GROUND-WATER-QUALITY-MONITORING PROGRAM IN IOWA:

NITRATE AND PESTICIDES IN SHALLOW AQUIFERS

By Mark G. Detroy, Pamela K.B. Hunt, and Maureen A. Holub

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound units	By	To obtain SI unit
foot	0.3048	meter
gallon per minute	0.06308	liter per second
ton, short	0.9072	megagram
acre	4,047	square meters

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F = 9/5 °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 if the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

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ABSTRACT

Concern exists about the occurrence of agricultural chemicals, primarily nitrate and pesticides, in shallow ground water. In response to this concern, the focus of the Iowa ground-water-quality-monitoring program has shifted to emphasize nonpoint contaminants. The program, which began in 1982, is operated by the U.S. Geological Survey in cooperation with the University of Iowa Hygienic Laboratory and the Iowa Department of Natural Resources, Geological Survey Bureau and Environmental Protection Division. The objectives are to describe and assess the long-term chemical quality of the principal aquifers in Iowa and to direct water-quality assessment and sampling toward regional ground-water-quality concerns.

In the spring of 1985, emphasis was placed on the analysis of pesticides in water samples collected from wells completed in surficial aquifers in Quaternary deposits or from wells less than 200 feet deep or both. Samples from these wells were analyzed for nitrate and selected pesticides. In water samples collected from 515 individual shallow wells, 6 percent had nitrate concentrations larger than the maximum contaminant level for public drinking water of 10 milligrams per liter as nitrogen. The concentrations ranged from less than 0.1 to 53 milligrams per liter as nitrogen. Eighteen percent of the samples had concentrations of nitrate between 5 and 10 milligrams per liter as nitrogen. Water samples from 355 individual municipal wells less than 200 feet deep have been analyzed for pesticides at least once. Detectable concentrations of at least one pesticide, including alachlor, atrazine, cyanazine, dicamba, metolachlor, or metribuzin, were detected in 20 percent of the samples. Atrazine was the most prevalent pesticide; concentrations, which ranged from 0.10 to 21 micrograms per liter, were detected in 18 percent of the samples.

The results of the monitoring program indicate a relation between decreasing well depth and the presence of detectable concentrations of nitrate and pesticides. Most nitrate and pesticide detection was in areas where surficial aquifers in Quaternary deposits are the principal source of ground water. Pesticides were detected in samples collected throughout the year; samples collected in late spring and early summer more frequently contained pesticides than the other samples.

INTRODUCTION

Among the more significant factors that have contributed to increased agricultural yields in the United States has been the extensive use of nitrogen fertilizers as plant-nutrient supplements and pesticides for weed and insect control. The use of these chemicals in Iowa is an integral part of the success of the large agricultural industry of the State. Although the extensive use of agricultural chemicals has been a benefit to the State's agricultural industry, contamination of ground water by nitrate and pesticides has become an environmental issue. Early concern about the relation of agricultural chemicals to water resources focused on nonpoint-source contamination of surface water by field runoff and soil erosion from row-crop areas. Nonpoint-source contamination involves the delivery of sediment, nutrients, and pesticides into surface waters from extensive areas of agricultural use where chemicals are applied areally to cultivated land. During the past 5 years, attention has been focused on nitrate and pesticides because many public and domestic water supplies depend on shallow ground water for large quantities of water. Although spills and misuse of chemicals have caused severe contamination locally, the widespread contamination of aquifers is the result of conventional usage of agricultural chemicals and constitutes a nonpoint-source contamination hazard (Hallberg, 1984).

Purpose and Scope

The Iowa ground-water-quality monitoring program is a Statewide data collection network operated by the U.S. Geological Survey in cooperation with the University of Iowa Hygienic Laboratory and the Iowa Department of Natural Resources, Geological Survey Bureau and Environmental Protection Division. The purpose of this report is to describe this program and then to summarize and assess nitrate and pesticide data collected from this program. Water samples collected from wells completed in Quaternary aquifers or from wells less than 200 ft (feet) deep, or both, are included. Concentration data from water analyses for nitrate and pesticides obtained since 1982 are summarized and evaluated with respect to aquifer type, areal distribution, depth, and seasonal variation.

Previous Investigations

Recent investigations by the U.S. Geological Survey and other agencies in Iowa document the presence of large nitrate concentrations and several pesticides in shallow ground water. A study by the U.S. Geological Survey of an alluvial aquifer along the Iowa River determined the nonuniform distribution of nitrate and the herbicides, atrazine and metribuzin, both areally and vertically within the alluvial aquifer (Detroy, 1986). Thompson and others (1986) also detected large concentrations of nitrate and a distinct vertical stratification of this constituent in several alluvial aquifers in western Iowa.

The herbicides, atrazine and alachlor, were detected in shallow ground water and springs in northeast Iowa in concentrations as large as 10 to 15 μg/L (micrograms per liter; Hallberg and others, 1983). A study in northeast Iowa by the Iowa Department of Natural Resources, Geological Survey Bureau indicate that infiltration-derived recharge through soil and the relatively thin mantle of glacial deposits delivers the largest concentration of nitrate and the greatest mass of nitrate and pesticides into the ground-water system (Libra and others, 1986).

A 1984 sampling survey by the Iowa Department of Water, Air, and Waste Management of public drinking-water supplies indicated that 28 of 70 wells sampled had measurable concentrations of herbicides (Kelley, 1985). Atrazine was the most commonly detected herbicide. Kelley and Wnuk (1986) detected pesticides in the Little Sioux alluvial aquifer in six of eight municipal wells sampled. A study by McDonald and Splinter (1982) indicated that nitrate concentrations in shallow wells and surface water has been increasing since 1950.

Iowa has only recently considered increased environmental protection of water resources, particularly ground water. In early 1987, the Iowa Environmental Protection Commission recommended to the legislature that it direct programs and resources to develop a prioritized list of contaminants in ground and surface water. After the list was developed, agricultural use of nitrogen fertilizer and of pesticides, both nonpoint sources affecting ground and surface water, were at the top of the list. In late summer 1987 the Iowa Groundwater Protection Act of 1987 was passed. The principal objectives of the act are to: (1) Provide education--to increase awareness and understanding of the responsibility the people of Iowa have to protect their ground water; (2) promote and fund research--to develop methods to improve resource management and understand effects of environmental contaminants; and (3) to implement demonstration projects--to help Iowans implement improved technologies that minimize or eliminate adverse effects on ground-water resources.

Acknowledgments

We greatly appreciate the efforts of Paul Van Dorpe from the Iowa Geological Survey Bureau for his diligent work in compiling and summarizing municipal-well records. His work made well selection and site visitation more manageable. We thank all the staff of the University of Iowa Hygienic Laboratory for their contribution of excellent sample analysis.

DESCRIPTION OF GROUND-WATER-QUALITY MONITORING NETWORK

The ground-water-quality monitoring program was begun in 1982 and is an extension of a previous program that had been in operation since 1950 by the State Health Department. This early program consisted of nonspecific periodic sampling of untreated water from municipal wells. The current program has two objectives: (1) A fixed objective--to describe and assess the long-term chemical quality of surficial aquifers in Quaternary deposits and shallow bedrock aquifers for the State, and (2) a variable objective--to direct sampling and water-quality assessment toward new or emerging areas of ground-water-quality concern (Detroy, 1985). The network was designed to meet data needs solicited from several State and Federal agencies during a planning period in 1982.

Initially, only 1,200 municipal wells were part of the program (fig. 1). These wells yielded water from five major aquifer categories as listed in table 1. However, the network was expanded to include domestic and test wells. Wells were selected as sampling sites based on accessibility, availability, well integrity, and reliable geologic information. The municipal wells used in the network had to be properly maintained, and data for each well, such as withdrawal rates, water levels, casing information, and sampling history, were recorded.

Table 1.--Summary of initial monitoring network

Aquifer type	Number of monitoring wells	Frequency of sampling	Number of samples per year
Quaternary deposits	500	2-4 years	90
Cretaceous rocks	100	4 years	10
Mississippian and Pennsylvanian rocks	130	4 years	20
Silurian-Devonian rocks	250	4 years	50
Cambrian-Ordovician rocks	220	6 years	30
Total	1,200		200

Initially wells that were completed in surficial aquifers in Quaternary deposits and that were less than 150 ft deep were sampled every 2 years. Wells completed in bedrock aquifers were sampled every 4 years except for the wells completed in aquifers in Cambrian and Ordovician rocks that were sampled every 6 years. From 1982 through 1987, water samples were analyzed for the constituents listed in table 2. Additionally, a small percentage of wells completed in surficial aquifers were sampled for priority contaminants and pesticides each year.

Because of the increasing concern and new legislation to protect the ground-water resources of Iowa, particularly from agricultural chemicals, the monitoring program was modified in the fall of 1987. Since 1985 the emphasis of the variable objective has been the chemical quality of the shallow aquifers as these aquifers are most susceptible to nonpoint contamination from agricultural chemicals. The 1988 monitoring program is an extension of the existing ground-water-quality monitoring network with changes made to satisfy the data needs expressed by the several State agencies and to adapt it to current initiatives spelled out in Groundwater Monitoring Strategy for Iowa (Iowa Department of Water, Air, and Waste Management, 1986) and recent ground-water protection legislation generated by the Iowa Groundwater Protection Strategy (Hoyer and others, 1987).

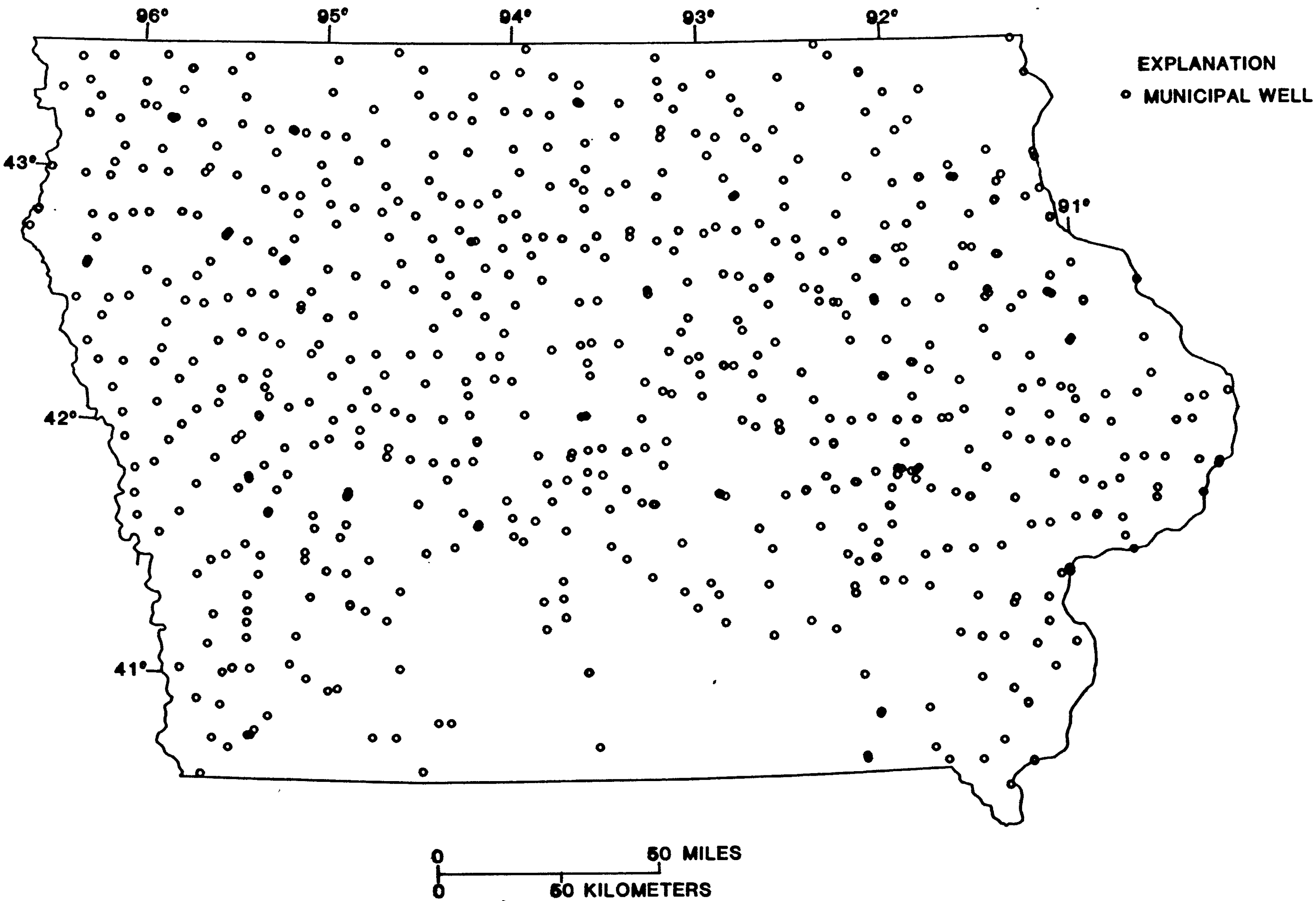

Figure 1.—Distribution of municipal wells in the ground-water-quality-monitoring program in Iowa.

Table 2.--Data collected by the U.S. Geological Survey at the sampling site and analyses performed by the University of Iowa Hygienic Laboratory

Measurements at sampling site

Pumping rate, in gallons per minute
Pumping period before sampling, in minutes
Water temperature, in degrees Celsius
Water level, in feet below land surface
pH, in units
Specific conductance, in microsiemens per centimeter at 25 °Celsius

Common minerals, in milligrams per liter

Alkalinity as $CaCO_3$	Carbonate, dissolved
Bicarbonate, dissolved	Chloride, dissolved
Sulfate, dissolved	Fluoride, dissolved
Calcium, dissolved	Magnesium, dissolved
Sodium, dissolved	Potassium, dissolved
Solids at 103 °Celsius, dissolved	Silica, dissolved

Nutrients, in milligrams per liter

Nitrate, nitrite plus nitrate, dissolved as nitrogen
Ammonia, dissolved as nitrogen
Orthophosphate, dissolved as phosphorus

Dissolved trace metals, in micrograms per liter

Arsenic	Manganese
Barium	Mercury
Cadmium	Selenium
Chromium	Silver
Iron	Zinc
Lead	

Radiochemicals, in picocuries per liter

Gross alpha, dissolved as uranium-natural	Radium-226, dissolved
Gross beta, dissolved as cesium-137	Radium-228, dissolved

Aside from the overall objectives of the program, the 1988 program has these specific objectives: (1) To describe and assess the long-term chemical quality of deep (greater than 150 ft) surficial and bedrock aquifers in Iowa; (2) to focus water-quality sampling and assessment on the problem of current degradation of shallow (less than 150 ft) ground-water resources by agricultural chemicals, which will include seasonal and geographic evaluation of contaminants detected in shallow ground water; and (3) to focus water-quality sampling and assessment on the problem of current degradation of shallow ground-water resources by SOC (synthetic organic chemicals).

The major focus of monitoring will be shallow aquifers. Seventy percent of the municipal wells to be sampled during 1988 are shallow wells. Municipal wells that will be sampled in 1988 are categorized in table 3.

Table 3.--Summary of wells to be sampled during 1988

130	Shallow Quaternary wells, depth less than 150 feet
35	Shallow bedrock wells, depth less than 150 feet
10	Quaternary wells, depth 150 to 300 feet
30	Bedrock wells, depth 150 to 300 feet
25	Deep bedrock wells, depth greater than 300 feet
230	Total

Sampling frequency is summarized in table 4. The majority of sampling will be done in middle to late summer when the probability of measuring larger or detectable concentrations, or both, of agricultural chemicals is greatest. Wells at which multiple samples will be collected during the year will be sampled according to a schedule that isolates significant hydrologic periods as they relate to the application or the detection of nitrogen-based fertilizers and pesticides, or both. Deep bedrock wells will be sampled during October to December.

Since the spring of 1985, wells less than 200 ft deep were sampled for commonly used pesticides (table 5) and the older chlorinated hydrocarbon insecticides (table 6). During 1988, samples are to be collected for the analysis of commonly used herbicides and SOC (table 7), but not for the common insecticides, acid herbicides, and older chlorinated hydrocarbon insecticides. The current program also deemphasizes trace-metal and radionuclide analyses. These are only performed when warranted by historical sampling results.

Table 4.--Current sampling schedule

[--, no samples collected]

Well type	1987 Oct	1987 Nov	1987 Dec	1988 Jan	1988 Feb	1988 Mar	1988 Apr	1988 May	1988 June	1988 July	1988 Aug	1988 Sept
Single sample per year												
Shallow Quaternary, depth less than 150 feet	--	--	--	--	--	--	--	--	30	40	30	--
Shallow bedrock, depth less than 150 feet	--	--	--	--	--	--	--	--	--	20	--	--
Quaternary, depth 150 to 300 feet	--	--	--	--	--	--	--	--	--	10	--	--
Bedrock, depth 150 to 300 feet		-------30------		--	--	--	--	--	--	--	--	--
Deep bedrock, depth greater than 300 feet		-------25------		--	--	--	--	--	--	--	--	--
Multiple samples per year					Thaw		Pre-application		First post application		Second post application	
Shallow Quaternary, depth less than 150 feet	--	--	--	--	----30----		----30----		-----30-----		--	30
Shallow bedrock, depth less than 150 feet	--	--	--	--	--	--	--	15	--	15	--	15

Table 5.--Pesticides commonly used and routinely analyzed by the University of Iowa Hygienic Laboratory

Common name	Trade name[1]	Class or type of pesticide
	HERBICIDE	
Alachlor	Lasso	Phenylamide (acylanilide)
Atrazine	Aatrex	S-triazine
Butylate	Sutan	Carbamate
Cyanazine	Bladex	S-triazine
Metolachlor	Dual	Phenylamide (acetamide)
Metribuzin	Sencor	S-triazine
Trifluralin	Treflan	Phenylamide (toluidine)
	INSECTICIDE	
Carbofuran	Furadan	Carbamate
Chlorpyrifos	Lorsban, Dursban	Organophosphate
Ethoprop	MoCap	Organophosphate
Fonofos	Dyfonate	Organophosphate
Phorate	Thimet	Organophosphate
Terbufos	Counter	Organophosphate
	ACID HERBICIDE	
Chloramben	Amiben	Benzoic
Dicamba	Banvel	Benzoic
Silvex		Phenoxy
2,4-D		Phenoxy

[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 6.--Chlorinated hydrocarbon insecticides routinely analyzed by the University of Iowa Hygienic Laboratory

Chemical name
Aldrin
Alpha-benzene hexachloride (BHC)
Beta-benzene hexachloride (BHC)
Chlordane
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Gamma-benzene hexachloride (BHC)
Heptachlor
Heptachlor epoxide
Toxaphene
1,1-dichloro-2,2-bis(p-chloropehnyl) ethane (DDD)
4,4-dichlorodiphenyldichloroethylene (DDE)
4,4-dichlorodiphenyltrichloroethane (DDT)

Table 7.--Synthetic organic compounds analyzed by the University of Iowa Hygienic Laboratory

Compound name	Compound name
Benzene	Cis-1,3-dichloropropene
Bromodichloromethane	Trans-1,3-dichloropropene
Bromoform	1,1 dichloroethane
2-chloroethylvinyl ether	1,1 dichloropropene
Chloroform	Ethylbenzene
Carbon tetrachloride	Dibromchloromethane
Chlorobenzene	Methylene chloride
1,1 dichloroethene	Styrene
1,2 dichloroethane	1,1,1 trichloroethane
1,2 dichlorobenzene (o-)	Tetrachloroethene
1,3 dichlorobenzene (m-)	1,2,3 trichloropropane
1,4 dichlorobenzene (p-)	1,1,1,2 tetrachloroethane
1,2 dichloropropane	1,1,2 trichloroethane
Trans-1,2 dichloroethene	Toluene
Cis-1,2 dichloroethene	1,3 dichloropropane
Dibromomethane	1,1,2,2 tetrachloroethane
Dichlorodifluoromethane	Trichloroethene
Vinyl chloride	Xylene (total)

The current data base consists of more than 1,300 wells, of which about 800 are shallow. In this study, municipal wells completed in surficial aquifers in Quaternary deposits and bedrock aquifers that are less than 200 ft deep are considered shallow. The areal distribution of wells completed in surficial aquifers that are included in the network is shown in figure 2 and shallow wells completed in bedrock aquifers that are included in the network are shown in figure 3. Municipalities usually have more than one well that provides the public water supply, hence the large number of wells available for sampling. If a municipality has multiple well fields, only one well is sampled in each well field, and the same well is sampled each time for consistency.

DESCRIPTION OF SURFICIAL AND SHALLOW BEDROCK AQUIFERS

Aquifers in Quaternary deposits and Cretaceous, Mississippian, Devonian, and Silurian rocks are the shallow ground-water resources in Iowa (table 8). The areal distribution of the shallow bedrock aquifers is shown in figure 4. Surficial aquifers in Quaternary deposits are present throughout the State. These surficial aquifers are composed of three types of unconsolidated deposits: alluvium, glacial drift, and buried-channel alluvium. The alluvium, composed of gravel, sand, silt, and clay, is at the land surface and underlies flood plains and terraces in the stream valleys. These deposits are 100 to 160 ft thick along the Missouri and Mississippi Rivers and 30 to 70 ft thick along the principal interior streams (Karsten and Burkart, 1984). The glacial drift aquifers are composed of sandy, pebbly clay (glacial till) and generally contain sand and gravel deposits of varying thickness and extent. The glacial drift underlies the upland area, whereas the alluvium is confined to the stream valleys. Buried-channel aquifers consist of stream alluvium that filled valleys before or after glacial intervals. Surficial aquifers are susceptible to infiltration of contaminants.

The Dakota aquifer in the Dakota Sandstone of Cretaceous age is in the northwest and west-central part of the State and consists of sandstone. In some areas the aquifer directly underlies and is hydraulically connected to the unconsolidated surficial deposits (Burkart, 1984; Runkle, 1985). Limestone, dolomite, and sandstone rocks comprise the aquifer in Mississippian rocks. Where it is overlain by glacial drift, the aquifer ranges in thickness from 100 to 300 ft (Karsten and Burkart, 1984). The shallow bedrock aquifers in northeast Iowa typify a karst aquifer system composed of limestone and dolomite of Silurian and Devonian age. This karst system is overlain by a thin mantle of glacial deposits. In some areas of the northeast, shale forms a thick covering and protects the aquifer from surficial infiltration (Hallberg and others, 1983).

NITRATE

The occurrence of nitrate contamination in ground water is being investigated throughout the midwest. Iowa is rated second in the Nation only to Illinois for nitrogen-fertilizer use (Hargett and Berry, 1986). Total nitrogen-fertilizer use for the four States that lead the Nation in fertilizer consumption is listed in table 9. Agricultural practices contribute to the nitrate concentrations in ground water (Hallberg and Hoyer, 1982).

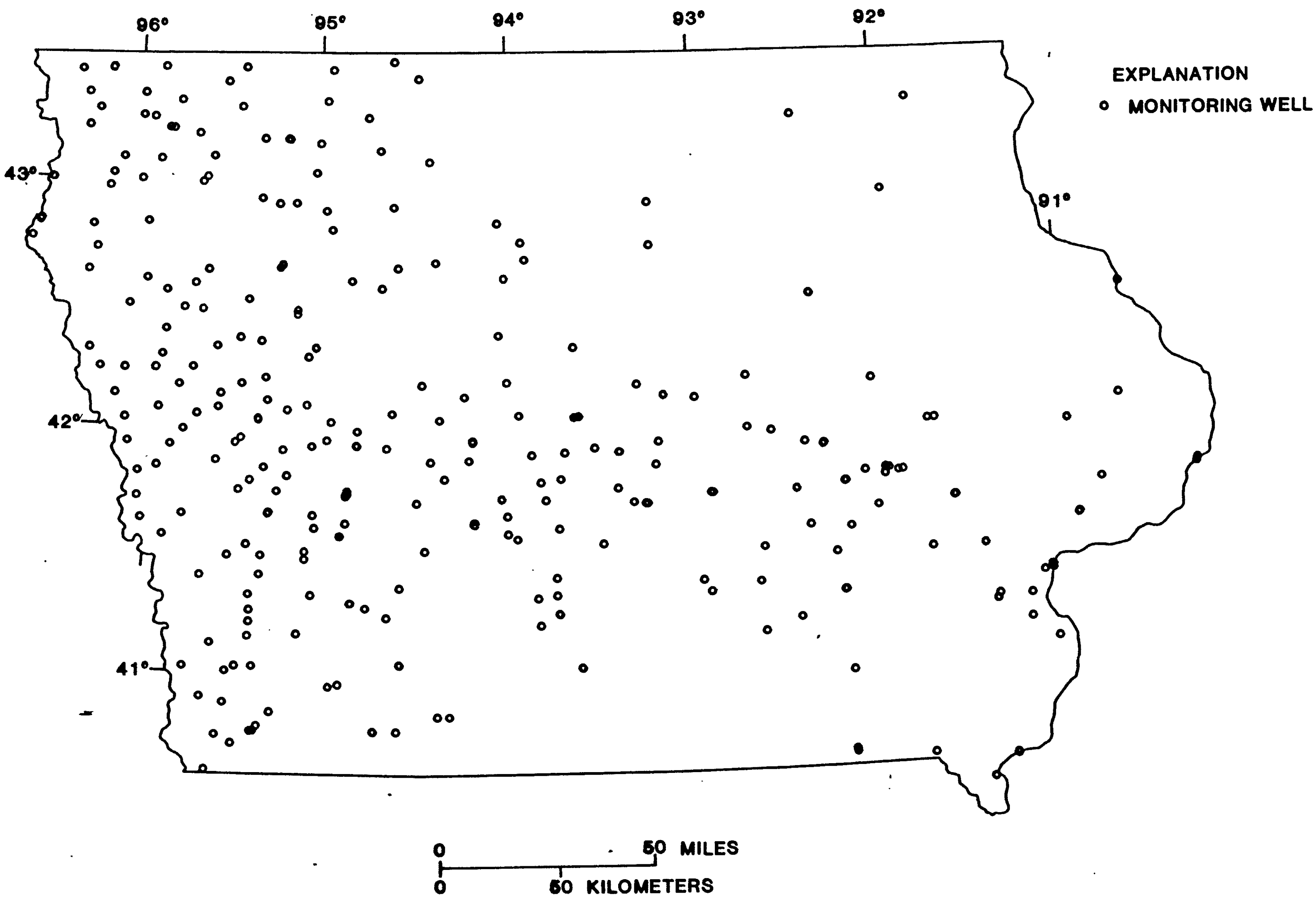

Figure 2.—Distribution of monitoring wells less than 200 feet deep completed in aquifers in Quaternary deposits.

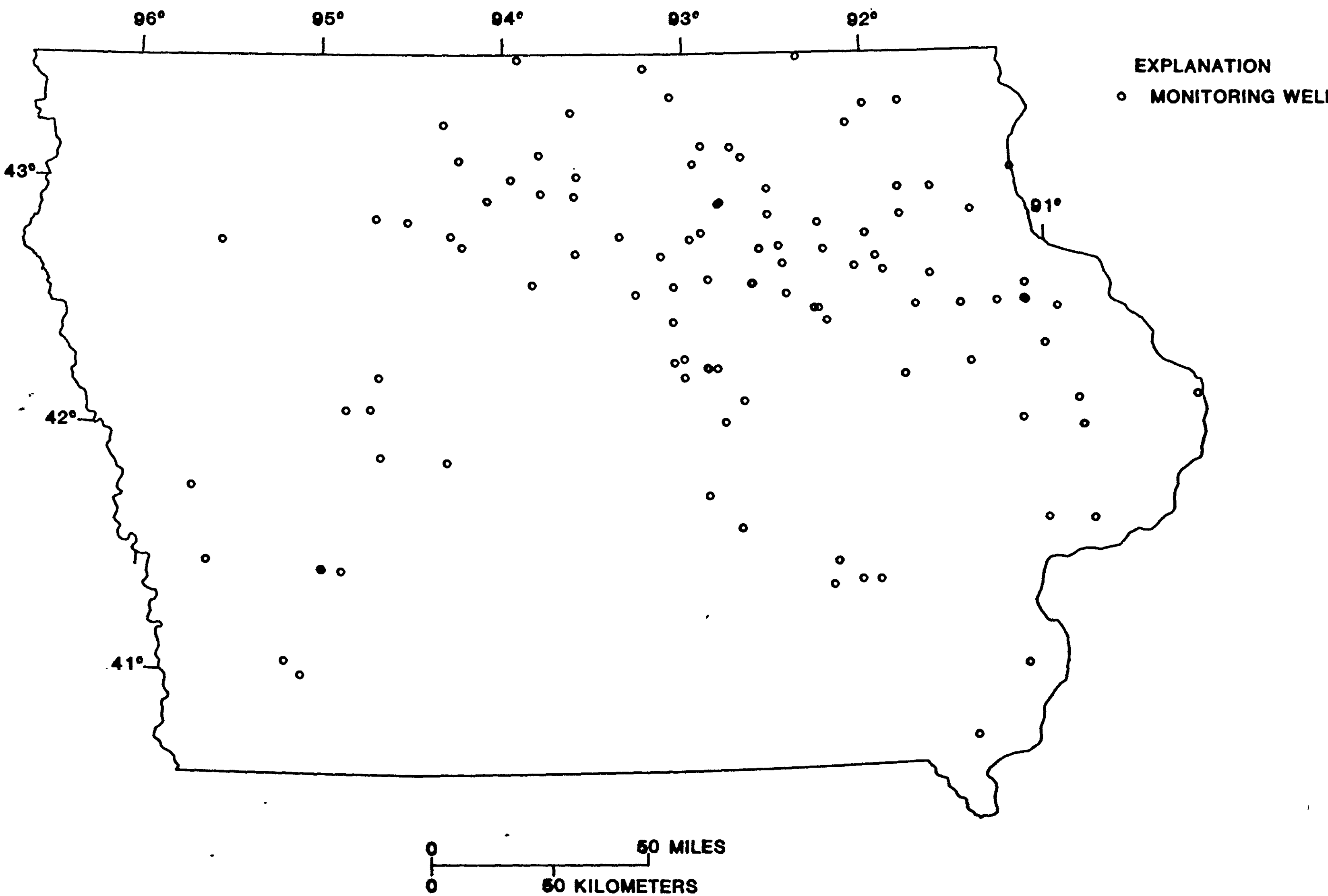

Figure 3.—Distribution of monitoring wells less than 200 feet deep completed in shallow bedrock aquifers

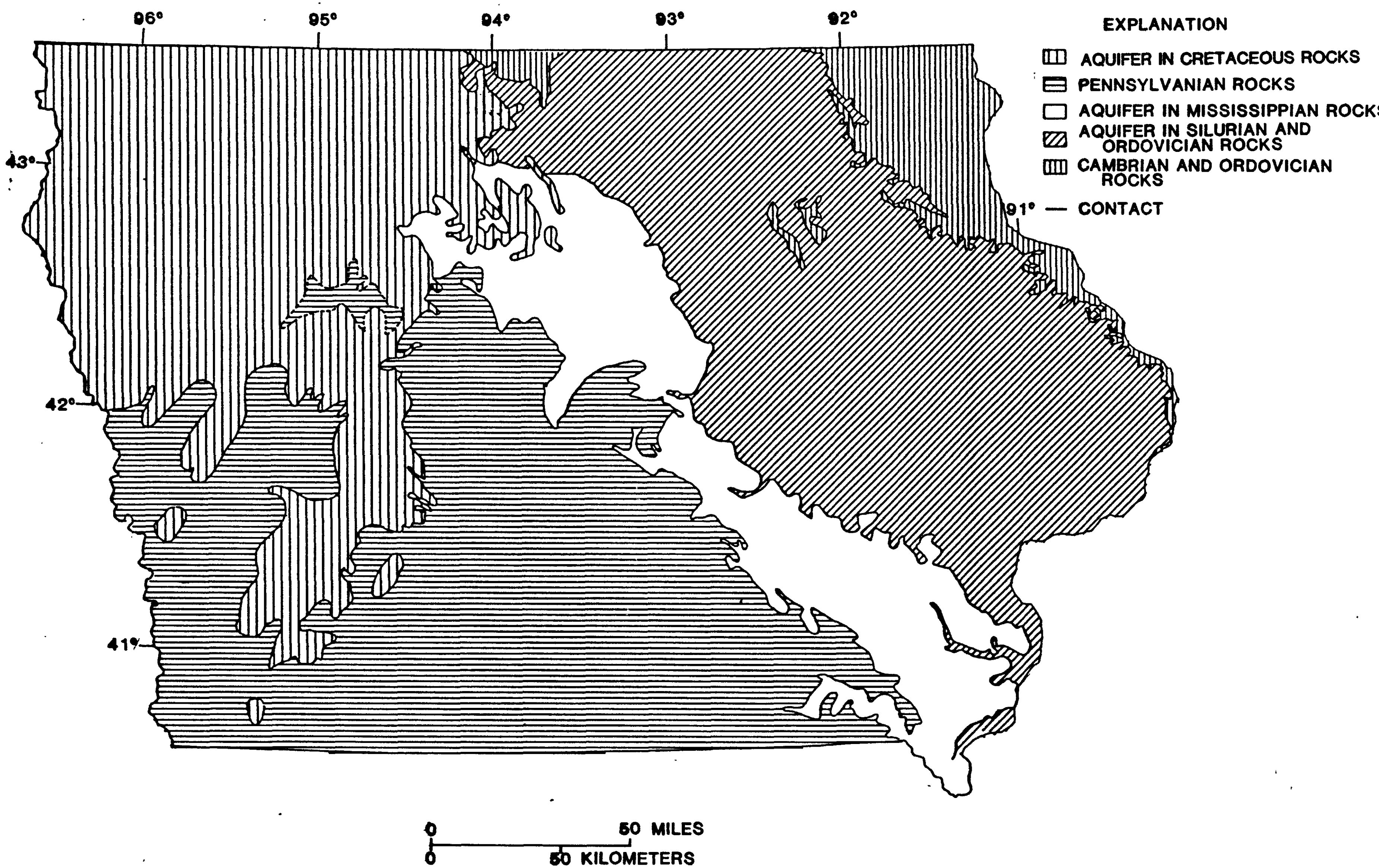

Figure 4.—Areal distribution of the shallow bedrock aquifers (modified from Hershey, 1969).

Table 8.--Shallow aquifers

Description	Depth, in feet	Remarks
Surficial aquifers in Quaternary deposits		
Alluvial: fine to coarse sand and gravel; unconfined.	30-100	Significant source of water for rural, public supply, and industrial use.
Glacial drift: pebbly and sandy drift, sand lenses, and poorly sorted sand and gravel; unconfined.	15-400	Significant source of water for farms and rural homes, especially in western and southern Iowa.
Buried channel: coarse gravel; unconfined.	50-100	Only of local significance in central and eastern Iowa.
Aquifer in Cretaceous rocks		
Fine to extremely coarse grained and poorly cemented sandstone: confined, includes Dakota aquifer.	100-600	Source of water for rural and public supply in northwest and west-central Iowa.
Aquifer in Mississippian rocks		
Limestone and dolomite: confined.	100-300	Source of water for rural and public supply in north-central Iowa.
Aquifer in Silurian and Devonian rocks		
Limestone and dolomite: confined.	100-800	Significant source of water for rural, public supply, and industrial use in northeast Iowa.

Table 9.--States leading in fertilizer use

State	Total fertilizer use, in millions of tons	State	Nitrogen-fertilizer use, in thousands of tons
Illinois	3.9	Illinois	951
Iowa	3.1	Iowa	934
California	2.9	Nebraska	748
Texas	2.5	Texas	714

Since the beginning of the ground-water-quality monitoring program in 1982, a total of 1,178 water samples have been collected from 887 different wells. Some wells have been sampled twice and a few sampled three or four times. The program has provided 806 chemical analyses of water samples collected from wells less than 200 ft deep. Nitrate data are available from all 1,178 analyses because nitrate analysis has always been part of the analytical schedule for all wells in the program. These data are contained in U.S. Geological Survey (1983-87).

Areal Distribution

The areal distribution of nitrate concentrations larger than 5 mg/L (milligrams per liter) as nitrogen is mainly confined to the northeast and western parts of Iowa (fig. 5). Both surficial aquifers in Quaternary deposits and shallow bedrock aquifers have nitrate concentrations larger than 5 mg/L as nitrogen. The surficial aquifers are primarily alluvial, whereas the bedrock aquifers are comprised of karst areas as well as some sandstone aquifers near land surface, primarily in northeast Iowa. The monitoring network provides data that generally outline the areas of the State that appear to be most susceptible to nitrate leaching into ground water.

Variation with Depth

The smallest concentration of nitrate analyzed in any sampled municipal well was less than the detection limit of 0.1 mg/L as nitrogen; the largest concentration in a shallow well was 53 mg/L as nitrogen. Wells that are less than 100 ft deep typify the alluvial aquifers. Median concentrations calculated for various depth ranges for wells less than 200 ft deep indicate that concentrations decrease with depth (table 10). Water from wells less than 50 ft deep had a statistical (interquartile) range of less than 0.1 to 6.4 mg/L and a median of 1.8 mg/L. Water from wells 151 to 200 ft deep had a median of less than 0.1 mg/L. Large concentrations of nitrate are in the deeper aquifers; however, the overall frequency of these large concentrations is small compared to the shallowest wells (less than 50 ft deep).

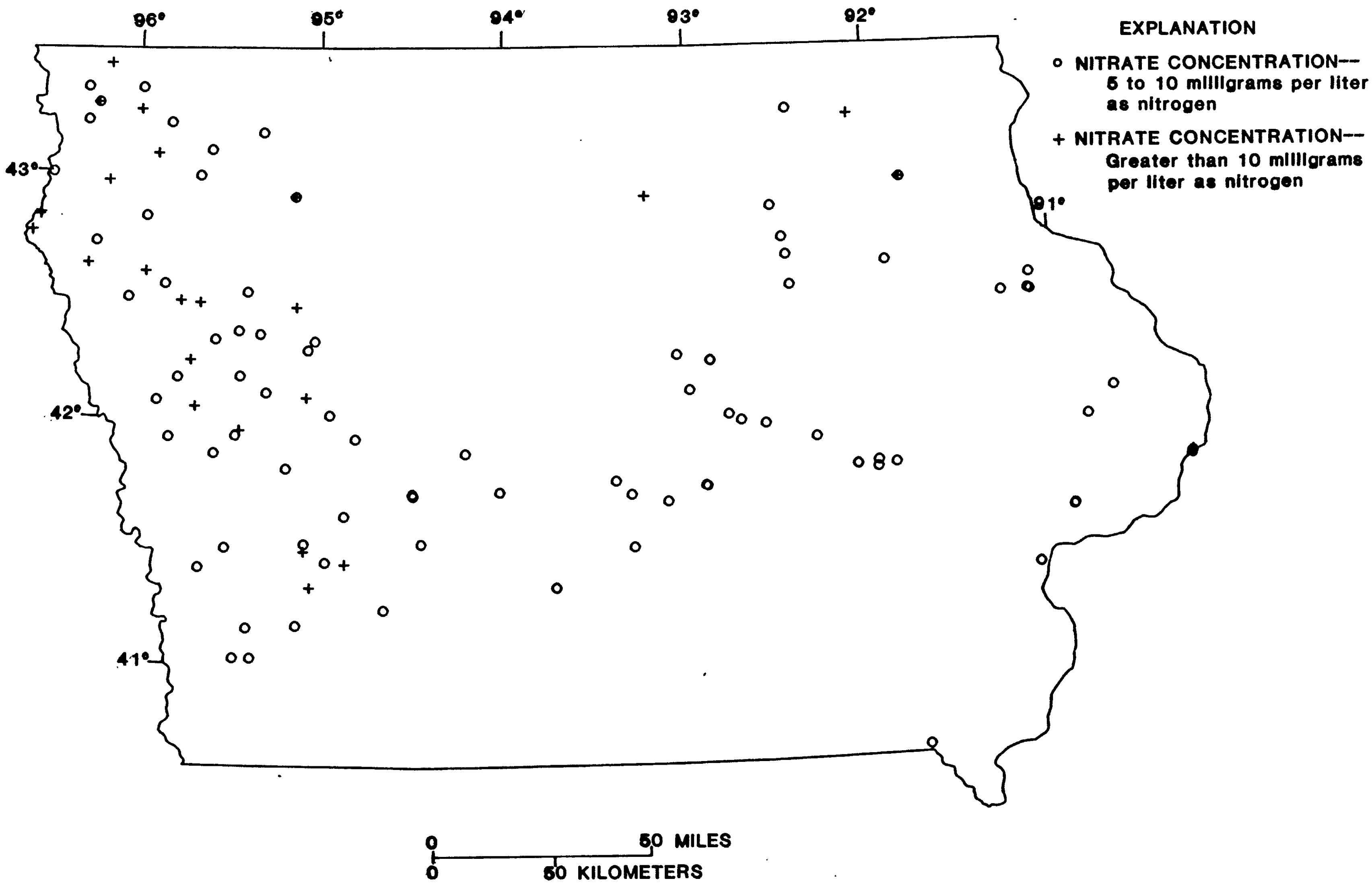

Figure 5.--Areal distribution of nitrate concentrations in ground water.

Table 10.--Nitrate concentrations in water from wells less than 200 feet deep

Well depth, in feet	Nitrate concentration as nitrogen, milligrams per liter				Number of samples
	Median	Interquartile Range	Minimum	Maximum	
Less than 50	1.8	<0.1 to 6.4	<0.1	53	191
51 to 100	1.3	<.1 to 5.5	<.1	17	147
101 to 150	<.1	<.1 to 2.1	<.1	11	92
151 to 200	<.1	<.1 to 0.2	<.1	8.6	85

The distribution of nitrate concentration ranges compared to 50-ft increments of well depth is shown in figure 6. The percentage of samples that had nitrate concentrations greater than 10 mg/L as nitrogen increased with decreasing well depth; the largest percentage of these samples were collected from the depth interval between 1 and 50 ft. This pattern indicates that water from the shallowest wells tends to be most affected by increased concentrations of nitrate. Samples that were collected from depths between 1 and 100 ft comprise about 80 percent of the samples that have nitrate concentrations greater than 1.0 mg/L as nitrogen. Shallow aquifers may be more vulnerable to infiltration of contaminants than deeper aquifers because most nitrate sources are on or near the land surface.

Madison and Brunett (1984) evaluated nitrate concentrations nationwide and determined that concentration ranges of nitrate as nitrogen may indicate differences between human and natural activities. Nitrate concentrations less than 3 mg/L as nitrogen may indicate natural or ambient concentrations from naturally occurring soil nitrogen or geologic deposits. Concentrations larger than 3 mg/L as nitrogen may indicate effects from human activities. Significant sources of nitrate contamination include septic systems, agricultural activities (fertilizers, irrigation, dryland farming, and livestock wastes), land disposal of wastes, and industrial wastes. In this report 5 mg/L concentration level is used for comparative purposes and not to indicate conclusive evidence of anthropogenic contamination.

The relation of depth and concentration of nitrate for water samples from all wells is shown in figure 7. Seven percent of the water samples from wells less than 200 ft deep had nitrate concentrations that exceeded the maximum contaminant level of 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1986a, b). Nineteen percent of the samples had nitrate concentrations that ranged from 5 to 10 mg/L as nitrogen; 21 percent had nitrate concentrations that ranged from 1 to less than 5 mg/L as nitrogen. Fifty-three percent of the samples had nitrate concentrations that were less than 1 mg/L as nitrogen for wells less than 200 ft deep. The relation of depth and nitrate concentration for wells greater than 200 ft deep that are in the program also are shown in figure 7. Less than 1 percent of the samples had nitrate concentrations greater than 10 mg/L as nitrogen. Two percent of the samples had nitrate concentrations from 5 to 10 mg/L as nitrogen. About 7 percent of the samples had nitrate concentrations from 1 to 5 mg/L as nitrogen. Ninety-one percent of the samples from wells greater than 200 ft deep had nitrate concentrations less than 1 mg/L as nitrogen.

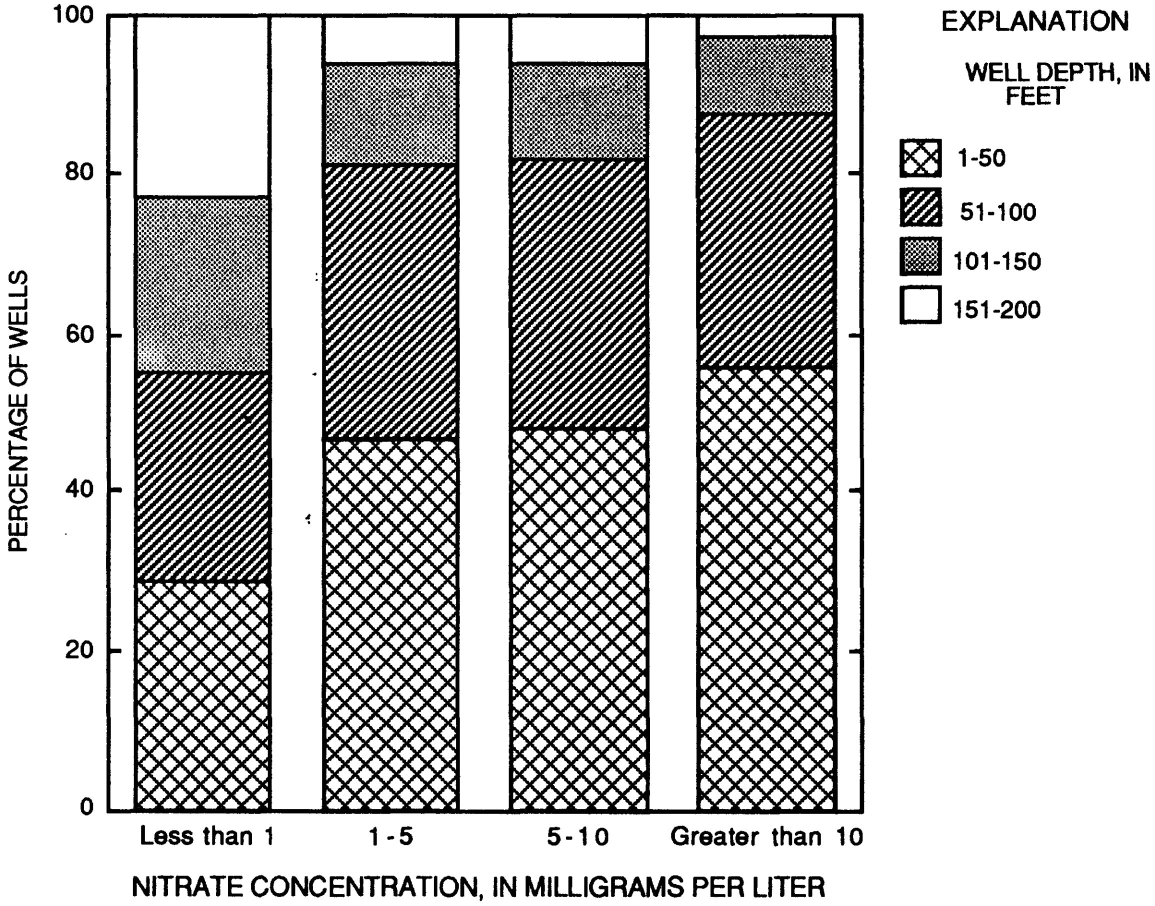

Figure 6.--Distribution of nitrate concentrations compared to well depth.

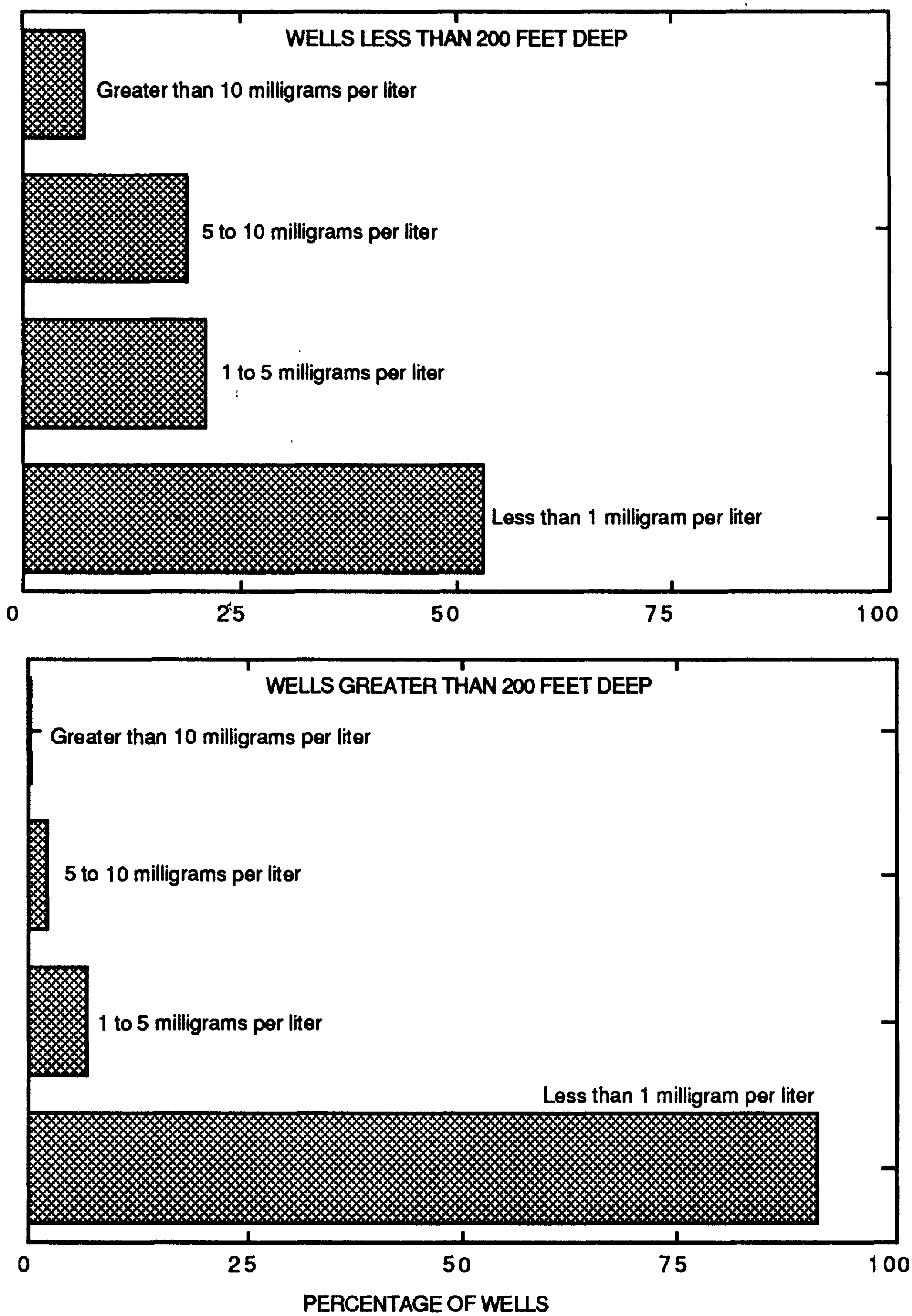

Figure 7.--Relation of nitrate as nitrogen in ground water to well depth.

Variation with Season

Seasonal variation of nitrate has been documented in many studies (Hallberg and Hoyer, 1982; Hallberg and others, 1983; Hallberg and others, 1984; Detroy, 1986) where individual wells were monitored throughout the year. If all nitrate concentrations from shallow wells are analyzed according to the particular month of sampling, a general seasonal variation of this constituent is obtained. The nitrate concentrations larger than 5 mg/L as nitrogen by month of sampling are listed in table 11. May through September generally were the months during which the largest percentage of samples containing nitrate concentrations greater than 10 mg/L as nitrogen were collected. No definitive seasonal relation is indicated by nitrate concentrations from 5 to 10 mg/L as nitrogen. However, the monitoring program is not specifically designed to detect seasonal trends, but it does provide an indication of the general variation of nitrate concentration in shallow ground water. At the present time (1988), 73 wells in this network have been sampled twice. Of these, 42 percent had nitrate concentrations that were greater in the second sample compared to the first sample.

Table 11.--Comparison of nitrate concentrations to month of sample collection

[mg/L, milligrams per liter; --, no data available]

Nitrate concentration, as nitrogen	Percentage of samples with indicated nitrate concentrations											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Less than 5 mg/L	1	6	10	9	6	8	10	25	15	3	4	3
5 to 10 mg/L	1	9	6	3	10	5	12	24	15	4	5	6
Greater than 10 mg/L	--	2	7	2	9	7	12	44	10	4	--	3
All samples	1	7	9	7	8	7	10	26	14	3	4	4
Total number of samples	8	54	73	57	59	57	82	208	116	28	33	31

PESTICIDES

As of fall 1987, 456 water samples from municipal wells less than 200 ft deep have been analyzed for pesticides. Of the 355 individual wells sampled at least once, 20 percent or 72 samples contained at least one detectable concentration of a pesticide (fig. 8). Atrazine was the pesticide most commonly detected; it was detected in 18 percent of the samples. Atrazine, alachlor, and metolachlor were detected in the largest concentrations of 21, 19, and 200 µg/L compared to cyanazine, dicamba, and metribuzin, detected in concentrations of 3.0, 2.3, and 2.0 µg/L. Generally the detection limit for pesticide analysis is 0.10 µg/L.

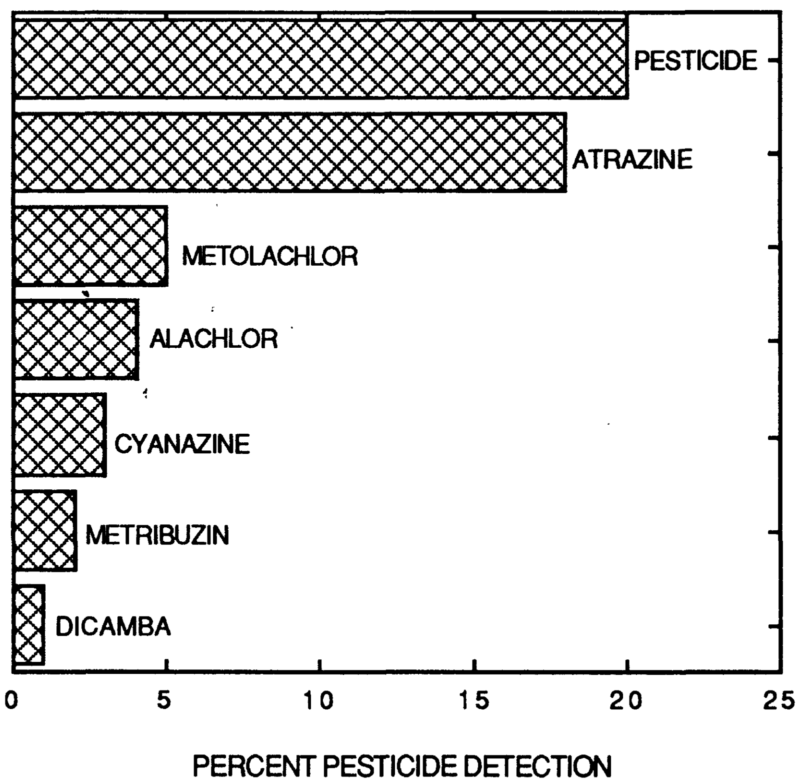

Figure 8.--Analytical results for pesticides.

Of the 113 samples with detectable pesticide concentrations, 18 percent contained more than one pesticide. One sample contained all six detected pesticides; 7 percent of the samples contained four or more pesticides. Of the pesticides detected, all were common herbicides, except for two detections of the acid herbicide dicamba. At the present time (1988), no organophosphate or chlorinated hydrocarbon insecticides has been detected in any samples.

Herbicides most frequently used on corn and soybeans in Iowa are listed in table 12. Of these, bentazon and bromoxynil were the only herbicides not analyzed by the University of Iowa Hygienic Laboratory. The widespread use of atrazine in some form (39 percent) helps explain why it is the most common herbicide detected in shallow ground water. However, other factors may be involved in the persistence of this or any other pesticide.

Table 12.--Herbicides and mixtures used in row crops in Iowa during 1986 (Delvo and others, 1987)

Corn (12,180,000 acres)		Soybeans (8,640,000 acres)	
Active ingredients	Percentage of total acreage	Active ingredients	Percentage of total acreage
Alachlor	14	Bentazon	12
Atrazine	6	Alachlor	6
Bromoxynil	6	Pendimethalin	6
Dicamba	9	Chloramben	7
Metolachlor	14	Trifluralin	35
Tank Mixes			
Atrazine + alachlor	11	Other 2-way mixes	13
Atrazine + cyanazine	10	Alachlor + metribuzin	5
Atrazine + metolachlor	12	Metribuzin + trifluralin	24
Dicamba + 2,4-D	7	Metribuzin + Pendimethalin	4
3-way mixes	6	3-way mixes	3

In 1986, Iowa farmers treated 99 percent of the their acreage of corn and soybeans with herbicides (Delvo and others, 1987). Of the herbicides listed in table 12, the monitoring program has detected six of them at least once. Those detected are applied on at least 80 percent of the corn acreage and about 25 percent of the soybean acreage. Trifluralin is extensively used on soybean acreage, but has not been detected.

Areal Distribution

The areal distribution of wells completed in surficial aquifers in Quaternary deposits and shallow bedrock aquifers sampled for pesticides is shown in figure 9. All the major aquifers are represented but the surficial aquifers account for 83 percent of the total wells because the depth of wells was restricted to less than 200 ft. The surficial aquifers primarily are in western Iowa and the shallow bedrock aquifers are elsewhere.

The location of municipal wells that have water containing detectable concentrations of pesticides is shown in figure 10. Bedrock aquifers account for 17 percent of the contaminated wells. The incidence of pesticide detection in those areas where the aquifer is near land surface with minimal protective covering has a pattern similar to that for nitrate concentrations.

Variation with Depth

Atrazine was the most prevalent pesticide detected in the ground-water-quality monitoring program. Samples from 18 percent of the shallow wells tested for pesticides had a detectable concentration of atrazine. Atrazine concentrations in water samples have a trend similar to that for nitrate with regard to well depth. Twenty-four percent of wells less than 50 ft deep yielded water contaminated with atrazine; 15 percent of the samples from wells 51 to 100 ft deep were contaminated with atrazine. For deeper well depths, the percentage of wells yielding water contaminated with pesticides is less (table 13).

Table 13.--Atrazine concentrations in water from contaminated wells less than 200 feet deep

Well depth, in feet	Atrazine concentration, micrograms per liter: Median	Interquartile range	Minimum	Maximum	Number of samples: Contaminated	Total	Percent detection
Less than 50	0.30	0.16 to 1.6	0.10	21	36	147	24
51 to 100	.29	.19 to .58	.10	2.7	17	110	15
101 to 150	.19	.14 to .38	.12	.55	8	62	13
151 to 200	.24	.19 to .29	.19	.29	2	36	6
Summary							
1 to 200	0.27	0.17 to 0.59	0.10	21	63	355	18

Depth is not clearly correlative with atrazine concentrations. One reason may be the limited range of concentrations detected. Ninety-five percent of the contaminated samples had less than 1.0 µg/L atrazine. The shallow bedrock aquifers accounted for 75 percent of the detected concentrations in depths from 101 to 200 ft.

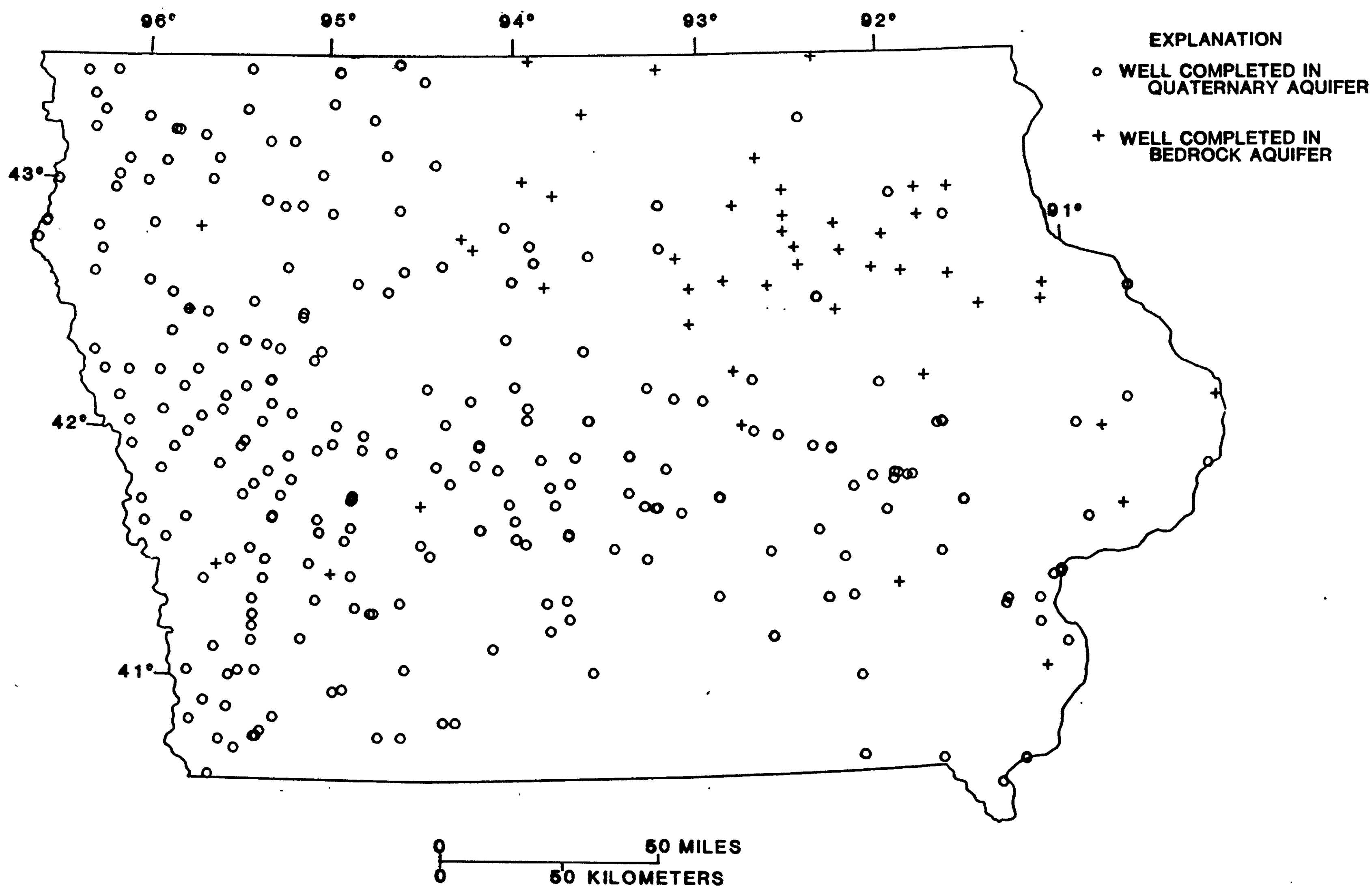

Figure 9.--Distibution of shallow wells sampled for pesticides.

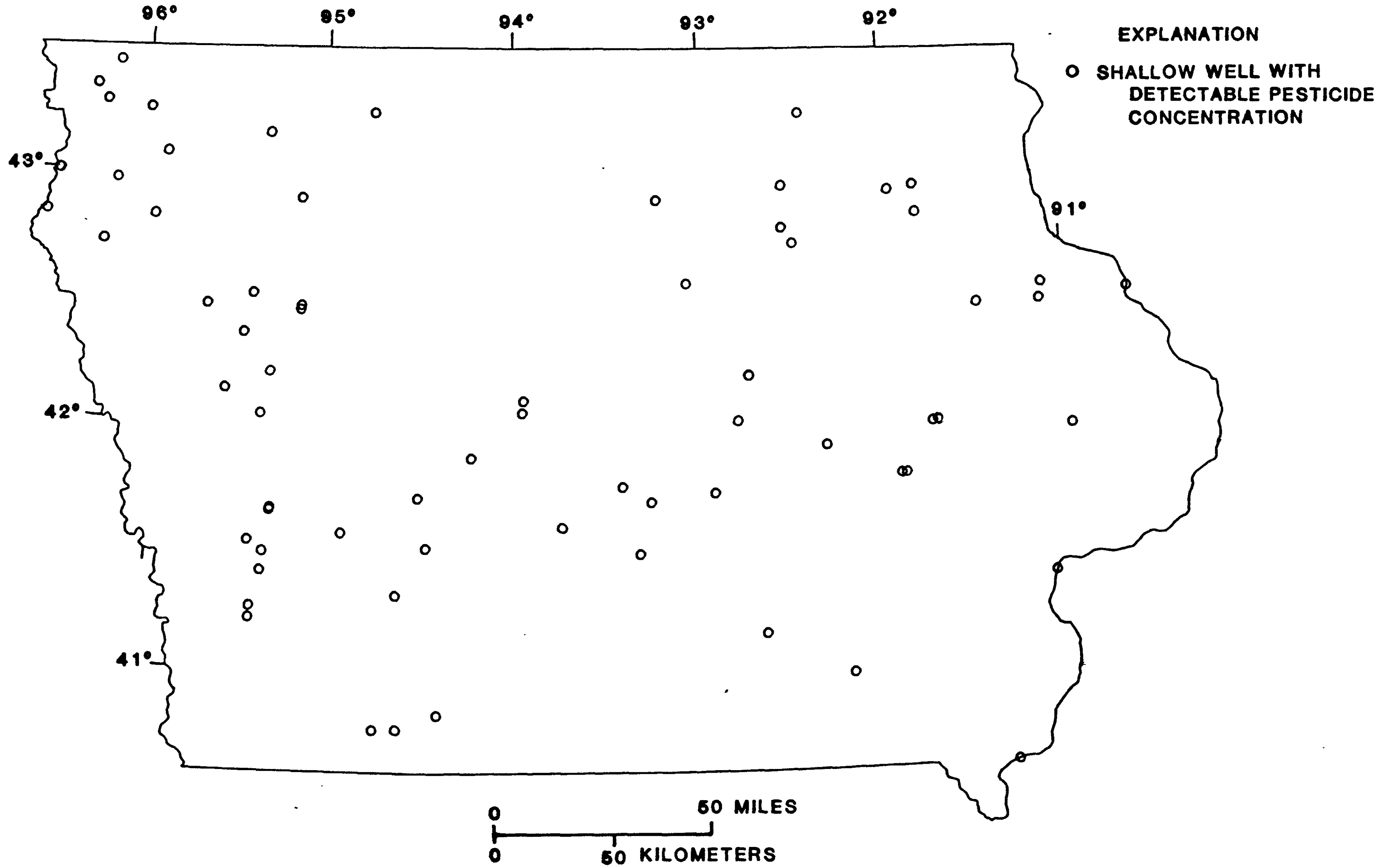

Figure 10.--Distribution of shallow wells with water containing detectable pesticide concentrations.

Variation with Season

Pesticides were detected in samples collected throughout most of the year. The percentage of samples with a pesticide detection on a month by month basis is listed in table 14. Similar to nitrate, May through October is the more likely time to measure detectable herbicides in shallow ground water. The time of pesticide detection may be somewhat dependent on application time. Preplant herbicides are applied before the crop is planted and may be incorporated in the soil. After planting and before the crop emerges, preemergence herbicides are applied. Postemergent treatments are applied after the crop has emerged and when weeds are at or near emergence (Fawcett and Owen, 1986). Snowmelt and spring rainfall occurs before chemical application, so the presence of these contaminants in March represents residual concentrations that have been leached through the soil from previous years. Other studies also have documented the persistence of pesticides throughout the year (Kelley, 1985; Detroy, 1986).

Table 14.--Pesticide detection by month

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Total number of samples											
1	24	21	14	30	48	49	152	61	26	23	10
Percentage containing detectable pesticides											
0	8	19	7	17	15	43	28	26	23	17	20

COMPARISON OF NITRATE AND PESTICIDE DATA

Aquifers that are susceptible to agricultural contamination have been described in Quaternary deposits, shallow bedrock near the land surface, and bedrock without an overlying confining unit. The geographic distribution of nitrate concentrations larger than 5 mg/L as nitrogen and detected pesticides are similar (fig. 11). The correlation of large concentrations of nitrate to detected pesticides is not as significant as the correlation between aquifer characteristics and these contaminants. Eighty-five percent of the water samples with nitrate concentrations greater than 10 mg/L as nitrogen had no detectable concentration of pesticides.

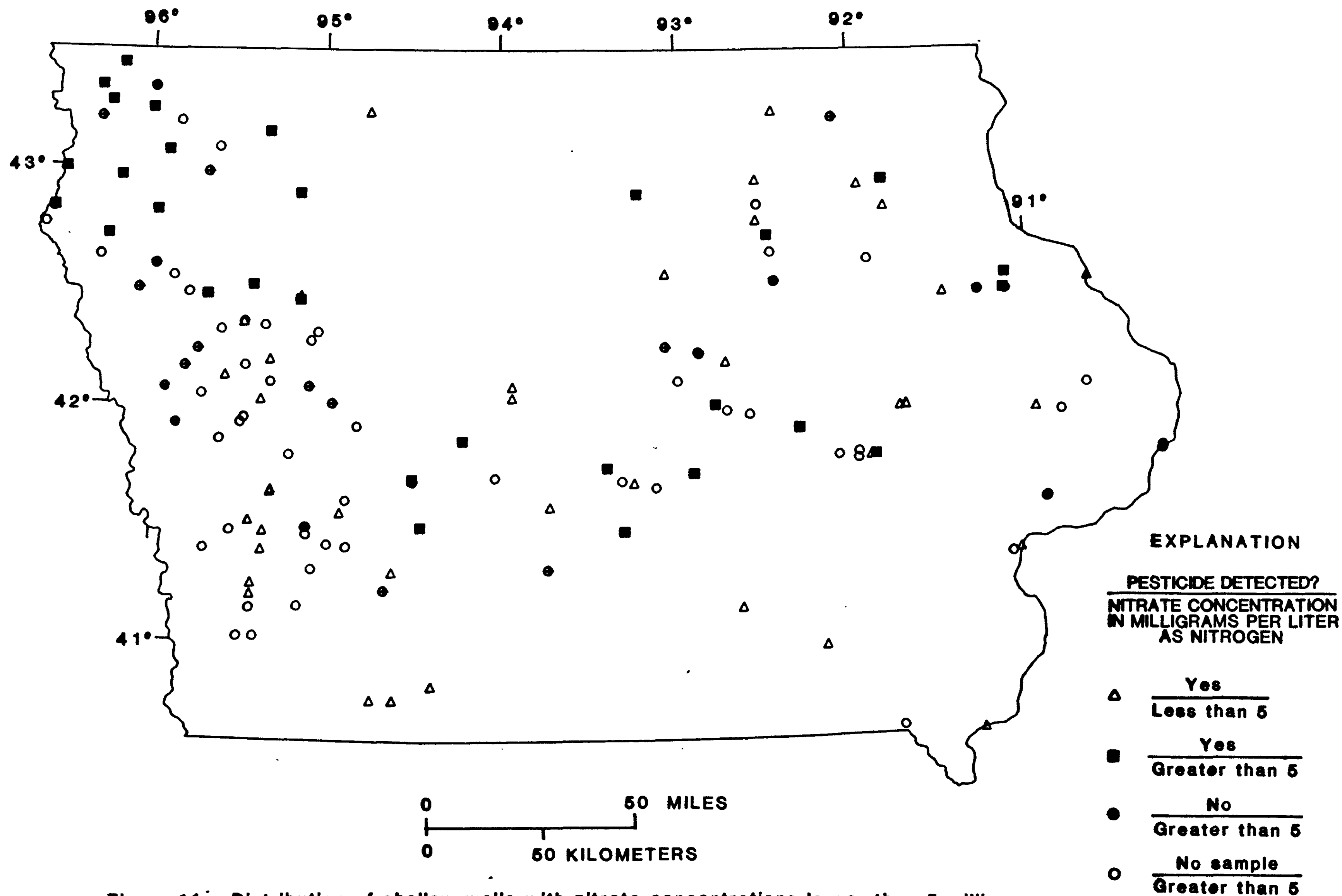

Figure 11.--Distribution of shallow wells with nitrate concentrations larger than 5 milligrams per liter as nitrogen and detectable pesticide concentrations.

SUMMARY

The Iowa ground-water-quality-monitoring program recently has emphasized nonpoint contaminants. A priority was placed on the analysis of pesticides in water samples collected from wells completed in surficial aquifers in Quaternary deposits or from wells less than 200 ft deep, or both. Samples from these wells were analyzed for nitrate and selected pesticides. In water samples collected from 515 individual shallow wells, 6 percent had nitrate concentrations larger than the maximum contaminant level for public drinking water (10 mg/L as nitrogen). The concentrations ranged from less than 0.1 to 53 mg/L as nitrogen. Eighteen percent of the samples had concentrations of nitrate between 5 and 10 mg/L as nitrogen. Water samples from 355 individual municipal wells less than 200 ft deep have been analyzed for pesticides at least once. Detectable concentrations of at least one pesticide--alachlor, atrazine, cyanazine, dicamba, metolachlor, or metribuzin, were detected in 20 percent of the samples. Atrazine was the most prevalent pesticide. Concentrations, which ranged from 0.10 to 21 μg/L, were detected in 18 percent of the samples.

The results of the monitoring program indicate a relation between decreasing well depth and the presence of detectable concentrations of nitrate and pesticides. Most nitrate and pesticide detection was in areas where surficial aquifers in Quaternary deposits are the principal source of ground water. Pesticides were detected in samples collected throughout the year; samples collected in late spring and early summer more frequently contained pesticides than the other samples.

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