GROUND-WATER QUALITY IN THE NEMAHA NATURAL RESOURCES DISTRICT, SOUTHEASTERN NEBRASKA, 1989

By D.Q. Tanner and G.V. Steele

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CONVERSION FACTORS

Multiply	By	To obtain
square mile (mi^2)	2,590	square kilometer
inch per hour (in/h)	25.4	millimeter per hour
foot (ft)	0.3048	meter
gallon per minute (gal/min)	0.06309	liter per second
degree Fahrenheit (°F)	(°F -32)/1.8	degree Celsius

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum 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 of 1929."

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ABSTRACT

Ground-water quality is a major concern throughout Nebraska. In the summer of 1989, water samples were collected from 80 wells located in the Nemaha Natural Resources District in southeastern Nebraska to characterize ground-water quality. The wells were selected to represent each of the four major aquifer types in the study area: the shallow aquifers, the Missouri River alluvial aquifer, the paleovalley alluvial aquifers, and the bedrock aquifers. Water from all 80 wells was analyzed for concentrations of nitrate and atrazine, a common herbicide. Water samples from about one-fourth of the 80 wells had nitrate concentrations greater than 5 milligrams per liter, as nitrogen, which probably indicates agricultural contamination. Nitrate concentrations in water from four wells exceeded the U.S. Environmental Protection Agency (USEPA) maximum contaminant level of 10 milligrams per liter. Atrazine was detected in samples from 7 of the 80 wells, but even the maximum concentration of 0.46 micrograms per liter was below the USEPA proposed maximum contaminant level of 3 micrograms per liter.

Water samples from 33 of the 80 wells were also analyzed for concentrations of major ions and selected trace elements to characterize the quality of water in each of the four aquifer types. Water samples from the shallow aquifers had relatively large concentrations of nitrate and atrazine, and samples from paleovalley aquifers had relatively large concentrations of nitrate. Water samples from the Missouri River alluvial aquifer had the largest median concentrations of iron (7,900 micrograms per liter) and manganese (990 micrograms per liter). Water from all seven Missouri River alluvial aquifer wells exceeded the USEPA secondary maximum contaminant levels for iron (300 micrograms per liter) and for manganese (50 micrograms per liter).

Water samples from the bedrock aquifers had the largest median concentrations of dissolved sulfate (250 milligrams per liter) and dissolved solids (708 milligrams per liter). Water from four of the eight sampled wells screened in bedrock aquifers exceeded 250 milligrams per liter of sulfate, which is the USEPA secondary maximum contaminant level. Water from seven wells screened in bedrock aquifers exceeded the USEPA secondary maximum contaminant level for dissolved solids (500 milligrams per liter). The USEPA maximum contaminant level for selenium (10 micrograms per liter) was exceeded in water samples from two wells screened in paleovalley alluvial aquifers and in two wells screened in shallow aquifers.

Further water-quality monitoring in the Nemaha Natural Resources District could address the only man-caused contaminants found in the present study -- nitrate and atrazine. Monitoring could focus on the paleovalley areas, which were the most susceptible to nitrate contamination and on the alluvium underlying the North Fork Big Nemaha River, which was most susceptible to atrazine contamination. Analysis of ground water for herbicides other than atrazine also would be useful in further characterizing the quality of ground

water in the District. The need for this additional monitoring is predicated on the detection of large concentrations of the herbicide, alachlor, in streams in the Nemaha Natural Resources District.

INTRODUCTION

The quality of ground water is a major concern throughout Nebraska because ground water is the principal source of water for agricultural, municipal, and domestic uses. The quality of ground water can be degraded by various activities, including those related to agriculture. In Nebraska, agricultural activities contribute to nonpoint-source or regional contamination of shallow aquifers through the use of fertilizers and pesticides, especially in irrigated areas that have well-drained sandy soils (Spalding and others, 1978; Gormly and Spalding, 1979; and Chen and Druliner, 1987).

Nebraska is divided into 23 resource-management units called Natural Resources Districts (NRD's). The boundaries of the NRD's generally follow surface-water drainage divides. The NRD's are State-authorized, are able to levy taxes, and are involved in a wide array of resources appraisal and management activities. Each NRD is required by State law to develop a ground-water management plan. To assist with this planning process, the U.S. Geological Survey entered into a cooperative agreement with the Nemaha NRD in April 1989 to assess the quality of water in aquifers in the NRD, with emphasis on agricultural chemicals.

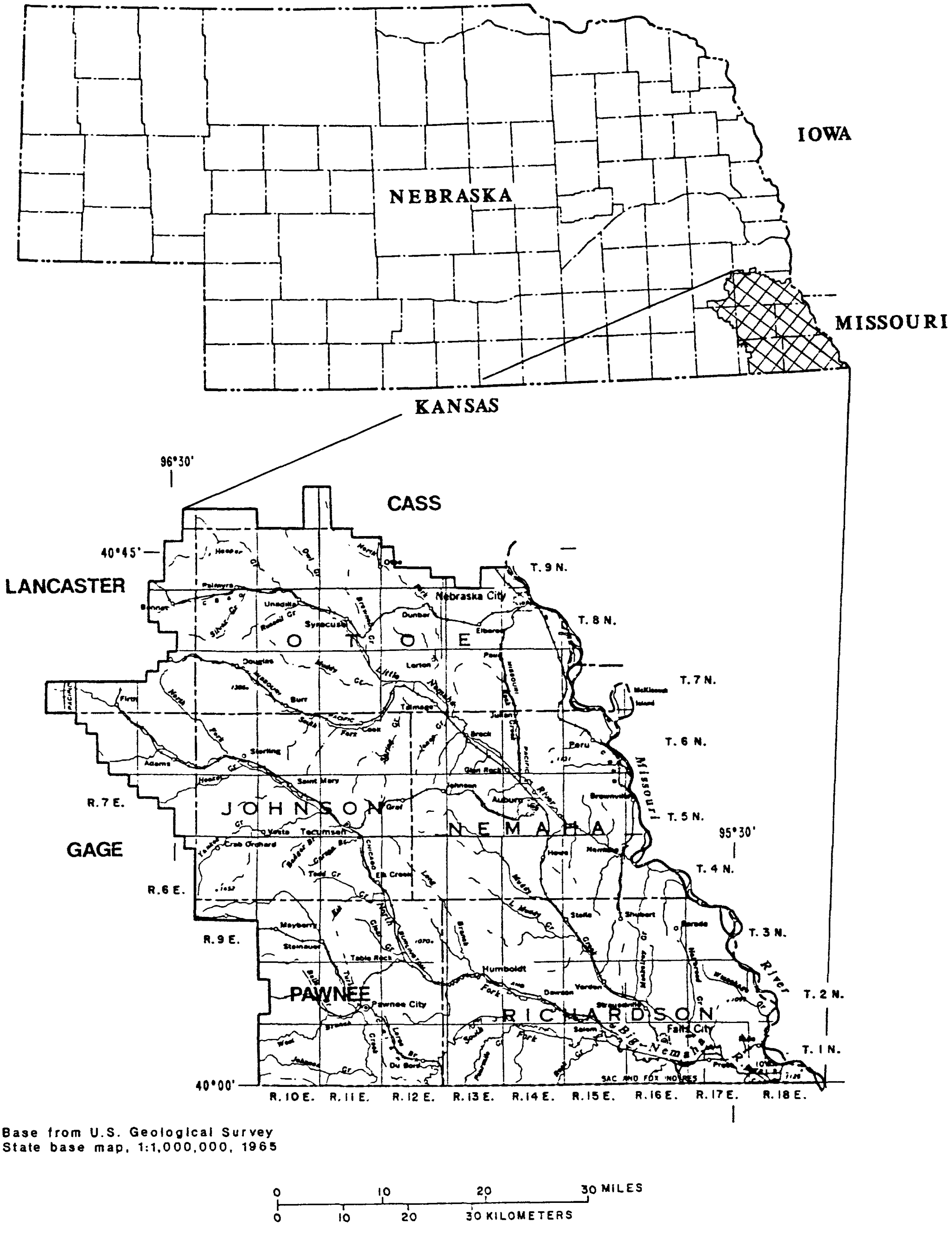
Purpose and Scope

This report describes the spatial distributions of nitrate, atrazine (a herbicide), and other selected constituents in surficial and bedrock aquifers in the Nemaha Natural Resources District. The primary emphasis is on concentrations of nitrate and atrazine in water samples collected from 80 wells during the summer of 1989. Concentrations of major constituents and selected trace elements in samples from 33 wells are also described. The general chemical quality of the ground water and a potential monitoring program are described.

Description of Study Area

The Nemaha NRD consists of about 2,400 square miles in the southeastern corner of Nebraska (fig. 1). Johnson, Nemaha, and Richardson Counties lie wholly within the study area, along with parts of Cass, Otoe, Gage, Lancaster, and Pawnee Counties. Land use in the Nemaha NRD is predominantly nonirrigated and irrigated agriculture. There are no major population centers; the largest town, Nebraska City, has a population of about 7,000.

The Nemaha Natural Resources District is located in the Dissected Till Plain section of the Central Lowland physiographic province (Fenneman, 1946). This area consists of rolling hills with rounded ridge tops and well-defined drainageways. Small, nearly level areas are present on the divides between major streams. Drainage is predominantly from northwest to southeast. About 90 percent of the area is drained by the Big Nemaha and Little Nemaha Rivers or their tributaries. The remainder of the area is drained by minor tributaries of the Missouri River.



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965

Figure 1.--Location of study area.

Soils

The principal soil associations within the Nemaha NRD have previously been mapped (U.S. Department of Agriculture Soil Conservation Service and University of Nebraska Conservation and Survey Division, 1980). The soils on the uplands are the Sharpsburg, Wymore-Pawnee, and Marshall-Ponca associations. These soils are composed principally of clay loam to silt loam subsoils formed on loess and glacial till deposits. The average permeabilities of these upland soils range from less than 1 to 1.5 inches per hour and the slope ranges from 0 to 17 percent (Dugan, 1984, p. 14-15).

The soils of the lowlands are principally represented by the Kennebec-Nodaway-Zook association. The lowland subsoils are principally silt loams that formed predominantly on clayey and silty alluvial and colluvial parent materials. The lowland subsoils have an average permeability between 1.0 and 1.5 inches per hour; the slopes of lowland subsoils range from 0 to 3 percent (Dugan, 1984, p. 14).

The principal soil representing areas where shale and limestone are near the surface is the Kipson-Benfield-Sogn association. These soils have an average permeability of less than 1 inch per hour and a slope that varies from 1 to 30 percent (Dugan, 1984, p. 14).

Climate

The climate of the study area, which is typical of areas with a mid-latitude, continental location, is characterized by hot summers, severe winters, and moderate amounts of precipitation. The following data show the average climatological conditions (1951-1980) and conditions in 1989 (National Oceanic and Atmospheric Administration, 1990). The average annual temperature for the study area is about 52 °F (degrees Fahrenheit). July, which is usually the hottest month, has an average temperature of 78 °F. During July 1989, the average temperature was 77 °F, and the highest recorded temperature was 102 °F at Falls City. January, which normally is the coldest month, has an average temperature of 23 °F. During January 1989, the average temperature was 34 °F, and the lowest recorded temperature was 7 °F at Falls City and Syracuse. Precipitation for the study area is usually moderate. The average annual precipitation is 30.33 inches. Of this, about 70 percent, or 22 inches, occurs during the growing season (April through September). During 1989, precipitation amounts were about 80 percent (24 inches) of the annual average and 95 percent (21 inches) of the growing-season average.

Previous Investigations

Relatively little has been written about the ground-water quality of the Nemaha NRD. A report addressing only Richardson County described ground-water quality as being generally satisfactory for most uses (Emery, 1964, p. 20-23). Hardness and large concentrations of iron and manganese were the most common and serious water-quality problems in water from the 14 wells sampled. It was not specified in which aquifers the wells were completed.

Ground-water resources were described for the Missouri River alluvial aquifer between Kansas City, Missouri, and the Iowa border by Emmett and Jeffery (1969). This area comprises the eastern edge of the Nemaha NRD. Water from the 15 wells sampled was classified as very hard ($CaCO_3$ greater than 180 mg/L), and most water samples had large concentrations of iron and manganese.

A state-wide study included water-quality data of the Paleozoic bedrock aquifer in southeastern Nebraska (Engberg, 1984, p. 45-48). The water samples were highly mineralized, but there was no indication of large concentrations of trace constituents.

A study of ground-water quality in parts of Johnson, Nemaha, Pawnee, and Richardson Counties showed contamination by nitrate and atrazine (Exner and Spalding, 1985). Of the 268 water samples collected from domestic and stock wells, 71 percent had nitrate concentrations larger than 10 mg/L (milligrams per liter). Twenty-eight percent of the 47 samples analyzed for atrazine had detectable concentrations. The nitrate sources were reported to be point sources, generally manure in barnyards and corrals. The highest incidence of nitrate contamination occurred in dug or augered wells with open-jointed casing. Nonpoint-source contamination was not observed.

The report of a study that modeled the stream-aquifer system near the town of Cook in Johnson County also included some water-quality data from wells screened in the paleovalley alluvial aquifer (Hiergesell, 1985, p. 48). The largest concentration of nitrate in five ground-water samples was 8.9 mg/L. The greatest potential for contamination was thought to exist in upland areas where recharge to the aquifer would be the greatest.

Twenty wells and three springs were sampled as part of a hydrogeologic study of northwestern Richardson County (Page, 1987, p. 119-126). Concentrations of nitrate as large as 94 mg/L were reported. Nitrate contamination was attributed to both point sources, such as feedlots and farmyards, and nonpoint sources, such as areas where agricultural fertilizer was applied. Water samples from bedrock wells had large concentrations of chloride, sulfate, and dissolved solids, but relatively small concentrations of nitrate.

The results of pesticide analyses for more than 2,000 ground-water samples in Nebraska were summarized by Spalding, Burbach, and Exner (1989). Most of the wells sampled were domestic. Water samples from 13 percent of the wells had detectable concentrations of atrazine. About 30 percent of the 50 water samples collected from wells in the Nemaha NRD had detectable concentrations of atrazine.

Well-Numbering System

Well numbers are based on the land subdivisions within the U.S. Bureau of Land Management's survey of Nebraska. The numeral preceding N (north) indicates the township, the numeral preceding E (east) indicates the range, and the numeral preceding the terminal letters indicates the section in which the well is located. The terminal letters denote, respectively, the quarter section, the quarter-quarter section, the quarter-quarter-quarter section, and the quarter-quarter-quarter-quarter section. They are assigned in counterclockwise direction beginning with "A" in the northeast corner of each subdivision. If two or more wells are located in the same subdivision, they are distinguished by adding a sequential digit to the well number. Thus, a second well inventoried in SW1/4 of the SE1/4 of the NW1/4 of the SE1/4, sec. 21, T.6 N., R.9 E. would be assigned the number 6N-09E-21DBDC2. An example is shown in figure 2. An "O" after an A, B, C, or D indicates the approximate center of the subdivision.

A USGS site identification number was assigned to each well. The first six digits represent the latitude in degrees, minutes, and seconds, and the next seven digits represent the longitude. The final two digits are sequence numbers, beginning with "01."

HYDROGEOLOGY

The hydrogeologic units described in this report are limited to those in unconsolidated Quaternary deposits (table 1) and to those in bedrock formations directly underlying the Quaternary deposits (table 2). The saturated thickness and distribution of selected Quaternary deposits are shown in figure 3. Because the alluvial and the isolated sand and gravel aquifers possess similar hydrologic characteristics, such as well yields, they are classified together as the shallow aquifers. The distribution and stratigraphic sequence of bedrock formations directly underlying Quaternary deposits in the study area are shown in figure 4.

Aquifers in bedrock formations directly underlying the unconsolidated Quaternary deposits are in rocks of Cretaceous, Permian, and Pennsylvanian age (table 2). Wells developed in these formations may obtain water from one or more of the stratigraphic units; however, this report makes no attempt to differentiate these bedrock aquifers. The Pennsylvanian formations are underlain by as much as 2,000 feet of older Paleozoic rocks. Available data indicate that there is no hydraulic connection between these older Paleozoic rocks and the bedrock aquifers in the study area.

There is a large hiatus in the geologic record between the deposition of bedrock units, as described in table 2, and the deposition of Pleistocene deposits. It is probable, during this time, that movement along the fault zone in western Nemaha and Richardson Counties (fig. 4) resulted in erosion of the bedrock surface. Available data indicate that in early Pleistocene time, major streams flowing east-southeast across the area eroded large valleys into the bedrock surface. Remnants of these valleys are as much as 5 miles wide and 200 feet deep, and are filled with sand and gravel deposits. Further uplifting along the fault zones and alternating periods of deposition and erosion related to the advancing and retreating of continental ice sheets probably has limited the areal extent of the Pleistocene sand and gravel filled paleovalleys to the western half of the study area (fig 3). The bedrock and paleovalleys are overlain by fine-grained, glacial deposits that are predominantly undifferentiated silts and clays intermixed with local sand and gravel lenses. In this report, these local sand and gravel deposits are combined with the Holocene alluvial deposits and described in table 1 as "shallow aquifers." Most of the glacial deposits are overlain by loess deposits, which average about 30-40 feet thick in the eastern part of the study area and thin toward the west.

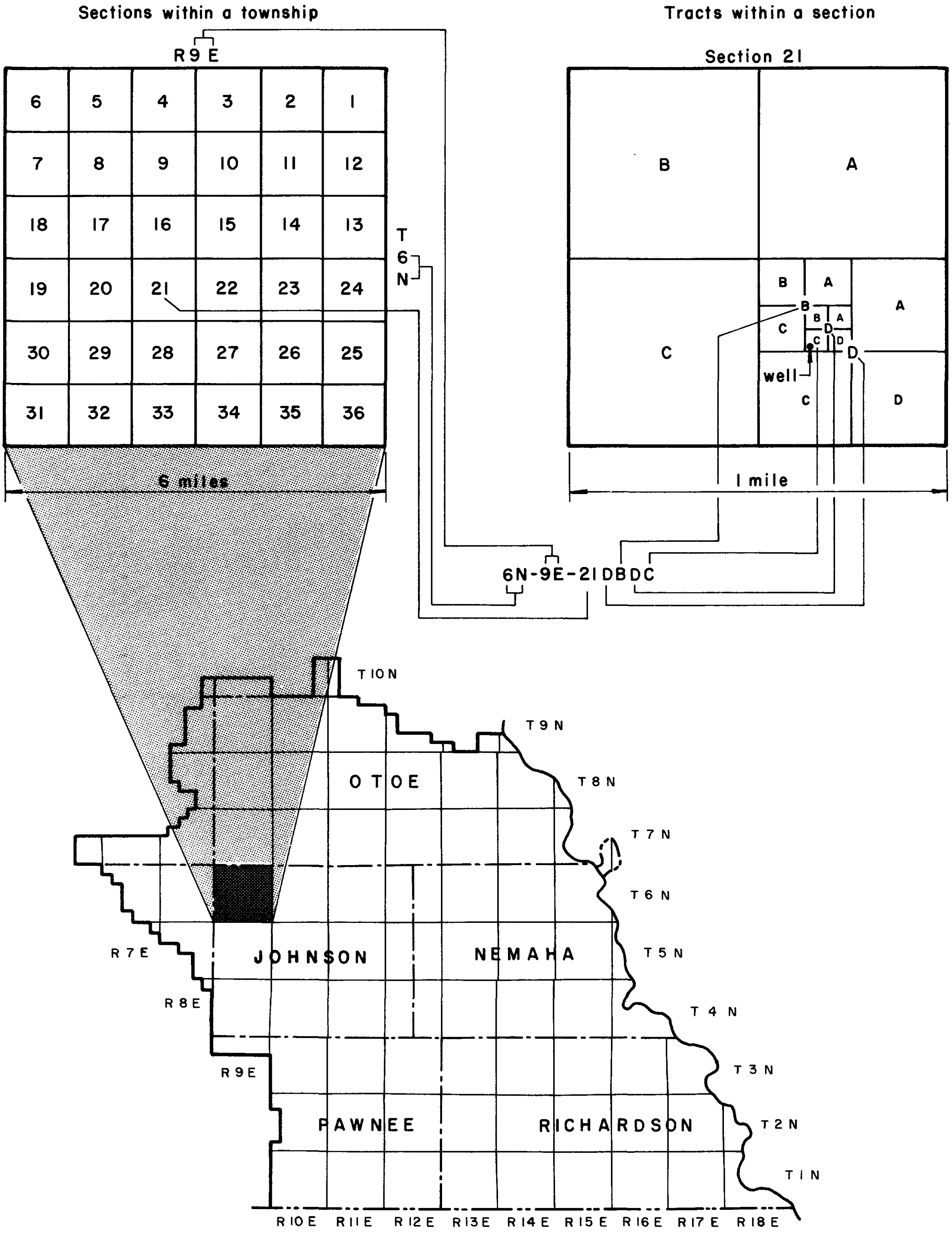


Figure 2.--Well-numbering system.

Table 1.--Aquifers in unconsolidated surficial deposits
[gal/min, gallons per minute; <, less than]

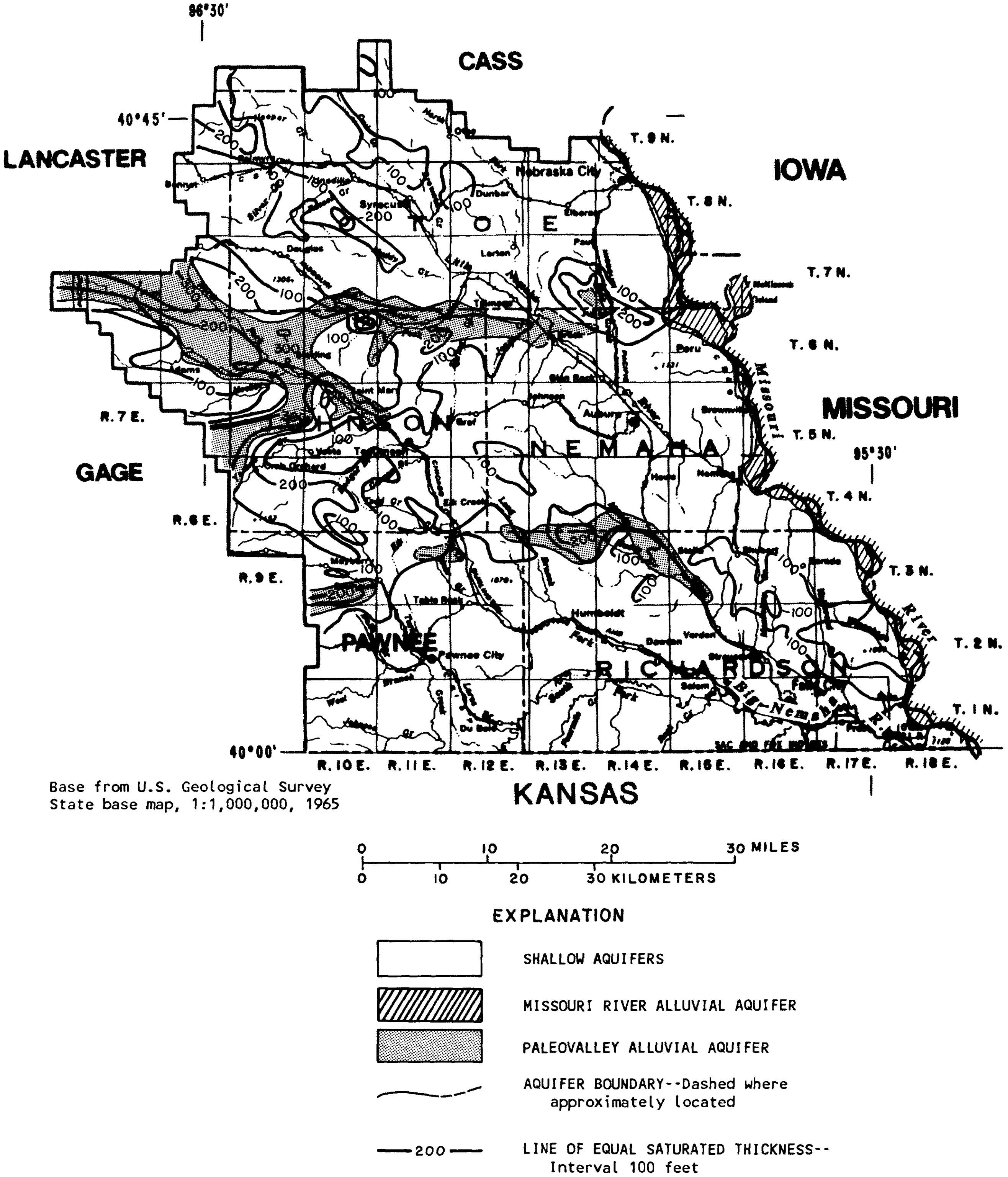
System	Hydrogeologic unit	Character and description	Maximum thickness, in feet	Hydrogeologic characteristics
Quaternary	Shallow aquifers	Shallow Holocene alluvium in valleys and discontinuous Pleistocene sand and gravel lenses in predominately fine-grained deposits.	10 to 150	Shallow valley aquifers, consisting of sand and gravel deposits, generally are unconfined to semi-confined and might be hydraulically connected to surface-water systems, other shallow aquifers or paleovalley alluvial aquifers. Wells generally yield 50 to 700 gal/min. Aquifers consisting of discontinuous sand and gravel lenses generally are confined to semi-confined. Some might be hydraulically connected to each other, but they tend to be areally restricted and isolated. Wells within these aquifers will yield 10 to 100 gal/min.
	Missouri River alluvial aquifer	Predominately Holocene and Pleistocene sand, gravel and silt deposits. Deposits are located within the incised bedrock valley of the Missouri River.	150	A major aquifer that generally is unconfined to semi-confined and hydraulically connected with the Missouri River. Wells generally yield 300 to 700 gal/min, and locally yield as much as 1,500 gal/min.
	Paleovalley alluvial aquifers	Predominately Pleistocene sand and gravel deposits within bedrock valleys. Generally deposits are thicker in the western part of the study area and thin toward the east. Local isolated remnants of paleovalleys may occur in other parts of study area.	<200	Major aquifers that are generally semi-confined to confined. Basic directional trend of paleovalleys seems to be west to east. Might be hydraulically connected to local shallow aquifers and surface-water systems. Wells yield 500 to 1,000 gal/min and locally as much as 1,500 gal/min.

Table 2.--Characteristics of bedrock aquifers (modified from Condra and Reed, 1959)
[gal/min, gallons per minute; <, less than]

System	Hydrogeologic unit	Character and description	Maximum thickness, in feet	Hydrogeologic characteristics
Cretaceous	Aquifer in Dakota Formation	Predominately massive to crossbedded friable sandstone with interbedded red to light gray, argillaceous to slightly sandy shales. Sandstone may contain ironstone or spherulitic siderite concretions, chert pebbles. Sandstones and shales may be micaceous.	<100	Generally an unconfined or semi-confined aquifer. Wells can yield 50 to 750 gal/min. Might be hydraulically connected to saturated sand and gravels in overlying unconsolidated deposits.
Permian	Aquifer in Chase Group	Predominately gray argillaceous shale with interbedded to massive limestones. Limestones may be geodal, fossiliferous , or very cherty. Some massive red shales are present. Lower third of unit has scattered beds of shale-sandstones, mudstone-shales and limestone-sandstones.	170	Generally an unconfined or semi-confined aquifer. Wells can yield 20 to 50 gal/min in areas where secondary porosity has developed in fractured zones in the limestone sequences. Might be hydraulically connected to saturated sand and gravel in overlying unconsolidated deposits.
	Aquifer in Council Grove Group	Predominately gray and red argillaceous shales with interbedded, massive, blocky, argillaceous limestones. Some limestones may be fossiliferous or variegated light to dark gray. Shales may be laminated, micaceous, arenaceous, calcareous, blocky or contain fine gypsum. One to two feet of siltstone present in top of lower third of unit.	320	Generally an unconfined or semi-confined aquifer. Wells can yield 20 to 50 gal/min in areas where secondary porosity has developed in fractured zones in the limestone sequences. Might function as a confining layer to local sandstones of underlying units and be hydraulically connected to saturated sand and gravel in overlying unconsolidated deposits.

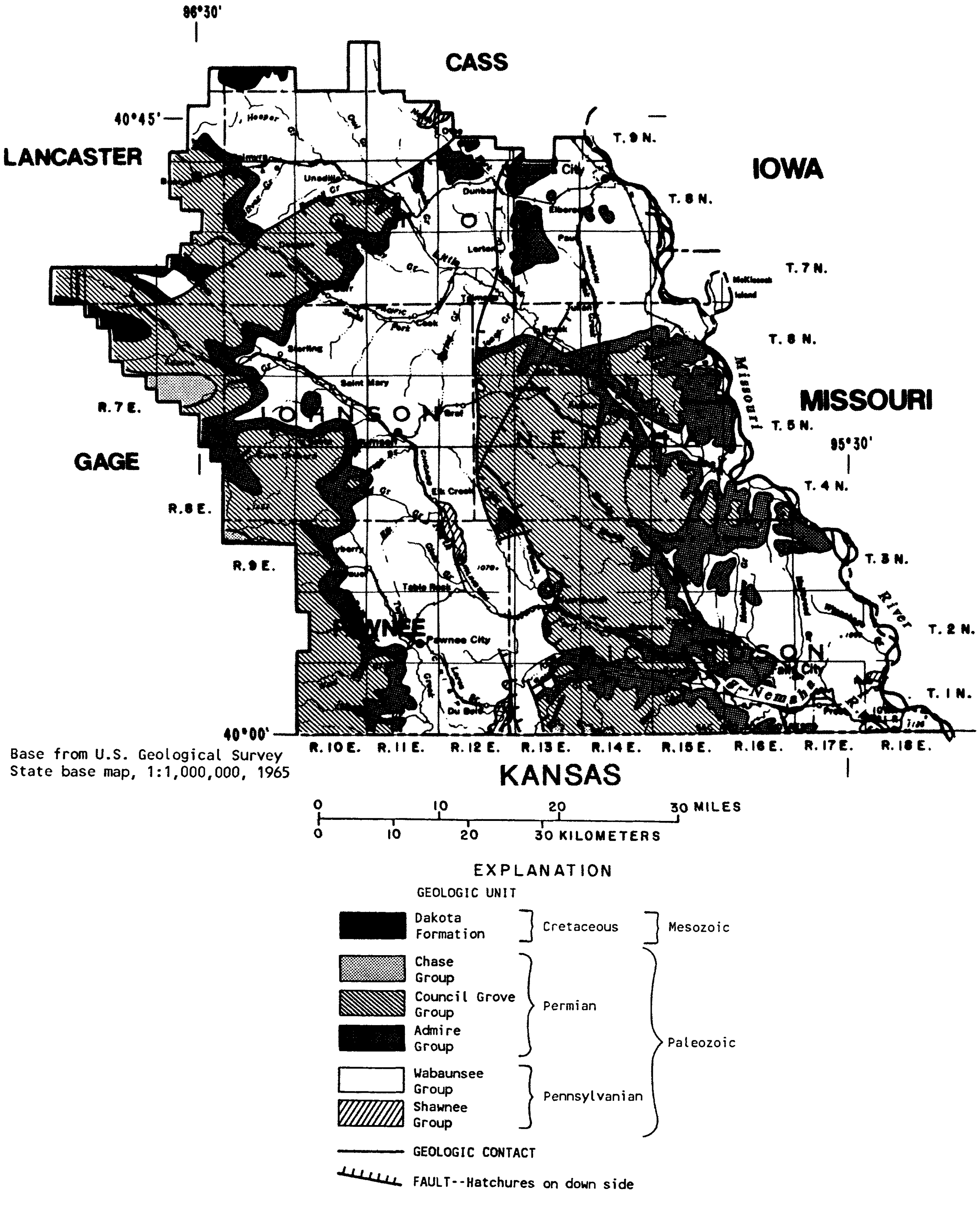
Table 2.--Characteristics of bedrock aquifers--Continued

System	Hydrogeologic unit	Character and description	Maximum thickness, in feet	Hydrogeologic characteristics
Permian	Aquifer in Admire Group	Predominately gray shale with interbedded, porous, argillaceous limestone and red shale. Top 45 ft. of shale contains 12- to 18-foot bed of fine-grained sandstone. Basal sandstones 0 to 50 feet thick occur locally.	130 180 with local basal sandstones	Generally a semi-confined or confined aquifer. Wells developed in fractured development zones in the limestone can yield 20 to 50 gal/min as a result of secondary porosity. Local besal sandstone might slightly increase yield. Might be hydraulically connected to saturated sand and gravels in overlying unconsolidated deposits.
Pennsylvanian	Aquifer in Wabaunsee Group	Predominately shale with some beds of limestone. Limestone may contain lenses or thin interbedded sandstones and coal beds. Shale is predominately gray to dark gray and argillaceous. Limestone and shale may be fossiliferous.	400	Not a major aquifer. Some wells developed in the limestone generally yield 20 to 50 gal/min as a result of the secondary porosity from fracturing. Some of the interbedded sandstones might be hydraulically connected.
	Aquifer in Shawnee Group	Predominately interbedded to massive limestones with argillaceous shales. The shales are predominately green and gray, but some red shale may be found. Limestones and shales may be highly fossiliferous.	175	Not a major aquifer. Because of secondary fracturing, some wells can be completed in the limestone sequences. Generally wells yield 20 to 50 gal/min.



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965

Figure 3.--Aquifer types and saturated thickness of Quaternary deposits. (Source: Modified from University of Nebraska Conservation and Survey Division, 1980.)



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965

Figure 4.--Bedrock geology. (Source: From Burchett, 1986.)

Within the study area, a hydraulic connection exists between some of the aquifers. Hiergesell (1985) showed that there is a distinct relation between the paleovalley alluvial aquifer in the Cook area and the streamflow of the Little Nemaha River. This indicates a hydraulic connection exists between the paleovalley alluvial aquifers and shallow alluvial aquifers in this area. Also, it is very likely that some of the sand and gravel lenses are in direct contact with the paleovalley alluvial or the bedrock aquifers.

Most of the recharge may be attributed to infiltration from precipitation within the study area; some recharge occurs as ground-water flow from aquifers outside the NRD or from ephemeral streams. The Missouri River alluvial aquifer is recharged by infiltration from the Missouri River and local precipitation.

SAMPLE COLLECTION AND LABORATORY PROCEDURES

Standard U.S. Geological Survey procedures were used for water-quality sampling, laboratory analyses, and quality assurance. This section presents an overview of the more important procedures.

Well Selection

On the basis of available hydrologic and chemical data, it was determined that approximately 80 water samples would be needed to describe the quality of ground water in the study area. Representative wells completed in each aquifer were selected for sampling -- 39 irrigation wells, 19 domestic wells, 19 municipal wells, 2 stock wells, and 1 industrial well (table 3, fig. 5). Criteria for selection included the absence of any potential point sources of contamination, the availability of a detailed driller's log, and availability for sampling. (Two of the sampled wells, B01 and B15, were of known depth and were located in areas of bedrock outcrops but did not have well logs available.) The well identification numbers (table 3, fig. 5) are classified by the type of aquifer in which each well is screened as follows: S01-S18 = shallow aquifers, M01-M13 = Missouri River alluvial aquifer, P01-P34 = paleovalley alluvial aquifers, and B01-B15 = bedrock aquifers. Altitudes (land-surface datum) for all wells were determined from 7-1/2 minute series topographic maps (scale 1:24,000), which have 5- or 10-foot contour intervals.

For the shallow aquifers and the bedrock aquifers, all of the wells that met the above criteria were sampled. For the Missouri River alluvial aquifer, approximately 40 wells met the criteria; and for the paleovalley alluvial aquifers, approximately 400 wells met the criteria. For these aquifers, sampling sites were randomly chosen from all sampling sites that met the criteria.

Water-Quality Sampling

Each well was sampled as close to the wellhead as possible. The following water-quality properties were measured onsite using a flow-through chamber: pH, temperature, specific conductance, and dissolved oxygen (when possible). When these properties had stabilized (usually within 15 minutes), the water samples were taken. These procedures were assumed to yield water samples that were representative of the aquifer near the well screen.

Table 3.--Wells sampled for water-quality analyses

Well identification number[1] (fig. 5)	Well number	U.S. Geological Survey site identification number	Elevation of land surface datum (feet above sea level)	Depth of well, total (feet)	Year drilled	Water use
S01	8N-09E-10AAAA1	404058096231601	1,210	54	1968	Domestic
S02	8N-12E-12CDCC1	404009096012901	1,047	47	1969	Municipal
S03	8N-11E-16CBBB1	403939096114601	1,045	52	1966	Municipal
S04	7N-11E-15DCDC1	403403096095601	1,060	110	1975	Irrigation
S05	7N-11E-36BBAA1	403216096081101	1,072	91	1975	Irrigation
S06	6N-08E-26DDCC1	402704096305001	1,243	40	1973	Domestic
S07	5N-12E-13BAAB1	402425096011201	1,161	83	1985	Municipal
S08	5N-14E-15BBBD1	402422095501101	918	46	1957	Municipal
S09	4N-15E-01CBBB1	402030095412301	907	64	1980	Municipal
S10	4N-11E-25ACAB1	401715096074401	1,078	62	1979	Municipal
S11	4N-11E-36BCDA1	401616096081401	1,071	57	1977	Irrigation
S12	3N-11E-31BABD1	401119096134601	1,195	39	1989	Domestic
S13	2N-15E-10DBDC1	400859095425501	935	42	1954	Municipal
S14	2N-14E-22ABCD1	400739095494901	950	48	1977	Municipal
S15	2N-10E-26BDCD1	400639096160101	1,370	36	1989	Domestic
S16	2N-11E-26CCCC1	400612096093501	1,130	42	1937	Irrigation
S17	1N-11E-02BCBD1	400500096093101	1,135	45	1989	Domestic
S18	1N-15E-03ACCD1	400449095425801	905	47	1970	Municipal
M01	8N-14E-04BADA1	404142095505901	920	74	1956	Municipal
M02	7N-15E-06DDBA1	403557095455901	912	85	1977	Irrigation
M03	7N-15E-07BABA1	403544095463301	912	109	1961	Irrigation
M04	7N-15E-30ABCD1	403257095461601	906	56	1975	Irrigation
M05	6N-15E-04C01	403045095442301	904	73	1976	Irrigation
M06	6N-15E-09A01	403019095434901	905	78	1975	Irrigation
M07	6N-15E-10CBDD1	402955095431701	898	84	1977	Irrigation
M08	6N-15E-16BBBC1	402935095443801	903	82	1977	Irrigation
M09	5N-16E-32BADA1	402141095382501	900	62	1968	Industrial
M10	2N-18E-32BBAA1	400605095252001	865	81	1970	Irrigation
M11	1N-18E-20DCAB1	400155095244601	855	62	1940	Municipal
M12	1N-19E-31CBBB1	400026095195101	856	53	1978	Irrigation
M13	1N-19E-31D01	400013095190401	852	72	1977	Irrigation
P01	7N-08E-21BDBB1	403348096320301	1,308	214	1975	Irrigation
P02	7N-08E-19CDCB1	403316096340501	1,420	325	1974	Irrigation
P03	7N-07E-25DDDB1	403223096342501	1,492	320	1956	Irrigation
P04	7N-10E-33ABAB1	403216096175701	1,133	111	1968	Municipal
P05	7N-10E-33ADAB1	403203096174401	1,118	105	1978	Irrigation
P06	7N-07E-35BCDC1	403154096362201	1,315	150	1954	Municipal
P07	6N-11E-05AAAA1	403123096115001	1,120	175	1977	Municipal
P08	6N-07E-02ACCB1	403105096355701	308	142	1967	Irrigation
P09	6N-13E-04CBAA1	403056095580501	965	58	1977	Irrigation
P10	6N-09E-06CCCB1	403039096274701	1,255	170	1965	Irrigation

Table 3.--Wells sampled for water-quality analyses--Continued

Well identification number [1] (fig. 5)	Well number	U.S. Geological Survey site identification number	Elevation of land surface datum (feet above sea level)	Depth of well, total (feet)	Year drilled	Water use
P11	6N-13E-09ADAA1	403018095571601	958	54	1982	Irrigation
P12	6N-13E-11CBBC1	402955095555101	975	59	1977	Irrigation
P13	6N-12E-07DACC1	402952096063401	1,090	156	1974	Irrigation
P14	6N-09E-16BDBC1	402924096251201	1,238	155	1976	Irrigation
P15	6N-08E-13D01	402903096280601	1,350	301	1979	Irrigation
P16	6N-13E-20AAAB1	402846095582101	1,011	77	1988	Municipal
P17	6N-08E-24BAD01	402837096313301	1,350	246	1989	Irrigation
P18	6N-09E-21DBDC1	402812096244701	1,197	170	1969	Irrigation
P19	6N-09E-21CCA01	402807096251901	1,203	130	1968	Irrigation
P20	6N-08E-26AACC1	402746096291201	1,247	112	1956	Irrigation
P21	6N-09E-25DABD1	402727096210801	1,178	190	1957	Irrigation
P22	6N-09E-25DCD01	402707096211601	1,165	150	1967	Irrigation
P23	5N-10E-09C01	402442096182401	1,195	188	1977	Irrigation
P24	5N-10E-10CCBC1	402437096173101	1,159	150	1973	Municipal
P25	5N-10E-15DCDD1	402338096164501	1,160	110	1977	Domestic
P26	3N-14E-03A01	401531095493701	1,030	147	1977	Irrigation
P27	3N-14E-03BDDD1	401520095495601	1,082	190	1976	Irrigation
P28	3N-14E-06DBCD1	401506095531101	1,090	174	1977	Irrigation
P29	3N-14E-11CDBB1	401424095491801	1,090	193	1977	Irrigation
P30	3N-11E-14BBBB1	401359096093501	1,220	145	1977	Municipal
P31	3N-13E-15BBAA1	401359095565901	1,169	124	1987	Municipal
P32	3N-14E-14BACC1	401348095490101	1,030	157	1977	Irrigation
P33	3N-14E-14DBDA1	401325095483101	1,030	146	1977	Irrigation
P34	3N-11E-13DDBB1	401320096073601	1,205	153	1978	Municipal
B01	7N-14E-01BCBD1	403620095475901	930	60	1979	Domestic
B02	7N-08E-22BABC1	403358096305501	1,365	220	1972	Domestic
B03	6N-08E-29BBBB1	402756096332801	1,320	204	1973	Domestic
B04	5N-08E-05AAAA1	402612096322401	1,350	123	1986	Domestic
B05	5N-07E-01AAAB2	402611096342502	1,383	230	1976	Domestic
B06	5N-07E-01AAAB1	402611096342501	1,383	60	1973	Domestic
B07	5N-08E-01DCDD1	402523096280801	1,305	195	1988	Domestic
B08	5N-08E-11ACAA1	402507096291601	1,341	174	1988	Domestic
B09	5N-09E-07BCBC1	402503096274701	1,330	171	1988	Stock
B10	5N-08E-12BCBA1	402502096310901	1,300	163	1986	Domestic
B11	5N-09E-08BCCA1	402500096263401	1,290	130	1981	Domestic
B12	4N-10E-06ADAD1	402041096195001	1,315	177	1988	Domestic
B13	3N-16E-01DDDC1	401453095334101	1,163	152	1986	Domestic
B14	2N-14E-07ADBD1	400920095525401	1,095	105	1938	Stock
B15	1N-13E-27DCBD1	400101095563301	1,151	102	1982	Domestic

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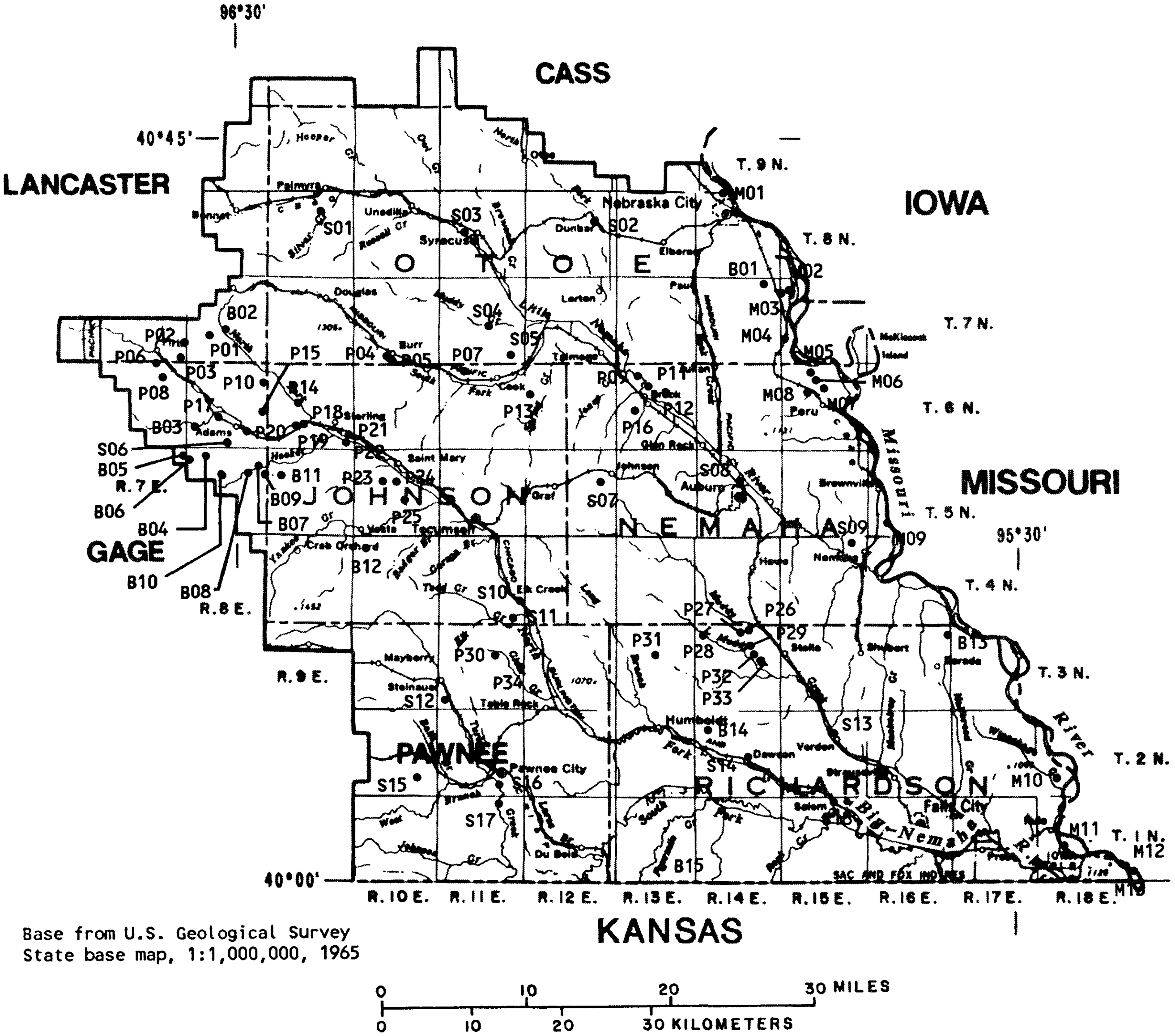
[1] Well screened in: S = shallow aquifer; M = Missouri River alluvial aquifer; P = paleovalley alluvial aquifer; and B = bedrock aquifer.



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965

EXPLANATION

● B01 WELL AND IDENTIFICATION NUMBER--
Letter indicates aquifer:
S--Shallow aquifer
M--Missouri River alluvial aquifer
P--Paleovalley alluvial aquifer
B--Bedrock aquifer

Figure 5.--Location of sampled wells.

A water sample from each of the 80 wells was immediately filtered, preserved, and kept chilled at 4 °C (degrees Celsius) for dissolved-nitrate analysis. At each site, an additional sample was collected in a glass bottle and kept chilled for the analysis of triazine herbicides. Water samples collected from 33 wells (seven to nine randomly selected wells from each of the four aquifers) were analyzed for concentrations of major cations and anions and trace elements. These samples were filtered and preserved in the field as appropriate (Pritt and Jones, 1989).

Laboratory Procedures

Analyses for concentrations of nitrite plus nitrate, major cations and anions, and trace elements were done using standard methods at the U.S. Geological Survey National Water Quality Laboratory (Fishman and Friedman, 1989). Because concentrations of nitrite in freshwater are generally negligible compared to nitrate (National Research Council, 1978, p. 118), the concentration from the nitrite plus nitrate analysis was considered to be all nitrate and will be referred to as such in this report.

Concentrations of triazine herbicides were determined using a two-tiered approach to reduce laboratory costs. All 80 samples were tested for total triazine herbicides, which includes atrazine, using an enzyme-assay test kit. If a water sample contained more than 0.1 μg/L (microgram per liter) of triazines according to the enzyme-assay test, it was subsequently analyzed using gas chromatography by Harris Environmental Technologies, Inc.[1], in Lincoln, Nebr. This method uses a liquid-liquid solvent extraction procedure and a nitrogen-phosphorous detector with a second-column confirmation to analyze for concentrations of atrazine, prometone, propazine, prometryne, simazine, and cyanazine.

Quality Control and Quality Assurance

The bottles and preservatives used for sampling had been subjected to quality-control measures to reduce the chance of contamination. The quality-assurance program at the National Water Quality Laboratory (NWQL) includes participation in U.S. Geological Survey and U.S. Environmental Protection Agency interlaboratory evaluations, and submission of blind standard reference water samples into the NWQL sample stream (Friedman and Fishman, 1982; Jones, 1987). In addition, cation-anion balances were calculated for each complete analysis to ensure internally consistent data.

As a quality-control check of the enzyme-assay triazine test, 16 (20 percent) of the samples having less than or equal to 0.1 μg/L of triazines were also analyzed by gas chromatography. This was done to ensure that the triazine screening test did not produce a substantial amount of false negatives; that is, that the test did not indicate the absence of triazines when they were, in fact, present in substantial concentrations. All 16 of these samples had

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

concentrations of total triazines that were less than 0.1 μg/L when analyzed by gas chromatography. Also, two (3 percent) of the enzyme-assay triazine tests were repeated on another aliquot of the sample as a measure of the test's reproducibility. Each of these replicated tests produced results identical to the first test. Quality control and quality assurance for the gas chromatography included a program of standard matrix spikes, blanks, and internal standards.

The quality-control data from the 16 samples that were analyzed for concentrations of atrazine by gas chromatography are addressed in this report. Even though their primary function was to evaluate the enzyme-assay triazine test, the information they provide on small concentrations of atrazine is useful for evaluating the overall water quality.

GROUND-WATER QUALITY

Ground-water quality data are presented in tables 4-7. All ground-water quality data, except the triazine enzyme-assay test results, are stored in the U.S. Geological Survey's National Water Information System (NWIS) and Water Data Storage and Retrieval (WATSTORE) data bases. The water-quality data from all four aquifers are summarized in table 8. The drinking-water regulations in table 8 are from the U.S. Environmental Protection Agency (1976, 1977, 1987). Primary drinking-water regulations for two constituents were exceeded in water from wells in the study area. The maximum contaminant level for dissolved nitrate (as nitrogen) was exceeded in water from four wells, and the maximum contaminant level for dissolved selenium was exceeded in water from four wells. The source of selenium probably was geologic, because no man-caused sources were present. Secondary drinking-water regulations are established mainly for contaminants that can adversely affect the odor or appearance of water. Concentrations in samples exceeded secondary maximum contaminant levels for four constituents: sulfate, dissolved solids, iron, and manganese.

Distribution of Nitrate and Atrazine

Nitrate and atrazine are associated with agricultural practices, and they were emphasized in this study. As such, they were analyzed in water samples from all 80 sampling sites in the Nemaha NRD.

The distribution of relatively large concentrations of nitrate in ground-water samples is shown in figure 6. About one-fourth of the water samples from the 80 wells had nitrate concentrations larger than 5 mg/L. Most nitrate concentrations larger than 5 mg/L occurred in or near areas of the paleovalley alluvial aquifers (see fig. 5). The largest of the paleovalley alluvial aquifers lies in the southeastern part of Lancaster County, the northeastern part of Gage County, and the northern part of Johnson and Nemaha Counties. A smaller paleovalley alluvial aquifer is in the northwestern part of Richardson County. Both areas are primarily irrigated agricultural land, and the paleovalley alluvial aquifers are the major water source. Large concentrations of nitrate in the ground water of these paleovalley alluvial aquifers and nearby

Table 4.--Results of onsite measurements

[°C, degree Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data]

Well identification number[1] (fig. 5)	Date sampled	Time	Water temperature (°C)	Specific conductance (µS/cm)	pH (Standard (units)	Oxygen, dissolved (mg/L)
S01	7-06-89	1630	14.0	--	7.09	3.9
S02	7-07-89	1450	12.5	244	7.08	.3
S03	7-06-89	1100	14.5	550	7.05	1.8
S04	8-14-89	1550	13.0	--	7.22	2.0
S05	8-03-89	1100	12.5	434	6.85	2.9
S06	8-21-89	1425	12.5	495	6.95	7.2
S07	6-22-89	1600	13.5	542	7.35	2.0
S08	6-22-89	1000	15.5	525	6.84	.2
S09	8-18-89	1040	13.0	382	7.14	1.4
S10	6-30-89	1315	15.0	--	6.91	2.4
S11	8-03-89	1620	13.5	--	7.39	--
S12	6-29-89	1545	13.5	553	7.16	.1
S13	9-20-89	1345	13.0	522	6.85	--
S14	6-23-89	1515	14.5	728	7.11	1.6
S15	6-29-89	1130	17.0	568	7.20	2.6
S16	6-29-89	1245	13.0	564	7.47	--
S17	6-29-89	1030	14.0	--	6.92	.1
S18	6-23-89	1315	14.0	555	7.19	--
M01	8-07-89	1445	14.0	580	7.48	.3
M02	8-02-89	0930	12.5	800	7.31	--
M03	8-02-89	1125	12.5	--	7.23	.6
M04	8-14-89	1215	13.0	--	7.41	--
M05	7-07-89	1210	12.5	--	7.09	.2
M06	8-04-89	1050	13.0	530	7.24	--
M07	8-04-89	1010	13.0	--	7.25	--
M08	8-07-89	1245	12.5	691	7.44	--
M09	6-22-89	1430	16.0	766	7.26	.1
M10	8-18-89	1235	12.5	494	7.14	--
M11	6-23-89	1115	14.5	--	7.15	3.0
M12	8-18-89	1345	13.0	--	7.54	--
M13	8-21-89	1135	13.0	714	7.05	.6

Table 4.--Results of onsite measurements--Continued

Well identification number[1] (fig. 5)	Date sampled	Time	Water temperature (°C)	Specific conductance (µS/cm)	pH (Standard units)	Oxygen, dissolved (mg/L)
P01	8-01-89	1445	13.0	515	7.25	0.3
P02	8-01-89	1600	13.5	756	7.17	3.9
P03	7-13-89	1415	13.5	482	7.40	--
P04	7-06-89	1430	14.5	507	7.40	7.5
P05	7-06-89	1515	15.0	686	7.18	2.3
P06	7-12-89	1530	18.5	448	7.30	8.3
P07	7-06-89	1330	13.5	456	7.22	7.9
P08	7-12-89	1630	13.0	447	7.37	8.0
P09	6-21-89	1330	15.5	578	7.22	1.2
P10	8-01-89	1345	13.0	578	7.24	--
P11	8-02-89	1505	12.0	474	6.95	6.0
P12	6-21-89	1130	13.0	486	7.17	--
P13	6-21-89	0930	17.5	800	7.11	2.8
P14	8-01-89	1430	15.5	551	7.30	--
P15	6-19-89	1300	15.5	--	7.41	1.4
P16	6-21-89	1500	14.5	424	7.04	8.2
P17	8-21-89	1545	13.0	--	7.14	4.2
P18	7-12-89	1330	14.0	575	7.01	3.2
P19	8-01-89	1050	13.0	460	7.38	--
P20	6-19-89	1415	17.0	464	6.85	4.1
P21	8-01-89	1140	13.0	461	7.16	3.5
P22	8-01-89	1210	13.5	449	7.29	6.1
P23	6-19-89	1000	15.0	654	7.30	1.6
P24	6-19-89	1130	15.0	630	7.29	3.8
P25	7-12-89	1030	14.5	394	7.47	.2
P26	8-03-89	1355	13.0	--	7.80	--
P27	8-03-89	1325	13.0	478	7.57	--
P28	8-03-89	1515	12.5	527	7.37	5.8
P29	8-04-89	1445	13.5	534	7.59	--
P30	6-29-89	1330	14.0	--	6.96	3.8
P31	6-30-89	1130	15.0	552	7.35	9.1
P32	8-04-89	1510	13.5	386	8.16	--
P33	8-04-89	1550	13.0	359	7.77	--
P34	6-29-89	1430	14.5	569	7.22	.1

Table 4.--Results of onsite measurements--Continued

Well identification number[1] (fig. 5)	Date sampled	Time	Water temperature (°C)	Specific conductance (µS/cm)	pH (Standard (units)	Oxygen, dissolved (mg/L)
B01	8-02-89	1200	12.5	755	7.11	3.6
B02	7-13-89	1530	15.0	--	7.48	.1
B03	7-05-89	1225	14.0	793	7.62	.2
B04	7-05-89	1430	13.5	573	7.53	.6
B05	7-05-89	1330	14.0	1,500	7.41	4.9
B06	7-05-89	1315	13.0	1,600	7.18	7.2
B07	7-05-89	1605	14.0	912	7.89	.1
B08	6-19-89	1500	13.5	597	7.56	.1
B09	7-05-89	1545	13.5	564	7.88	.1
B10	8-21-89	1500	13.5	396	7.47	.1
B11	7-13-89	1215	15.0	489	7.50	.1
B12	6-30-89	1445	14.5	--	7.26	.1
B13	8-04-89	1350	13.5	476	7.47	--
B14	6-30-89	1045	14.5	--	6.99	1.2
B15	6-23-89	1630	14.0	--	7.33	--

[1] Well screened in: S = shallow aquifer; M = Missouri River alluvial aquifer; P = paleovalley alluvial aquifer; and B = bedrock aquifer.

Table 5.--Results of analyses for nitrate and atrazine
[mg/L as N, milligrams per liter as nitrogen; >, more than; µg/L, micrograms per liter; <, less than; --, no data]

Well identification number[1] (fig. 5)	Nitrate, dissolved (mg/L as N)	Triazines, enzyme-assay test (>0.1 µg/L)	Atrazine, by gas chromatography (µg/L)
S01	5.00	no	--
S02	1.10	no	--
S03	11.00	no	--
S04	5.80	no	0.09
S05	9.80	no	.09
S06	23.00	no	--
S07	2.40	no	--
S08	<.10	no	--
S09	2.40	no	--
S10	5.60	no	--
S11	<.10	no	.07
S12	.94	no	--
S13	7.00	no	--
S14	<.10	no	--
S15	1.30	no	--
S16	1.10	no	--
S17	<.10	no	--
S18	<.10	yes	.46
Median	1.85		.09
M01	<.10	no	<.04
M02	<.10	no	--
M03	<.10	no	--
M04	<.10	no	--
M05	<.10	no	--
M06	<.10	no	--
M07	<.10	no	--
M08	<.10	no	--
M09	<.10	no	--
M10	<.10	no	--
M11	<.10	no	--
M12	<.10	no	--
M13	<.10	no	.09
Median	<.10		.06
P01	.69	no	--
P02	<.10	no	--
P03	1.00	no	--
P04	6.10	no	--
P05	2.50	no	--
P06	5.40	no	<.02
P07	5.90	no	--
P08	3.20	no	--
P09	<.10	no	--
P10	.46	no	<.04

Table 5.--Results of analyses for nitrate and atrazine--Continued

Well identification number[1] (fig. 5)	Nitrate, dissolved (mg/L as N)	Triazines, enzyme-assay test (>0.1 µg/L)	Atrazine, by gas chromatography (µg/L)
P11	<0.10	no	--
P12	5.90	no	--
P13	7.10	no	--
P14	.65	no	--
P15	.19	no	--
P16	12.00	no	--
P17	4.70	no	--
P18	1.80	no	--
P19	1.50	no	<0.04
P20	7.70	no	<.02
P21	.31	no	--
P22	.31	no	--
P23	1.10	no	--
P24	1.50	no	.02
P25	.12	no	--
P26	2.50	no	--
P27	2.70	no	--
P28	5.60	no	--
P29	2.80	no	--
P30	1.10	no	<.02
P31	9.20	no	<.02
P32	8.40	no	--
P33	6.30	no	--
P34	.33	no	--
Median	2.15		<.02
B01	.77	no	--
B02	<.10	no	<.02
B03	<.10	no	--
B04	.52	no	<.02
B05	.32	no	--
B06	60.00	no	--
B07	<.10	no	--
B08	<.10	no	--
B09	<.10	no	--
B10	<.10	no	--
B11	<.10	no	<.02
B12	.20	no	--
B13	9.30	no	<.04
B14	1.20	yes	*.14
B15	.93	no	--
Median	.20		<.02

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[1] Well screened in: S = shallow aquifer; M = Missouri River alluvial aquifer; P = paleovalley alluvial aquifer; and B = bedrock aquifer.

* Prometone also was detected at a concentration of 0.02 µg/L.

Table 6.--Results of analyses for major constituents

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

Well identification number[1] (fig.5)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity lab (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)
S01	140	33	36	2.8	347	210	7.6	0.3	29	689
S03	61	13	37	2.8	198	48	9.8	.3	27	366
S04	65	10	37	1.9	241	15	6.7	.2	27	333
S07	72	20	37	1.4	301	33	1.4	.4	24	380
S08	73	13	21	2.0	180	86	11.0	.2	26	341
S10	120	23	51	3.8	319	150	18.0	.3	20	604
S11	79	16	29	2.9	276	28	8.1	.3	23	352
S17	81	20	35	1.9	291	49	18.0	.3	32	417
S18	84	17	48	1.6	247	82	27.0	.5	25	436
Median	79	17	37	2.0	276	49	9.8	.3	26	380
M01	70	21	60	5.7	228	150	19.0	.4	18	485
M03	140	46	42	6.5	543	33	10.0	.3	30	644
M04	170	51	63	7.7	--	70	14.0	.3	27	412
M05	120	35	29	5.8	490	16	3.4	.3	33	545
M07	--	--	--	--	487	9	5.5	.3	--	--
M09	120	34	20	5.8	418	25	9.3	.4	31	509
M11	140	40	31	4.6	517	54	5.3	.4	28	626
M12	130	40	19	5.6	--	20	5.7	.3	27	251
Median	130	40	31	5.8	488	29	7.5	.3	28	509
P07	63	9.8	23	2.1	208	16	3.3	.2	32	300
P12	64	15	30	2.6	201	56	10.0	.3	23	347
P15	81	16	24	3.3	286	31	8.3	.3	31	367
P18	84	17	36	2.8	283	69	11.0	.3	29	427
P24	80	19	40	3.7	274	85	8.3	.4	30	437
P26	72	19	34	1.3	268	28	5.8	.3	27	359
P30	86	18	18	2.9	283	42	2.4	.3	26	370
P33	57	13	27	1.2	201	14	10.0	.2	24	295
Median	76	16	28	2.7	271	36	8.3	.3	28	363
B01	120	57	19	5.4	523	54	11.0	.4	24	608
B02	78	36	170	5.1	306	230	150.0	.6	21	874
B03	54	21	88	4.6	245	170	11.0	.7	25	522
B07	90	35	61	3.8	214	270	11.0	.5	19	619
B08	65	23	35	3.7	280	50	6.6	.5	20	372
B12	89	40	130	6.3	334	290	49.0	.8	22	829
B14	370	52	23	2.4	283	920	11.0	.3	16	1,570
B15	170	52	18	1.9	327	330	9.6	.5	16	798
Median	90	38	48	4.2	294	250	11.0	.5	20	708

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[1] Well screened in: S = shallow aquifer; M = Missouri River alluvial aquifer; P = paleovalley alluvial aquifer; and B = bedrock aquifer.

Table 7.--Results of analyses for selected trace elements
[μg/L, micrograms per liter; <, less than; --, no data]

Well identification number[1] (fig. 3)	Arsenic, dissolved, (μg/L as As)	Iron, dissolved (μg/L as Fe)	Manganese dissolved (μg/L as Mn)	Selenium, dissolved (μg/L as Se)	Zinc, dissolved (μg/L as Zn)
S01	<1	14	24	3	77
S03	1	9	2	9	33
S04	1	6	98	6	10
S07	1	9	26	25	8
S08	2	390	230	<1	13
S10	1	38	1,500	23	17
S11	1	180	210	3	7
S17	5	4,000	1,600	<1	42
S18	2	170	2,500	<1	110
Median	1	38	210	3	17
M01	11	3,400	990	<1	16
M03	13	9,500	850	<1	7
M04	14	6,200	3,200	<1	25
M05	3	7,900	550	<1	6
M07	--	--	--	--	--
M09	12	12,000	900	<1	4
M11	10	9,600	2,600	<1	6
M12	10	870	2,500	<1	12
Median	11	7,900	990	1	7
P07	3	<3	<1	2	18
P12	2	9	1	21	7
P15	4	8	2	9	25
P18	2	4	160	16	4
P24	1	4	120	3	3
P26	1	20	11	2	7
P30	2	10	3	6	11
P33	1	<3	1	2	59
Median	2	6	2	4	9
B01	1	17	2	5	48
B02	5	56	110	<1	21
B03	2	22	400	<1	11
B07	1	39	120	<1	22
B08	12	150	95	<1	23
B12	<1	33	570	<1	26
B14	<1	18	7	2	94
B15	<1	65	5	3	6
Median	1	36	102	1	22

[1] Well screened in: S = shallow aquifer; M = Missouri River alluvial aquifer; P = paleovalley alluvial aquifer; and B = bedrock aquifer.

Table 8.--Summary of results of analyses

[Concentrations in milligrams per liter (mg/L) unless otherwise noted, and all except atrazine are dissolved concentrations. USEPA, U.S. Environmental Protection Agency; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; --, not applicable; <, less than]

Constituent	Concentrations			USEPA drinking water regulation a/	Number of wells sampled	Number of wells exceeding regulation
	Minimum	Median	Maximum			
Specific conductance, field (µS/cm)	244	542	1,600	--	61	--
pH, field (standard units)	6.84	7.25	8.16	*6.5 -8.5	80	0
Dissolved oxygen	.1	2.0	9.1	--	57	--
Calcium	54	82	370	--	32	--
Magnesium	9.8	21	57	--	32	--
Sodium	18	35	170	--	32	--
Potassium	1.2	3.1	7.7	--	32	--
Alkalinity as $CaCO_3$	180	283	543	--	31	--
Sulfate	9	54	920	*250	33	4
Chloride	1.4	9.8	150	*250	33	0
Fluoride	.2	.3	.8	4.0, *2.0	33	0
Silica	16	26	33	--	32	--
Dissolved solids	251	432	1,570	*500	32	13
Nitrate	<.10	.85	60	10	80	4
Arsenic (µg/L)	<1	2	14	50	32	0
Iron (µg/L)	<3	35	12,000	*300	32	9
Manganese (µg/L)	<1	120	3,200	*50	32	20
Selenium (µg/L)	<1	2	25	10	32	4
Zinc (µg/L)	3	14	110	*5,000	32	0
Atrazine (µg/L)	<.02	<.04	.46	b/ 3	80	0

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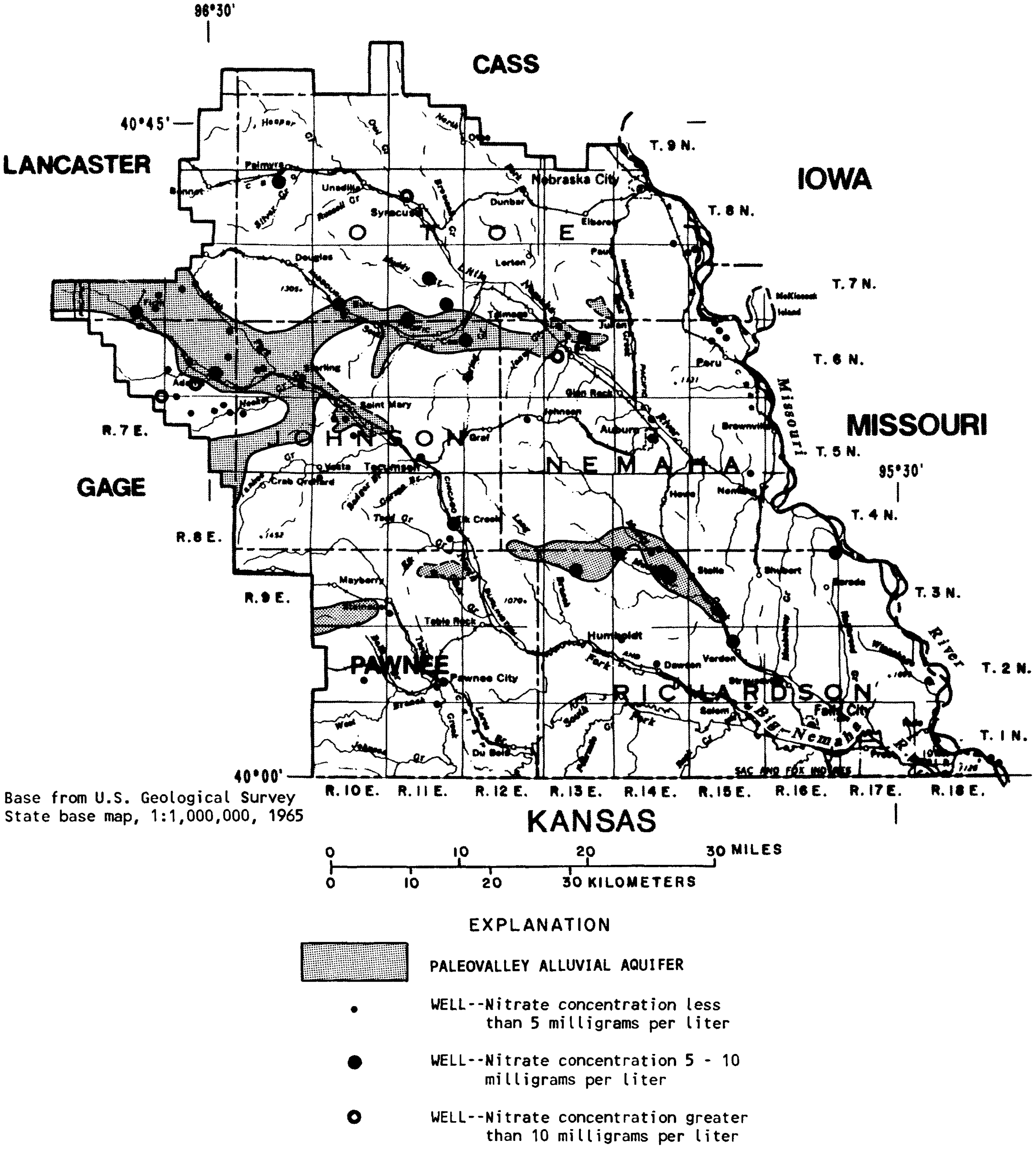
a Primary drinking-water regulation unless noted with an asterisk, in which case the figure is a secondary drinking-water regulation.

b Proposed maximum contaminant level.



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965

Figure 6.--Nitrate concentrations in water from sampled wells and location of paleovalley alluvial aquifers.

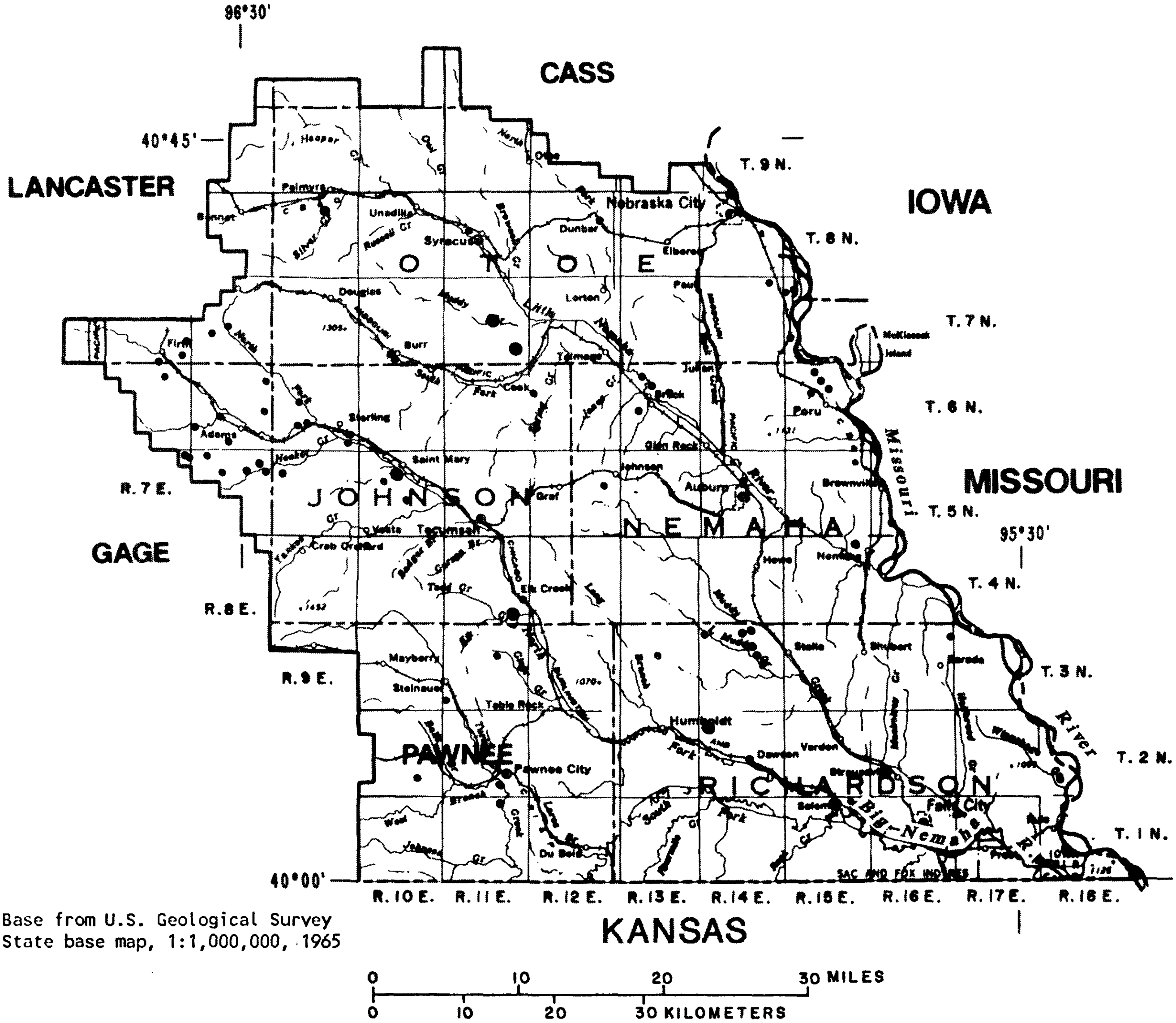
shallow aquifers probably are from the application of nitrogen-containing fertilizers in these agricultural areas. Most nitrate concentrations in the 5-10 mg/L range were in samples from wells 100-200 feet deep. This fact, along with widespread spatial distribution, indicates that the nitrate contamination was from a nonpoint source such as agricultural fertilizers. All nitrate concentrations larger than 10 mg/L were in samples from wells less than 80 feet in depth.

Of the 80 samples tested for triazines at the 0.1 µg/L detection limit, only those from wells B14 and S18 tested positive. Five of 16 samples analyzed for quality-assurance purposes also had atrazine concentrations greater than the 0.02 or 0.04 µg/L detection level (fig. 7, table 5). In all seven samples, the concentration of atrazine was well below the USEPA proposed maximum contaminant level (tables 5 and 8). However, because atrazine is not naturally occurring, any presence indicates contamination. The frequency of triazine detections based on randomly selected samples for quality-assurance purposes indicates a high probability of detecting trace levels of atrazine in the shallow aquifer. Most detections of atrazine were in samples from wells completed in the shallow aquifer at depths of less than 100 feet.

Three of the seven detections of atrazine were from wells P24, S11, and S18, completed in the alluvium of the North Fork Big Nemaha River (fig. 5). Downgradient from these sites at Falls City, atrazine was detected in the Big Nemaha River at a concentration of 19.8 µg/L during a runoff event in June 1989 (U.S. Geological Survey files, unpublished data). The same river sample exceeded the USEPA proposed maximum contaminant level (0.002 µg/L) of alachlor, an acid amide herbicide (U.S. Environmental Protection Agency, 1987). Due to the impervious nature of the glacial tills in Pawnee and Richardson Counties, surface runoff probably carries agricultural contaminants such as atrazine directly to the main streams, with little opportunity for infiltration. Concentrations in ground water usually would be small. There is, however, potential for substantial infiltration to occur in the coarse-grained alluvium along the North Fork Big Nemaha River. Under these conditions, atrazine would easily be introduced into the alluvium, resulting in elevated concentrations in the ground water, as measured.

Concentrations of nitrate and atrazine were not well correlated with each other; the overall correlation coefficient was -0.174. This result is different from that of a study of shallow unconfined aquifers in Nebraska, which showed a higher positive correlation between nitrate and atrazine concentrations (Chen and Druliner, 1987, p. 59). A possible explanation is that the greater depths of the paleovalley alluvial aquifers may prevent atrazine from reaching the water table before it is degraded, whereas nitrate would move conservatively downward to the water table.

The explanations of nitrate and atrazine occurrence and distribution that are outlined above could be refined if more data were available. Detailed information on land use and agricultural chemical applications could further test the hypotheses about the occurrences of agricultural chemicals. For instance, it may be that applications of atrazine along the North Fork Big Nemaha River are larger than in other parts of the study area, which could explain the concentrations of atrazine measured in the river and in the associated alluvium.



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965

EXPLANATION

• WELL--Atrazine not detected in water

● WELL--Atrazine detected in water

Figure 7.--Location of sampled wells and wells having water that contained detectable concentrations of atrazine.

Distribution of Major Constituents and Trace Elements

Trilinear diagrams were made to illustrate the differences of major ion composition among the aquifer groups (fig. 8). By plotting the percentages (based on milliequivalents) of the major ions, the predominant cation(s) and anion(s) can be determined.

There were statistically significant differences in concentrations of several constituents among aquifers. The Kruskal-Wallis multiple-comparisons test (Conover, 1980) was used to test for overall differences among the four aquifer types for each water-quality constituent in tables 4-7. The null hypothesis for this test was that all four population distribution functions were identical. If the null hypothesis was rejected for any constituent (at a confidence level of 95 percent), the Mann-Whitney pairwise rank-sum test (Conover, 1980) was used to determine which aquifer-type pairs differed. Constituents that had median concentrations that were significantly different from those of other aquifer types, according to the Mann-Whitney tests, are shown in tables 9-12. The null hypothesis was that the median concentrations of the two populations were equal. If the probability that the null hypothesis could be accepted was less than 0.05, the probability was shown in tables 9-12.

Diagrams showing a summary of the analyses for the same constituents are shown in figures 9-20. In the following sections, the concentrations of these selected constituents in samples from each aquifer type will be discussed.

Shallow Aquifers

Calcium and bicarbonate were the predominant ions in water samples from the shallow aquifers (fig. 8A) The median dissolved nitrate concentration was significantly larger in samples from the shallow aquifers than in samples from the Missouri River alluvial aquifer (table 5, fig. 9), and the median atrazine concentration was significantly larger in the shallow aquifers than in the paleovalley alluvial aquifers (table 9, fig. 10). Two of the four exceedences of the nitrate maximum contaminant level (10 mg/L as nitrogen) were in samples from the shallow aquifers as were four of the seven detections of atrazine (table 5). Samples from two shallow-aquifer wells (S07 and S10) had concentrations of selenium exceeding the maximum contaminant level of 10 µg/L (table 7).

The term "shallow aquifers" as used in this report was not directly related to well depth. The deepest shallow-aquifer well was 110 feet deep, but many wells in other aquifers were completed at lesser depths.

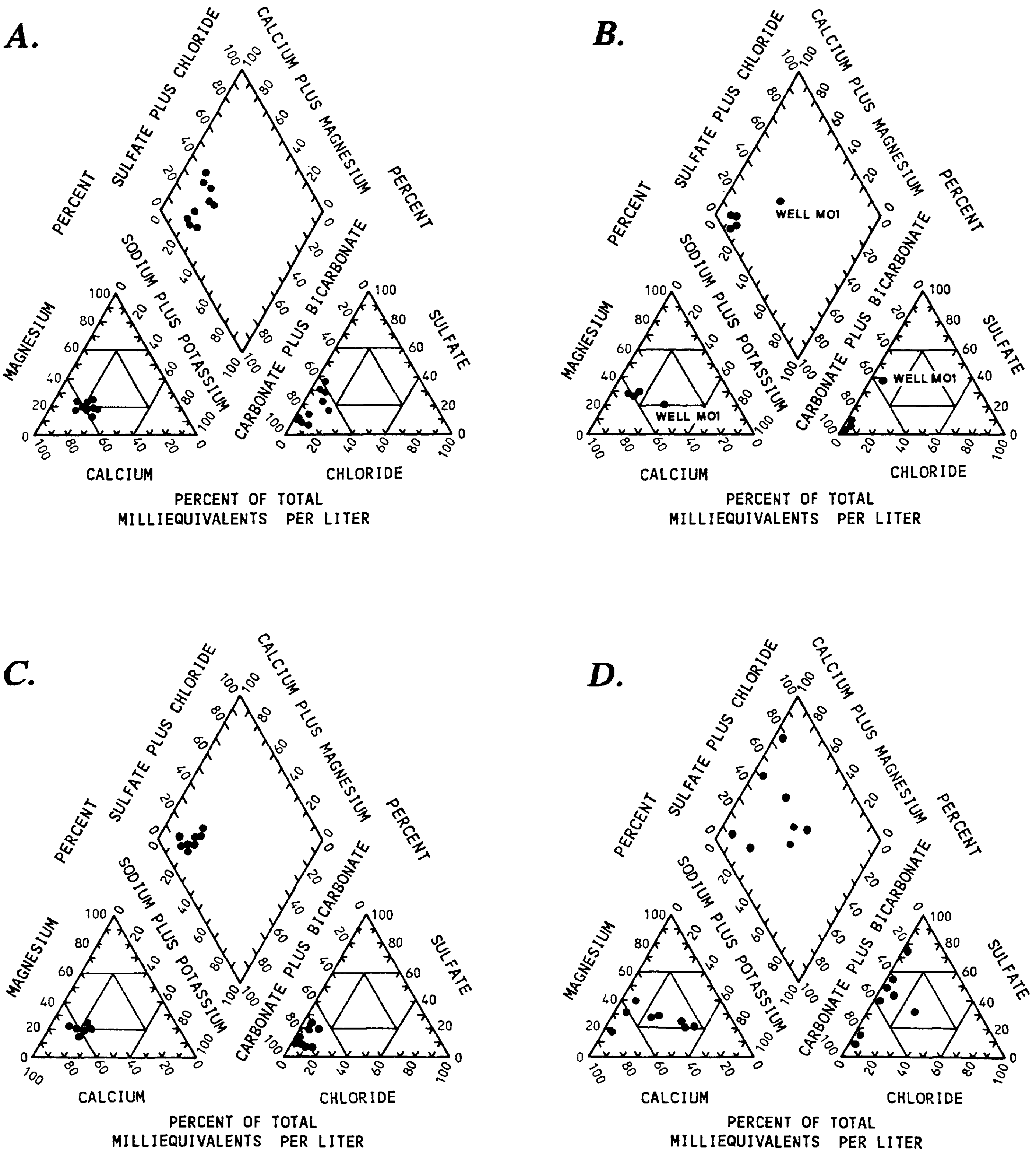


Figure 8.--Ionic composition of ground water by aquifer type: A, Shallow aquifers; B, Missouri River alluvial aquifer; C, Paleovalley alluvial aquifers; D, Bedrock aquifers.

Table 9.--Water-quality constituents for which the shallow aquifers had a significantly larger median concentration than the other aquifers

[The null hypothesis was that the median concentrations of the two populations were equal. Tabled values indicate the probability that the null hypothesis can be accepted]

Constituent	Probability that the median concentration for the shallow aquifers was equal to the median concentration for the:		
	Missouri River alluvial aquifer	Paleovalley alluvial aquifers	Bedrock aquifers
Nitrate, dissolved	0.0005		
Atrazine, by gas chromatography		0.0107	

Table 10.--Water-quality constituents for which the Missouri River alluvial aquifer had a significantly larger median concentration than the other aquifers

[The null hypothesis was that the median concentrations of the two populations were equal. Tabled values indicate the probability that the null hypothesis can be accepted]

Constituent	Probability that the median concentration for the Missouri River alluvial aquifer was equal to the median concentration for the:		
	Shallow aquifers	Paleovalley alluvial aquifers	Bedrock aquifers
Alkalinity	0.0216	0.0169	
Iron, dissolved	.0021	.0015	0.0015
Manganese, dissolved	.0502	.0015	.0022
Potassium, dissolved	.0010	.0015	.0206
Arsenic, dissolved	.0015	.0026	.0109

Table 11.--Water-quality constituents for which the paleovalley alluvial aquifers had a significantly larger median concentration than the other aquifers

[The null hypothesis was that the median concentrations of the two populations were equal. Tabled values indicate the probability that the null hypothesis can be accepted]

Constituent	Probability that the median concentration for the paleovalley alluvial aquifers was equal to the median concentration for the: Shallow aquifers	Missouri River alluvial aquifer	Bedrock aquifers
Nitrate, dissolved		0.0000	0.0092
Oxygen, dissolved	0.0131	.0060	.0013

Table 12.--Water-quality constituents for which the bedrock aquifers had a significantly larger median concentration than the other aquifers

[The null hypothesis was that the median concentrations of the two populations were equal. Tabled values indicate the probability that the null hypothesis can be accepted]

Constituent	Probability that the median for the bedrock aquifers was equal to the median for the: Shallow aquifers	Missouri River alluvial aquifer	Paleovalley alluvial aquifers
Magnesium, dissolved	0.0021		0.0009
Sulfate, dissolved	.0108	0.0063	.0074
Dissolved solids	.0108		.0019
Fluoride, dissolved	.0071	.0101	.0039

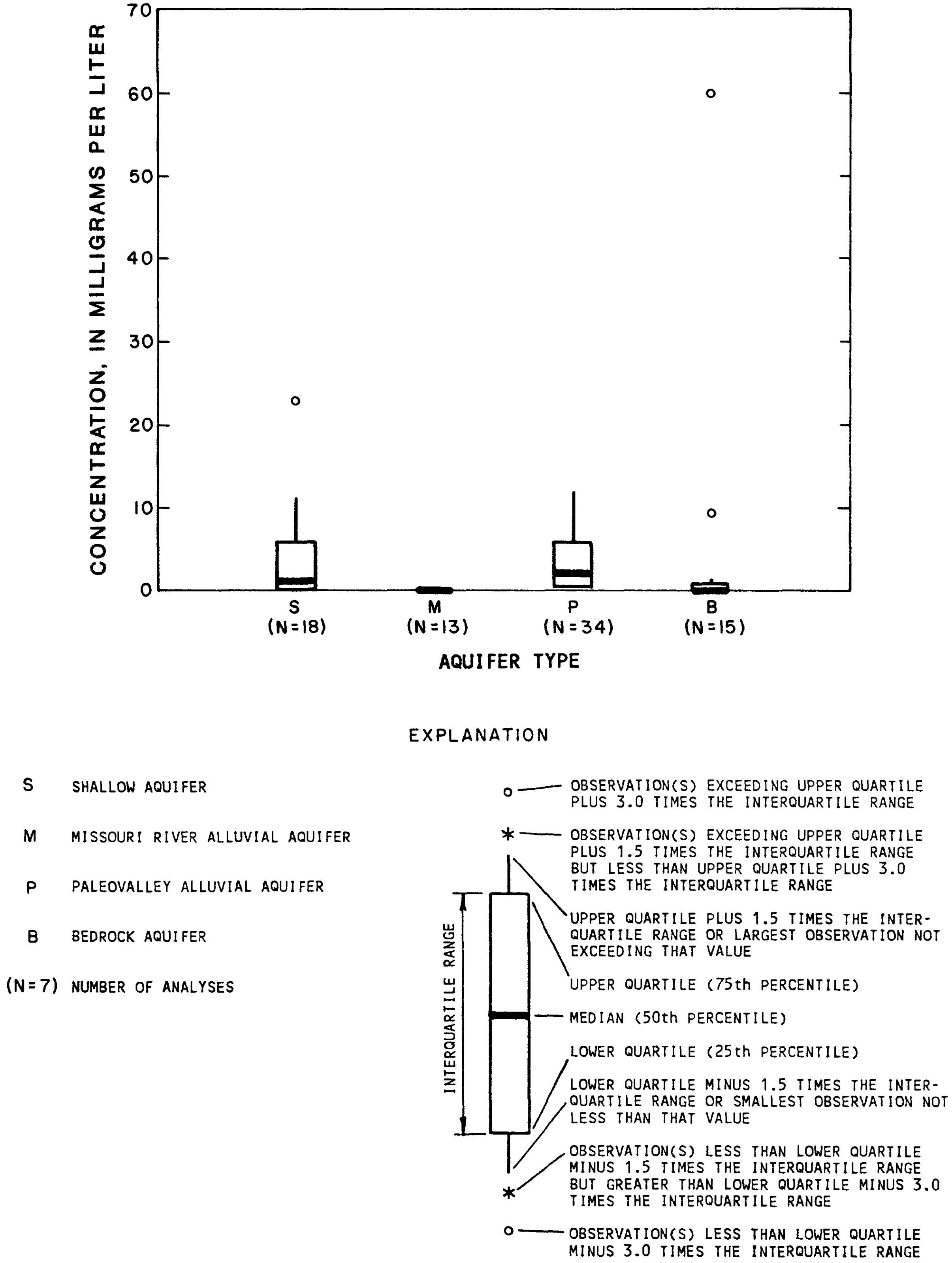
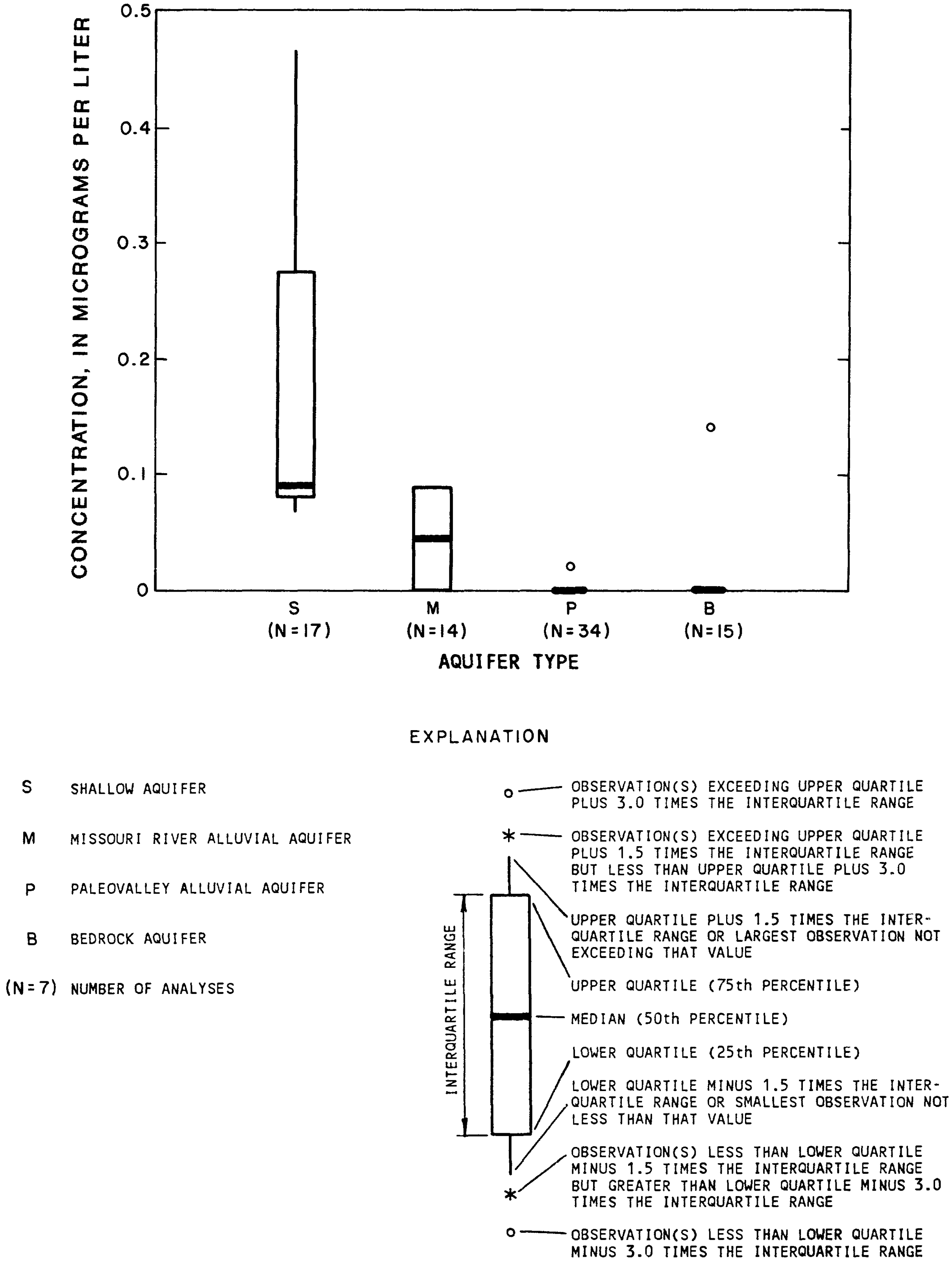


Figure 9.--Dissolved nitrate by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES

o — OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

* — OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE BUT LESS THAN UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE OR LARGEST OBSERVATION NOT EXCEEDING THAT VALUE

UPPER QUARTILE (75th PERCENTILE)

MEDIAN (50th PERCENTILE)

LOWER QUARTILE (25th PERCENTILE)

LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE OR SMALLEST OBSERVATION NOT LESS THAN THAT VALUE

OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE BUT GREATER THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

o — OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

Figure 10.--Atrazine by aquifer type.

Missouri River Alluvial Aquifer

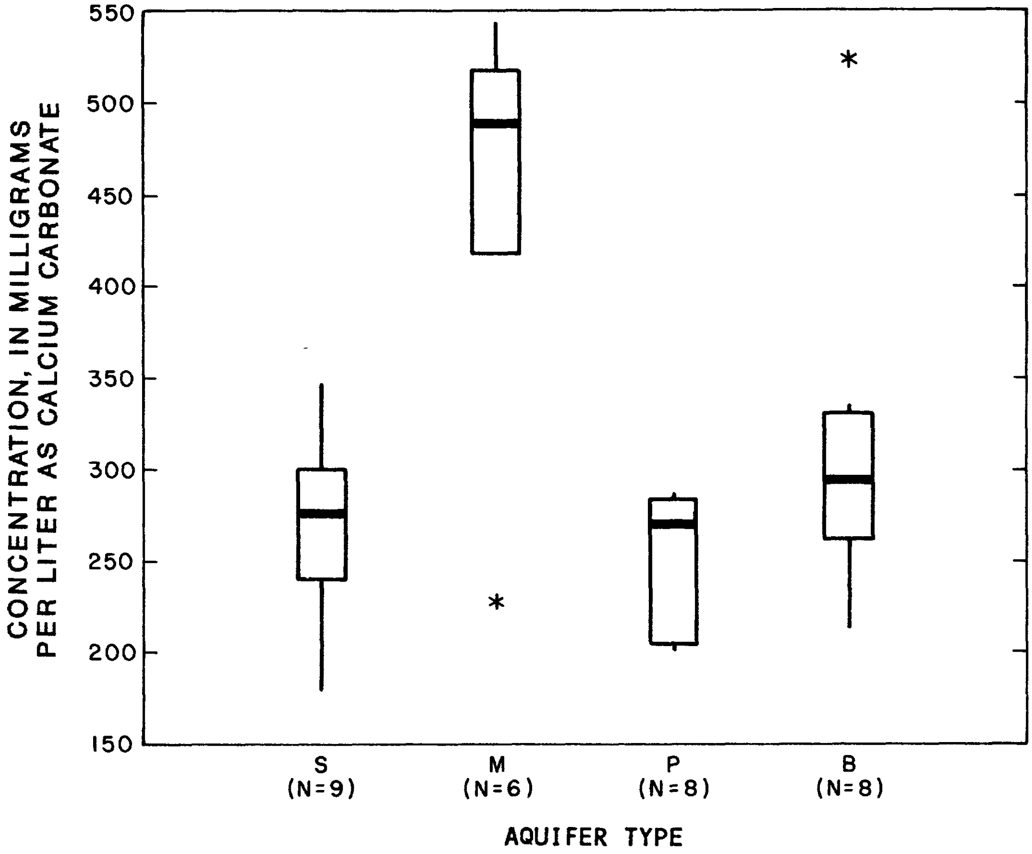
Water samples from the Missouri River alluvial aquifer had the strongest tendency of any aquifer toward the predominance of the calcium, magnesium, and bicarbonate ions (fig. 8B). Alkalinity, of which bicarbonate is a major component, had a significantly larger median concentration in samples from the Missouri River alluvial aquifer (488 mg/L, table 6) than in samples from the paleovalley alluvial and shallow aquifers (table 10, fig. 11). The source of alkalinity may be carbon dioxide from decaying organic matter in the Missouri River, which recharges the alluvial aquifer during high flow (Emmett and Jeffery, 1969).

Dissolved iron was significantly larger in samples from the Missouri River alluvial aquifer (median 7,900 μg/L, table 7) than in samples from the other aquifers (table 10, fig. 12), and dissolved manganese was significantly larger in samples from the Missouri River alluvial aquifer (median 990 μg/L, table 7) than in samples from the bedrock and the paleovalley alluvial aquifers (table 10, fig. 13). All samples from wells in the Missouri River alluvial aquifer had concentrations of iron and manganese exceeding the maximum contaminant levels of 300 and 50 μg/L, respectively. Iron and manganese are involved in oxidation-reduction processes in weathering environments (Hem, 1985, p. 85). Water samples from the Missouri River alluvial aquifer were low in dissolved oxygen (table 4, fig. 14), probably because recharge to the Missouri River alluvial aquifer would be chiefly in a lateral direction from the river. In this situation, less oxygen would be introduced than if recharge were in a downward direction through the unsaturated zone, as in the other aquifers of this study. In addition, iron is often complexed with organic matter, which is relatively abundant in the Missouri River.

Median concentrations of dissolved potassium (5.8 mg/L, table 6) and dissolved arsenic (11 μg/L, table 7) were significantly larger in samples from the Missouri River alluvial aquifer than in the other aquifers (table 10, figs. 15, 16). Arsenic concentrations were well under the maximum contaminant level of 50 μg/L for all wells sampled. The relatively large concentrations of dissolved arsenic in samples from the Missouri River alluvial aquifer are probably due to reducing conditions.

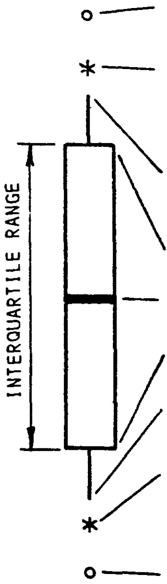
Dissolved nitrate was less than the detection limit in all samples from the Missouri River alluvial aquifer wells (table 5). This might be expected if the recharge was from the Missouri River and not from infiltration. In addition, any nitrate that would be present under reducing conditions would tend to be converted to more reduced forms.

Well M01 is the anomalous Missouri River alluvial aquifer well in figure 8B. This well had a sulfate concentration that was more characteristic of the bedrock aquifer (table 6). The well driller's logs for well M01 showed that limestone and shale were penetrated at a depth of 62 feet in the 74-foot deep well. Penetration into the bedrock "floor" of the Missouri River alluvial aquifer probably accounted for the anomalous water quality of well M01.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES



OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE BUT LESS THAN UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE OR LARGEST OBSERVATION NOT EXCEEDING THAT VALUE

UPPER QUARTILE (75th PERCENTILE)

MEDIAN (50th PERCENTILE)

LOWER QUARTILE (25th PERCENTILE)

LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE OR SMALLEST OBSERVATION NOT LESS THAN THAT VALUE

OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE BUT GREATER THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

Figure 11.--Alkalinity by aquifer type.

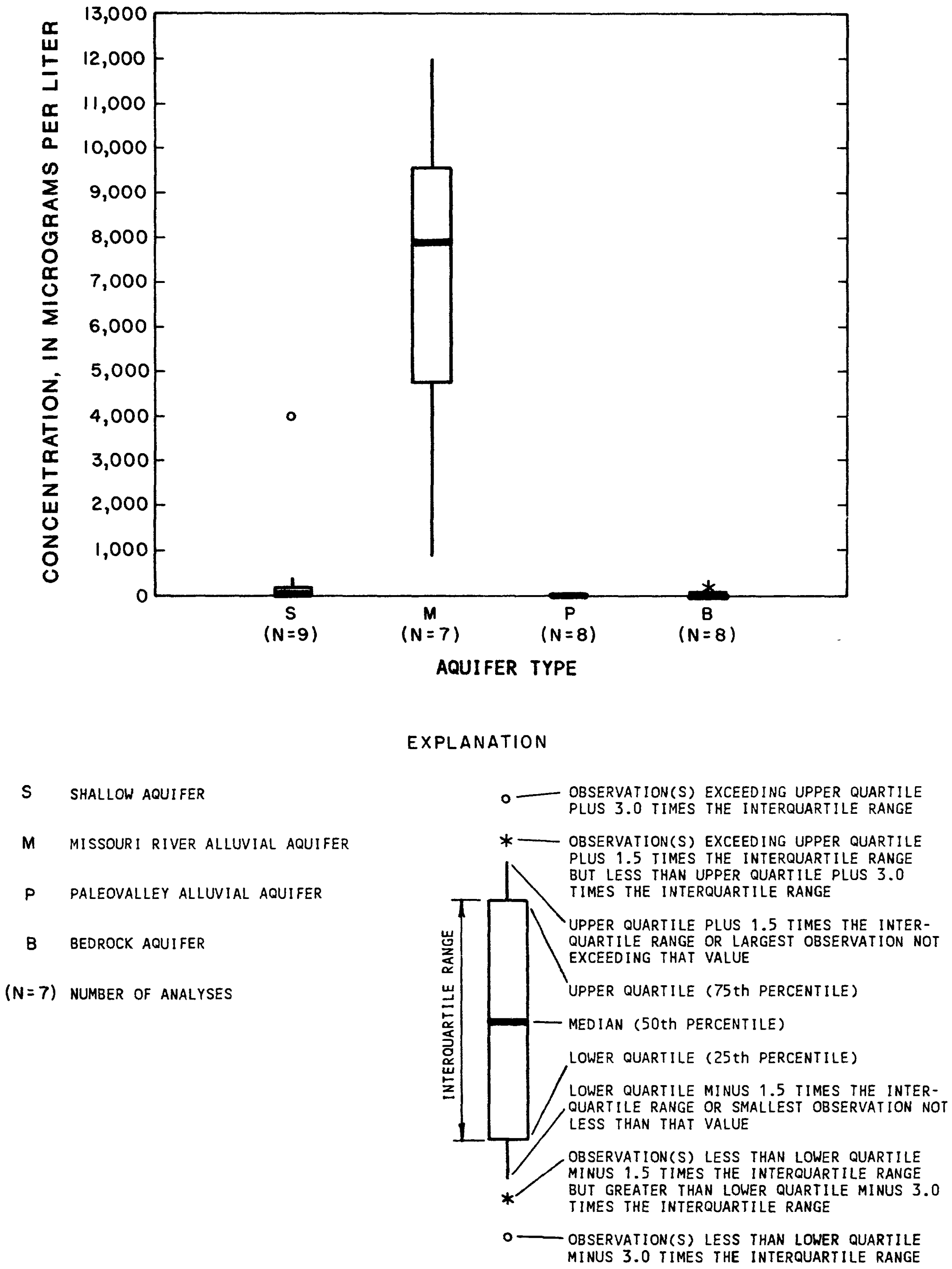
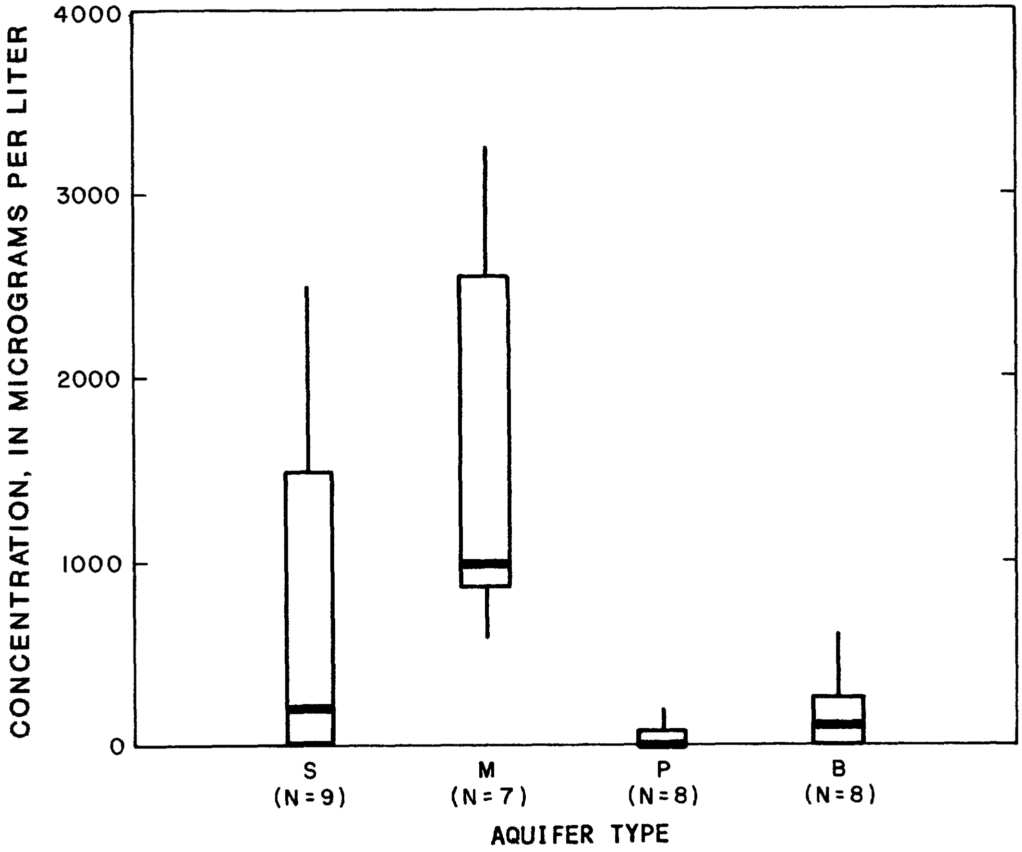


Figure 12.--Dissolved iron by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES

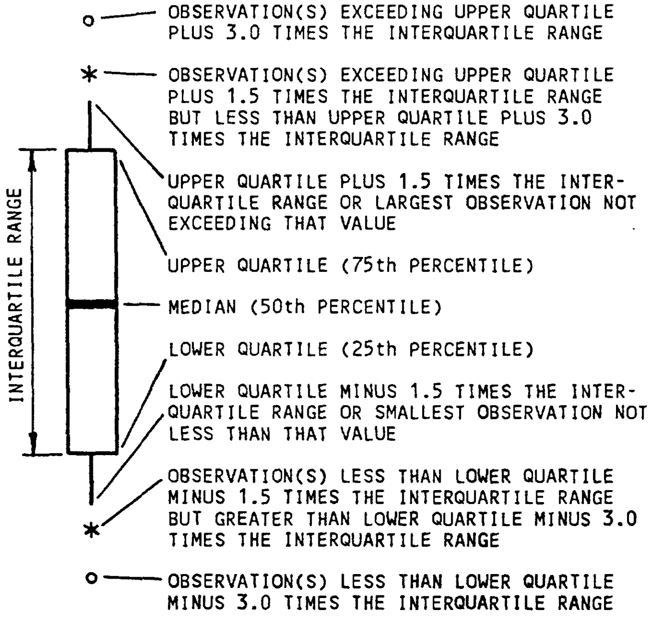
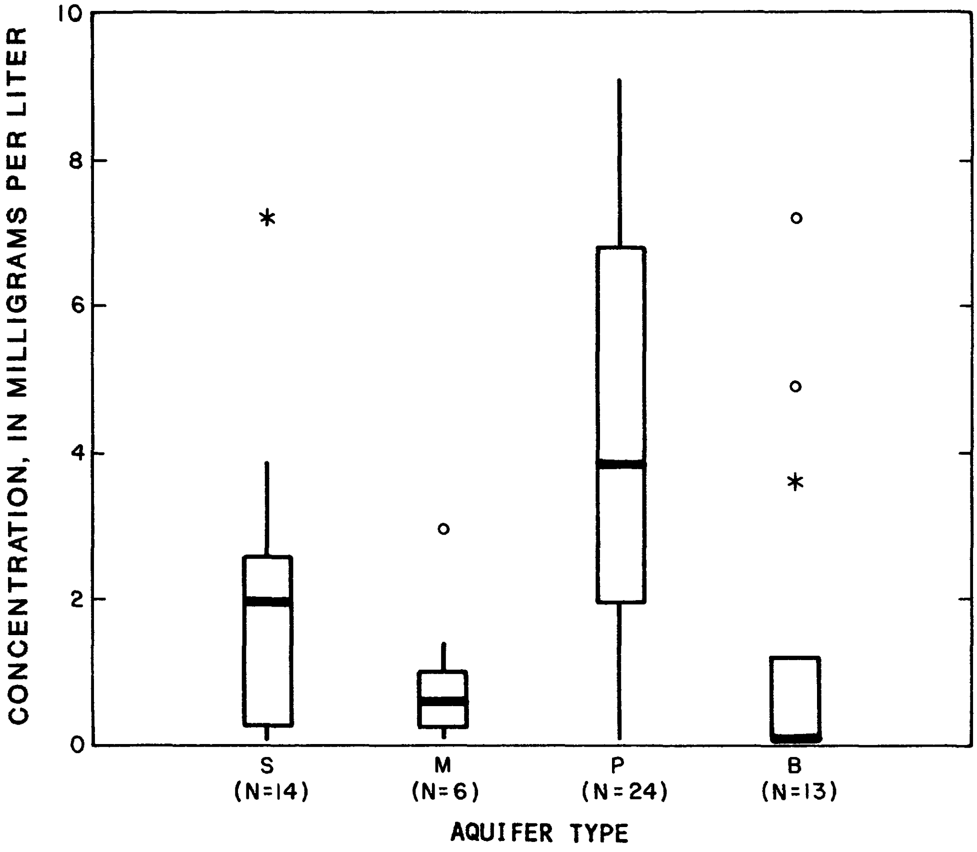


Figure 13.--Dissolved manganese by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES

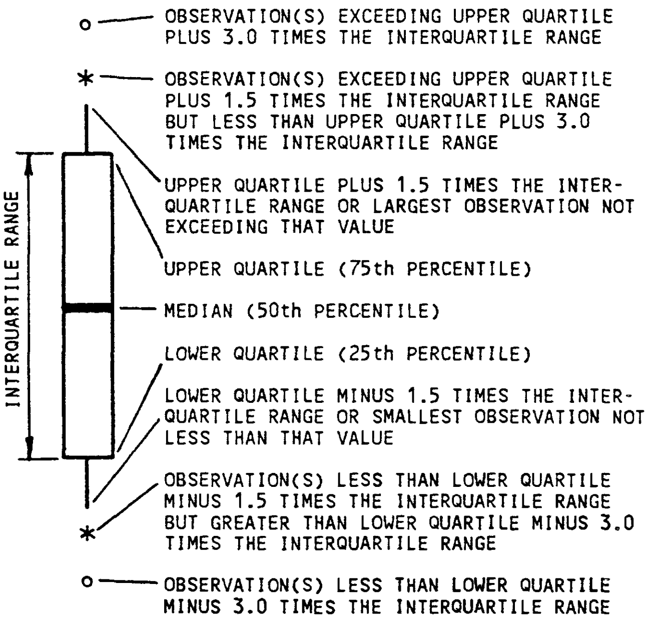
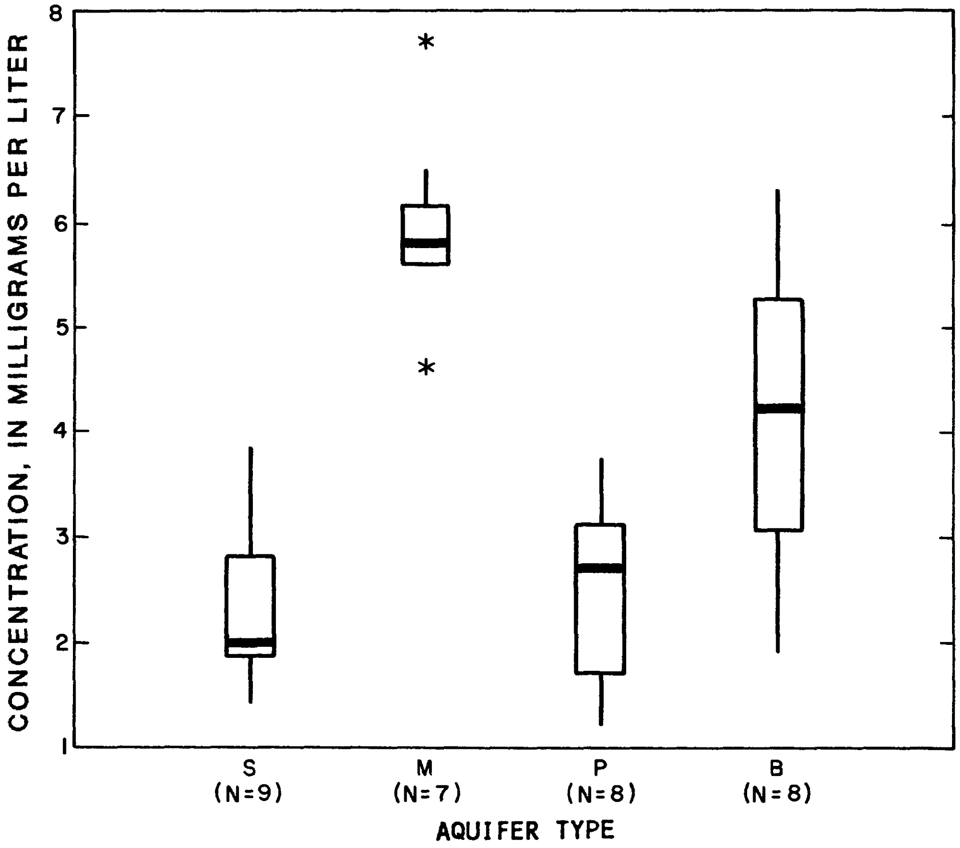


Figure 14.--Dissolved oxygen by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES

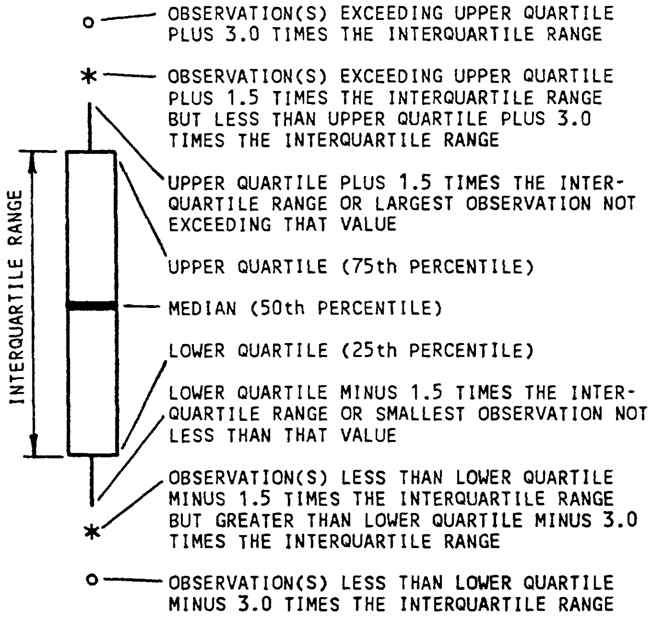
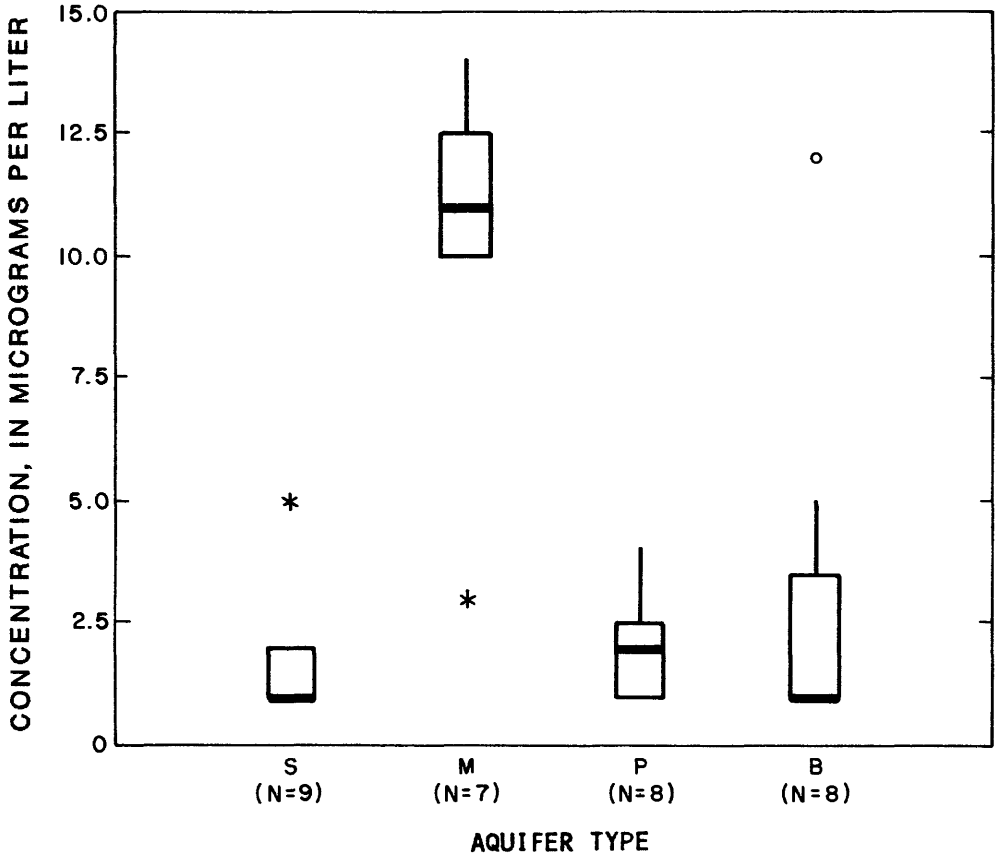
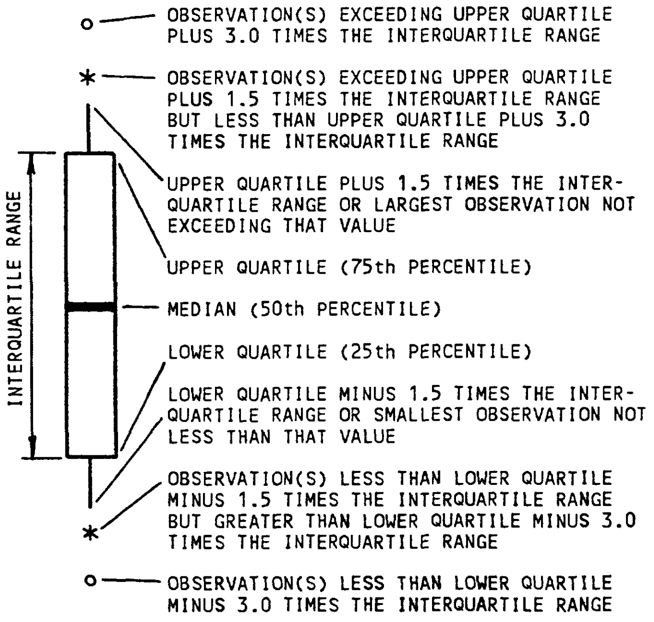


Figure 15.--Dissolved potassium by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES



o OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

* OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE BUT LESS THAN UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE OR LARGEST OBSERVATION NOT EXCEEDING THAT VALUE

UPPER QUARTILE (75th PERCENTILE)

MEDIAN (50th PERCENTILE)

LOWER QUARTILE (25th PERCENTILE)

LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE OR SMALLEST OBSERVATION NOT LESS THAN THAT VALUE

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o OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

Figure 16.--Dissolved arsenic by aquifer type.

Paleovalley Alluvial Aquifers

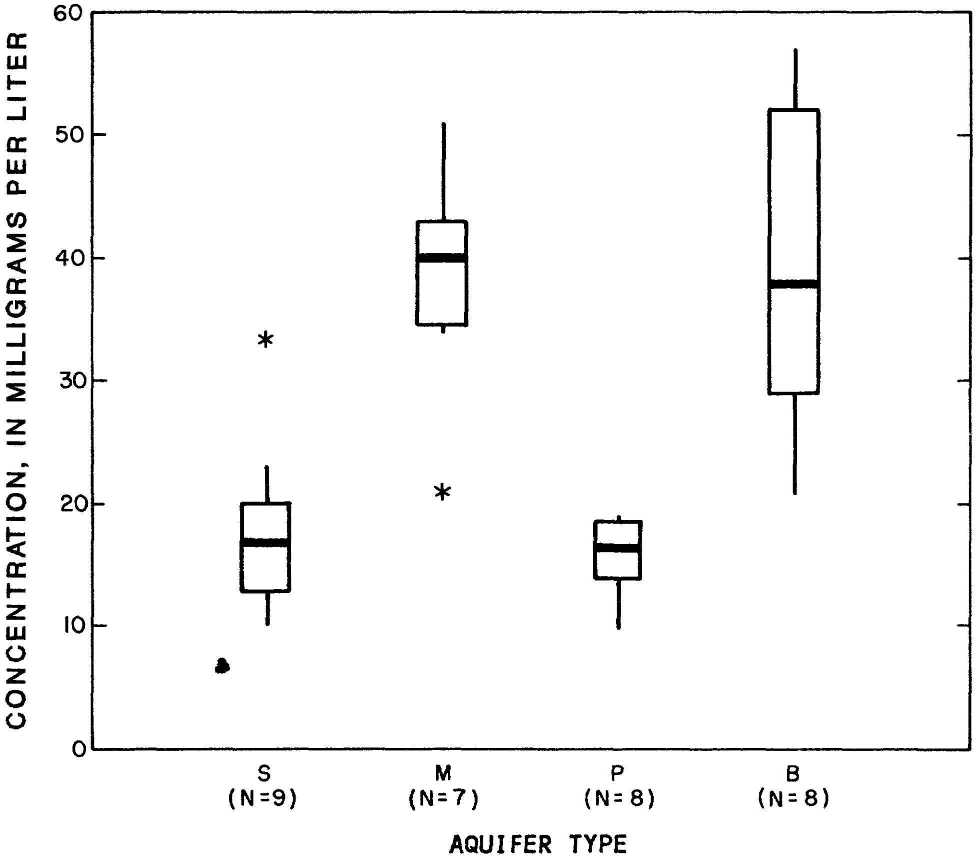
Water samples from the paleovalley alluvial aquifers were grouped closely together in the calcium-bicarbonate area of the trilinear diagram (fig. 8C). The median dissolved nitrate concentration (2.15 mg/L, table 6) in the paleovalley alluvial aquifers was significantly larger than medians for the bedrock and Missouri River alluvial aquifers (table 11, fig. 9). Moderately elevated nitrate concentrations (5-10 mg/L) were associated with 100-200 feet deep wells in paleovalley areas (fig. 6). This distribution of moderately large nitrate concentrations in ground water likely is due to widespread agricultural activity in the vicinity of the paleovalley alluvial aquifers. A nitrate concentration greater than the maximum contaminant level of 10 mg/L occurred in only one water sample from a paleovalley alluvial aquifer: well P16, which is 77 feet deep. Samples from two paleovalley alluvial aquifer wells, P12 and P18, had selenium concentrations larger than the maximum contaminant level.

The median dissolved oxygen concentration in the paleovalley alluvial aquifers (3.8 mg/L) was significantly larger than in all three other aquifers (table 11, fig. 14). The comparatively coarse-grained and exposed nature of the paleovalley deposits probably allowed more oxygenation than the other aquifers. The oxygenated environment of the paleovalley alluvial aquifers may have contributed to a more rapid aerobic degradation of atrazine, which could result in the smaller atrazine concentrations measured in these aquifers.

Bedrock Aquifers

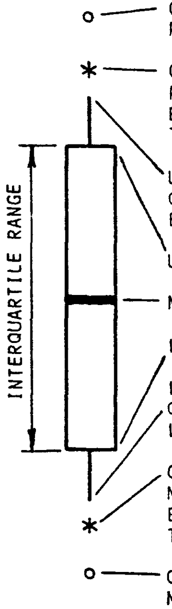
Water from the bedrock aquifers had more of a magnesium-sulfate character than water from the other aquifers (fig. 8D). Additional evidence of the magnesium-sulfate character of water from the bedrock aquifers is shown in table 12, which indicates that the median magnesium concentration in the bedrock aquifer (38 mg/L, table 6) was significantly larger than the medians for the paleovalley alluvial and shallow aquifers, and that the median sulfate concentrations in the bedrock aquifer (250 mg/L, table 6) was significantly larger than the medians for the other three aquifers. Samples from four of the eight wells in the bedrock aquifers had sulfate concentrations above the secondary maximum contaminant level of 250 mg/L. No samples from other aquifers exceeded this level. Magnesium data are summarized in figure 17 and sulfate data are summarized in figure 18.

The median dissolved-solids concentration in samples from the bedrock aquifers (708 mg/L, table 6) was significantly larger than the medians for the paleovalley alluvial and shallow aquifers, and the median fluoride concentration in the bedrock aquifers (0.5 mg/L, table 6) was significantly larger than the medians for the other three aquifers (table 12, figs. 19 and 20). Water samples from all wells in the bedrock aquifers, except well B08, exceeded the secondary maximum contaminant level of 500 mg/L for dissolved solids. A nitrate concentration greater than the maximum contaminant level of 10 mg/L occurred in the water sample from well B06.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES



○ OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

* OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE BUT LESS THAN UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE OR LARGEST OBSERVATION NOT EXCEEDING THAT VALUE

UPPER QUARTILE (75th PERCENTILE)

MEDIAN (50th PERCENTILE)

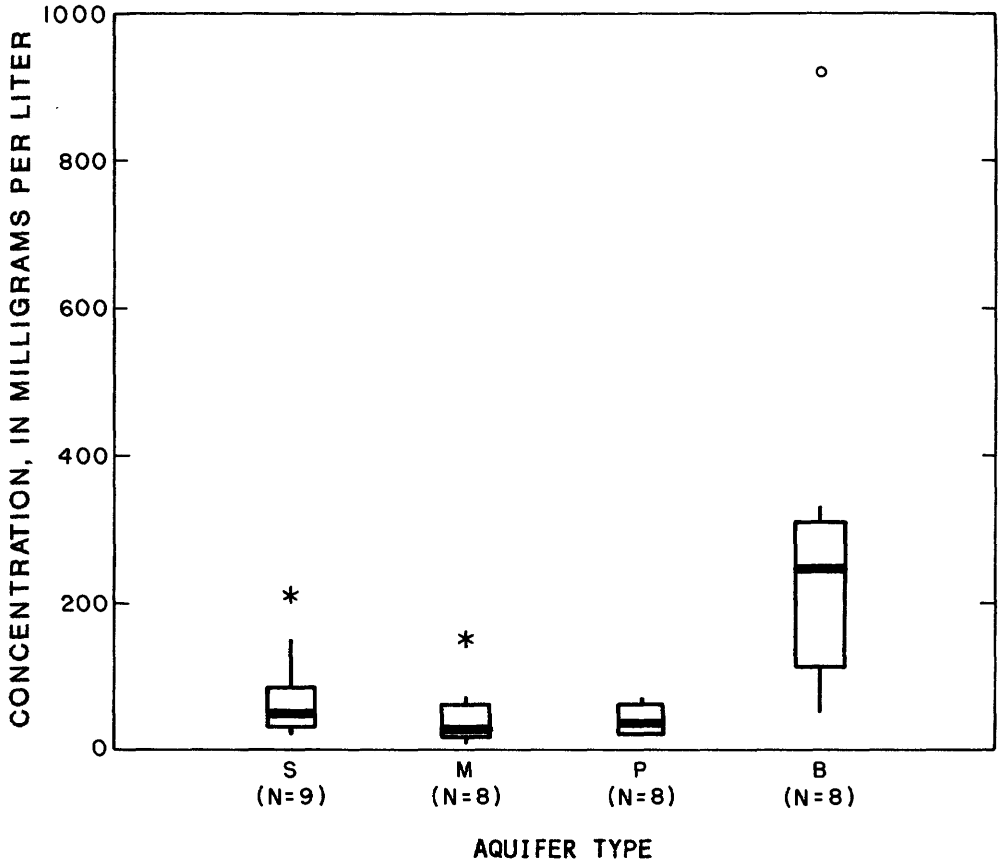
LOWER QUARTILE (25th PERCENTILE)

LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE OR SMALLEST OBSERVATION NOT LESS THAN THAT VALUE

OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE BUT GREATER THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

○ OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

Figure 17.--Dissolved magnesium by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES

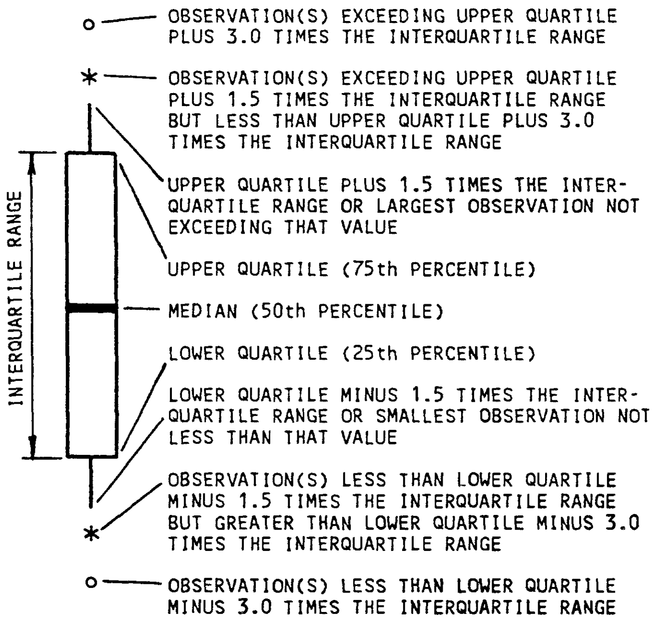
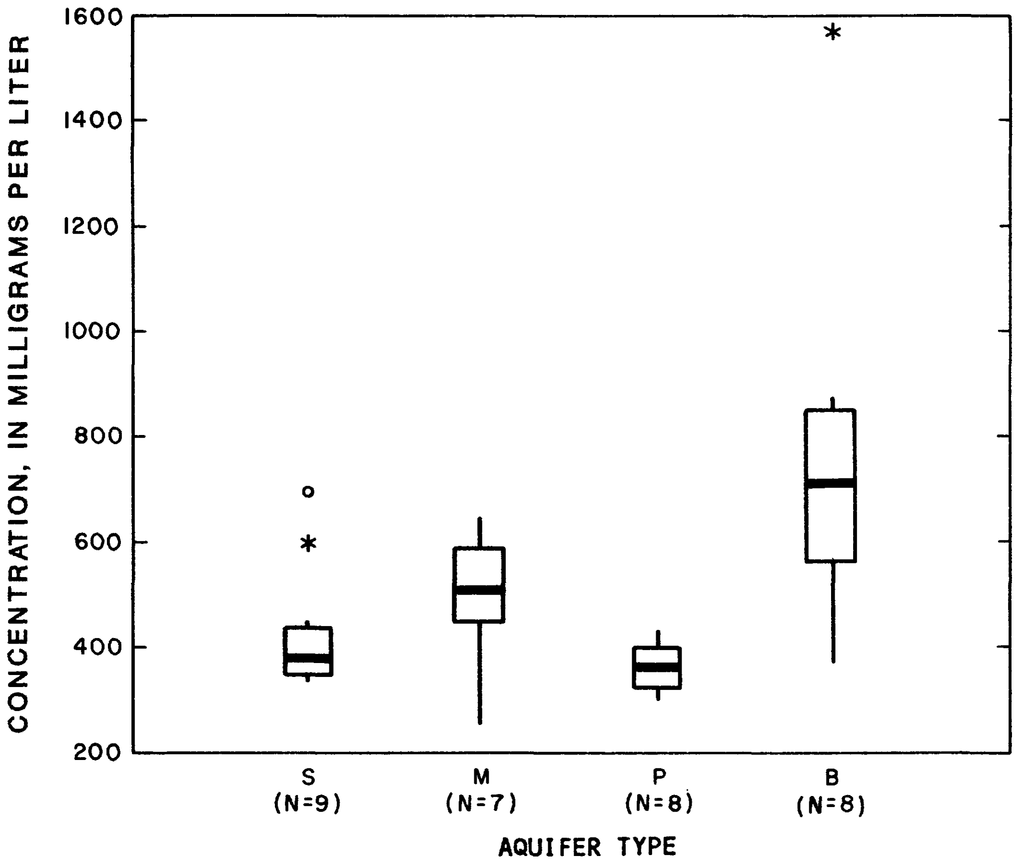
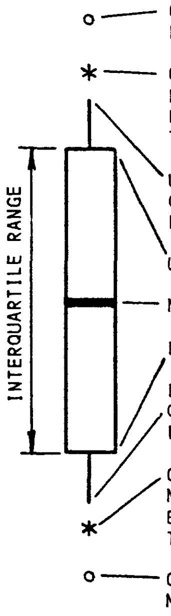


Figure 18.--Dissolved sulfate by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES



o OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

* OBSERVATION(S) EXCEEDING UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE BUT LESS THAN UPPER QUARTILE PLUS 3.0 TIMES THE INTERQUARTILE RANGE

UPPER QUARTILE PLUS 1.5 TIMES THE INTERQUARTILE RANGE OR LARGEST OBSERVATION NOT EXCEEDING THAT VALUE

UPPER QUARTILE (75th PERCENTILE)

MEDIAN (50th PERCENTILE)

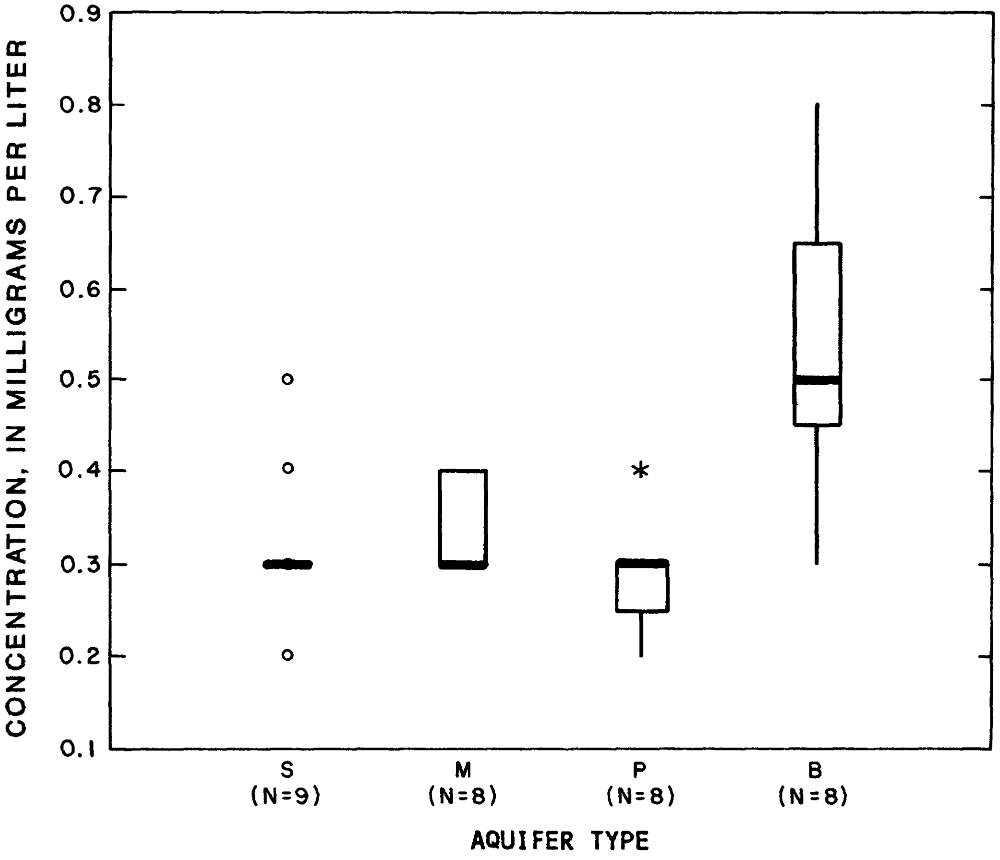
LOWER QUARTILE (25th PERCENTILE)

LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE OR SMALLEST OBSERVATION NOT LESS THAN THAT VALUE

* OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 1.5 TIMES THE INTERQUARTILE RANGE BUT GREATER THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

o OBSERVATION(S) LESS THAN LOWER QUARTILE MINUS 3.0 TIMES THE INTERQUARTILE RANGE

Figure 19.--Dissolved solids by aquifer type.



EXPLANATION

S	SHALLOW AQUIFER
M	MISSOURI RIVER ALLUVIAL AQUIFER
P	PALEOVALLEY ALLUVIAL AQUIFER
B	BEDROCK AQUIFER
(N=7)	NUMBER OF ANALYSES

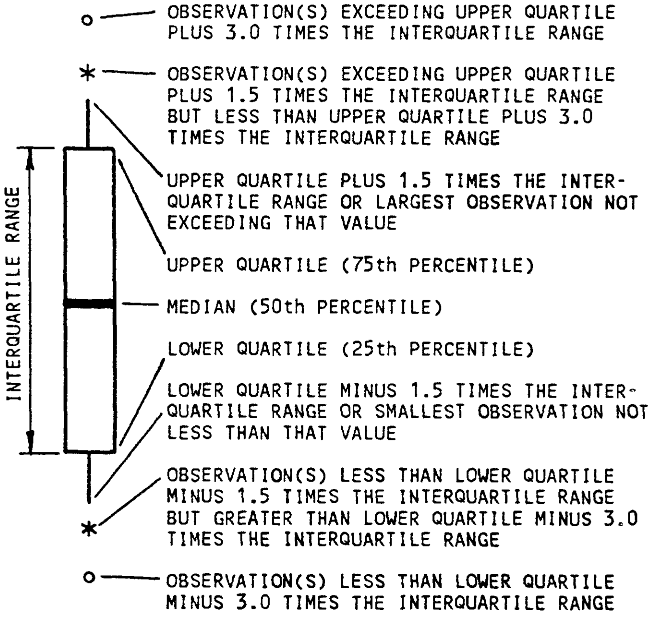


Figure 20.--Dissolved fluoride by aquifer type.

Magnesium and sulfate concentrations in water from the bedrock aquifers were probably elevated due to dissolution of limestone and shale minerals. The dissolution of these minerals also contributed to large concentrations of dissolved solids. The source of fluoride could have been fluorite or apatite, or other minerals in which hydroxide ions in the water exchange for fluoride ions.

POTENTIAL MONITORING PROGRAM

The following monitoring activities would provide data to help answer various questions pertaining to ground-water quality in the Nemaha NRD. Implementation of these activities depends upon local needs, objectives, and the availability of funding. Careful planning and an ongoing commitment are needed to ensure that the most appropriate of the following elements are implemented in a timely manner. Because nitrate and atrazine were the only man-caused contaminants found in this study, the objective of further monitoring could be to better document the extent, variability, source, and transport of these agricultural contaminants.

To improve understanding of the extent of agricultural contamination, about 20 additional wells need to be sampled (on a one-time basis) in the paleovalley aquifers, which had the highest median concentration of nitrate. These samples would be analyzed for concentrations of nitrate and atrazine. Results from these analyses, when considered along with data from the present study, could help define the extent of the contamination and provide information on its nonpoint-source character.

Seasonal variations in potential agricultural contaminants could be better understood if water from about 10 selected wells in the paleovalley alluvial and shallow aquifers were sampled semiannually and analyzed for concentrations of nitrate and atrazine. If such a program was continued for about 3 years, an estimate could be made of seasonal variations that could be useful in determining an optimal time of year to sample in the future.

To examine long-term trends in the concentrations of agricultural contaminants, a network of 15-20 wells needs to be established to include all of the four aquifer types in the Nemaha NRD. This network of wells could be sampled every 3-5 years and it would need to be somewhat flexible to allow for possible changes in ownership and condition of a particular well. In order for this network to be useful in the evaluation of trends, data on herbicides other than atrazine (such as alachlor) also need to be collected.

Deep soil-coring and nitrogen-isotope analysis in the paleovalley alluvial aquifers and unsaturated zone could provide information on the loading and source of nitrate concentrations. In conjunction with demonstration plots of controlled agricultural practices, the monitoring activity could provide an improved estimate of future trends.

Further monitoring also is needed on the North Fork Big Nemaha River and the adjacent shallow aquifer. Concentrations of atrazine and alachlor that exceed USEPA drinking-water regulations have been reported during spring runoff in the Big Nemaha River, and atrazine was detected in ground water. A more intensive study in this area could provide data that might be useful to decision makers and water managers.

A detailed hydrologic study would be needed to synthesize all of the above elements to understand contaminant concentrations. Data on land use, water use, stratigraphy, topography, and regional ground-water flow could be synthesized by use of geographic information system technology.

SUMMARY

The systematic selection and sampling of 80 wells located in the Nemaha Natural Resources District (NRD) allowed a statistical evaluation of ground-water quality. Water from wells completed in shallow aquifers, the Missouri River alluvial aquifer, the paleovalley alluvial aquifers, and the bedrock aquifers was sampled and analyzed. The shallow aquifers and the paleovalley alluvial aquifers had the highest concentrations of nitrate and atrazine, two widely occurring chemicals associated with agricultural activities. About one-fourth of the 80 wells sampled had nitrate concentrations larger than 5 mg/L. Water from four wells exceeded the USEPA maximum contaminant level of 10 mg/L. The distribution of large nitrate concentrations in the paleovalley alluvial aquifers likely is due to widespread agricultural activity.

Atrazine was detected in samples from 7 of 80 wells; each detection was well below the proposed USEPA maximum contaminant level. Three of the seven water samples were from wells screened in the alluvium of the North Fork Big Nemaha River. On the basis of analysis of quality-assurance samples for atrazine at the 0.02 or 0.04 g/L detection limit, trace levels of atrazine might be common in the shallow aquifers.

Water samples from 33 of the 80 wells were analyzed for concentrations of major ions and selected trace elements to characterize the water quality of each aquifer. Samples from the shallow aquifers had the largest median nitrate and atrazine concentrations.

Samples from the Missouri River alluvial aquifer had the largest median concentrations of calcium, alkalinity, iron, manganese, potassium, and arsenic. Water samples from every well completed in the Missouri River alluvial aquifer had iron and manganese concentrations that exceeded the USEPA secondary maximum contaminant levels. Arsenic concentrations in ground water were below USEPA maximum contaminant levels. All these constituents can be related to the recharge of the Missouri River alluvial aquifer by water from the Missouri River.

Samples from paleovalley alluvial aquifers had relatively large concentrations of nitrate and dissolved oxygen. The spatial distribution of nitrate concentrations in ground water could indicate that agricultural activity was the source of nitrate. The large concentrations of dissolved oxygen in ground water were probably due to aeration in the coarse-grained aquifer material and proximity of the water table to the land surface.

The bedrock aquifers contained water having the highest median concentrations of sulfate, dissolved solids, magnesium, and fluoride. These large concentrations probably were the result of dissolution of limestone and other bedrock minerals. None of the constituents were present in concentrations sufficient to cause serious health concerns.

Samples from four wells exceeded the maximum contaminant level of 10 µg/L for selenium. Two of these wells were completed in paleovalley alluvial aquifers and two were completed in shallow aquifers.

The results of the present study could be used to design a ground-water quality monitoring program in the Nemaha NRD. Sampling water from additional wells completed in the paleovalley alluvial aquifer could document the extent of nitrates and pesticides in ground water. Sampling a network of wells completed in the paleovalley alluvial and shallow aquifers semiannually could provide an estimate of the variability of concentrations of potential agricultural contaminants. A monitoring network for studying long-term trends in all four aquifer types could be sampled every 3-5 years. Data from these and other monitoring activities could help understand the occurrence of agricultural contaminants.

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