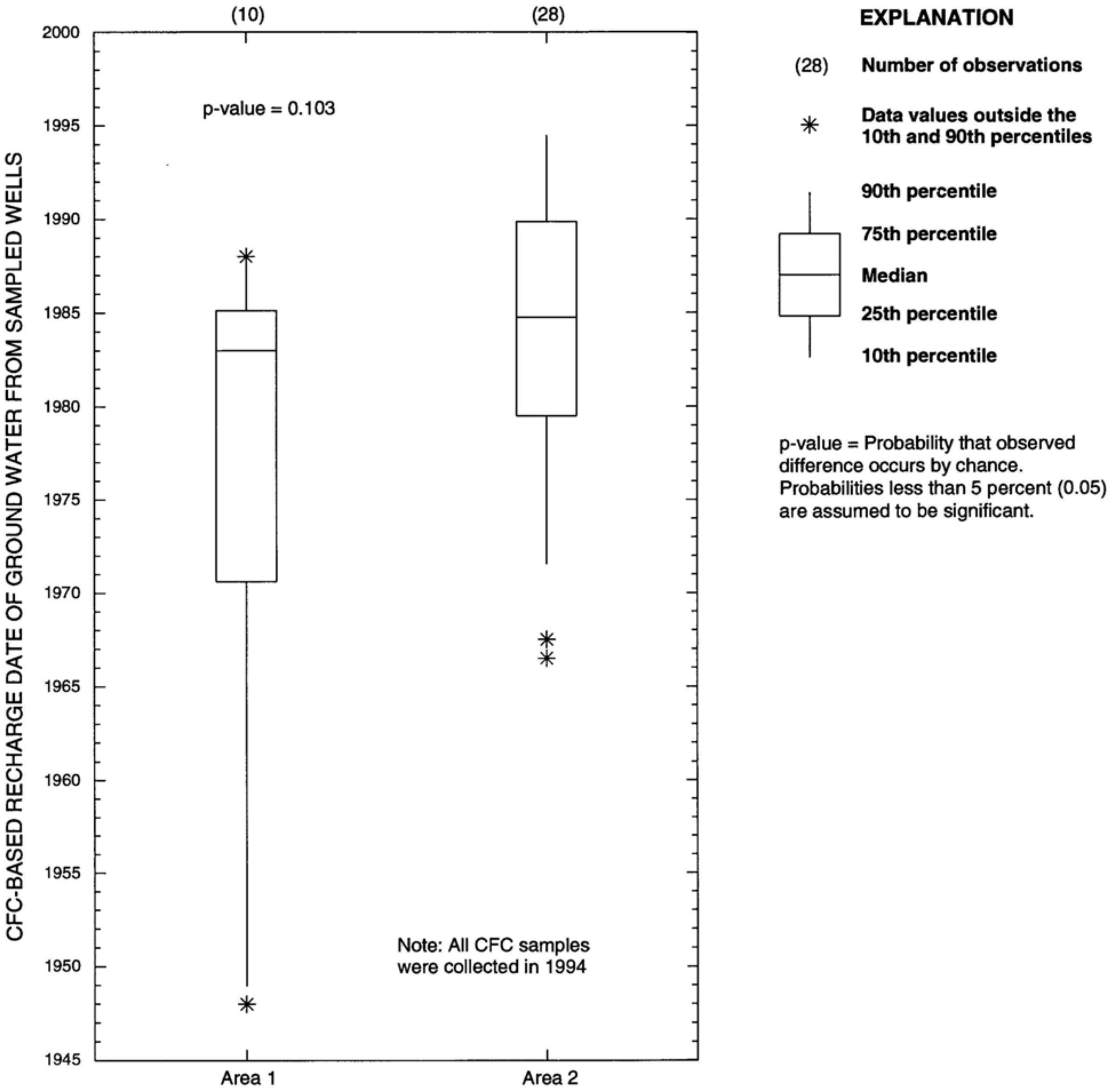


Figure 7. Boxplots of CFC-based ground-water recharge dates for the study areas.

the dominant major ions in both areas (fig. 10). The ion compositions were also similar to that described by Kammerer (1984) for the sand and gravel aquifer in Wisconsin. Chloride and nitrate were also important ions in one well in area 2, where the concentration of bicarbonate was relatively low and the concentrations of chloride and nitrate were relatively high. The dominant ions in most samples in both areas probably resulted from the dissolution of carbonate minerals, such as dolomite [$CaMg(CO_3)_2$], in the unconsolidated deposits and also possibly from agricultural applications of carbonate materials applied at the land surface to increase soil pH. The results of CFC and tritium samples from both areas indicated that the age of sampled water was generally older in area 1 than in area 2, however, there was no apparent relation between the

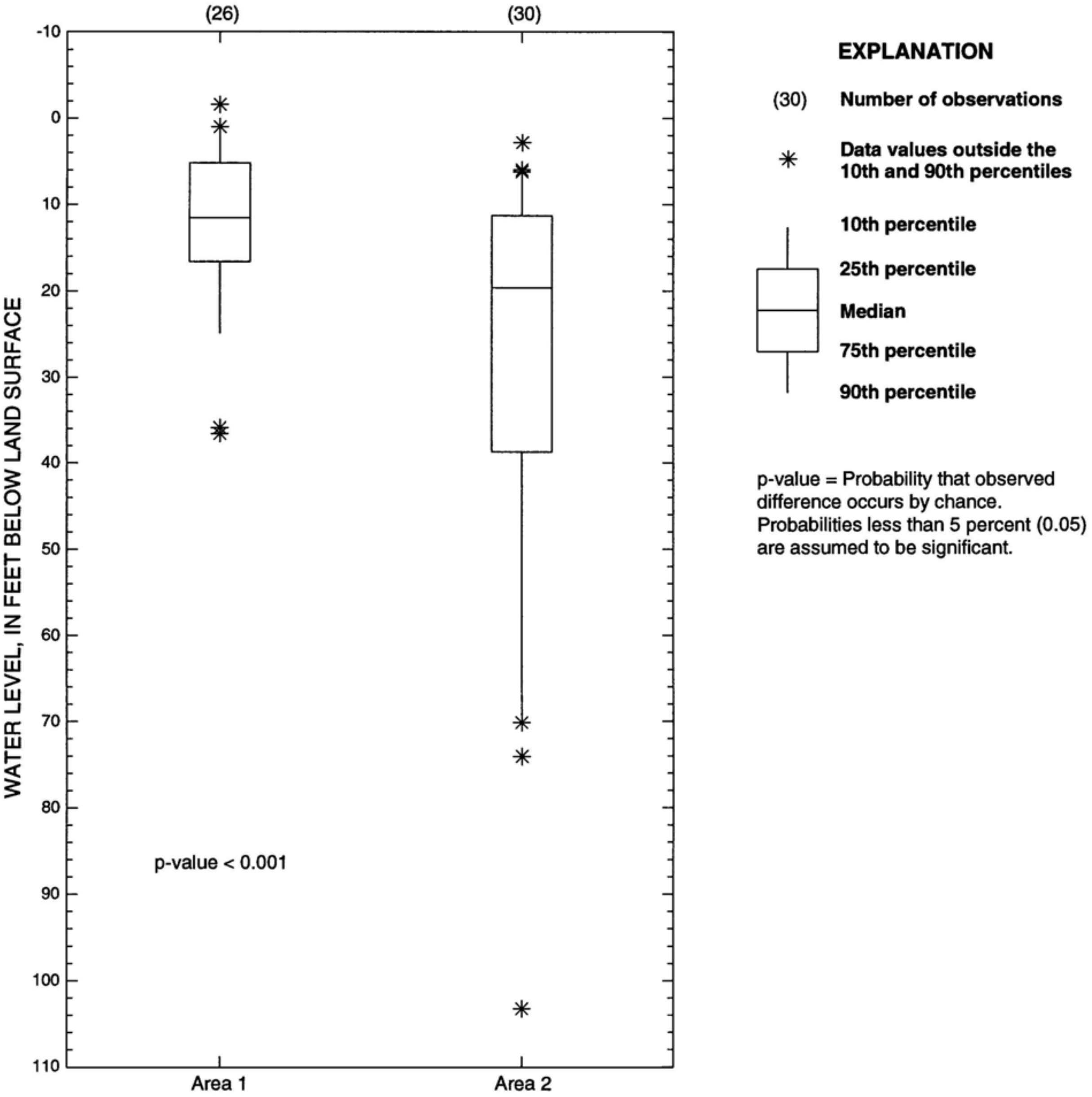
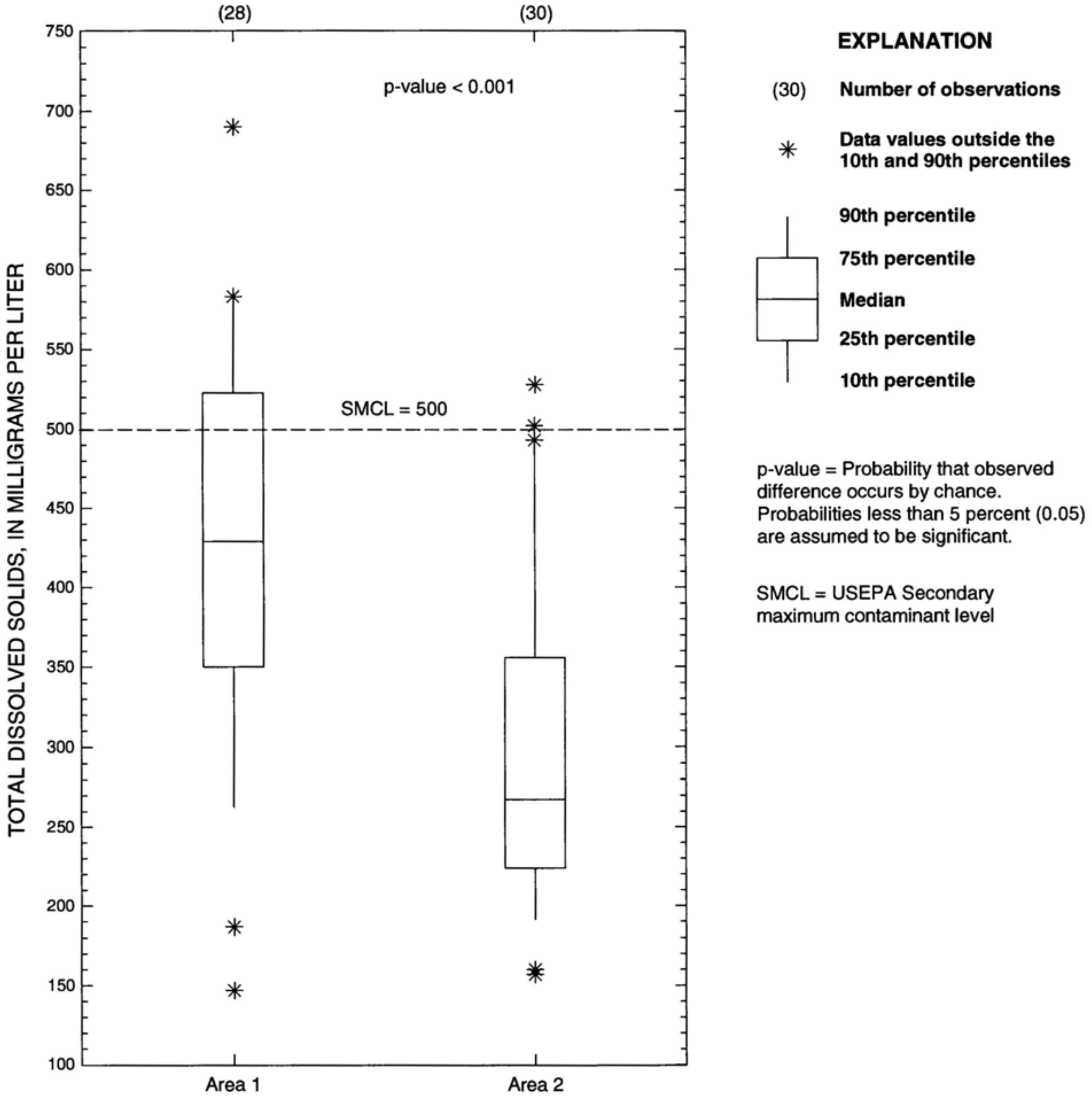


Figure 8. Boxplots of measured water levels in sampled wells in the study areas.

concentrations of dissolved solids and the age of the ground water. The difference in the concentration of total dissolved solids between the study areas may be due to the proximity of sampling locations in area 1 to the underlying carbonate bedrock.

X-ray diffraction analysis of unconsolidated materials from two surficial-deposit cores near well 1-1f in area 1 showed that dolomite, followed by quartz, plagioclase, and microcline, were the most abundant minerals present. Minerals that were present in small amounts included chlorite, hornblende, and mica. Surficial deposits from area 2 were not analyzed by X-ray diffraction, however, the similarity of major ions in ground-water samples from both areas indicates that the lithology is probably similar. Dolomite saturation indices for six samples, three from each study area,



p-value = Probability that observed difference occurs by chance. Probabilities less than 5 percent (0.05) are assumed to be significant.

SMCL = USEPA Secondary maximum contaminant level

Figure 9. Boxplots of total dissolved solids in ground water from sampled wells in the study areas.

which approximately represent the minimum, maximum, and mean concentrations of the dominant ions, were calculated using WATEQ4F (Ball and others, 1987). Dolomite was undersaturated in each of the six samples, and, therefore, it should dissolve if it is in contact with the ground water in both study areas.

The dissolution of dolomite in near-neutral pH conditions, such as those in areas 1 and 2, should result in a molar ratio of calcium plus magnesium to bicarbonate of 1:2 (Siegel, 1989). Figure 11 shows a linear relationship (r^2=.84), and most of the samples from the two study areas plot near the theoretical slope of 1:2 (or 0.5). However, most of the data plot slightly above the theoretical line and with a slightly steeper slope (0.59). This may indicate that dissolution of dolomite is occurring, but that there is an additional source of calcium or

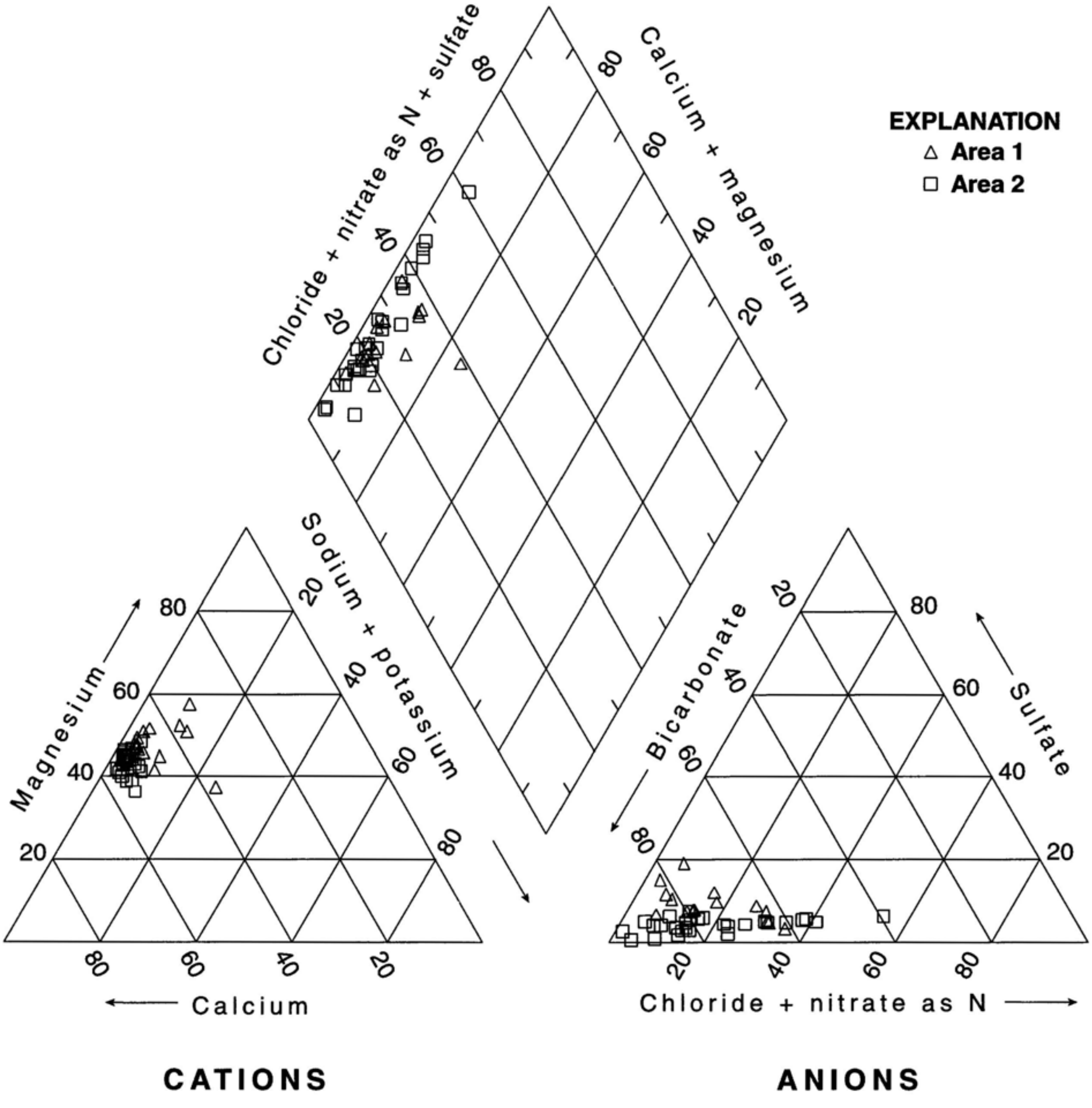


Figure 10. Trilinear diagram of percent equivalents of major cations and anions in ground-water samples from the study areas.

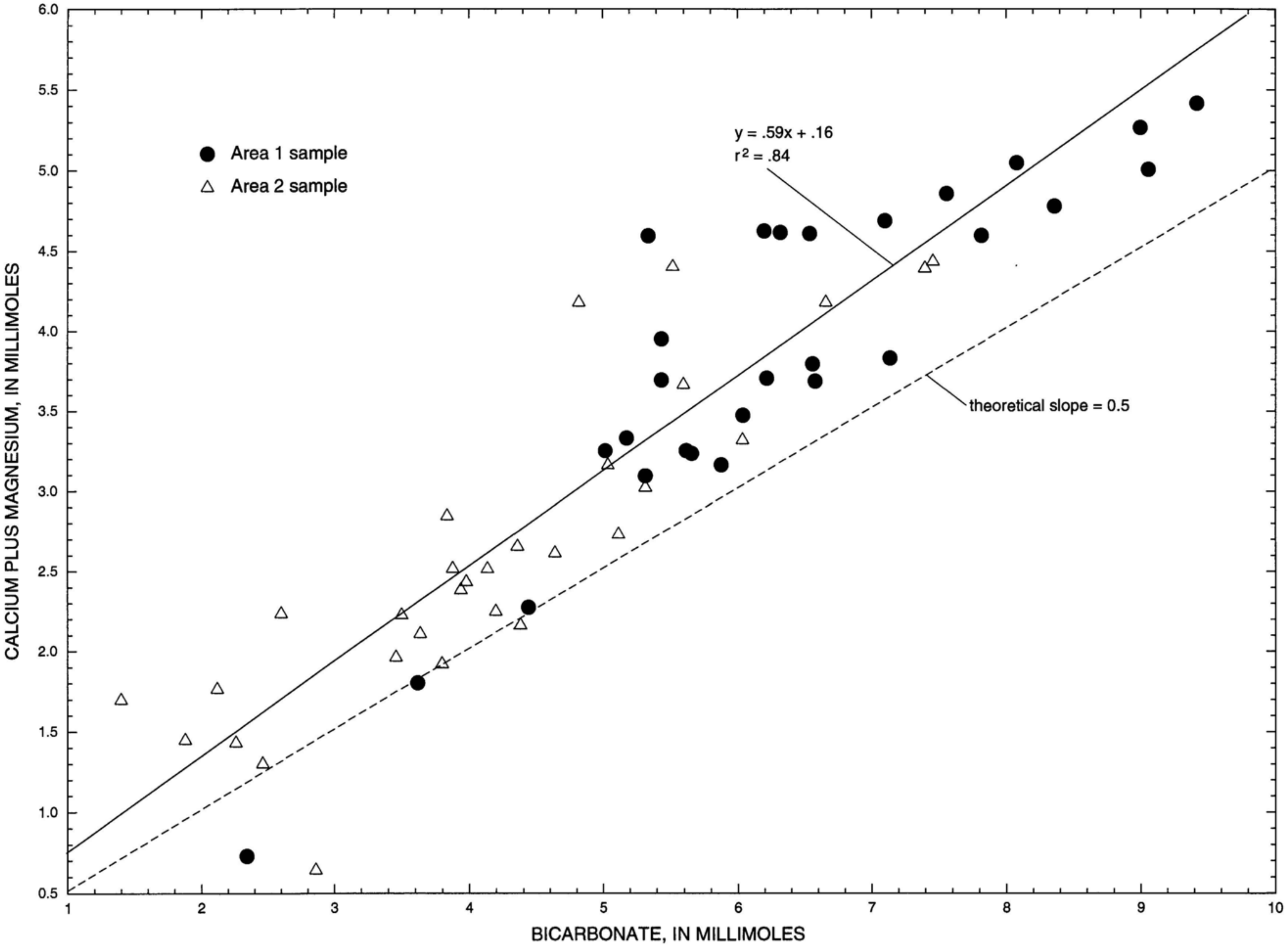


Figure 11. Relation between calcium plus magnesium and bicarbonate in ground-water samples from the study areas.

magnesium or both, or that bicarbonate is being removed from ground water. Additional sources of calcium and magnesium could come from minerals identified by X-ray diffraction (chlorite and plagioclase) or other minerals such as gypsum ($CaSO_4 \cdot 2H_20$) or anhydrite ($CaSO_4$) which were not identified by X-ray diffraction analyses but could still possibly be present. Many agriculturally applied materials contain calcium and magnesium. These include gypsum, agricultural lime, magnesium sulfate ($MgSO_4 \cdot 7H_20$), ordinary superphosphate [$Ca(H_2PO_4)_2 + CaSO_4$], and potassium magnesium sulfate ($K_2SO_4 \cdot 2MgSO_4$). Dissolved sulfate, which is the predominant form of sulfur found in Wisconsin's ground water (Kammerer, 1981), was detectable in all of the samples from both study areas, and it could have resulted from the dissolution of many of these minerals or agricultural materials.

Water-quality standards set by the U.S. Environmental Protection Agency (USEPA) or the State of Wisconsin, or both, define limits on the health aspects or aesthetic qualities of drinking water (U.S. Environmental Protection Agency, 1991a, 1991b) and ground water (Wisconsin Department of Natural Resources, 1994) for some of the constituents collected as part of these studies. USEPA drinking-water standards include maximum contaminant levels (MCL), which are health-based, and secondary maximum contaminant levels (SMCL), which are for constituents that can affect the aesthetic qualities of drinking water. The USEPA also has some proposed maximum contaminant levels (PMCL) for constituents that may have negative health effects in drinking water. Wisconsin has ground-water-quality standards that include enforcement standards (ES) and preventive action limits (PAL).

The USEPA SMCL of 500 mg/L for total dissolved solids was exceeded in 11 of 28 samples in area 1, and in 2 of 30 samples in area 2. Dissolved iron exceeded the SMCL of 300 µg/L in 6 of 58 samples, and dissolved manganese exceeded the SMCL of 50 µg/L in 25 of 58 samples. Concentrations of dissolved iron and manganese above the SMCL were found in water samples from many parts of both study areas. Iron is found in several of the minerals identified by X-ray diffraction, and small amounts of manganese are commonly present in dolomite, where it substitutes for calcium (Hem, 1985). Another possible source of iron and manganese is fertilizer that has been supplemented with iron or manganese for use on soils deficient in those elements. Dissolved uranium, which occurs naturally, has a PMCL of 20 µg/L; dissolved uranium concentrations in all samples were below that level.

VOCs can be found in the inert ingredients in some liquid formulations of pesticides (Wang and others, 1995) and, therefore, could potentially leach to ground water. Only two wells had detectable VOCs that were not associated with the contamination problems discussed in the "Study Design and Methods" section of this report. Water samples from two wells had detectable concentrations of chloroform, and one of those wells also had detectable concentrations of dichlorobromomethane. Chloroform and dichlorobromomethane are both used as solvents and in fire extinguisher fluid. Chloroform is also used in the making of pesticides and it can occur naturally. Neither of these VOCs were identified in the studies done by Wang and others (1995) and there were no obvious sources of contamination near the sampling locations.

Nutrients in ground water can originate from several sources including wet and dry atmospheric deposition, biologically-mediated fixation, and from the decomposition of organic matter. However, elevated nutrient concentrations are often associated with releases from septic systems or agricultural practices that apply fertilizer and manure to the land surface. Sampling locations for the two study areas were chosen to eliminate the possibility of septic-tank influences. Water samples taken from all wells and springs were analyzed for dissolved nitrogen species, including analyses of ammonium, ammonium plus organic nitrogen, nitrite, and nitrite plus nitrate. Water samples were also analyzed for phosphorus, including analyses of dissolved phosphorus and dissolved orthophosphate. Dissolved nitrite plus nitrate, ammonium, and phosphorus were the most commonly detected nutrients. They were detected in at least half of all samples. Dissolved nitrite generally was not detected, however, one water sample from area 2 had a detectable concentration of 2.1 mg/L which exceeded the USEPA MCL of 1.0 mg/L.

Dissolved nitrite plus nitrate, hereafter referred to as nitrate, is the contaminant that most often exceeds Wisconsin's ground-water-quality standards (Wisconsin Department of Natural Resources, 1990). Nitrate was detected in 43 of 58 samples (fig. 12), and concentrations were significantly higher ($p\text{-level} < 0.001$) in area 2 than in area 1 (fig. 13). In area 2, nitrate concentrations in 25 of 30 samples exceeded the PAL of 2.0 mg/L, and nitrate concentrations in 11 of 30 samples

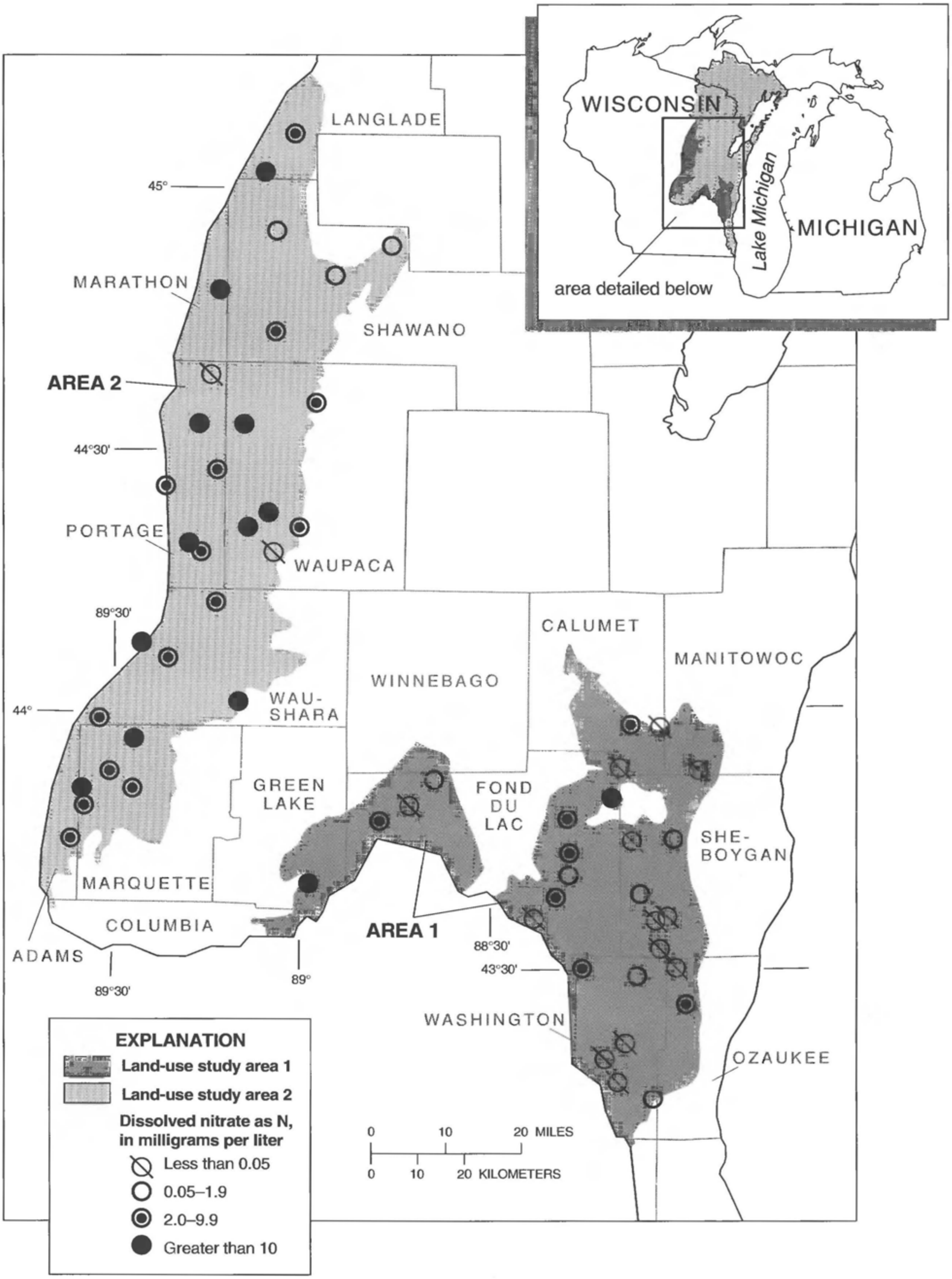


Figure 12. Concentration of dissolved nitrate from wells and springs in the study areas.

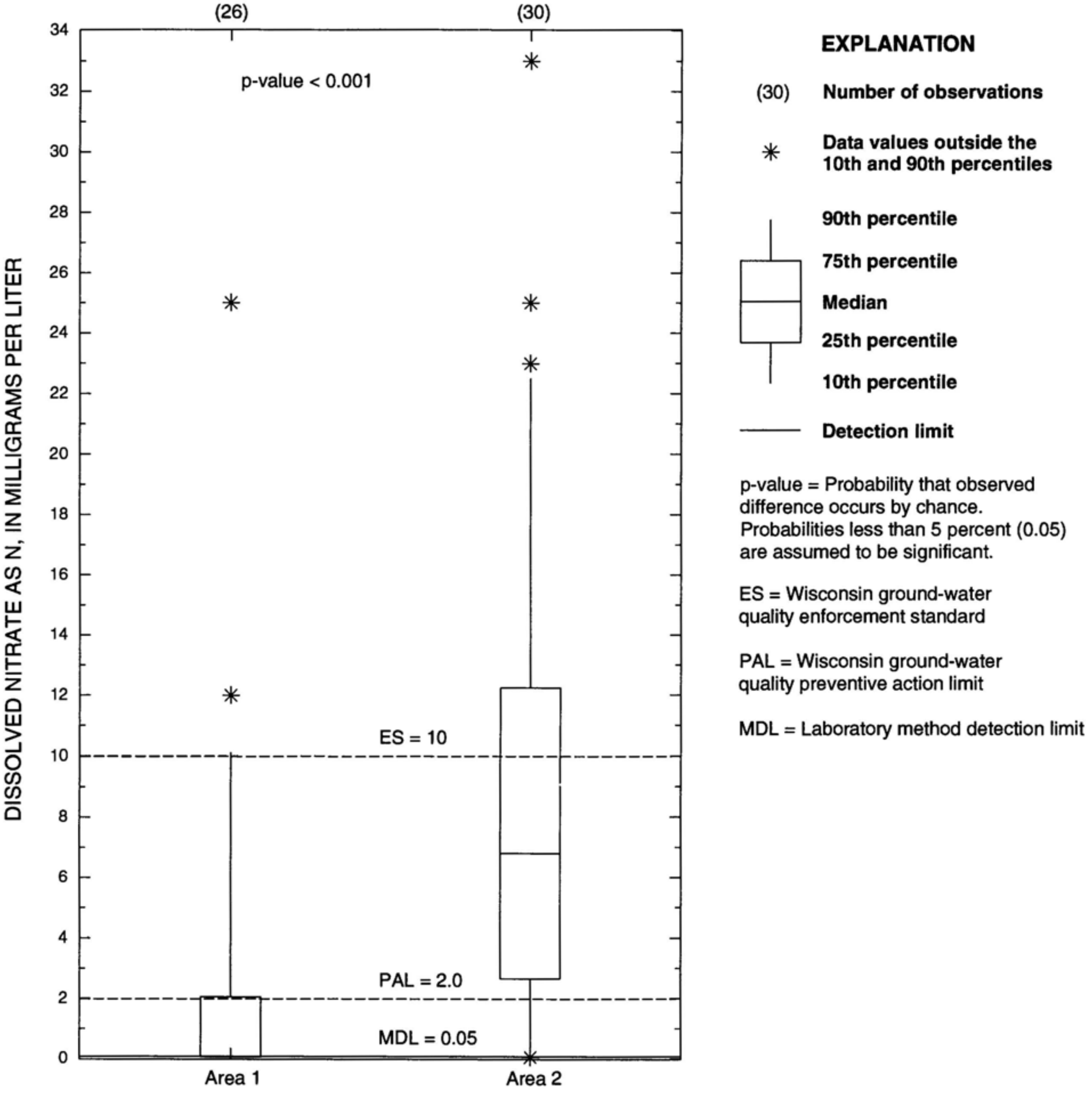


Figure 13. Boxplots of dissolved nitrate in ground water from sampled wells in the study areas.

exceeded the ES of 10 mg/L, compared to 9 of 28 and 2 of 28 samples, respectively, from area 1.

Nitrate is soluble and readily transported through the unsaturated zone to ground water in areas where the water table is shallow and the surficial deposits are permeable. Although the water table is significantly deeper in area 2 than in area 1 (fig. 8), nitrate concentrations were significantly higher in area 2 than area 1. Part of the reason for this could be that nitrogen applications were slightly higher in area 2, but it is more likely due to the more permeable surficial deposits in area 2 and smaller amounts of soil-organic matter. Permeable surficial deposits can result in greater recharge which facilitates the movement of nitrate below the root zone and to the water table. Figure 14 shows that the highest nitrate concentrations generally correspond

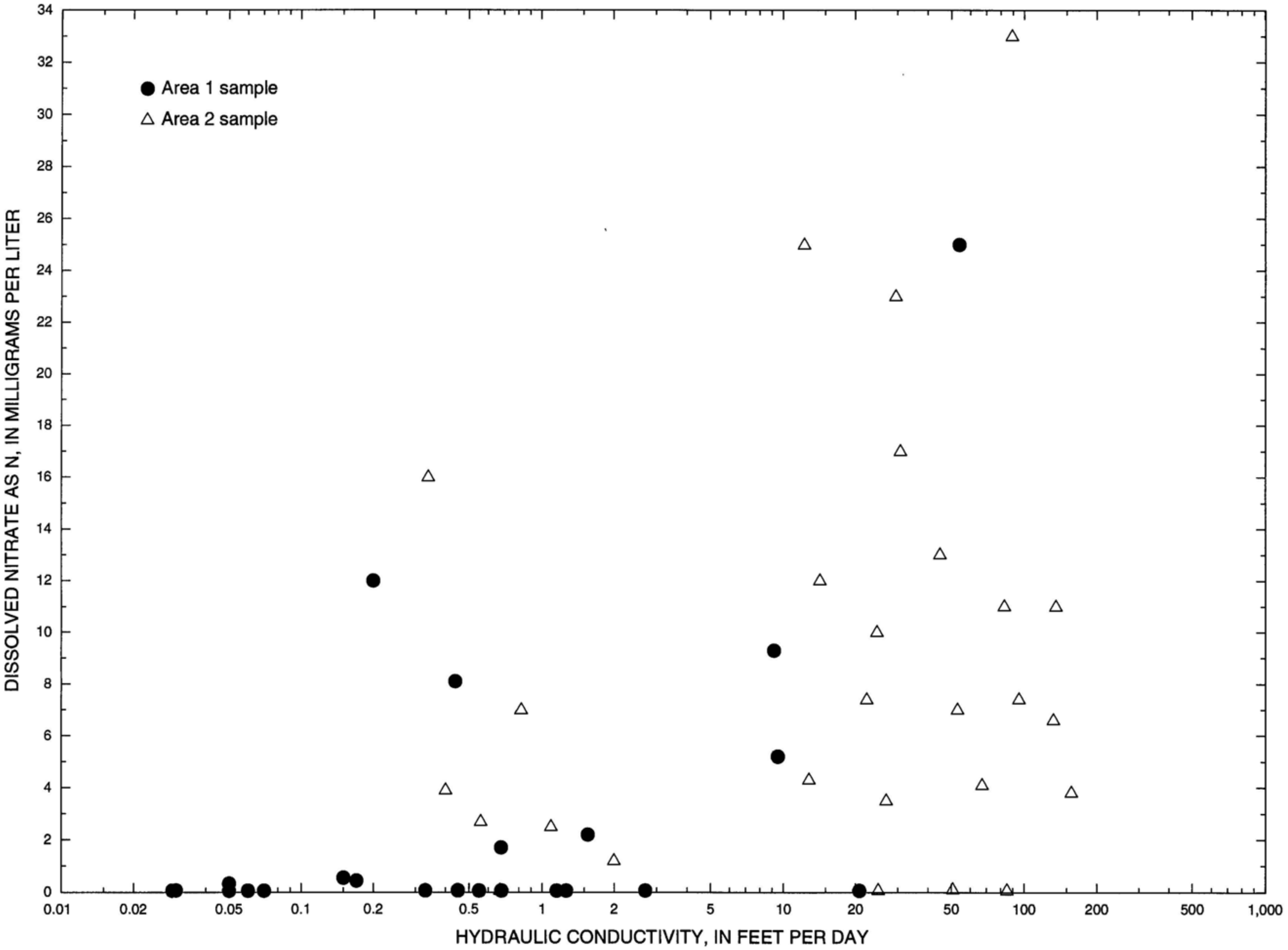


Figure 14. Relation between dissolved nitrate and hydraulic conductivity for the study areas.

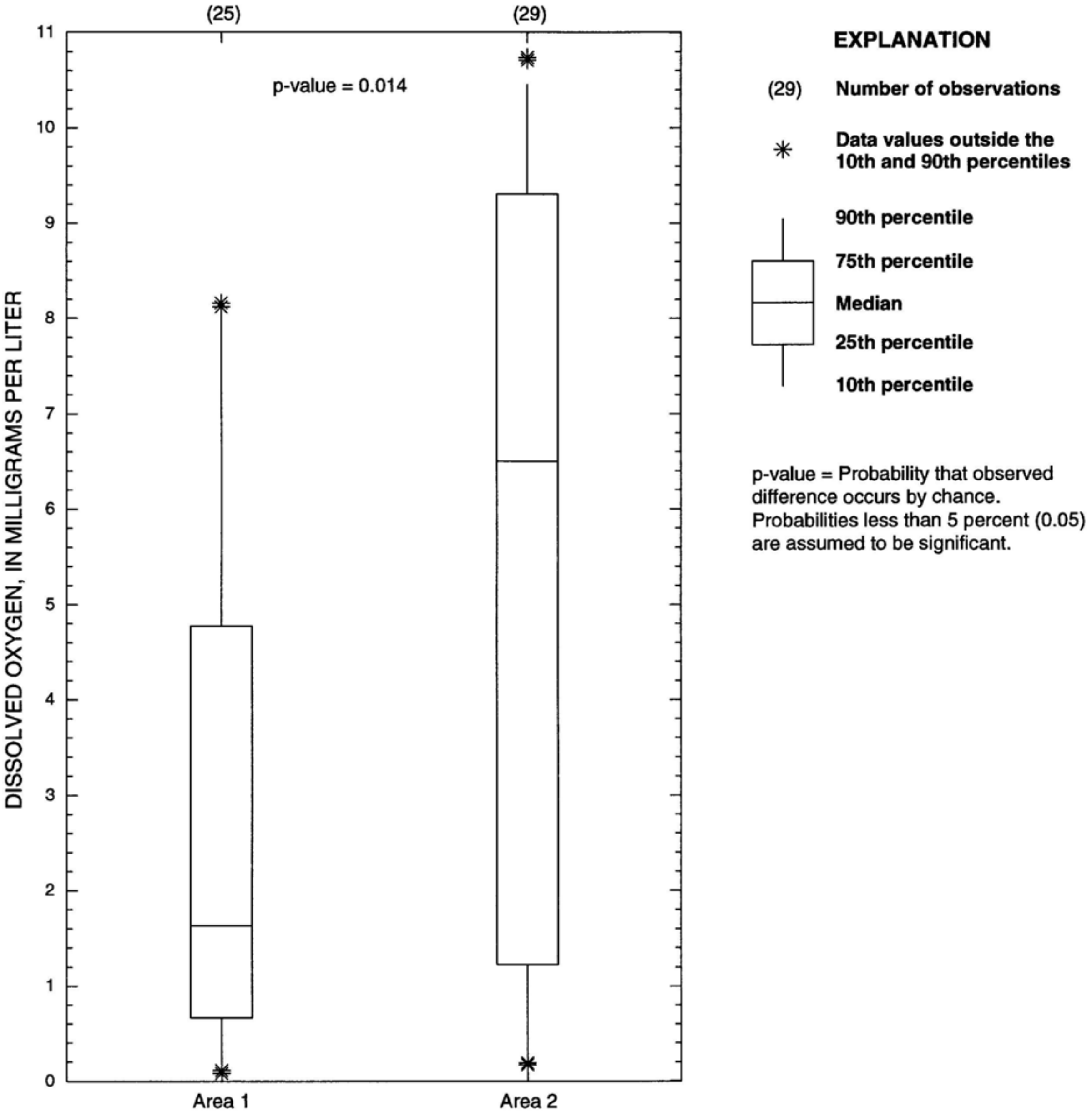


Figure 15. Boxplots of dissolved oxygen in ground water from sampled wells in the study areas.

to locations with the highest measured hydraulic conductivity values, both of which were significantly higher in area 2 than in area 1. In area 2, where there may be little or no soil-organic matter to consume oxygen as it decays (Freeze and Cherry, 1979, p. 245), dissolved oxygen concentrations can remain relatively high in recharge as it moves to ground water and at depth below the water table. Dissolved oxygen concentrations are significantly higher (p-value = 0.014) in area 2 than in area 1 (fig. 15), and dissolved oxygen concentrations remain relatively high with depth below the water table (fig. 16). These aerobic conditions prevent denitrification and assimilative uptake from occurring and allow nitrate to remain at relatively high concentrations throughout the saturated zone in area 2 (fig. 17). In area 1, where there is probably more

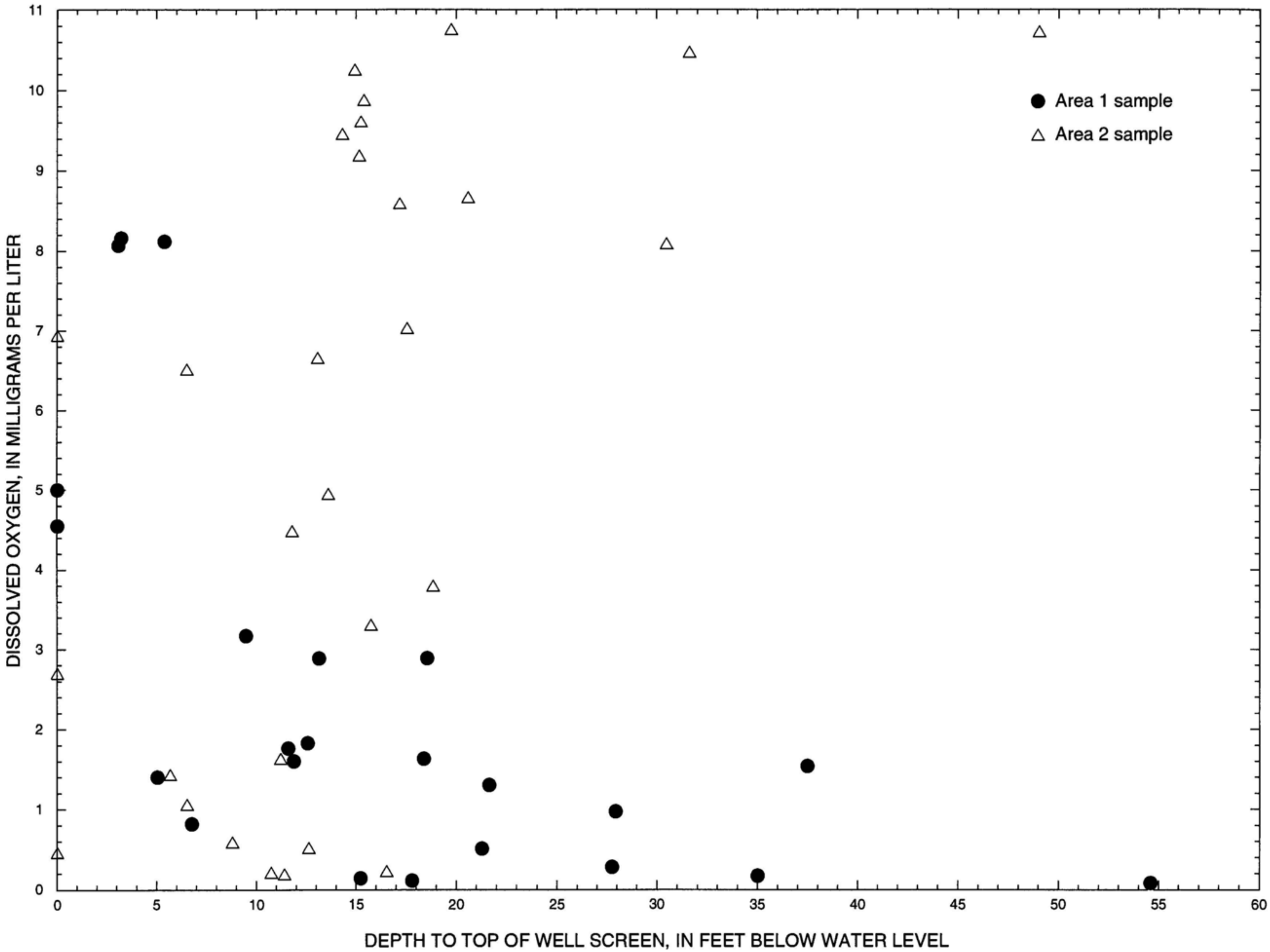


Figure 16. Relation between dissolved oxygen and depth to top of well screen, in feet below water level, for the study areas. (For water levels within the screened interval, depth to top of well screen, in feet below water level, was set equal to zero.)

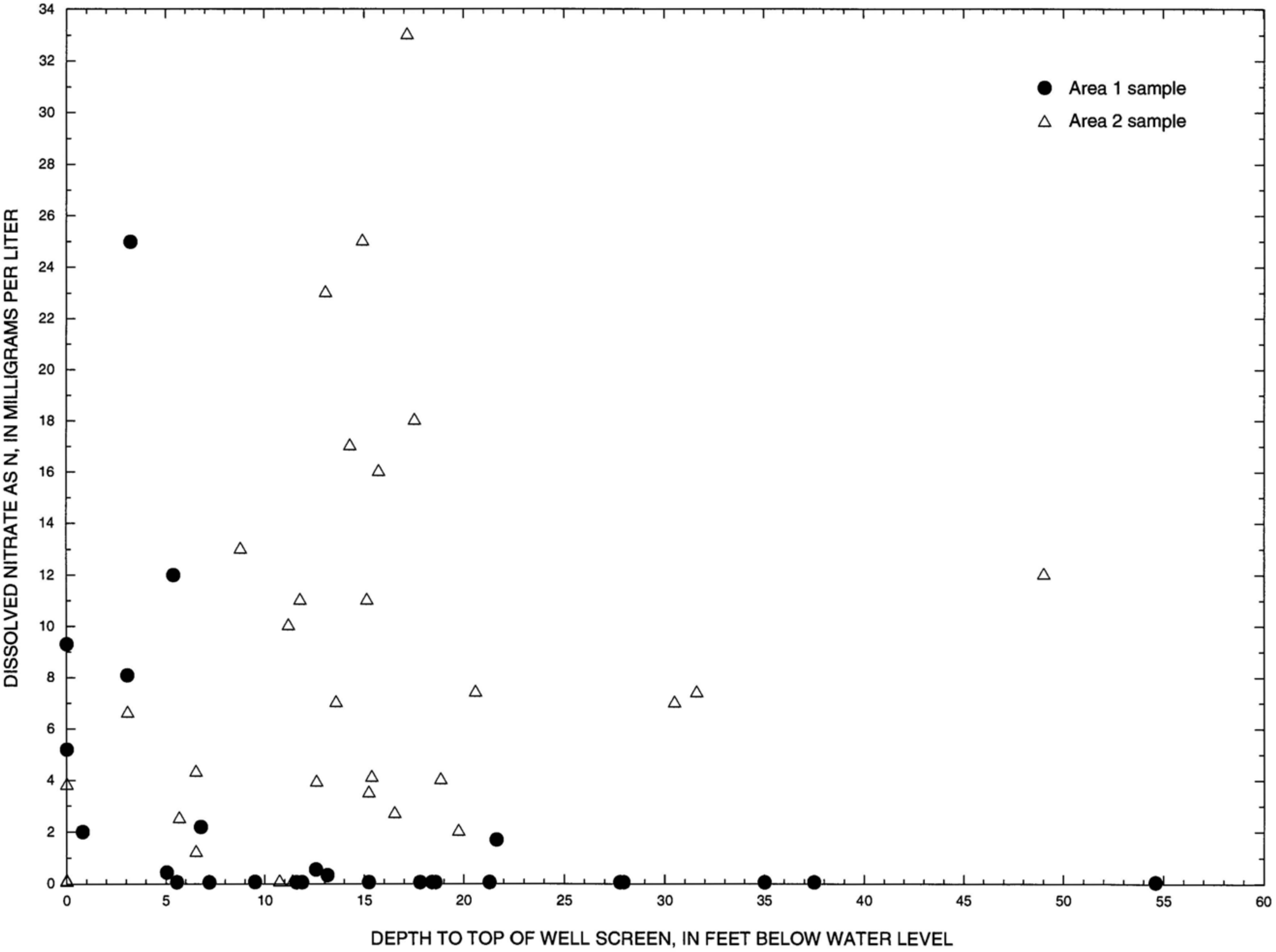


Figure 17. Relation between dissolved nitrate and depth to top of well screen, in feet below water level, for the study areas. (For water levels within the screened interval, depth to top of well screen, in feet below water level, was set equal to zero.)

organic matter in the subsurface, both dissolved oxygen and nitrate concentrations generally decrease with depth below the water table (figs. 16 and 17). This indicates that denitrification or assimilative uptake is probably occurring as water moves to greater depths below the water table in area 1.

Additional evidence of denitrification or assimilative uptake in area 1 is a decrease in the molar ratio of nitrate to chloride with depth below the water table (fig. 18). If the assumption is made that the nitrate to chloride ratio is similar for most fertilizers and manures applied in the study areas and that fertilizers and manure are a major source of nitrate and chloride in ground water, then the molar ratio should be similar in ground water. Denitrification or assimilative uptake with depth below the water table would remove nitrate from the system and cause a decrease in the molar ratio (Gambrell and others, 1975) such as that seen in area 1 from zero to approximately seven feet below the water table (fig. 18). At greater than seven feet below the water table in area 1 the nitrate to chloride ratio appears to be constant. The nitrate to chloride ratio for area 2 does not show a decreasing trend, which indicates that denitrification or assimilative uptake is not quantitatively significant.

Dissolved ammonium was detected in more samples (51 of 58) than was nitrate, but dissolved ammonium generally was detected in smaller concentrations than was nitrate. Dissolved ammonium was found in all samples from area 1 and in 23 of 30 samples from area 2, and concentrations were significantly higher (p-level = 0.002) in area 1 (fig. 19). Ammonium in ground water can come from biological-mediated decomposition of organic matter, but a more likely source in the study areas is fertilizer and manure applied to the land surface. Ammonium is not very mobile because the cations are strongly adsorbed to mineral surfaces (Hem, 1985). Ammonium applied at the land surface can be nitrified to nitrate in aerobic soils, which is then easily transported to ground water where it can be reduced back to ammonium under anaerobic conditions. Since fertilizer and manure application rates are similar or slightly higher in area 2 the higher concentrations of ammonium in the ground water in area 1 probably results from the reduction of nitrate. This is consistent with observed patterns in nitrate and oxygen.

Dissolved phosphorus, primarily in the form of orthophosphate (PO_4^{3-}), was detected in 38 of 58 samples and it probably also results from fertilizer and manure applications at the land surface. Phosphorus is not very mobile because it is readily adsorbed to sediment and aquifer matrix (Kolpin and others, 1994, p. 32; Drever, 1988, p. 89). As expected, most concentrations of dissolved phosphorus and dissolved orthophosphate were relatively low (appendix 2c).

Pesticides in ground water result from the leaching of pesticides applied or spilled at the land surface. Sampling locations in the land-use study areas were located away from obvious point sources, such as pesticide mixing, washing, and storage areas. Fifty-eight samples from the two study areas were analyzed for approximately 85 pesticides and soil metabolites. A total of 12 pesticides or metabolites were detected (table 5). Ten pesticides or metabolites were detected in samples from area 1 and nine were detected in samples from area 2. Metabolites in this report refer to the biotically-produced products of the parent compound. It should be noted that a single pesticide can have a number of different metabolites and some metabolites have been shown to be present in a higher percentage of ground-water samples than the parent products (Kolpin and others, 1996). Only a few metabolites were analyzed in ground-water samples for these land-use studies.

At least one pesticide or metabolite was detected in 23 of 28 samples from area 1 and in 29 of 30 samples from area 2 (fig. 20). Pesticides or metabolites were detected in ground-water samples from all parts of both study areas and under a wide range of geohydrologic conditions. There are Wisconsin ground-water-quality standards for atrazine and its metabolites, carbofuran, cyanazine, DCPA, metolachlor, and simazine, however, only concentrations of atrazine or atrazine plus deethyl atrazine exceeded standards in a few samples.

Most of the detected pesticides are herbicides and they are primarily used in Wisconsin to control annual grasses and broadleaf weeds in corn. Three of the detected herbicides, DCPA, prometon, and triallate, are not associated with use on corn. DCPA is used to control annual grasses and broadleaf weeds in many vegetable crops but it was mostly used for lawn care and gardens. Prometon and tebuthiuron are nonselective herbicides that are used primarily for clearing foliage. Triallate is used to control wild oats in crops such as barley and winter wheat, which are sometimes included in the crop rotation patterns of both land-use study areas. Some of the detected pesticides are very persistent, in fact, p,p'-DDE is a metabolite of the

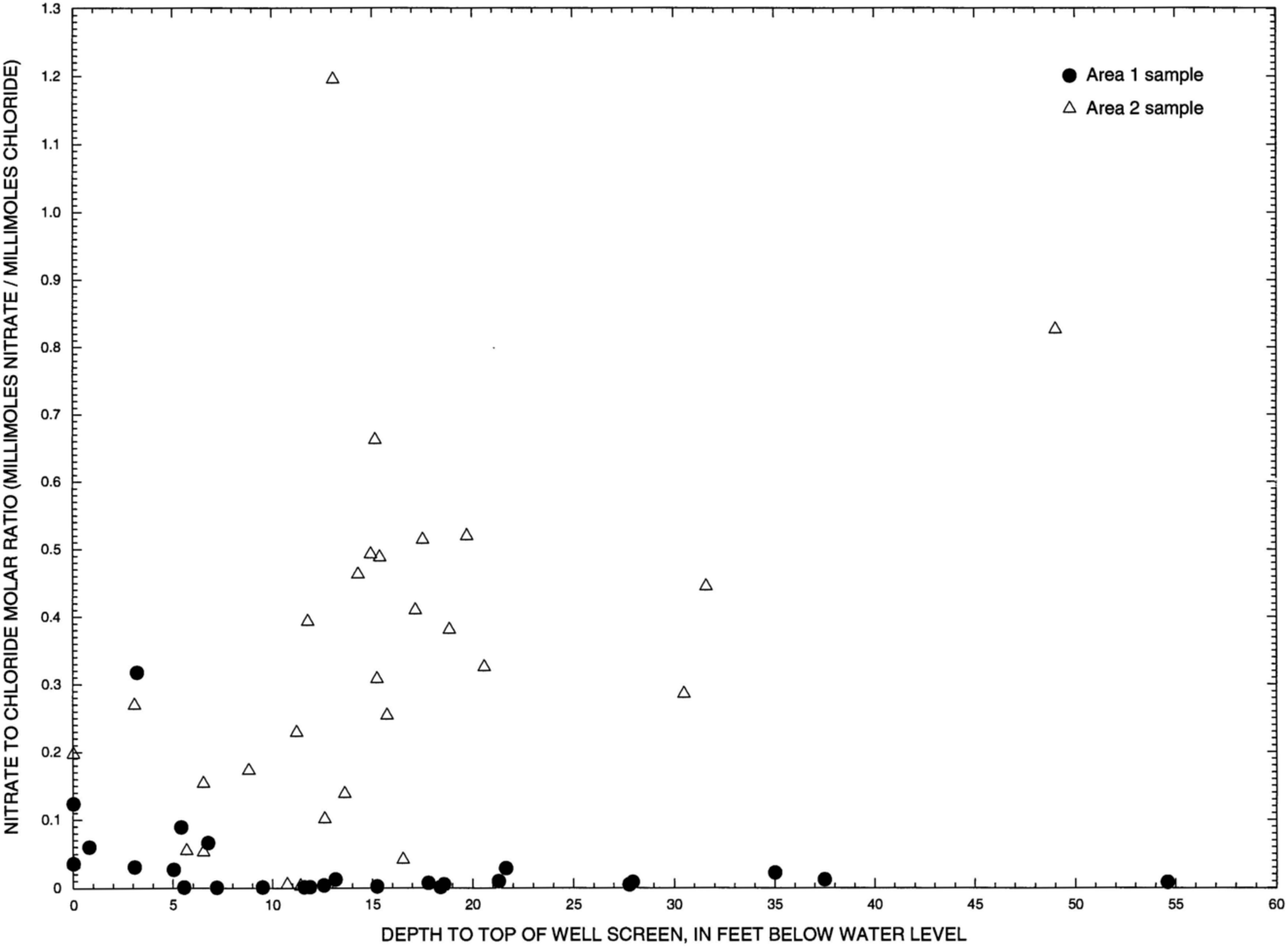


Figure 18. Relation between nitrate to chloride molar ratio and depth to top of well screen, in feet below water level, for the study areas. (For water levels within the screened interval, depth to top of well screen, in feet below water level, was set equal to zero.)

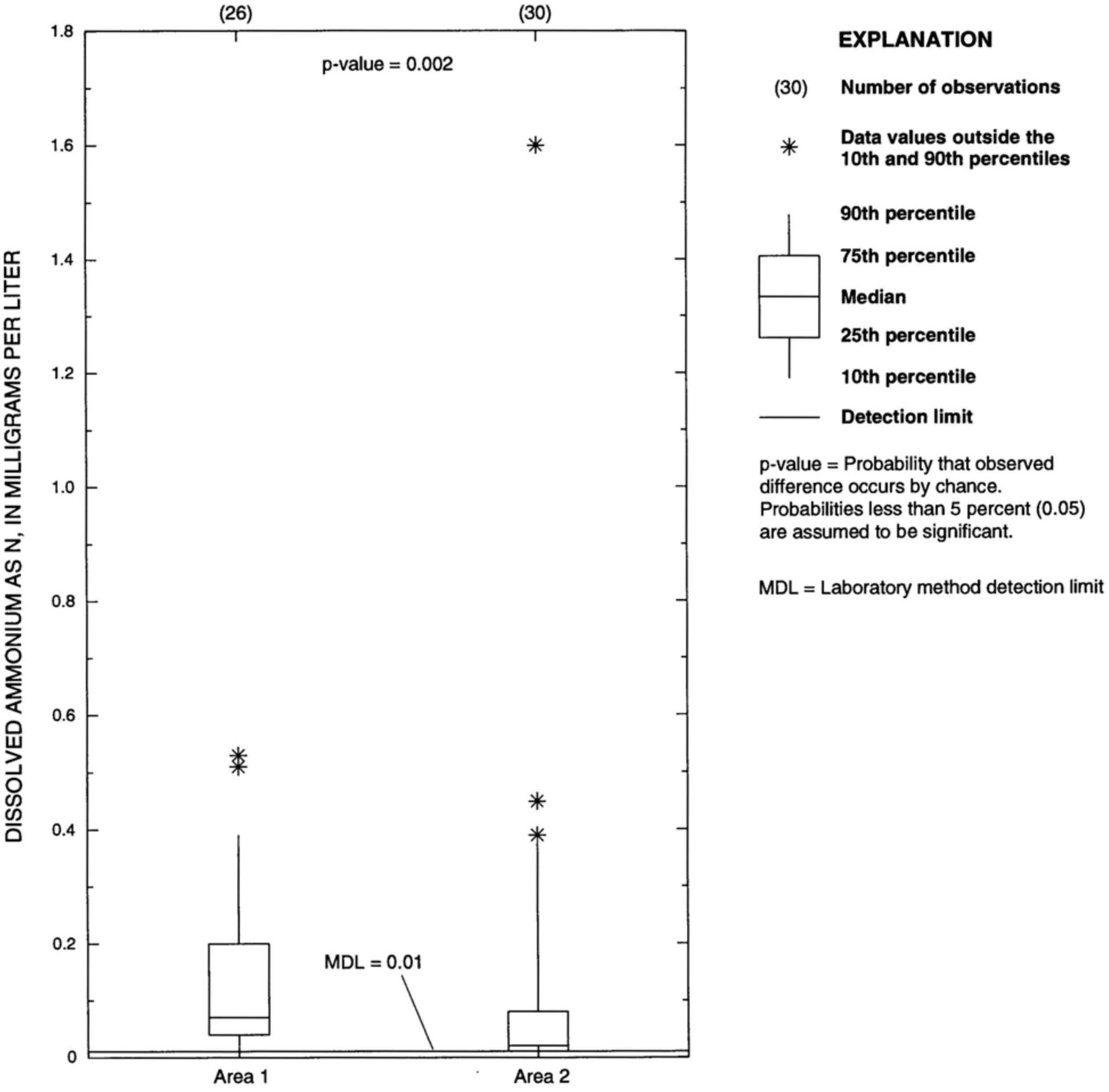


Figure 19. Boxplots of dissolved ammonium in ground water from sampled wells in the study areas.

insecticide DDT, which was banned in the United States in 1972.

Some of the most widely used pesticides in the two study areas have included alachlor, atrazine, cyanazine, and metolachlor. However, cyanazine was detected only twice and an alachlor metabolite (2'6-diethylaniline) was detected once, whereas metolachlor was detected in a large percentage of samples from area 1 and atrazine was detected in a large percentage of samples from both areas. Part of the reason for these differences is due the leaching potential of the different pesticides. Based on their soil half-lives, which is the amount of time it takes for half of the amount of the parent compound to degrade in soil, water solubilities, and soil organic carbon adsorption coefficients (K_{oc}), atrazine and metolachlor have large

Table 5. Pesticides and metabolites detected in ground-water samples collected in land-use study areas 1 and 2
[<, less than; ES, Wisconsin ground-water-quality enforcement standard; PAL, Wisconsin ground-water-quality preventive action limit; µg/L, micrograms per liter]

Pesticide or metabolite	Percent detection[1] area 1 / area 2	Maximum concentration, in µg/L area 1 / area 2	ES/PAL, in µg/L	Use or origin
Atrazine	64 / 90	0.24 / 1.3	3 / 0.3	Herbicide
Carbofuran	3.6 / 3.3	.004 / .012	40 / 8	Insecticide
Cyanazine	3.6 / 3.3	.007 / .014	12.5 / 1.25	Herbicide
DCPA	3.6 / 0	.001 / <.002	4000 / 800	Herbicide
Deethyl atrazine	57 / 93	.39 / 2.6	3 / .3	Herbicide metabolite (atrazine)
2'6-diethylanaline	0 / 3.3	<.003 / .003	NONE	Herbicide metabolite (alachlor)
Metolachlor	29 / 0	.016 / <.002	15/ 1.5	Herbicide
p,p'-DDE	7.1 / 13	.002 / .001	NONE	Insecticide metabolite (DDT)
Prometon	14 / 3.3	.14 / .009	NONE	Herbicide (noncrop land)
Simazine	7.1 / 17	.015 / .046	4 / .4	Herbicide
Tebuthiuron	3.6 / 0	.019 / <.01	NONE	Herbicide (noncrop land)
Triallate	0 / 6.7	<.001 / .002	NONE	Herbicide

[1] N=28 in area 1, N=30 in area 2.

leaching potentials compared to a medium potential for cyanazine and a small to medium potentials for alachlor (Goss, 1992; Montgomery, 1993). This difference in leachability is primarily due to longer soil half-lives for atrazine and metolachlor.

Atrazine, and one of its metabolites, deethyl atrazine, were the most commonly detected pesticide or metabolite in water samples from both areas. In order to better understand the effects of atrazine on ground-water quality, atrazine plus deethyl atrazine concentrations between the study areas were compared. As discussed earlier in this report, recent and historic atrazine application rates may be slightly higher in area 1, however atrazine plus deethyl atrazine concentrations were significantly higher (p-level < 0.001) in area 2 (fig. 21). The PAL of 0.30 µg/L for atrazine plus its metabolites was exceeded in 10 of 30 ground-water samples from area 2 and in only 3 of 28 samples in area 1. The ES of 3.0 µg/L was only exceeded in only one sample from a well in area 2. These exceedences may be lower than actual due to the poor recoveries of deethyl atrazine.

Higher atrazine plus deethyl atrazine concentrations were probably due to the more permeable surficial deposits in area 2. As with nitrate, the highest atrazine plus deethyl atrazine concentrations generally correspond to the highest measured K values (fig. 22). Figure 23 shows that relatively high concentrations of atrazine plus deethyl atrazine were present at depth below the water table in area 2. In contrast, concentrations decrease with depth below the water table in area 1. It appears that very little atrazine or deethyl atrazine makes it to depths greater than about 7 ft below the water table in area 1 (fig. 23).

The concentration of atrazine plus deethyl atrazine was related to the age of the sampled water. Samples identified as old water (water recharged before about 1955) generally had very low or non-detectable concentrations of atrazine or deethyl atrazine; atrazine was not registered until 1958 and was not widely used in Wisconsin until the early 1960s (Wollenhaupt and others, 1990). Several samples of old water did have detectable, but relatively low, concentrations of atrazine, as well as several other pesticides, probably from some mixing with younger waters.

CFC- and tritium-based recharge dates also showed that historic patterns of atrazine plus deethyl atrazine concentrations in ground water mimic historic patterns of atrazine use. Nationally, atrazine use on corn increased steadily from the early 1960s, until the late 1970s and early 1980s [(Biing-Hwan and others, 1995) (fig. 24)]. Based on CFC and tritium recharge dates, detectable concentrations of atrazine plus deethyl atrazine became more common as atrazine use increased (fig. 24). Atrazine use on corn in Wisconsin,

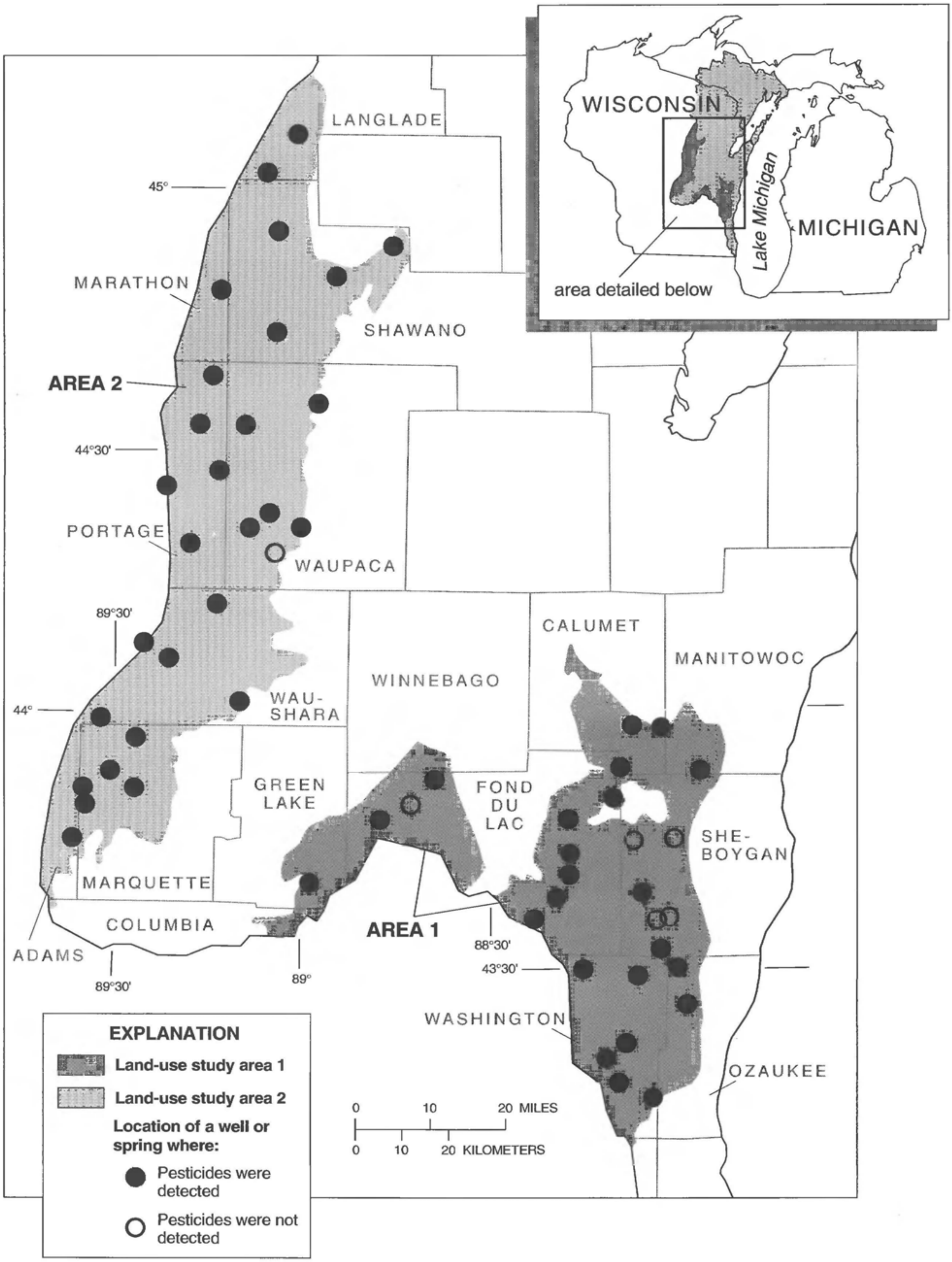


Figure 20. Locations of wells and springs in the study areas where pesticides were detected in ground-water samples.

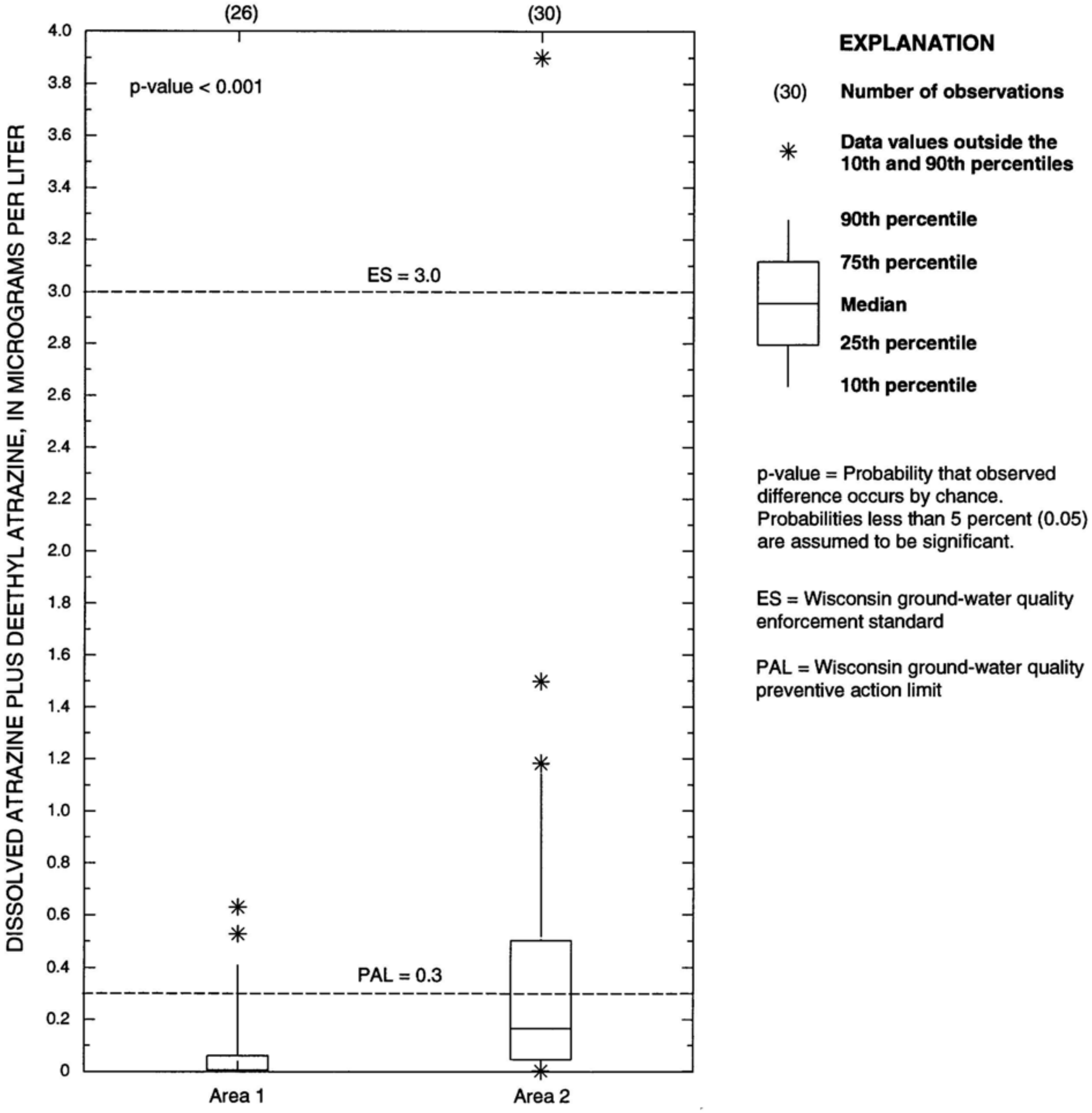


Figure 21. Boxplots of dissolved atrazine plus deethyl atrazine in ground water from sampled wells in the study areas.

and presumably in the study areas, peaked somewhere between 1978 and 1990 (fig. 24). Between 1978 and 1985 the total amount of atrazine used on corn in Wisconsin, and the rate of application increased from 4.4 million pounds and 1.5 lb/acre, respectively, to 5.2 million pounds and 1.6 lb/acre, respectively (WASS, 1979; WASS, 1986). In 1990, atrazine use and rates decreased to 2.9 million pounds and 1.43 lb/acre respectively (WASS, 1991). The period between 1978 and 1990 also corresponds to the recharge date of some of the highest measured concentrations of atrazine plus deethyl atrazine in ground-water samples from both study areas (fig. 24). If atrazine use continues to decrease, then it should be expected that concentrations of atrazine plus deethyl atrazine in shallow ground-water will also decrease. However, because ground-

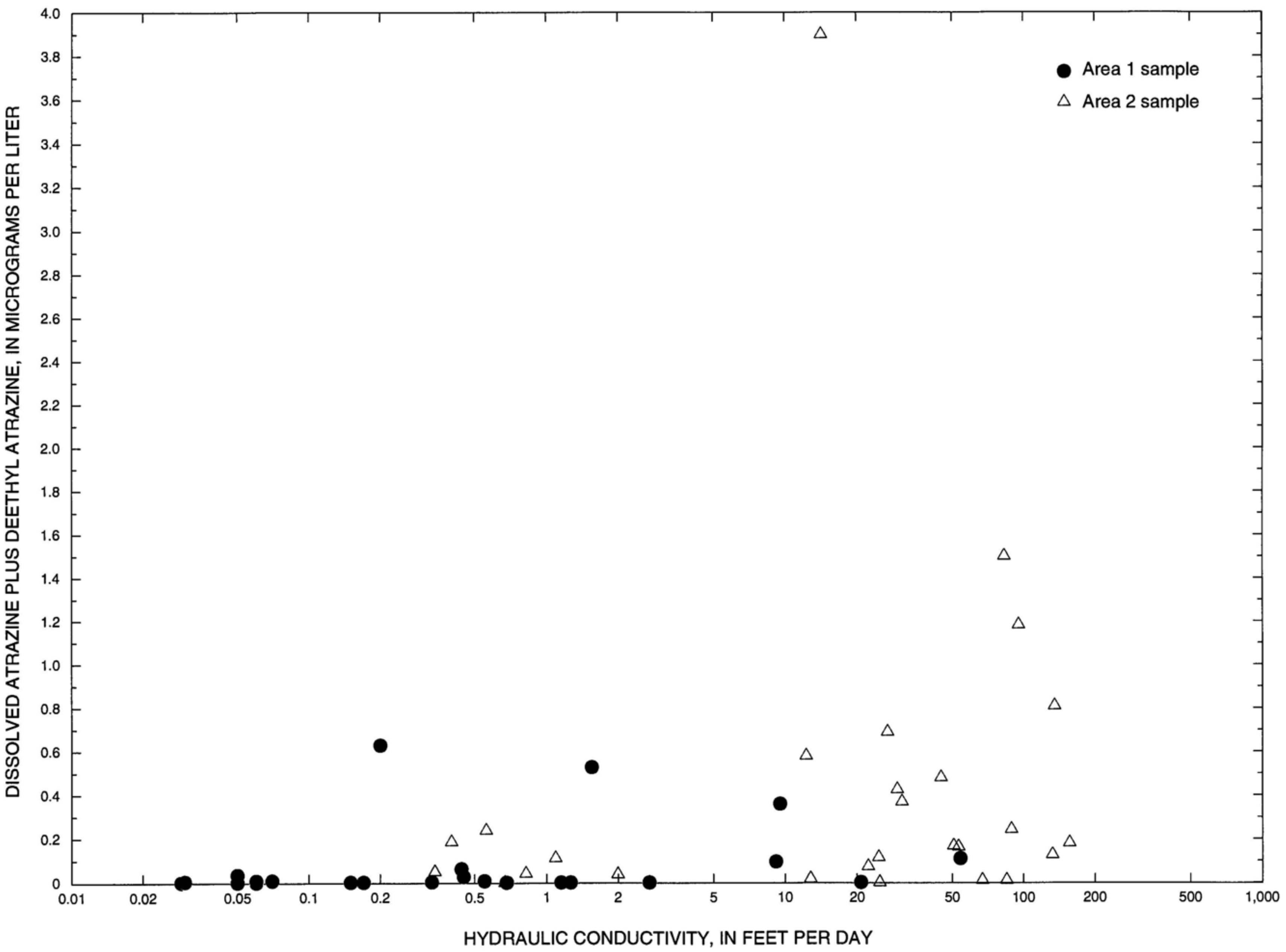


Figure 22. Relation between dissolved atrazine plus deethyl atrazine and hydraulic conductivity for sampled wells in the study areas.

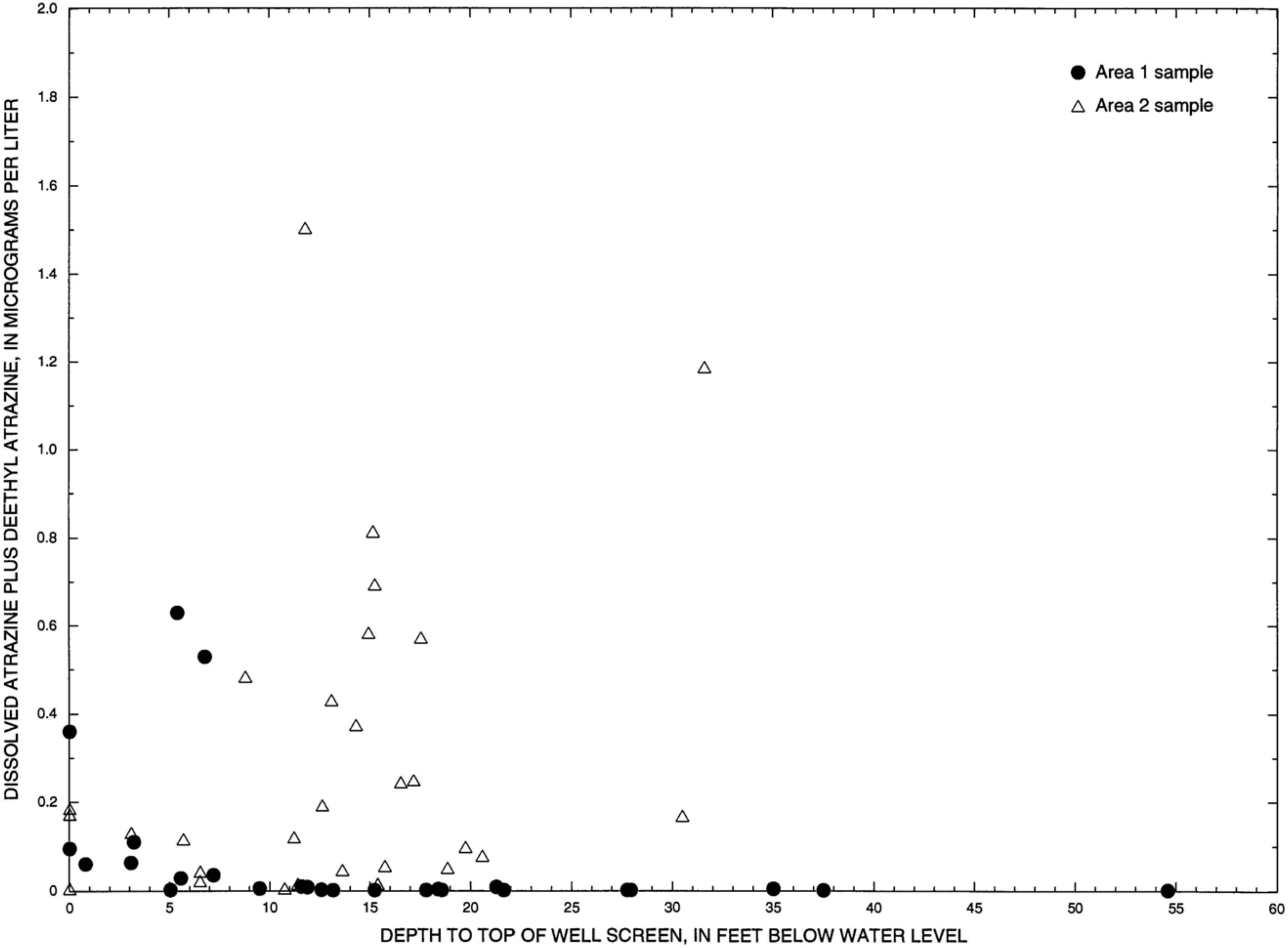


Figure 23. Relation between dissolved atrazine plus deethyl atrazine and depth to top of well screen, in feet below water level, for the study areas. (For water levels within the screened interval, depth to top of well screen, in feet below water level, was set equal to zero.)

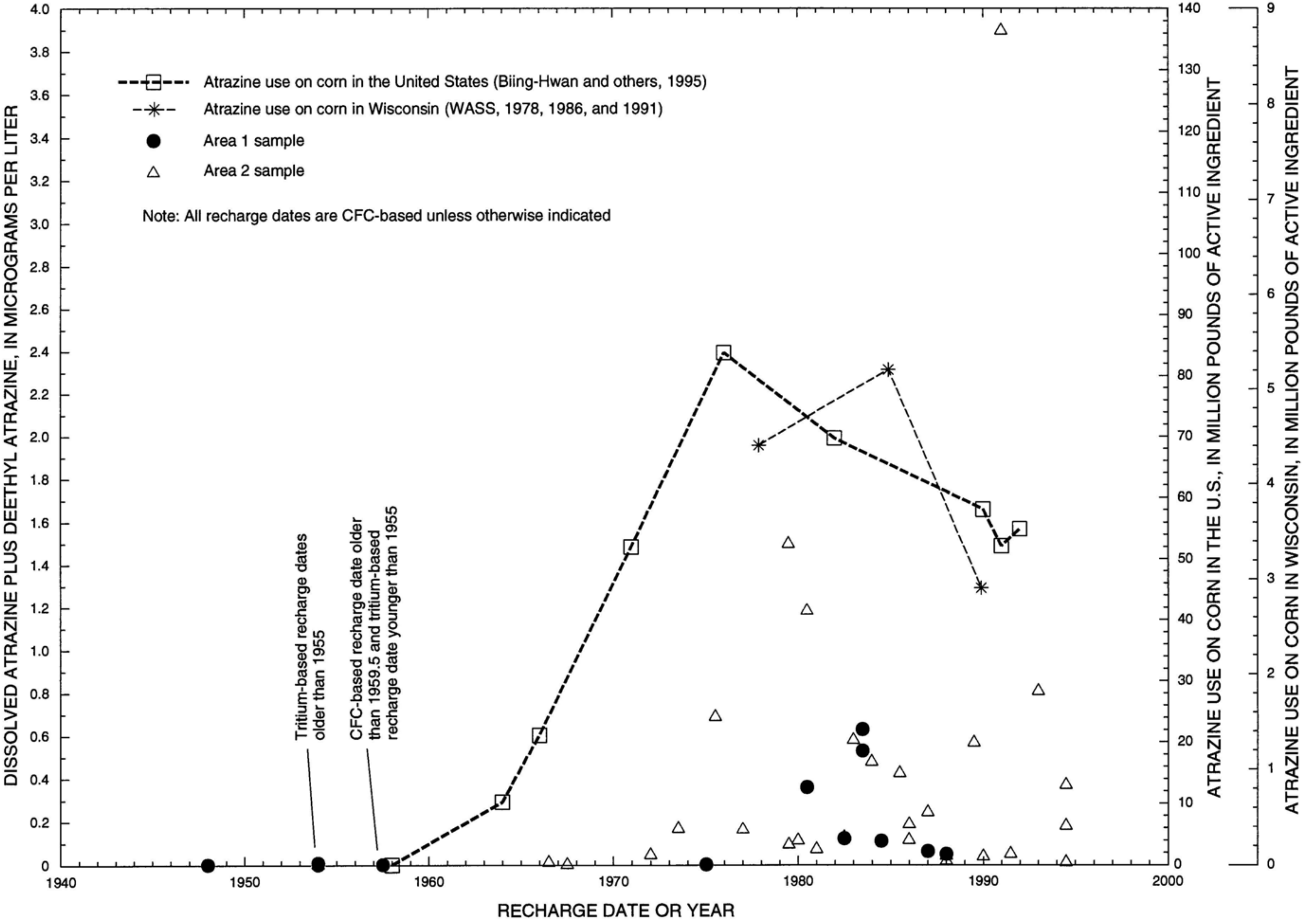


Figure 24. Relation between dissolved atrazine plus deethyl atrazine and recharge date for ground-water samples from the study areas, and historical atrazine use on corn in the United States and in Wisconsin.

water samples, even for shallow ground water, generally represent water that is already several years old, it will take years to see the effects of reduced atrazine use on ground-water quality in the study areas.

SUMMARY

The two areas studied for this report had similar agricultural land uses but different geohydrologic characteristics. Sampled monitor wells and springs were located downgradient from farm fields having similar crop rotation patterns, mainly corn and alfalfa. Area 1 is characterized by sand and clay surficial deposits overlying carbonate bedrock, and area 2 is characterized by sand and gravel surficial deposits overlying sandstone or crystalline bedrock. Depths to water were significantly deeper, and the hydraulic conductivity of the surficial deposits were significantly greater, in area 2.

Water-quality analyses indicate that agricultural land use has affected the ground-water quality of both of the study areas, however, Wisconsin ground-water-quality enforcement standards were exceeded in only 22 percent (13 of 58) of samples for dissolved nitrate and 2 percent (1 of 58) of samples for dissolved atrazine plus deethyl atrazine. There was a significant difference in the concentrations of dissolved nitrate and dissolved atrazine plus deethyl atrazine, in the shallow ground water in the two areas. Although the amount of nitrogen fertilizer and manure applied to the land surface was similar or slightly higher in area 2, as compared to area 1, and atrazine application rates may have been slightly higher in area 1, area 2 had significantly higher concentrations of both dissolved nitrate and atrazine plus deethyl atrazine in shallow ground water. The main reasons for this difference in concentrations were likely the higher permeability and lower soil-organic matter content of the surficial deposits in area 2. The permeable surficial deposits allowed nitrate and atrazine and its metabolites to readily leach to ground water in area 2. Additionally, the lower soil-organic matter content in area 2 helped to maintain higher dissolved oxygen concentrations in recharging water and throughout the saturated zone, thereby reducing the possibility of denitrification or assimilative uptake.

Recharge dates based on tritium and CFCs showed that historic patterns of atrazine plus deethyl atrazine concentrations in ground water mimic historic patterns of atrazine use on corn. Atrazine plus deethyl atrazine concentrations in ground water that recharged before the early 1960s, when atrazine started to become widely used on corn in Wisconsin, were very low or not detectable. As atrazine use on corn steadily increased from the late 1960s to the late 1970s and early 1980s, detectable concentrations of atrazine plus deethyl atrazine in ground water became more common. The recharge dates of some of the highest measured concentrations of atrazine plus deethyl atrazine in ground water from both study areas correspond to the period of highest atrazine use on corn in the State.

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APPENDIXES 1–3

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages

[na, not applicable; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter]

Constituent	NWQL parameter code	Number of samples / number of detections Area 1	Number of samples / number of detections Area 2	Laboratory method detection limit (MDL)
FIELD MEASUREMENTS				
Water temperature (°C)	00010	28 / 28	30 / 30	na
Specific conductance (µS/cm at 25°C)	00095	28 / 28	30 / 30	na
Dissolved oxygen, mg/L	00300	25 / 25	29 / 29	na
pH (standard units)	00400	28 / 28	30 / 30	na
INORGANICS				
Total dissolved solids, (residue at 180°C)	70300	28 / 28	30 / 30	1
Major ions (sample passed through 0.45 micron filter; MDL in mg/L unless otherwise noted)				
Alkalinity, lab	90410	28 / 28	30 / 30	1
Bromide	71870	28 / 25	30 / 28	0.01
Calcium	00915	28 / 28	30 / 30	.02
Chloride	00940	28 / 28	30 / 30	.1
Fluoride	00950	28 / 22	30 / 9	.1
Iron	01046	28 / 20	30 / 18	3.0 µg/L
Magnesium	00925	28 / 28	30 / 30	.01
Manganese	01056	28 / 27	30 / 26	1.0 µg/L
Potassium	00935	28 / 28	30 / 30	.1
Silica	00955	28 / 28	30 / 30	.01
Sodium	00930	28 / 28	30 / 30	.2
Sulfate	00945	28 / 28	30 / 30	.1
Nutrients (sample passed through 0.45-micron filter; MDL in mg/L)				
Ammonia, as N (described as ammonium in text and appendix 2)	00608	28 / 28	30 / 23	.01
Ammonia plus organic nitrogen, as N (described as ammonium plus organic in text and appendix 2)	00623	28 / 14	30 / 8	.2
Nitrite, as N	00613	28 / 6	30 / 10	.01
Nitrite plus nitrate, as N	00631	28 / 15	30 / 28	.05
Orthophosphate, as P	00671	28 / 14	30 / 3	.01
Phosphorus, as P	00666	28 / 22	30 / 16	.01
Radionuclides				
Tritium (whole water sample)	07000	19 / 19	30 / 30	.3 pCi/L
Uranium (sample passed through 0.45-micron filter)	22703	27 / 20	30 / 13	.4 µg/L
Isotopes (whole water sample)				
Deuterium/hydrogen ratio, reported in per mil relative to Standard Mean Ocean Water (SMOW)	82082	28 / 28	30 / 30	2 per mil precision
$^{18}O/^{16}O$ ratio, reported in per mil relative to SMOW	82085	28 / 28	30 / 30	0.2 per mil precision
ORGANICS				
Dissolved organic carbon (sample passed through 0.45- micron silver filter)	00681	28 / 28	30 / 30	.1 mg/L
Pesticides or metabolites (Schedules 2001 and 2010[1]; sample passed through 0.7-micron filter; MDL in µg/L)				
Acetochlor	49260	28 / 0	30 / 0	.002
Alachlor	46342	28 / 0	30 / 0	.002
Atrazine	39632	28 / 18	30 / 27	.001

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Constituent	NWQL parameter code	Number of samples / number of detections Area 1	Number of samples / number of detections Area 2	Laboratory method detection limit (MDL)
Pesticides or metabolites (Schedules 2001 and 2010)—Continued				
Atrazine, deethyl-[2]	04040	28 / 16	30 / 28	.002
Azinphos, methyl-[2]	82686	28 / 0	30 / 0	.001
Benfluralin	82673	28 / 0	30 / 0	.002
Butylate	04028	28 / 0	30 / 0	.002
Carbaryl[2]	82680	28 / 0	30 / 0	.003
Carbofuran[2]	82674	28 / 1	30 / 1	.003
Chlorpyrifos	38933	28 / 0	30 / 0	.004
Cyanazine	04041	28 / 1	30 / 1	.004
DCPA	82682	28 / 1	30 / 0	.002
DDE, p,p`-	34653	28 / 2	30 / 4	.006
Diazinon	39572	28 / 0	30 / 0	.002
Dieldrin	39381	28 / 0	30 / 0	.001
Diethylaniline, 2'6-	82660	28 / 0	30 / 1	.003
Disulfoton	82677	28 / 0	30 / 0	.017
EPTC	82668	28 / 0	30 / 0	.002
Ethalfluralin	82663	28 / 0	30 / 0	.004
Ethoprop	82672	28 / 0	30 / 0	.003
Fonofos	04095	28 / 0	30 / 0	.003
HCH, alpha	34253	28 / 0	30 / 0	.002
Lindane	39341	28 / 0	30 / 0	.004
Linuron	82666	28 / 0	30 / 0	.002
Malathion	39532	28 / 0	30 / 0	.005
Metolachlor	39415	28 / 8	30 / 0	.002
Metribuzin	82630	28 / 0	30 / 0	.004
Molinate	82671	28 / 0	30 / 0	.004
Napropamide	82684	28 / 0	30 / 0	.003
Parathion, ethyl-	39542	28 / 0	30 / 0	.004
Parathion, methyl-	82667	28 / 0	30 / 0	.006
Pebulate	82669	28 / 0	30 / 0	.004
Pendimethalin	82683	28 / 0	30 / 0	.004
Permethrin, cis-	82687	28 / 0	30 / 0	.005
Phorate	82664	28 / 0	30 / 0	.002
Prometon	04037	28 / 4	30 / 1	.018
Pronamide	82676	28 / 0	30 / 0	.003
Propachlor	04024	28 / 0	30 / 0	.007
Propanil	82679	28 / 0	30 / 0	.004
Propargite	82685	28 / 0	30 / 0	.013
Simazine	04035	28 / 2	30 / 5	.005
Thiobencarb	82670	28 / 0	30 / 0	.002
Tebuthiuron	82665	28 / 1	30 / 0	.010
Terbacil[2]	82675	28 / 0	30 / 0	.007
Terbufos	82681	28 / 0	30 / 0	.013
Triallate	82678	28 / 0	30 / 2	.001
Trifluralin	82661	28 / 0	30 / 0	.002

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Constituent	NWQL parameter code	Number of samples / number of detections Area 1	Number of samples / number of detections Area 2	Laboratory method detection limit (MDL)
Pesticides or metabolites (Schedules 2050 and 2051; sample passed through .7-micron filter, MDL in µg/L)				
2,4,5-T	39742	28 / 0	30 / 0	.035
2,4-D	39732	28 / 0	30 / 0	.035
2,4-DB	38746	28 / 0	30 / 0	.035
Acifluorfen	49315	28 / 0	30 / 0	.035
Aldicarb	49312	28 / 0	30 / 0	.016
Aldicarb sulfone	49313	28 / 0	30 / 0	.016
Aldicarb sulfoxide	49314	28 / 0	30 / 0	.021
Bentazon	38711	28 / 0	30 / 0	.014
Bromacil	04029	28 / 0	30 / 0	.035
Bromoxynil	49311	28 / 0	30 / 0	.035
Carbaryl	49310	28 / 0	30 / 0	.008
Carbofuran	49309	28 / 0	30 / 0	.028
Carbofuran, 3-hydroxy-	49308	28 / 0	30 / 0	.014
Chloramben	49307	28 / 0	30 / 0	.011
Chlorothalonil[2]	49306	28 / 0	30 / 0	.035
Clopyralid	49305	28 / 0	30 / 0	.05
Dacthal, mono-acid-	49304	28 / 0	30 / 0	.017
Dicamba	38442	28 / 0	30 / 0	.035
Dichlobenil[2]	49303	28 / 0	30 / 0	.02
Dichlorprop	49302	28 / 0	30 / 0	.032
Dinoseb	49301	28 / 0	30 / 0	.035
Diuron	49300	28 / 0	30 / 0	.02
DNOC[2]	49299	28 / 0	30 / 0	.035
Esfenvalerate[2]	49298	28 / 0	30 / 0	.019
Fenuron	49297	28 / 0	30 / 0	.013
Fluometuron	38811	28 / 0	30 / 0	.035
Linuron	38478	28 / 0	30 / 0	.018
MCPA	38482	28 / 0	30 / 0	.05
MCPB	38487	28 / 0	30 / 0	.035
Methiocarb	38501	28 / 0	30 / 0	.026
Methomyl	49296	28 / 0	30 / 0	.017
1-Naphthol[2]	49295	28 / 0	30 / 0	.007
Neburon	49294	28 / 0	30 / 0	.015
Norflurazon	49293	28 / 0	30 / 0	.024
Oryzalin	49292	28 / 0	30 / 0	.019
Oxamyl	38866	28 / 0	30 / 0	.018
Picloram	49291	28 / 0	30 / 0	.05
Propham	49236	28 / 0	30 / 0	.035
Propoxur	38538	28 / 0	30 / 0	.035
Silvex	39762	28 / 0	30 / 0	.021
Triclopyr	49235	28 / 0	30 / 0	.05
Volatile organic compounds (whole water sample; MDL in µg/L)				
Benzene[3]	34030	28 / 2	30 / 0	.2
Benzene, 1,2,3-trichloro-	77613	28 / 0	30 / 0	.2

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Constituent	NWQL parameter code	Number of samples / number of detections Area 1	Number of samples / number of detections Area 2	Laboratory method detection limit (MDL)
Volatile organic compounds—Continued				
Benzene, 1,2,4-trichloro-	34551	28 / 0	30 / 0	.2
Benzene, 1,2,4-trimethyl-	77222	28 / 0	30 / 0	.2
Benzene, 1,2-dichloro-	34536	28 / 0	30 / 0	.2
Benzene, 1,3,5-trimethyl-	77226	28 / 0	30 / 0	.2
Benzene, 1,3-dichloro-	34566	28 / 0	30 / 0	.2
Benzene, 1,4-dichloro-	34571	28 / 0	30 / 0	.2
Benzene, 1-chloro-2-methyl-	77275	28 / 0	30 / 0	.2
Benzene, 1-chloro-4-methyl-	77277	28 / 0	30 / 0	.2
Benzene, isopropyl-	77223	28 / 0	30 / 0	.2
Benzene, bromo-	81555	28 / 0	30 / 0	.2
Benezene, chloro-	34301	28 / 0	30 / 0	.2
Benzene, dimethyl-(Xylene)	81551	28 / 0	30 / 0	.2
Benzene, ethyl-	34371	28 / 0	30 / 0	.2
Benzene, 1-methyl-4-isopropyl-	77356	28 / 0	30 / 0	.2
Benzene, methyl-(Toluene)[3]	34010	28 / 13	30 / 2	.2
Benzene, n-butyl-	77342	28 / 0	30 / 0	.2
Benzene, n-propyl-	77224	28 / 0	30 / 0	.2
Benzene, sec-butyl-	77350	28 / 0	30 / 0	.2
Benzene, tert-butyl-	77353	28 / 0	30 / 0	.2
Ethane, 1,1,1,2-tetrachloro-	77562	28 / 0	30 / 0	.2
Ethane, 1,1,1-trichloro-	34506	28 / 0	30 / 0	.2
Ethane, 1,1,2,2-tetrachloro-	34516	28 / 0	30 / 0	.2
Ethane, 1,1,2-trichloro-	34511	28 / 0	30 / 0	.2
Ethane, 1,1-dichloro-	34496	28 / 0	30 / 0	.2
Ethane, 1,2-dibromo-	77651	28 / 0	30 / 0	.2
Ethane, 1,2-dichloro-	32103	28 / 0	30 / 0	.2
Ethane, chloro-	34311	28 / 0	30 / 0	.2
Ethane, trichlorotrifluoro-	77652	28 / 0	30 / 0	.2
Ethylene, 1,1-dichloro-	34501	28 / 0	30 / 0	.2
Ethylene, chloro-(Vinyl chloride)	39175	28 / 0	30 / 0	.2
Ethylene, cis-1,2-dichloro-	77093	28 / 0	30 / 0	.2
Ethylene, tetrachloro-	34475	28 / 0	30 / 0	.2
Ethylene, trans-1,2-dichloro-	34546	28 / 0	30 / 0	.2
Ethylene, trichloro-	39180	28 / 0	30 / 0	.2
Hexachlorobutadiene	39702	28 / 0	30 / 0	.2
Methane, bromo-	34413	28 / 0	30 / 0	.2
Methane, bromochloro-	77297	28 / 0	30 / 0	.2
Methane, chloro-(methyl chloride)[4]	34418	28 / 14	30 / 22	.2
Methane, dibromo-	30217	28 / 0	30 / 0	.2
Methane, dibromochloro-	32105	28 / 0	30 / 0	.2
Methane, dichloro-(methylene chloride)	34423	28 / 0	30 / 0	.2
Methane, dichlorobromo-	32101	28 / 0	30 / 1	.2
Methane, dichlorodifluoro-	34668	28 / 0	30 / 0	.2

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Constituent	NWQL parameter code	Number of samples / number of detections Area 1	Number of samples / number of detections Area 2	Laboratory method detection limit (MDL)
Volatile organic compounds—Continued				
Methane, tetrachloro-	32102	28 / 0	30 / 0	.2
Methane, tribromo-	32104	28 / 0	30 / 0	.2
Methane, trichloro-(chloroform)	32106	28 / 0	30 / 2	.2
Methane, trichlorofluoro-	34488	28 / 0	30 / 0	.2
Naphthalene	34696	28 / 0	30 / 0	.2
Propane, 1,2,3-trichloro-	77443	28 / 0	30 / 0	.2
Propane, 1,2-dibromo-3-chloro-	82625	28 / 0	30 / 0	1.0
Propane, 1,2-dichloro-	34541	28 / 0	30 / 0	.2
Propane, 1,3-dichloro-	77173	28 / 0	30 / 0	.2
Propane, 2,2-dichloro-	77170	28 / 0	30 / 0	.2
Propene, 1,1-dichloro-	77168	28 / 0	30 / 0	.2
Propene, 2-methoxy-2-methyl-(MTBE)	78032	28 / 0	30 / 0	.2
Propene, cis-1,3-dichloro-	34704	28 / 0	30 / 0	.2
Propene, trans-1,3-dichloro-	34699	28 / 0	30 / 0	.2
Styrene	77128	28 / 0	30 / 0	.2

[1] The pesticide dimethoate was originally included on schedules 2001 and 2010, but it was later deleted because of poor recoveries and it is not included in this report.

[2] These pesticides demonstrated variable recoveries and are reported as estimated values in appendix 2 if measured concentrations were above the MDL.

[3] Detections were due to contamination from the PVC used to construct the monitoring wells. Therefore, water-quality data for these constituents are not included in appendix 2.

[4] Methyl chloride is believed to result from preservation of the sample with hydrochloric acid. Therefore, water-quality data for this constituent is not included in appendix 2.

Appendix 2a. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages

[All concentrations in milligrams per liter, unless otherwise indicated; yyyy, year; mm, month; dd, day; °C, degrees Celsius; µS/cm, microsiemens per centimeter; <, less than; --, no data]

Well number (study area)	Sample date (yyyymmdd)	Sample time	Water temperature (°C)	Specific conductance (µS/cm at 25°C)	Dissolved oxygen	pH (standard units)	Lab alkalinity (as $CaCO_3$)	Lab bicarbonate (as HCO_3^-)[1]	Bromide	Calcium	Chloride
Well 1-1f (area 1)	19940616	1200	9.8	605	2.9	7.2	280	343	0.02	71	5.9
Well 1-1a (area 1)	19940804	0900	15.3	965	8.1	7.1	310	378	.06	93	77
Spring 1-3 (area 1)	19940803	1400	9.5	700	7.1	7.1	310	379	.05	76	20
Well 1-4 (area 1)	19930901	1300	11.5	918	.1	7.3	450	549	.09	94	15
Well 1-5 (area 1)	19940803	0900	13.0	990	--	7.3	471	575	.13	100	33
Spring 1-7 (area 1)	19940804	1430	9.9	732	5.1	7.2	328	400	.05	78	26
Well 1-9 (area 1)	19940714	1310	10.9	638	2.9	7.6	294	359	.11	46	15
Well 1-10 (area 1)	19940712	1000	19.3	1,220	8.1	7.0	418	510	.05	96	150
Well 1-11 (area 1)	19940713	0900	14.7	888	--	7.7	391	477	.31	87	52
Well 1-12 (area 1)	19930908	0840	11.9	318	.2	7.8	181	221	<.01	36	1.3
Well 1-13 (area 1)	19940712	1230	13.6	900	--	7.4	404	493	.04	110	19
Well 1-14 (area 1)	19940712	1630	14.5	876	.8	6.8	453	553	.09	110	19
Well 1-15 (area 1)	19940714	0930	10.5	916	8.2	7.2	316	386	.07	91	45
Well 1-16 (area 1)	19930905	1200	17.1	703	1.6	7.3	272	332	.05	69	28
Well 1-17 (area 1)	19930905	1520	17.8	890	4.6	6.9	378	461	.04	99	43
Well 1-18 (area 1)	19930902	1130	13.5	576	.3	7.3	251	306	.02	66	6.3
Well 1-19 (area 1)	19940802	1230	11.2	818	1.8	7.4	272	332	.12	66	88
Well 1-20 (area 1)	19940802	0900	12.2	690	3.2	7.3	259	316	.27	56	41
Well 1-21 (area 1)	19930908	1200	11.2	665	.1	7.2	357	436	.02	81	3.6

Appendix 2a. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	Sample date (yyyymmdd)	Sample time	Water temperature (°C)	Specific conductance (µS/cm at 25°C)	Dissolved oxygen	pH (standard units)	Lab alkalinity (as $CaCO_3$)	Lab bicarbonate (as HCO_3^-)[1]	Bromide	Calcium	Chloride
Well 1-22 (area 1)	19930907	1430	16.3	725	1.8	7.6	329	401	.25	39	35
Well 1-23 (area 1)	19930907	1220	17.9	378	1.4	7.1	355	433	.07	89	9.1
Well 1-24 (area 1)	19940801	1330	10.3	966	5.0	7.2	327	399	.06	99	83
Well 1-25 (area 1)	19930906	1650	13.8	616	1.6	7.5	266	325	.18	63	28
Well 1-26 (area 1)	19930906	1430	13.7	849	.5	7.3	267	326	<.01	110	3.0
Well 1-27 (area 1)	19940711	1320	12.7	463	1.0	7.8	222	271	.01	45	3.5
Well 1-28 (area 1)	19930902	1430	14.7	620	1.3	7.2	302	368	.03	70	34
Well 1-29 (area 1)	19930906	0920	9.9	583	.1	7.4	283	345	.02	67	4.1
Well 1-30 (area 1)	19930903	1045	15.0	244	1.5	7.8	117	143	<.01	16	2.4
Well 2-1 (area 2)	19940920	0930	11.9	523	9.6	7.0	256	312	.03	60	6.5
Well 2-2 (area 2)	19940920	1230	12.0	481	10.5	7.4	207	253	.02	53	9.5
Well 2-3 (area 2)	19940920	1520	12.4	511	4.5	7.1	194	237	.02	58	16
Well 2-4 (area 2)	19940920	1250	11.6	514	8.7	7.2	218	266	.02	57	13
Well 2-5 (area 2)	19940920	1530	11.4	438	9.9	7.2	210	256	.02	49	4.8
Well 2-6 (area 2)	19940916	0900	11.8	881	10.2	6.9	276	337	.06	94	29
Well 2-7 (area 2)	19940914	1400	11.7	867	8.6	7.4	241	294	.05	90	46
Well 2-8 (area 2)	19940914	1540	11.4	644	8.1	7.0	302	368	.04	72	14
Well 2-9 (area 2)	19940915	0900	11.9	444	9.2	7.3	175	214	.02	48	9.5
Well 2-10 (area 2)	19940921	0900	11.2	313	10.7	6.8	94	115	.02	30	8.3
Well 2-11 (area 2)	19940920	0950	11.7	828	.2	7.0	373	455	.06	92	37

Appendix 2a. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	Sample date (yyyymmdd)	Sample time	Water temperature (°C)	Specific conductance (µS/cm at 25°C)	Dissolved oxygen	pH (standard units)	Lab alkalinity (as CaCO$_3$)	Lab bicarbonate (as HCO$_3^-$)[1]	Bromide	Calcium	Chloride
Well 2-12 (area 2)	19940916	1230	13.2	398	10.7	7.6	182	222	.02	45	2.2
Well 2-13 (area 2)	19940915	1200	11.4	414	6.9	7.4	173	211	.02	44	11
Well 2-14 (area 2)	19940914	1630	11.9	461	3.8	7.4	197	240	.03	51	6
Well 2-15 (area 2)	19940914	1100	9.4	299	.2	6.4	123	150	.07	29	10
Well 2-16 (area 2)	19940913	1300	11.7	750	.6	7.0	280	342	.04	81	43
Well 2-17 (area 2)	19940912	1300	10.6	766	3.3	7.0	333	406	.03	90	36
Well 2-18 (area 2)	19940913	0930	21.3	288	2.7	6.3	113	138	.02	31	1.3
Well 2-19 (area 2)	19940914	1310	13.5	381	1.6	7.2	106	129	.01	41	25
Well 2-20 (area 2)	19940915	1100	12.2	582	7.0	7.1	192	234	.04	63	20
Well 2-21 (area 2)	19940916	0830	14.4	481	--	7.3	199	243	.03	53	14
Well 2-22 (area 2)	19940916	1140	11.7	473	9.4	7.1	130	159	.04	50	21
Well 2-23 (area 2)	19940915	1530	16.0	287	.4	8.2	143	175	<.01	17	.8
Well 2-24 (area 2)	19940915	1320	13.0	395	6.6	7.0	70	85	.02	40	11
Well 2-25 (area 2)	19940915	1530	12.1	823	4.9	7.0	370	451	.07	87	29
Well 2-26 (area 2)	19940914	1000	12.9	626	1.4	7.2	252	307	.05	69	26
Well 2-27 (area 2)	19940913	1400	14.2	593	.5	7.0	266	325	.02	70	22
Well 2-28 (area 2)	19940913	1345	10.6	361	.2	6.7	190	232	<.01	44	6.2
Well 2-29 (area 2)	19940913	1615	14.2	463	1.0	6.4	219	267	.02	52	13
Well 2-30 (area 2)	19940913	0930	9.4	496	6.5	7.3	232	283	.02	57	16

[1] Bicarbonate equals alkalinity x 1.22.

Appendix 2b. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages

[All concentrations in milligrams per liter, unless otherwise indicated; µg/L, micrograms per liter; <, less than]

Well number (study area)	Fluoride	Iron, in µg/L[1]	Magnesium	Manganese, in µg/L	Potassium	Silica	Sodium	Sulfate	Total dissolved solids	Ammonium, as N	Ammonium plus organic nitrogen, as N	Nitrite, as N
Well 1-1f (area 1)	0.1	< 3	36	78	1.4	18	3.2	21	306	0.51	0.7	< 0.01
Well 1-1a (area 1)	.2	6	56	300	3.6	17	21	22	566	.22	.3	.2
Spring 1-3 (area 1)	.2	< 3	44	1	2.2	18	6.9	28	410	.03	< .2	< .01
Well 1-4 (area 1)	.1	710	71	34	1.3	36	8.3	49	519	.1	< .2	< .01
Well 1-5 (area 1)	.2	6	71	340	2.4	22	9.3	58	581	.06	< .2	< .01
Spring 1-7 (area 1)	.1	< 3	45	< 1	2.1	15	9.4	32	448	.03	< .2	< .01
Well 1-9 (area 1)	.2	< 3	49	69	4	15	13	40	373	.1	.3	< .01
Well 1-10 (area 1)	< .1	< 3	58	26	2.4	15	72	22	690	.02	< .2	.05
Well 1-11 (area 1)	.2	< 3	59	220	1	12	11	34	508	.02	.3	< .01
Well 1-12 (area 1)	.3	1,300	22	99	1.3	20	27	5.1	187	.2	.3	< .01
Well 1-13 (area 1)	.1	< 3	56	5	.4	11	6.7	100	571	.02	< .2	< .01
Well 1-14 (area 1)	< .1	9	55	180	.8	14	4.1	34	517	.06	.2	.14
Well 1-15 (area 1)	< .1	3	57	17	1.2	13	5.1	25	577	.07	.3	< .01
Well 1-16 (area 1)	.1	16	48	240	2.3	19	5	72	389	.06	< .2	< .01
Well 1-17 (area 1)	< .1	17	58	7	1.4	18	8	49	513	.04	.2	< .01
Well 1-18 (area 1)	.1	42	39	140	1	19	3.6	27	333	.06	< .2	< .01
Well 1-19 (area 1)	.2	590	56	28	1.2	13	20	31	463	.06	< .2	.01
Well 1-20 (area 1)	.6	< 3	47	40	13	13	14	42	376	.34	.5	.01
Well 1-21 (area 1)	.2	260	44	180	1.2	27	3.9	18	348	.1	< .2	< .01

Appendix 2b. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	Fluoride	Iron, in µg/L[1]	Magnesium	Manganese, in µg/L	Potassium	Silica	Sodium	Sulfate	Total dissolved solids	Ammonium, as N	Ammonium plus organic nitrogen, as N	Nitrite, as N
Well 1-22 (area 1)	.3	8	66	59	3.2	27	16	17	398	.2	.3	<.01
Well 1-23 (area 1)	.2	10	60	270	2.2	17	6.3	64	474	.07	<.2	<.01
Well 1-24 (area 1)	.2	6	52	28	4.1	19	22	43	524	.03	<.2	.03
Well 1-25 (area 1)	<.1	10	37	220	4.1	14	14	51	358	.11	.3	<.01
Well 1-26 (area 1)	.3	230	45	340	2.5	20	13	220	583	.53	.6	<.01
Well 1-27 (area 1)	.2	130	28	63	.7	20	14	34	271	.25	.3	<.01
Well 1-28 (area 1)	.2	13	42	12	1	17	4.9	29	356	.04	<.2	<.01
Well 1-29 (area 1)	<.1	28	38	45	1.1	17	2.9	41	326	.03	<.2	<.01
Well 1-30 (area 1)	.3	40	8	67	1.4	13	28	8.4	147	.13	.2	<.01
Well 2-1 (area 2)	<.1	12	30	19	.5	17	4.2	12	286	.02	<.2	<.01
Well 2-2 (area 2)	<.1	5	29	6	.4	14	1.7	7.3	279	.02	<.2	<.01
Well 2-3 (area 2)	<.1	<3	26	1	.7	13	3.6	10	279	.01	<.2	<.01
Well 2-4 (area 2)	<.1	<3	30	<1	.4	11	4	15	263	<.01	<.2	<.01
Well 2-5 (area 2)	<.1	3	25	<1	.3	18	2.2	10	246	.02	<.2	<.01
Well 2-6 (area 2)	<.1	<3	50	4	.8	15	7.8	21	502	<.01	<.2	<.01
Well 2-7 (area 2)	<.1	4	47	3	1.6	12	4.4	21	528	.01	<.2	<.01
Well 2-8 (area 2)	.5	8	37	9	2.1	15	5.2	12	388	.05	<.2	.02
Well 2-9 (area 2)	<.1	<3	25	1	.5	13	2	10	247	<.01	<.2	<.01
Well 2-10 (area 2)	<.1	35	17	20	1	11	1.5	7	191	.02	<.2	.02
Well 2-11 (area 2)	.2	13	52	47	1	16	6.3	34	493	.02	<.2	.02

Appendix 2b. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	Fluoride	Iron, in µg/L[1]	Magnesium	Manganese, in µg/L	Potassium	Silica	Sodium	Sulfate	Total dissolved solids	Ammonium, as N	Ammonium plus organic nitrogen, as N	Nitrite, as N
Well 2-12 (area 2)	< .1	< 3	24	4	.6	11	1.4	10	223	.01	< .2	< .01
Well 2-13 (area 2)	< .1	6	21	< 1	2.5	6.5	2.8	5.7	223	< .01	< .2	< .01
Well 2-14 (area 2)	.3	4	27	1	1.4	13	2.7	14	259	< .01	< .2	< .01
Well 2-15 (area 2)	< .1	4,300	14	240	2.1	4.6	2.8	.3	157	.45	.8	< .01
Well 2-16 (area 2)	< .1	< 3	40	6	1.7	16	13	17	435	.02	< .2	< .01
Well 2-17 (area 2)	.2	< 3	47	24	2.3	16	7.5	9.5	485	.04	< .2	.47
Well 2-18 (area 2)	< .1	23,000	16	1,800	.5	23	1.1	3	191	.17	.4	.01
Well 2-19 (area 2)	< .1	3	18	21	1.4	12	2.7	9.8	224	.02	< .2	.03
Well 2-20 (area 2)	< .1	< 3	31	< 1	1.3	14	2.9	14	320	< .01	< .2	< .01
Well 2-21 (area 2)	< .1	< 3	27	2	.8	14	6	15	264	.01	< .2	< .01
Well 2-22 (area 2)	< .1	4	24	300	1.8	15	2.3	13	293	.04	< .2	.02
Well 2-23 (area 2)	.8	7	5.3	23	1.3	22	41	5.4	160	.39	.5	< .01
Well 2-24 (area 2)	< .1	< 3	17	5	1.1	15	4.2	11	250	< .01	< .2	< .01
Well 2-25 (area 2)	.2	5	54	120	3	19	6.4	16	470	.32	.4	.11
Well 2-26 (area 2)	.3	< 3	35	63	3.1	14	8.4	16	345	.11	.2	.09
Well 2-27 (area 2)	.3	240	31	300	7.7	14	5.5	15	334	.14	.3	.01
Well 2-28 (area 2)	< .1	1,600	20	110	.7	15	1.6	1.3	202	1.6	2.1	< .01
Well 2-29 (area 2)	< .1	15	21	780	10	8.7	3.8	2.1	253	.06	.3	< .01
Well 2-30 (area 2)	.1	< 3	29	79	2.9	12	2.6	4.5	271	.07	< .2	< .01

[1] Dissolved iron was detected in field blank samples at concentrations ranging from < 3 to 8 µg/L. For this reason low concentrations of dissolved iron may be an artifact of sample collection and processing.

Appendix 2c. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages

[All concentrations in milligrams per liter, unless otherwise indicated; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than; E, estimated; --, no data]

Well number (study area)	Nitrite plus nitrate, as N	Phosphorus, as P	Ortho phosphate, as P	Uranium, in µg/L	Tritium, in pCi/L	Deuterium/ hydrogen ratio, in per mil	$^{18}O/^{16}O$ ratio, in per mil	Dissolved organic carbon (DOC)[1]	Atrazine, in µg/L	Carbofuran, in µg/L	Cyanazine, in µg/L	DCPA, in µg/L
Well 1-1f (area 1)	< 0.05	< 0.01	< 0.01	--	68	-70.2	-10.4	1.6	< 0.001	< 0.003	< 0.004	< 0.002
Well 1-1a (area 1)	12	< .01	< .01	1.8	--	-63.7	-9.55	1.4	.24	< .003	< .004	< .002
Spring 1-3 (area 1)	6.2	.03	< .01	< .4	--	-69.2	-10.1	1.1	.023	< .003	< .004	< .002
Well 1-4 (area 1)	< .05	.02	.01	< .4	55	-61.6	-9.38	1.1	< .001	< .003	< .004	< .002
Well 1-5 (area 1)	.05	< .01	< .01	.5	62	-64.0	-9.68	1.8	.015	< .003	< .004	E .001
Spring 1-7 (area 1)	6.5	.03	< .01	.5	--	-65.3	-9.69	1.1	.056	< .003	< .004	< .002
Well 1-9 (area 1)	.32	.04	.02	1.5	11	-68.3	-10.2	2.6	< .001	< .003	< .004	< .002
Well 1-10 (area 1)	8.1	.02	< .01	.5	--	-63.3	-9.55	1.5	.011	< .003	< .004	< .002
Well 1-11 (area 1)	< .05	.01	< .01	5.5	37	-66.3	-9.90	3.7	< .001	< .003	< .004	< .002
Well 1-12 (area 1)	< .05	.07	.06	< .4	1	-64.3	-9.65	2.4	.002	< .003	< .004	< .002
Well 1-13 (area 1)	2	.01	< .01	.9	42	-79.6	-11.6	3.2	.023	< .003	< .004	< .002
Well 1-14 (area 1)	2.2	.01	< .01	.9	--	-66.8	-10.1	1.9	.24	< .003	< .004	< .002
Well 1-15 (area 1)	25	.01	< .01	< .4	--	-57.0	-8.76	2.2	< .001	< .003	< .004	< .002
Well 1-16 (area 1)	< .05	.04	.03	2.1	120	-63.9	-9.62	1.4	.004	< .003	< .004	< .002
Well 1-17 (area 1)	9.3	.04	.04	.8	55	-70.4	-10.5	2.6	.023	< .003	< .004	< .002
Well 1-18 (area 1)	< .05	.05	.03	.4	.7	-77.4	-11.4	.7	< .001	< .003	< .004	< .002
Well 1-19 (area 1)	.54	< .01	< .01	3.6	--	-75.3	-10.8	1.1	.002	< .003	< .004	< .002
Well 1-20 (area 1)	.06	< .01	< .01	.7	44	-67.5	-9.86	2.4	< .001	< .003	< .004	< .002
Well 1-21 (area 1)	< .05	.02	.02	< .4	3.2	-67.5	-10.1	1.2	.001	< .003	< .004	< .002

Appendix 2c. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	Nitrite plus nitrate, as N	Phosphorus, as P	Ortho phosphate, as P	Uranium, in µg/L	Tritium, in pCi/L	Deuterium/hydrogen ratio, in per mil	$^{18}O/^{16}O$ ratio, in per mil	Dissolved organic carbon (DOC)[1]	Atrazine, in µg/L	Carbofuran, in µg/L	Cyanazine, in µg/L	DCPA, in µg/L
Well 1-22 (area 1)	<.05	.03	.02	.5	12	-63.0	-9.75	6.1	.005	E.004	<.004	<.002
Well 1-23 (area 1)	.43	.02	.01	1.4	67	-59.8	-9.32	7.1	.002	<.003	<.004	<.002
Well 1-24 (area 1)	5.2	<.01	<.01	.9	--	-61.0	-9.11	1.3	.24	<.003	<.004	<.002
Well 1-25 (area 1)	<.05	.01	<.01	1	130	-72.0	-10.7	3	.003	<.003	.007	<.002
Well 1-26 (area 1)	<.05	.02	.02	.7	.4	-63.6	-9.90	2	.004	<.003	<.004	<.002
Well 1-27 (area 1)	<.05	.03	.01	<.4	--	-67.3	-10.0	1.2	<.001	<.003	<.004	<.002
Well 1-28 (area 1)	1.7	.01	.01	.7	57	-70.6	-10.6	.5	<.001	<.003	<.004	<.002
Well 1-29 (area 1)	<.05	.01	.01	<.4	73	-70.6	-10.5	.7	.001	<.003	<.004	<.002
Well 1-30 (area 1)	<.05	.12	.12	.8	6.5	-64.8	-9.71	1.8	<.001	<.003	<.004	<.002
Well 2-1 (area 2)	3.5	.02	<.01	<.4	65	-61.5	-9.35	.9	.19	<.003	<.004	<.002
Well 2-2 (area 2)	7.4	<.01	<.01	<.4	51	-65.6	-9.87	1.2	.084	<.003	<.004	<.002
Well 2-3 (area 2)	11	<.01	<.01	<.4	40	-53.0	-7.28	1.6	1.2	E.012	<.004	<.002
Well 2-4 (area 2)	7.4	.02	<.01	<.4	62	-63.9	-9.60	1.7	.027	<.003	<.004	<.002
Well 2-5 (area 2)	4.1	<.01	<.01	<.4	38	-64.6	-9.76	.8	<.001	<.003	<.004	<.002
Well 2-6 (area 2)	25	<.01	<.01	<.4	48	-59.2	-9.21	1.3	.35	<.003	<.004	<.002
Well 2-7 (area 2)	33	.02	<.01	1.1	47	-64.0	-9.69	2.2	.015	<.003	<.004	<.002
Well 2-8 (area 2)	7	.03	<.01	2.3	46	-72.5	-10.7	1.4	.067	<.003	<.004	<.002
Well 2-9 (area 2)	11	.01	<.01	<.4	49	-66.4	-9.88	.9	.37	<.003	<.004	<.002
Well 2-10 (area 2)	12	<.01	<.01	<.4	50	-62.8	-9.62	.8	1.3	<.003	<.004	<.002
Well 2-11 (area 2)	2.7	.01	<.01	2.5	61	-58.3	-9.01	1.2	.11	<.003	.014	<.002

Appendix 2c. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	Nitrite plus nitrate, as N	Phosphorus, as P	Ortho phosphate, as P	Uranium, in µg/L	Tritium, in pCi/L	Deuterium/ hydrogen ratio, in per mil	$^{18}O/^{16}O$ ratio, in per mil	Dissolved organic carbon (DOC)[1]	Atrazine, in µg/L	Carbofuran, in µg/L	Cyanazine, in µg/L	DCPA, in µg/L
Well 2-12 (area 2)	2	< .01	< .01	< .4	52	-66.8	-9.96	1.5	.023	< .003	< .004	< .002
Well 2-13 (area 2)	3.8	< .01	< .01	< .4	46	-110	-15.3	.6	.13	< .003	< .004	< .002
Well 2-14 (area 2)	4	.01	< .01	3	62	-69.5	-10.3	.4	.009	< .003	< .004	< .002
Well 2-15 (area 2)	< .05	.02	.02	< .4	44	-59.3	-7.08	6.5	.008	< .003	< .004	< .002
Well 2-16 (area 2)	13	.01	< .01	1	61	-69.3	-10.1	1.9	.38	< .003	< .004	< .002
Well 2-17 (area 2)	16	< .01	< .01	1.8	42	-68.7	-10.4	2.2	.008	< .003	< .004	< .002
Well 2-18 (area 2)	.08	< .01	< .01	< .4	42	-64.3	-9.74	5.1	.15	< .003	< .004	< .002
Well 2-19 (area 2)	10	.02	< .01	1.8	54	-62.0	-9.42	1.6	.042	< .003	< .004	< .002
Well 2-20 (area 2)	18	< .01	< .01	< .4	53	-66.7	-9.73	.8	.099	< .003	< .004	< .002
Well 2-21 (area 2)	6.6	.01	< .01	< .4	56	-65.9	-9.82	.6	.037	< .003	< .004	< .002
Well 2-22 (area 2)	17	.02	< .01	< .4	42	-64.6	-9.44	.6	.15	< .003	< .004	< .002
Well 2-23 (area 2)	< .05	.08	.1	< .4	.5	-66.9	-9.77	2.9	< .001	< .003	< .004	< .002
Well 2-24 (area 2)	23	.02	< .01	< .4	54	-62.8	-9.49	.8	.077	< .003	< .004	< .002
Well 2-25 (area 2)	7	< .01	< .01	.7	61	-60.6	-9.11	1.2	.01	< .003	< .004	< .002
Well 2-26 (area 2)	2.5	< .01	< .01	2.1	51	-68.3	-10.1	2.2	.078	< .003	< .004	< .002
Well 2-27 (area 2)	3.9	.01	< .01	2.5	46	-68.5	-10.1	3.5	.097	< .003	< .004	< .002
Well 2-28 (area 2)	.05	.04	.03	7.1	66	-69.9	-10.3	5.7	< .001	< .003	< .004	< .002
Well 2-29 (area 2)	1.2	< .01	< .01	.5	43	-67.6	-9.83	5.4	.028	< .003	< .004	< .002
Well 2-30 (area 2)	4.3	< .01	< .01	.9	48	-76.3	-11.1	.8	.008	< .003	< .004	< .002

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[1] DOC was detected in field blank samples at concentrations ranging from < 0.1 to 1.0 mg/L. For this reason measured DOC concentrations in ground-water samples may be questionable.

Appendix 2d. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages

[All concentrations in milligrams per liter, unless otherwise indicated; µg/L, micrograms per liter; <, less than; E, estimated]

Well number (study area)	DDE, p,p'-, in µg/L	Deethyl atrazine, in µg/L	2,6-Diethylaniline, µg/L	Metolachlor, in µg/L	Prometon, in µg/L	Simazine, in µg/L	Tebuthiuron, in µg/L	Triallate, in µg/L	Chloroform, in µg/L	Dichloro-bromomethane, in µg/L
Well 1-1f (area 1)	< 0.006	< 0.002	< 0.003	< 0.002	< 0.018	< 0.005	< 0.01	< 0.001	< 0.2	< 0.2
Well 1-1a (area 1)	< .006	E .39	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Spring 1-3 (area 1)	< .006	E .027	< .003	< .002	< .018	< .005	.019	< .001	< .2	< .2
Well 1-4 (area 1)	< .006	< .002	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-5 (area 1)	< .006	E .013	< .003	.016	< .018	< .005	< .01	< .001	< .2	< .2
Spring 1-7 (area 1)	< .006	E .066	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-9 (area 1)	< .006	< .002	< .003	< .002	.06	< .005	< .01	< .001	< .2	< .2
Well 1-10 (area 1)	< .006	E .052	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-11 (area 1)	< .006	E .035	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-12 (area 1)	< .006	E .002	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-13 (area 1)	< .006	E .037	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-14 (area 1)	< .006	E .29	< .003	.012	< .018	E .003	< .01	< .001	< .2	< .2
Well 1-15 (area 1)	< .006	E .11	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-16 (area 1)	E .002	E .004	< .003	.002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-17 (area 1)	< .006	E .072	< .003	< .002	< .018	.015	< .01	< .001	< .2	< .2
Well 1-18 (area 1)	< .006	< .002	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-19 (area 1)	< .006	< .002	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-20 (area 1)	< .006	E .005	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 1-21 (area 1)	E .001	< .002	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2

Appendix 2d. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	DDE, p,p'-, in µg/L	Deethyl atrazine, in µg/L	2,6-Diethylaniline, µg/L	Metolachlor, in µg/L	Prometon, in µg/L	Simazine, in µg/L	Tebuthiuron, in µg/L	Triallate, in µg/L	Chloroform, in µg/L	Dichloro-bromomethane, in µg/L
Well 1-22 (area 1)	<.006	E .004	<.003	.006	.14	<.005	<.01	<.001	<.2	<.2
Well 1-23 (area 1)	<.006	<.002	<.003	.003	<.018	<.005	<.01	<.001	<.2	<.2
Well 1-24 (area 1)	<.006	E .12	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 1-25 (area 1)	<.006	<.002	<.003	.005	.11	<.005	<.01	<.001	<.2	<.2
Well 1-26 (area 1)	<.006	E .004	<.003	.003	<.018	<.005	<.01	<.001	<.2	<.2
Well 1-27 (area 1)	<.006	<.002	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 1-28 (area 1)	<.006	<.002	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 1-29 (area 1)	<.006	<.002	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 1-30 (area 1)	<.006	<.002	<.003	.002	E .005	<.005	<.01	<.001	<.2	<.2
Well 2-1 (area 2)	<.006	E .50	<.003	<.002	<.018	<.0005	<.01	<.001	<.2	<.2
Well 2-2 (area 2)	E .001	E1.1	<.003	<.002	<.018	<.0005	<.01	<.001	<.2	<.2
Well 2-3 (area 2)	<.006	E .30	<.003	<.002	<.018	E .007	<.01	<.001	<.2	<.2
Well 2-4 (area 2)	E .001	E .047	<.003	<.002	<.018	.01	<.01	<.001	<.2	<.2
Well 2-5 (area 2)	<.006	E .011	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 2-6 (area 2)	<.006	E .23	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 2-7 (area 2)	<.006	E .23	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 2-8 (area 2)	<.006	E .097	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 2-9 (area 2)	<.006	E .44	<.003	<.002	<.018	<.005	<.01	<.001	<.2	<.2
Well 2-10 (area 2)	<.006	E2.6	<.003	<.002	<.018	E .006	<.01	<.001	<.2	<.2
Well 2-11 (area 2)	<.006	E .13	<.003	<.002	<.018	E .005	<.01	<.001	<.2	<.2

Appendix 2d. Selected water-quality data for ground-water samples from wells and springs in land-use study areas 1 and 2, Western Lake Michigan Drainages—Continued

Well number (study area)	DDE, p,p'-, in µg/L	Deethyl atrazine, in µg/L	2,6-Diethylaniline, µg/L	Metolachlor, in µg/L	Prometon, in µg/L	Simazine, in µg/L	Tebuthiuron, in µg/L	Triallate, in µg/L	Chloroform, in µg/L	Dichloro-bromomethane, in µg/L
Well 2-12 (area 2)	< .006	E .071	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-13 (area 2)	< .006	E .051	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-14 (area 2)	< .006	E .038	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-15 (area 2)	< .006	E .003	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-16 (area 2)	E .001	E .1	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-17 (area 2)	< .006	E .043	< .003	< .002	< .018	< .005	< .01	< .001	1.1	.3
Well 2-18 (area 2)	< .006	E .018	.003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-19 (area 2)	< .006	E .074	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-20 (area 2)	< .006	E .47	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-21 (area 2)	< .006	E .09	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-22 (area 2)	< .006	E .22	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-23 (area 2)	< .006	< .002	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-24 (area 2)	< .006	E .35	< .003	< .002	< .018	< .005	< .01	.002	< .2	< .2
Well 2-25 (area 2)	< .006	E .032	< .003	< .002	< .018	< .005	< .01	.002	< .2	< .2
Well 2-26 (area 2)	< .006	E .035	< .003	< .002	E .009	< .005	< .01	< .001	.3	< .2
Well 2-27 (area 2)	< .006	E .091	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-28 (area 2)	< .006	< .002	< .003	< .002	< .018	.046	< .01	< .001	< .2	< .2
Well 2-29 (area 2)	< .006	E .011	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2
Well 2-30 (area 2)	E .001	E .01	< .003	< .002	< .018	< .005	< .01	< .001	< .2	< .2

Appendix 3. Example of nitrogen and pesticide use questionnaire sent to landowners who participated in the land-use studies

NITROGEN AND PESTICIDE USE QUESTIONNAIRE

The following questions refer to the agricultural fields within about 100 yards of the ground-water well installed on your property, by the U.S. Geological Survey, in 1993 or 1994 (see enclosed map for approximate well location). Please give your best estimate for typical nitrogen (fertilizer and manure) and pesticide application rates. If there is a neighboring property within 100 yards of the well please answer the questions for your property only.

1. What is a typical crop rotation for fields near the USGS well (Examples: corn,corn,alf,alf, alf,alf or corn,corn,soybean,wheat, etc.)________________

FERTILIZER (***Indicate if application is anhydrous***)

2. How many units of nitrogen fertilizer were typically applied to nearby fields in 1994? (Examples: 160 units per acre or 160 pounds per acre, etc.)________________

3. How much was typically applied to nearby fields in 1993?________________

4. If 1993 and 1994 were non-typical years or fertilizer was not applied during that period how much has typically been applied per year to nearby fields prior to 1993?________________

MANURE

5. How many units of manure were typically applied to nearby fields in 1994? (Examples: 60 units per acre or 60 pounds per acre, etc.)________________

6. How much was typically applied to nearby fields in 1993?________________

7. If 1993 and 1994 were non-typical years or manure was not applied during that period how much has typically been applied per year to nearby fields prior to 1993?________________

PESTICIDES

8. What pesticides were used on nearby fields in 1994?________________

9. What pesticides were used on nearby fields in 1993?________________

10. What were the names and application rates of the most used pesticides

    (For example: atrazine, 1 pound per acre)........

    in 1994?________________

    in 1993?________________

11. What pesticides have been used on nearby fields prior to 1993 and approximately what year did you start using it? (Examples: atrazine in 1970, roundup in 1992)________________