

# Assessment of Nonpoint-Source Contamination of the High Plains Aquifer in South-Central Kansas, 1987

United States  
Geological  
Survey  
Water-Supply  
Paper 2381-C



---

## AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

---

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that may be listed in various U.S. Geological Survey catalogs (see back inside cover) but not listed in the most recent annual "Price and Availability List" may no longer be available.

Reports released through the NTIS may be obtained by writing to the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161; please include NTIS report number with inquiry.

Order U.S. Geological Survey publications **by mail** or **over the counter** from the offices listed below.

### BY MAIL

#### Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Earthquakes & Volcanoes, Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

**U.S. Geological Survey, Map Distribution  
Box 25286, MS 306, Federal Center  
Denver, CO 80225**

Subscriptions to periodicals (Earthquakes & Volcanoes and Preliminary Determination of Epicenters) can be obtained **ONLY** from the

**Superintendent of Documents  
Government Printing Office  
Washington, DC 20402**

(Check or money order must be payable to Superintendent of Documents.)

#### Maps

For maps, address mail orders to

**U. S. Geological Survey, Map Distribution  
Box 25286, Bldg. 810, Federal Center  
Denver, CO 80225**

Residents of Alaska may order maps from

**U.S. Geological Survey, Earth Science Information Center  
101 Twelfth Ave., Box 12  
Fairbanks, AK 99701**

### OVER THE COUNTER

#### Books and Maps

Books and maps of the U.S. Geological Survey are available over the counter at the following U.S. Geological Survey offices, all of which are authorized agents of the Superintendent of Documents.

- **ANCHORAGE, Alaska**—Rm. 101, 4230 University Dr.
- **LAKEWOOD, Colorado**—Federal Center, Bldg. 810
- **MENLO PARK, California**—Bldg. 3, Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**—USGS National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**—Federal Bldg., Rm. 8105, 125 South State St.
- **SPOKANE, Washington**—U.S. Post Office Bldg., Rm. 135, West 904 Riverside Ave.
- **WASHINGTON, D.C.**—Main Interior Bldg., Rm. 2650, 18th and C Sts., NW.

#### Maps Only

Maps may be purchased over the counter at the following U.S. Geological Survey offices:

- **FAIRBANKS, Alaska**—New Federal Bldg, 101 Twelfth Ave.
- **ROLLA, Missouri**—1400 Independence Rd.
- **STENNIS SPACE CENTER, Mississippi**—Bldg. 3101

Chapter C

# Assessment of Nonpoint-Source Contamination of the High Plains Aquifer in South-Central Kansas, 1987

By JOHN O. HELGESEN, LLOYD E. STULLKEN, and  
A.T. RUTLEDGE

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2381-C

ANALYSIS OF NONPOINT-SOURCE GROUND-WATER CONTAMINATION IN  
RELATION TO LAND USE

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



U.S. GEOLOGICAL SURVEY  
ROBERT M. HIRSCH, Acting Director

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

UNITED STATES GOVERNMENT PRINTING OFFICE: 1994

---

For sale by  
U.S. Geological Survey, Map Distribution  
Box 25286, MS 306, Federal Center  
Denver, CO 80225

**Library of Congress Cataloging in Publication Data**

Helgesen, John O.

Assessment of nonpoint-source contamination of the high plains aquifer in south-central Kansas, 1987 / by John O. Helgesen, Lloyd E. Stullken, and A.T. Rutledge.

p. cm. — (Analysis of nonpoint-source ground-water contamination in relation to land use ; ch. C) (U.S. Geological Survey water-supply paper ; 2381-C)

Includes bibliographical references.

1. Land use—Environmental aspects—Kansas. 2. Nonpoint source pollution—Kansas. 3. Groundwater—Kansas—Quality. 4. Land use—Environmental aspects—High Plains Aquifer. 5. Nonpoint source pollution—High Plains Aquifer. 6. Groundwater—High Plains Aquifer—Quality.

I. Stullken, Lloyd E. II. Rutledge, A.T. III Title. IV. Series. V. Series: U.S. Geological Survey water-supply paper ; 2381-C.

TD428.L35 1995 ch. C

628.1'68'09781—dc20

93-32047  
CIP

# CONTENTS

Abstract.....	C1
Introduction.....	C1
Background.....	C2
Purpose and Scope.....	C4
Acknowledgments .....	C4
Description of Nonpoint-Source Contamination.....	C5
Agricultural Contaminants.....	C5
Petroleum-Production Contaminants.....	C6
Study Approach and Methods .....	C8
Characterization of Contaminant Sources .....	C8
Agricultural Land.....	C8
Petroleum-Production Land.....	C8
Factors Relevant to the Development and Assessment of Contamination .....	C9
Land Use.....	C9
Unsaturated-Zone Lithology.....	C10
Type of Well Sampled.....	C11
Sampling Design and Procedures .....	C11
Sampling Design.....	C11
Sampling Procedures .....	C13
Statistical Testing.....	C14
Results of Data Analysis and Statistical Testing .....	C14
Inorganic Constituents .....	C14
Comparisons by Land Use.....	C15
Comparisons by Unsaturated-Zone Lithology.....	C16
Comparisons by Type of Well Sampled.....	C18
Pesticides .....	C19
Comparisons by Land Use.....	C19
Comparisons by Unsaturated-Zone Lithology.....	C19
Comparisons by Type of Well Sampled .....	C20
Hydrocarbons.....	C20
Chromatogram Interpretation .....	C20
Comparisons by Land Use.....	C22
Comparisons by Unsaturated-Zone Lithology.....	C24
Discussion of Results.....	C27
Irrigated Cropland.....	C27
Petroleum-Production Land.....	C30
Rangeland .....	C32
Summary and Conclusions .....	C33
References Cited.....	C34

## FIGURES

1. Map of High Plains aquifer and location of study area .....	C3
2. Map of generalized predominant land use in Kansas .....	C4
3. Diagram showing pathways of pesticide transport and degradation .....	C5
4. Map showing locations of oil and gas fields in Kansas, 1983.....	C7
5. Diagram showing movement of brine from an unlined brine-disposal pond.....	C8
6. Map of discrete land-use areas delineated as basis for ground-water sampling.....	C10
7. Map of generalized unsaturated-zone lithology .....	C12

8.	Diagram showing testing framework for statistical comparisons among various sampling factors.....	C13
9–17.	Graphs showing:	
9.	Concentrations of dissolved solids and selected major ions in water samples from small-yield wells, grouped according to land-use area.....	C15
10.	Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in different land-use areas .....	C16
11.	Concentrations of dissolved solids and selected major ions in water samples from small-yield wells in areas of irrigated cropland, grouped according to unsaturated-zone lithology .....	C17
12.	Confidence levels of differences in median property values or inorganic-constituent concentrations in water samples from small-yield wells in areas of clayey and sandy unsaturated-zone lithology, grouped according to land-use areas.....	C18
13.	Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from irrigation wells in areas of clayey and sandy unsaturated-zone lithology.....	C19
14.	Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in different land-use areas, grouped according to unsaturated-zone lithology .....	C21
15.	Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in areas of irrigated cropland and petroleum-production land, grouped according to unsaturated-zone lithology .....	C22
16.	Concentrations of dissolved solids and selected major ions in water samples from areas of irrigated cropland, grouped according to type of well sampled .....	C23
17.	Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells and irrigation wells in areas of irrigated cropland.....	C24
18.	Map showing locations of wells from which water samples were tested for atrazine.....	C25
19.	Chromatogram produced from analysis of a ground-water sample by gas chromatography with flame-ionization detection (GC/FID).....	C29
20.	Chromatograms for a collected ground-water sample and a laboratory blank that were compared to identify peaks representing organic compounds present in the sample.....	C30
21.	Chromatogram showing method of measuring peak height to determine relative concentration of an organic compound in a ground-water sample .....	C30
22.	Graph of estimated total concentrations of organic compounds in ground-water samples from small-yield wells in petroleum-production areas and rangeland.....	C31
23.	Graphs of frequencies of occurrence of individual organic compounds in petroleum-production areas and rangeland, based on gas-chromatograph retention time.....	C32

## TABLES

1.	Summary of Selected Water-Quality Data Grouped According to Land-Use Areas .....	C14
2.	Frequency of Detections of Pesticides in Ground-Water Samples From Irrigated Cropland and Rangeland, Grouped According to Unsaturated-Zone Lithology and Type of Well Sampled.....	C20
3.	Summary of Statistical Comparisons of Median Property Values and Inorganic-Constituent Concentrations in Ground-Water Samples, Grouped According to Land-Use Areas, Unsaturated-Zone Lithology, and Type of Well Sampled .....	C26
4.	Summary of Statistical Comparisons of Atrazine Detections in Ground-Water Samples, Grouped According to Land-Use Areas, Unsaturated-Zone Lithology, and Type of Well Sampled .....	C27
5.	Summary of Statistical Comparisons of Hydrocarbon-Compound Detections and Relative Concentrations in Ground-Water Samples, Grouped According to Land-Use Areas and Unsaturated-Zone Lithology .....	C28
6.	Results of Water-Quality Analyses, Grouped According to Land-Use Areas, Unsaturated-Zone Lithology, and Type of Well Sampled .....	C38

## IV Contents

## CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	square hectometer
square mile (mi <sup>2</sup> )	2.590	square kilometer
foot per day (ft/d)	0.30489	meter per day
gallon per minute (gal/min)	0.06309	liter per second
pound (lb)	0.4536	kilogram
barrel (bbl)	0.1590	cubic meter

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

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

# Assessment of Nonpoint-Source Contamination of the High Plains Aquifer in South-Central Kansas, 1987

By John O. Helgesen, Lloyd E. Stullken, and A.T. Rutledge

## Abstract

Ground-water quality was assessed in a 5,000-square-mile area of the High Plains aquifer in south-central Kansas that is susceptible to nonpoint-source contamination from agricultural and petroleum-production activities. Of particular interest was the presence of agricultural chemicals and petroleum-derived hydrocarbons that might have been associated with brines that formerly were disposed into unlined ponds.

Random sampling of ground water was done within a framework of discrete land-use areas (irrigated cropland, petroleum-production land containing former brine-disposal ponds, and undeveloped rangeland) of 3–10 square miles. Although true baseline water-quality conditions probably are rare, in this region they are represented most closely by ground water in areas of undeveloped rangeland. The sampling design enabled statistical hypothesis testing, using nonparametric procedures, of the effects of land use, unsaturated-zone lithology, and type of well sampled.

Results indicate that regional ground-water quality has been affected by prevailing land-use activities, as shown by increased concentrations of several inorganic constituents. Ground water beneath irrigated cropland was characterized by significantly larger concentrations of hardness, alkalinity, calcium, magnesium, potassium, fluoride, and nitrite plus nitrate than was water beneath undeveloped rangeland. Few nondegraded pesticides were detected in the aquifer, probably because of degradation and sorption. Atrazine was the most common, but only in small concentrations.

Ground water beneath petroleum-production land was characterized by significantly larger concentrations of hardness, alkalinity, dissolved solids, sodium, and chloride than was water beneath undeveloped rangeland. Nonpoint-source contamination by oil-derived hydrocarbons was not discernible. The occurrences of trace organic compounds were similar between petroleum-production land and undeveloped rangeland, which indicates a natural origin for these compounds.

The unsaturated zone in the study area is lithologically heterogeneous and contains substantial amounts of clay that inhibit the downward movement of water and solutes. Within the aquifer, the rate of lateral regional flow and solute transport is slow enough so that the ground-water quality reflects overlying land use in discrete areas of several square miles, but it is still sufficiently rapid so that the type of well sampled is not important in regional characterizations of water quality beneath irrigated cropland; the seasonal pumping of irrigation wells does not appear to divert regional flow enough to cause substantial local anomalies of more mineralized ground water.

## INTRODUCTION

Increased public concern about the environment has directed attention toward the varied and complex issue of ground-water contamination. Assessing and understanding the effects of human activities on ground-water quality for the purpose of effectively addressing contamination problems have become a

matter of national importance. In light of this, the U.S. Geological Survey is conducting its Toxic Waste—Ground-Water Contamination Program, with the objective of assessing the current quality of the Nation's ground-water reserves and the nature and extent of the contamination problem (Helsel and Ragone, 1984).

The study of nonpoint-source ground-water contamination is a part of this program. It involves analyses that are designed to be regional in scope and statistical in approach, and that allow for subsequent work directed toward the extrapolation of results or the focusing on particular aspects important to the understanding of nonpoint-source contamination. Seven areas with diverse representative environments in terms of climate, geohydrology, and human activity were selected for study. Three of the seven are in the Midwestern United States, and one of these, part of the High Plains aquifer in Kansas, is the subject of this report.

## Background

Ground water is a vital resource in the Midwestern United States. The most common sources of water supply are shallow, unconfined, unconsolidated, and possibly extremely transmissive aquifers that have large storage capacities. The alluvial High Plains aquifer is the most areally extensive of these, but smaller alluvial or glacial-outwash aquifers are present throughout the Midwest. They all provide readily available water for public-supply, agricultural, industrial, domestic, and stock-raising purposes. Although contamination of any water resource could have substantial health-related and economic consequences, ground-water contamination can be a particularly serious problem because movement of ground water is slow and does not favor dispersal of contaminants; cleanup of contaminated ground water usually is difficult or impossible.

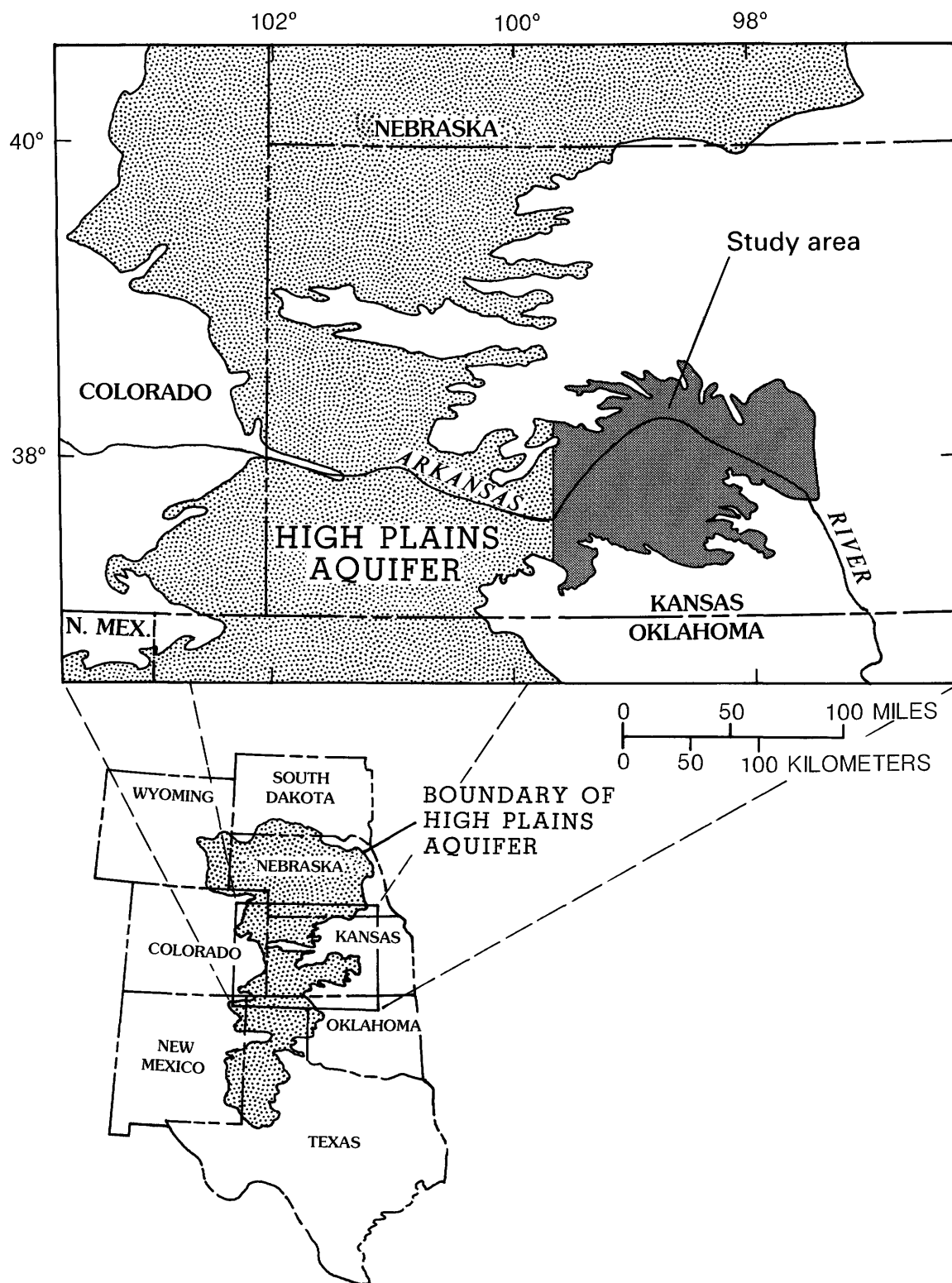
Aquifers with substantial permeability and a shallow water table are especially susceptible to contamination by local (point source) or widespread (nonpoint source) human activities at or near the land surface. This study includes a focus on nonpoint-source organic contaminants associated with two activities practiced extensively across much of the Midwest: agricultural-chemical application and the disposal of brines associated with petroleum production. Application of

agricultural chemicals, especially on irrigated land, provides an opportunity for these chemicals to move down to the water table. Brines produced with oil, and oil-derived hydrocarbons that can occur in association with brines, also might be a problem, particularly as a result of brine-disposal practices prior to regulation. This study explores contaminant concentrations in relation to three variables—land use, unsaturated-zone lithology, and type of well sampled.

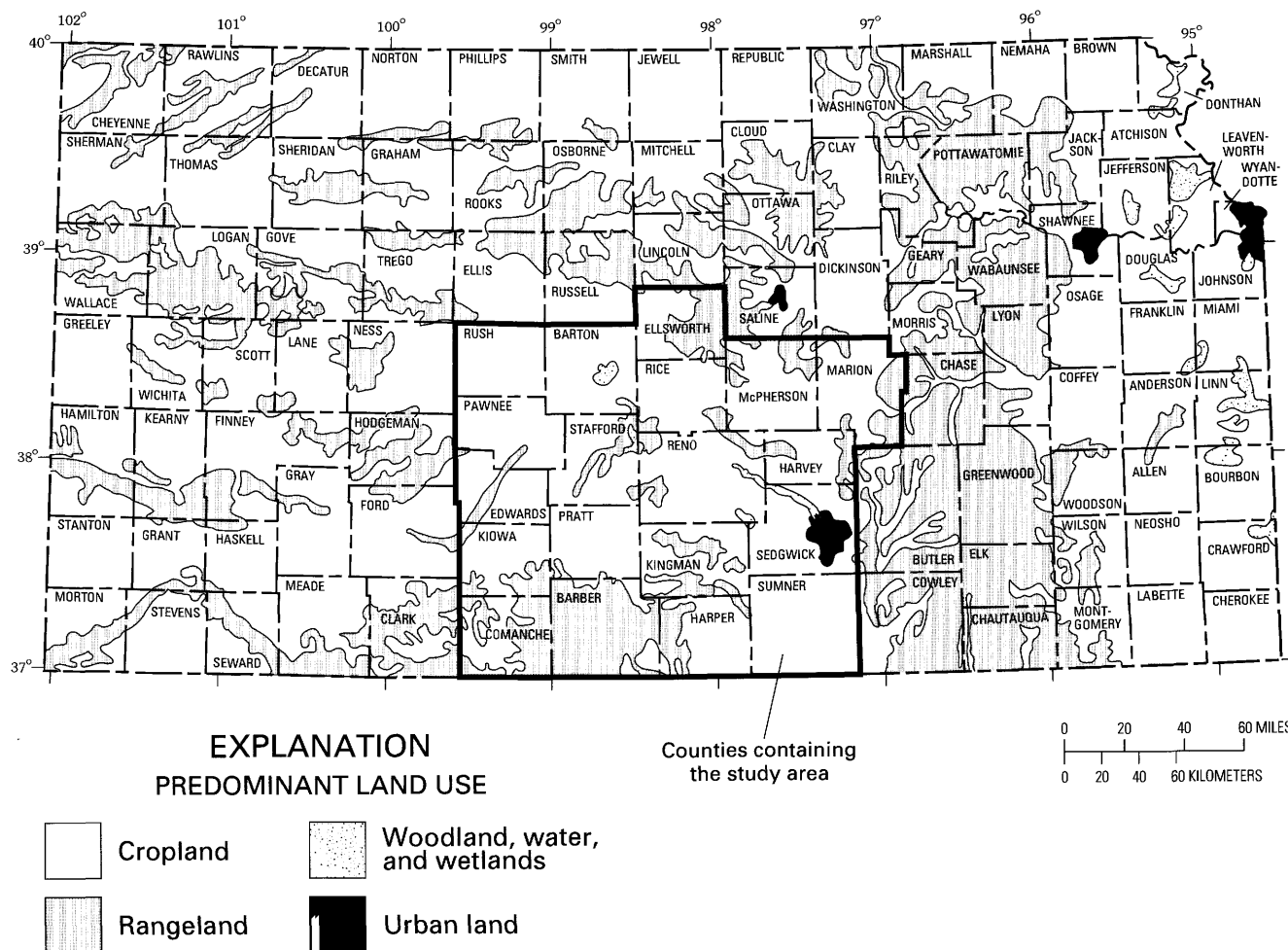
Delineation of contaminant distributions, in conjunction with improved understanding of the major factors affecting these distributions, will help in assessing the current problem and will contribute toward effective monitoring and predictive capabilities and, ultimately, the protection of water resources. The contamination problem is complex. The velocity of regional ground-water flow potentially is a major factor affecting the regional distribution of contaminants in an aquifer. Superimposed on the regional hydrology are local factors, such as natural hydrogeologic variations or local flow-pattern distortions caused by pumping. Many other processes that affect contaminant distribution, such as rate and timing of recharge, degradation, and sorption, also need to be considered.

The area selected for this study (fig. 1) is a small part of the High Plains aquifer, yet it is sufficiently large (5,000 m<sup>2</sup>) to address the regional scale of the problem. The study area is a logical unit for investigation of nonpoint-source contaminant distribution in ground water because it is characterized by permeable soils and a shallow water table (typically less than 30 ft below the land surface). The potential for contamination of ground water in the area is reflected by previous information showing large nitrate concentrations in ground water relative to other areas of Kansas (Spruill, 1983).

The aquifer hydrology of this area is well defined (Williams and Lohman, 1949; Stramel, 1956, 1967; Fader and Stullken, 1978; Hathaway and others, 1978, 1981; Cobb and others, 1983; Sophocleous, 1983; Spinazola and others, 1985; and Stullken and others, 1985). The aquifer consists of a heterogeneous sequence of clay, silt, sand, and gravel that is principally of alluvial origin. The aquifer contains and transmits water derived mainly from local precipitation that percolates downward to the water table. Unconfined conditions predominate, and regional ground-water flow generally is from west to east.



**Figure 1.** The High Plains aquifer and location of the study area.



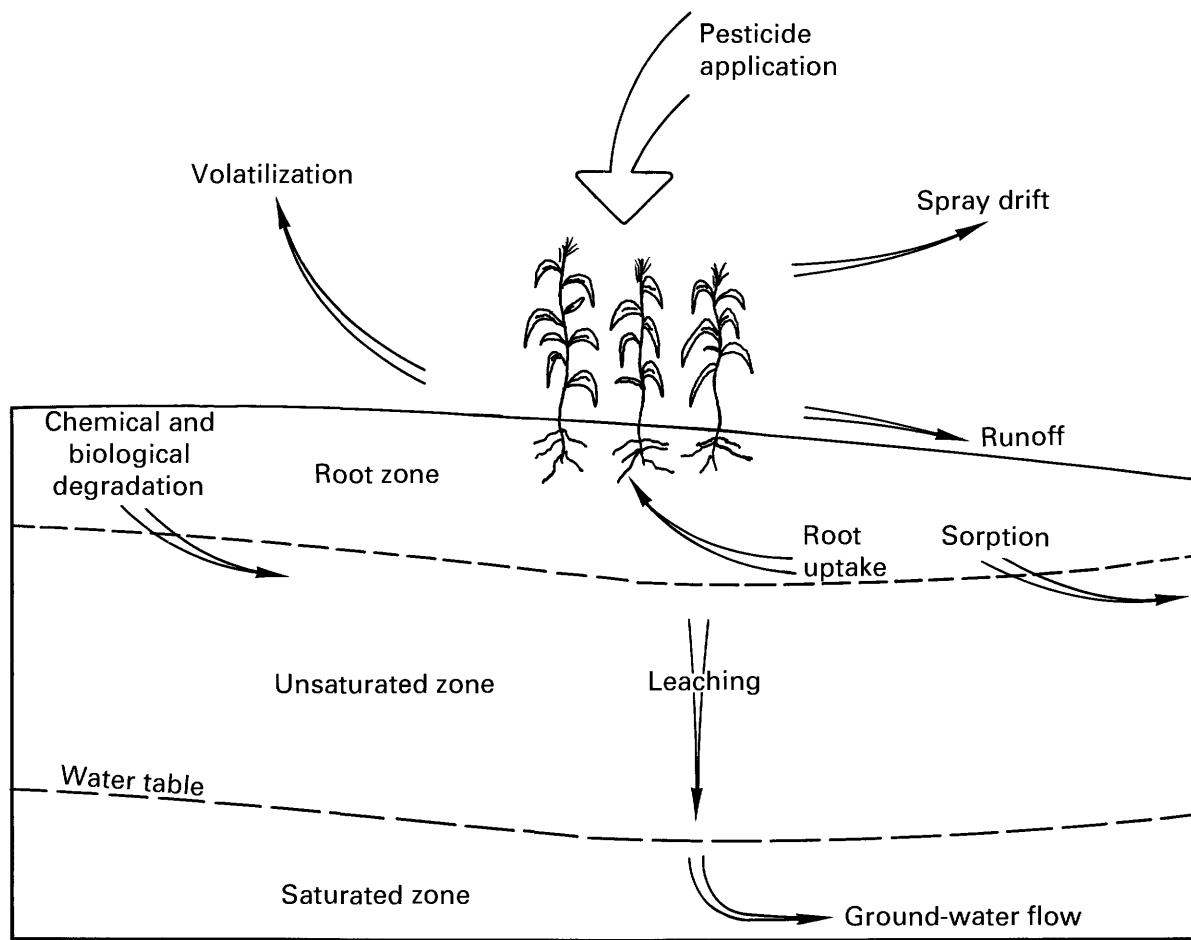
**Figure 2.** Generalized predominant land use in Kansas. Modified from Williams and Barker (1974).

## Purpose and Scope

This report characterizes the occurrences of non-point-source contaminants in the High Plains aquifer in south-central Kansas and evaluates these occurrences in relation to land use, unsaturated-zone lithology, and type of well sampled. The report addresses overall ground-water quality including a focus on the occurrence of organic contaminants (pesticides and oil-derived hydrocarbons) associated with agriculture and petroleum production. Certain pesticides, such as atrazine and 2,4-D, are of particular concern because of their extensive use, relative persistence, and mobility. Specific hydrocarbons are not targeted, however, because potential petroleum-related contaminants include a wide variety of compounds.

## Acknowledgments

The cooperation of many individuals and agencies was essential for the completion of this study. The authors appreciate the permission granted by well owners for collection of water samples. Also acknowledged are: the Kansas Department of Health and Environment (Topeka) for providing water-well records; the Kansas Geological Survey (Lawrence) for sharing gamma-log and water-well data; the Kansas Corporation Commission (Topeka) for information concerning brine-disposal ponds; and Kansas Groundwater Management Districts Nos. 2 (Halstead) and 5 (Stafford) for sharing their information and experience pertaining to the study area.



**Figure 3.** Pathways of pesticide transport and degradation. Modified from Severn (1987).

## DESCRIPTION OF NONPOINT-SOURCE CONTAMINATION

### Agricultural Contaminants

Land use in Kansas (fig. 2) is largely agricultural, which is typical of much of the Midwest. Pesticides (synthetic organic chemicals used principally for weed and insect control) are applied extensively to enhance crop productivity. Widespread application of many different pesticides is common but, in most instances, application histories are not documented. The timing of applications with respect to natural recharge and irrigation is an important factor that affects pesticide infiltration. Other factors include properties of the unsaturated zone, chemical properties that relate to contamination potential (such as solubility, degradability, and sorption characteristics),

and lithologic and hydraulic properties that affect the distribution of the compound in the saturated zone.

The multiple distribution pathways available to a pesticide (Cheng and Koskinen, 1986; Severn, 1987) make its tracking through the natural environment difficult. This complexity is illustrated schematically in figure 3. After application, the pesticide can be discharged with surface runoff, lost to volatilization, or infiltrated into the soil. Within the root zone, part of the pesticide can undergo chemical or biological degradation, part may go to plant uptake, and part might leach into and percolate through the unsaturated zone. A substantial portion also may be sorbed onto organic or clay materials. If the pesticide reaches the saturated zone, degradation normally is slowed considerably (Severn, 1987), and subsequent distribution probably is determined largely by flow patterns prevailing within the aquifer. The great number of possible combinations of pesticides, their

characteristics, and a variety of hydrologic conditions severely restrict the ability to predict the effects of pesticides on ground-water quality.

Due to increased awareness of ground-water contamination by pesticides during the last few years, several Midwestern States have conducted surveys to begin defining and monitoring the problem. Most of the data from these surveys are available but unpublished. Pesticides targeted for study vary by State, but the most common are alachlor, aldicarb, atrazine, carbofuran, cyanazine, metolachlor, metribuzin, and 2,4-D. The surveys generally have not systematically evaluated the nonpoint-source contamination problem, but they have provided initial indications of pesticide occurrences in ground-water supplies. Some of the largest concentrations detected probably represent localized point-source problems.

U.S. Environmental Protection Agency data from 1984 show that 58 out of 1,736 samples (3 percent) collected from water wells across Kansas between 1972 and 1984 had detectable pesticide concentrations. The most common pesticides detected were 2,4-D, aldrin, dieldrin, and dacthal. A study by Koelliker and others (1987) involved a 1985-86 random sampling of 103 farmstead wells in Kansas, of which 9 percent had detectable pesticides. Atrazine was the most frequent, with concentrations as large as 7.4 µg/L (micrograms per liter). Other pesticides, detected only once, were alachlor, chlordane, heptachlor epoxide, picloram, 2,4-D, and 2,4,5-T. Picloram concentration was 5.6 µ/L, and concentrations of other compounds were less than 1.3 µg/L. Perry and others (1988) summarized agricultural-chemical use, factors affecting leaching, and ground-water quality assessments in Kansas. Those authors reported that 56 wells in areas of permeable soils and shallow water table were sampled and analyzed for triazine herbicides during 1985-86, and that these herbicides were detected in 20 percent of the samples, with atrazine again being the most frequent.

The common practice of irrigation inadvertently aids in the leaching of pesticides and thus might be an important factor affecting pesticide migration. Luckey and others (1986) estimated that return flows to the water table from irrigation on the High Plains are substantial and might be as much as 30-50 percent of pumpage withdrawal. Concern has developed regarding the practice of chemigation (application of agricultural chemicals by injection into irrigation water and distribution through the irrigation system)

in intensively irrigated areas in many parts of Kansas (Genna Ott, Kansas Department of Health and Environment, written commun., 1984). Direct potential for contamination exists due to back-siphoning of chemicals into the supply well if the pump apparatus is not properly equipped with a backflow-prevention device. Also, chemicals could contaminate the aquifer as a result of defective well construction. Analyses of water from 138 chemigation wells in 1988 showed detectable pesticides in 4 percent of the samples. However, the chemigation process itself does not appear to result in a greater incidence of contamination (Perry and Anderson, 1991).

Pesticide compounds vary considerably in their persistence characteristics in the subsurface environment. Half-lives in soil are on the order of weeks or months for many pesticides, but might be much longer in the saturated zone. Study of a point-source contamination problem near Hesston, Kansas (Perry, 1990), determined half-lives in the saturated zone on the order of years for atrazine and other herbicides. The potential for long-term persistence also is demonstrated by results of stream-water analyses; for example, H.E. Bevans (U.S. Geological Survey, written commun., 1989) reports atrazine in the base flow of northeastern Kansas streams, reflecting transport through the ground-water system that probably took years.

An initial reconnaissance sampling of part of the study area described in this report was done in August and September of 1984 (Stullken and others, 1987). Thirteen samples were collected from wells in areas of irrigated cropland, and 14 samples were collected from areas of rangeland. Analyses were performed for several classes of pesticides: triazine and other nitrogen-containing herbicides, chlorophenoxy-acid herbicides, and carbamate, organochlorine, and organophosphate insecticides. The only pesticides detected were 2,4-D, atrazine, and propazine. The herbicide 2,4-D was reported in 23 of the 27 samples, atrazine was detected in 2 samples, and propazine was detected in 1 sample. All concentrations were small, with the largest being 0.20 µg/L for atrazine.

## **Petroleum-Production Contaminants**

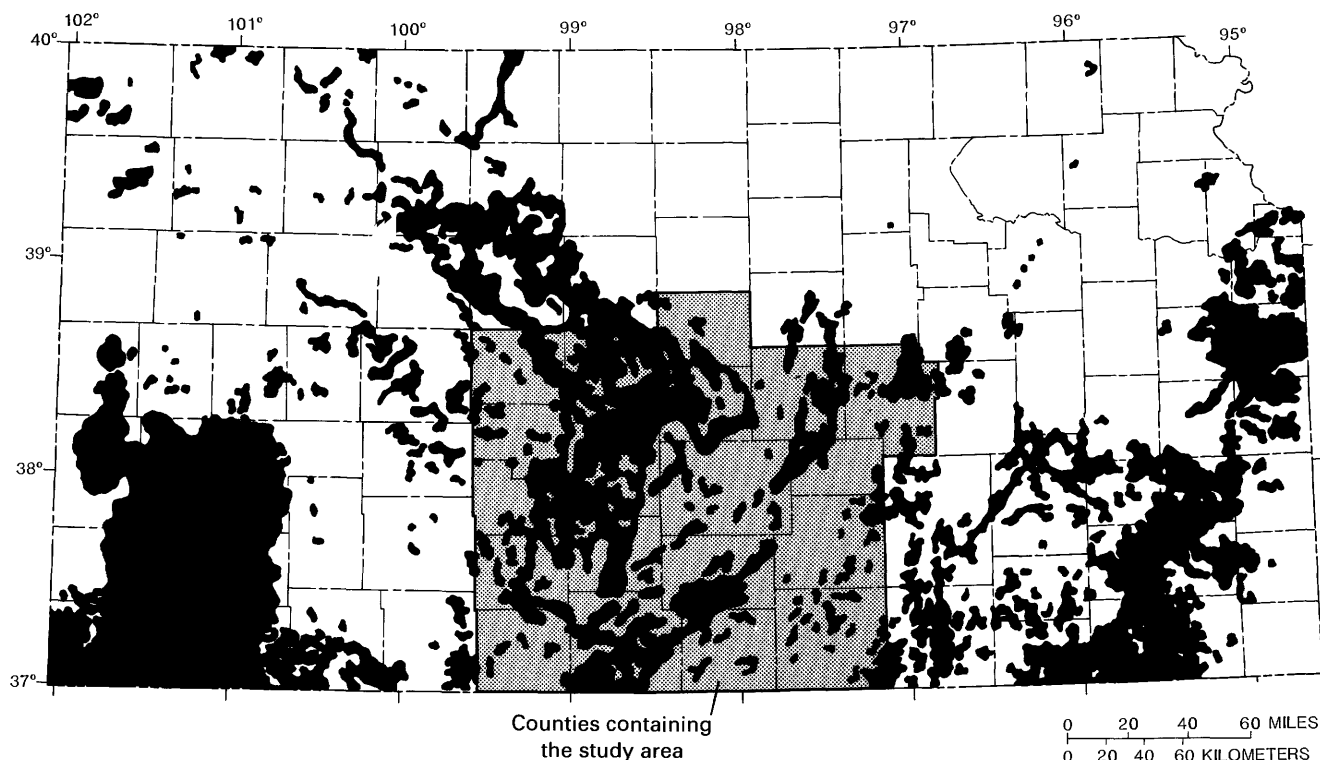
Hydrocarbons, a large group of organic compounds with widely varying properties, typically are associated with petroleum-related activities. Virtually no documentation of nonpoint-source hydrocarbon

contamination of ground water exists. Recognition of the potential for contamination on a regional scale is based mainly on conceptual inference in combination with a few instances of reported hydrocarbon occurrence in ground water.

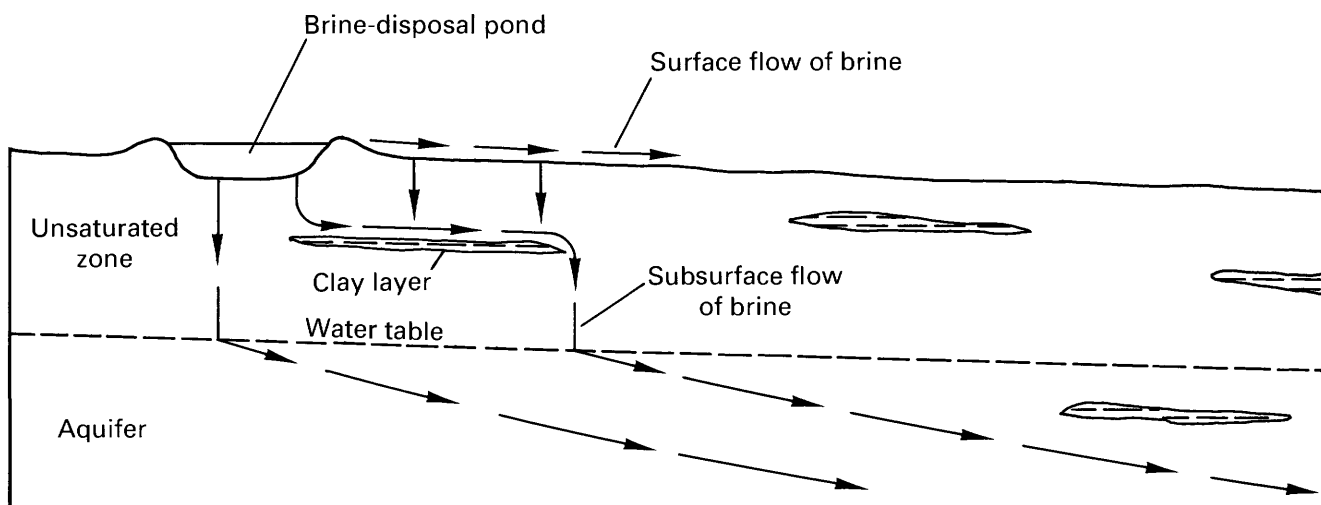
The extent of petroleum production in Kansas (fig. 4) is indicative of the potential regional effect of this activity on water quality of the High Plains aquifer. Surface areas affected by petroleum production range from about 0.1 acre containing a single well to large tracts devoted exclusively to petroleum-related operations such as refining and storage. Brine produced in conjunction with oil is the major potential ground-water contaminant in Kansas in terms of volume generated (Power, 1982). According to the Kansas Department of Health and Environment (1982), an average of 23 bbl of brine accompanies each barrel of oil produced. Most of the brine currently produced is reinjected into the producing zone or other saltwater-bearing formations. Prior to the 1960's, however, it was not an uncommon practice to dispose of oil-field wastes (mostly brine) into shallow, unlined pits. The attendant potential contamination problem has long been recognized (Frye and Brazil, 1943). Infiltration of the wastes through

the soil and into the freshwater of the underlying aquifer (fig. 5) has been documented. Leonard and Berry (1961) described such a contamination problem northwest of the study area, in Ellis County (fig. 2). In western Harvey and eastern Reno Counties (within the study area), brine contamination of ground water originated from former disposal pits, a leaky pipeline collection system, and possibly in response to increased hydraulic pressure from below the aquifer caused by brine injection (Burrton Task Force, 1984).

Because brine is in direct contact with petroleum during production, some hydrocarbons are present in the brine during disposal. Thus, where ground water has been affected by improper disposal of oil-field brine, hydrocarbons from the associated petroleum also might constitute contaminants. Volatile organic compounds occasionally have been detected in ground-water samples collected in Kansas. In the 1985-86 sampling of 103 farmstead wells, 2 percent had detectable volatile organic compounds (Koelliker and others, 1987). Many sources for such compounds exist, and oil-production activity is one possibility. The existence and extent of this problem currently is unknown.



**Figure 4.** Locations of oil and gas fields, shown in black, in Kansas, 1983. Modified from Steeples and Buchanan (1983).



**Figure 5.** Movement of brine from an unlined brine-disposal pond. Modified from Leonard and Berry (1961).

## STUDY APPROACH AND METHODS

The study of nonpoint-source contamination entails: (1) characterization of the contaminant sources; (2) consideration of factors relevant to the development and assessment of contamination; (3) formulation of an appropriate sampling design and sampling procedures for collection of pertinent and representative data; and (4) application of statistical methods to evaluate the importance of relevant factors.

### Characterization of Contaminant Sources

The types of contaminants examined in this study have different origins that can be characterized in terms of land use. Attention to land use is paramount for maintaining consistency with the overall program emphasis of defining relations between ground-water quality and prevailing human activities (Helsel and Ragone, 1984). Quantification of contaminant sources probably would be done best on the basis of chemical-application volumes (of pesticides on agricultural land) and disposal volumes (of petroleum-derived hydrocarbons on petroleum-production land). However, such data are limited, thereby precluding a quantitative appraisal of contamination in the study area.

#### Agricultural Land

The regional occurrence of pesticides in ground water was defined in reference to agricultural land use. Nearly the entire area is cropland or rangeland (fig. 2);

the largest nonagricultural areas are a wildlife refuge and principal communities. Attention was directed to areas of irrigated cropland and rangeland; both of these types of land receive pesticide applications (although irrigated cropland receives much more), with irrigation increasing the potential for downward leaching of chemicals.

Some general information about pesticide applications is available. Nilson and Johnson (1980) assembled 1978 pesticide-use data for multicounty areas within Kansas; Perry and others (1988) also summarized these data. During 1978, 28.1 million pounds of active pesticide ingredients were applied statewide. Herbicides accounted for 85 percent of the total, and atrazine was the most intensively used (21 percent of the total). In terms of acreage, 2,4-D was the most extensively applied.

Atrazine and 2,4-D were the two most intensively used pesticides in south-central Kansas (Perry and others, 1988), the region that approximately coincides with the study area. During 1978, application of atrazine exceeded 370,000 lb (mostly on sorghum or corn), and application of 2,4-D exceeded 400,000 lb (mostly on pasture and rangeland). These herbicides have been detected in ground-water samples from the area (Stullken and others, 1987; Bevans, 1989) and, therefore, are the principal pesticides considered in this study.

#### Petroleum-Production Land

The regional occurrence of hydrocarbons in ground water was defined in reference to petroleum-production land use in the study area. Petroleum-

derived hydrocarbons might have accompanied brines as they percolated downward from former brine-disposal ponds. Most petroleum-production activity is located within designated oil fields ranging in size from a fraction of a square mile to several square miles or larger. Virtually all disposal ponds also are situated within the boundaries of the fields; therefore, these oil fields form a logical frame of reference for studying water quality that might be related to this activity.

Amounts of organic contaminants that might be associated with the brines are unknown. Reported rates of brine disposal at pond locations are available and could indicate relative potential for hydrocarbon contamination. Concentrations of hydrocarbons in the brines, however, could vary considerably depending on the brine-oil ratio and effectiveness of the separation process.

## **Factors Relevant to the Development and Assessment of Contamination**

Many factors might affect the development and assessment of nonpoint-source contamination. Factors considered most important to the design of this study were land use, unsaturated-zone lithology, and type of well sampled.

### **Land Use**

Regional ground-water quality was characterized in relation to predominant land use. Discrete areas of 3–10 mi<sup>2</sup> were identified as irrigated cropland, petroleum-production land, and virtually undeveloped rangeland (fig. 6). This size was considered appropriate for establishing associations between contaminant occurrence and prevailing land use in view of the slow movement of ground water. Regional lateral-flow velocity generally is less than 1 ft/d (Stullken and others, 1987). During the last few decades, when most contamination has occurred, ground water would not have moved much beyond these areas; therefore, ground-water quality can be related to general areas of overlying land use. Delineation of the areas as narrow, elongated shapes was avoided to decrease the possibility that sampled ground-water quality does not reflect the overlying land use because of displacement by regional flow.

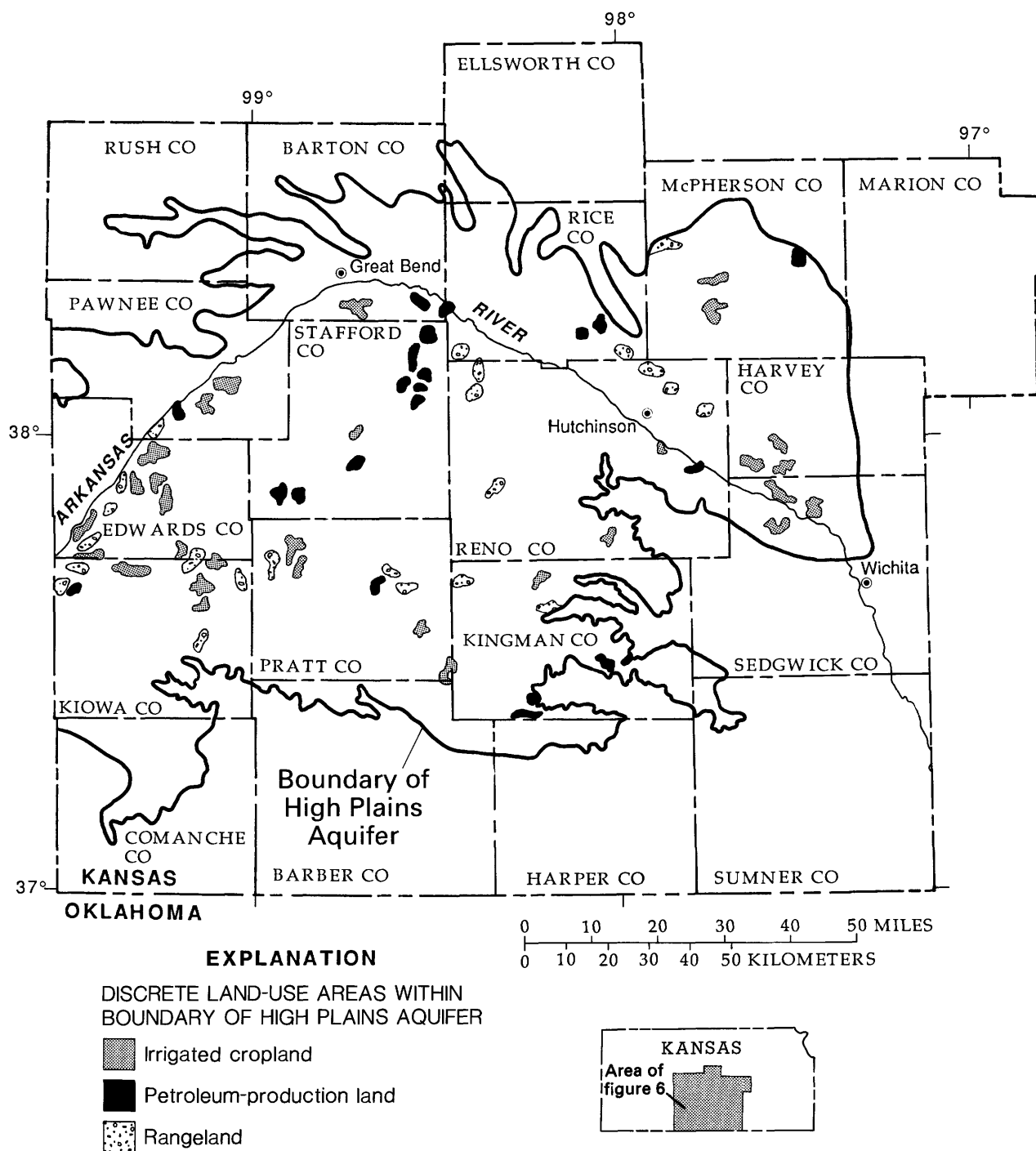
The discrete land-use areas were outlined so as to be as mutually exclusive as possible, because spatial

independence is important for distinguishing overall ground-water quality. Accordingly, areas of irrigated cropland were chosen that do not overlap with oil fields; areas of petroleum-production land were delineated to contain as little irrigated cropland as possible (that is, rangeland predominates except for the sites containing oil wells and associated structures); and areas of undeveloped rangeland were outlined to exclude irrigated cropland and oil fields.

Although pesticides are applied to some rangeland, 1978 data from Nilson and Johnson (1980) showed that only about 7 percent of pasture and rangeland received applications. Fertilizer use on rangeland also is limited (P.D. Ohlenbusch, Kansas State University, written commun., 1990). Therefore, rangeland is mostly undeveloped and serves as a useful control category for establishing baseline conditions.

Landsat satellite imagery for late July and early August of 1984 was selected as the primary tool for delineating agricultural land-use areas. Imagery for this period had virtually no cloud-cover interference and provided sufficiently recent land-use information. Coverage was obtained from black-and-white band-2 images containing tonal contrasts useful for identifying irrigated crops at midsummer growth stages. Rangeland was mapped on the basis of textural and tonal qualities of the imagery with reference to 1974 land-use maps prepared by the U.S. Geological Survey (1979a; 1979b; 1979c; 1979d). Relatively minor changes in rangeland distribution in the study area between 1974 and 1984 permitted the older information to be used as an effective guide. Use of the older maps for identifying irrigated cropland was not possible, however, because irrigated and nonirrigated cropland are not differentiated on those maps.

For purposes of this study, areas of petroleum production were chosen that exhibited collective occurrences of inactive brine ponds, those generally of pre-1957 construction from which leakage could be a residual problem and, thus, of importance to this study. Active ponds mostly are those installed after regulations requiring proper construction were imposed in 1957 and are unlikely to be sources of contamination. Active ponds are much fewer, and most are used only for temporary storage of brine before subsurface disposal through deep wells. Information describing the locations of inactive brine-disposal ponds had to be obtained from the Kansas Corporation Commission because disposal methods were not used uniformly across oil-field areas; some production companies injected brine through deep



wells. The compilation of brine-pond locations is incomplete, but enough sections of land containing inactive ponds were identified to provide sufficient coverage in defining areas of pond aggregations. Several contiguous sections of rangeland containing inactive brine ponds and forming a discrete 3- to 10-mi<sup>2</sup> area were used to define a petroleum-production area.

### Unsaturated-Zone Lithology

Another factor affecting the occurrence and distribution of contaminants in the ground-water system is the presence of fine-grained materials in the unsaturated zone, which can inhibit downward movement of water and chemicals (fig. 5). Differences in ground-

water quality associated with lithologic variations in the unsaturated zone could demonstrate the significance of this factor on downward movement of contaminants to the aquifer.

Clay deposits are common at shallow depths within the study area, according to Stullken and Fader (1976), Sophocleous and Perry (1987), and other workers familiar with the area; however, the lithology has not been mapped. Lithologic mapping for this study was conducted using existing information for the top 20 ft of the unsaturated zone (this interval comprises most of the unsaturated zone throughout the study area). The interpretation was based on about 80 gamma-ray logs and about 350 descriptive logs available for the area. Although data were obtained from several different sources, it was possible to map generalized regional patterns of clay composition (fig. 7). However, because of the scarcity of definitive log data in parts of the area and considerable local lithologic variability, the interpretation contained only two categories—clayey areas defined as containing at least 25 percent clay in the unsaturated zone (an arbitrary percentage assumed to represent enough clay to effectively inhibit downward flow) and sandy areas containing less than 25 percent clay. All delineated land-use areas then were identified as occurring in either a clayey or sandy area for the purpose of evaluating results in terms of unsaturated-zone lithology.

### **Type of Well Sampled**

A further consideration in evaluating ground-water contamination is the source of the samples on which the description of water quality is based. Results might be dependent on the location and yield of the sampled well to the extent that: (1) the introduction of contaminants to the ground-water system is nonuniform within the specified land-use area of concern, and (2) the distribution of contaminants within the aquifer is modified by the natural or induced hydraulic conditions of the system. Nonuniform introduction of contaminants to the system can result from nonuniform source distribution or spatial variations of factors that affect the movement or persistence of constituents in the subsurface. Variations in constituent concentrations with depth have been reported within the study area (Huntzinger and Stullken, 1988) and in the Nebraska portion of the High Plains aquifer (Chen and Druliner, 1987; Druliner, 1989). Local

conditions might have a substantial effect on ground-water quality at any given location. Site-specific definition of these complexities, however, is not practical for this regional assessment, necessitating a statistical sampling approach.

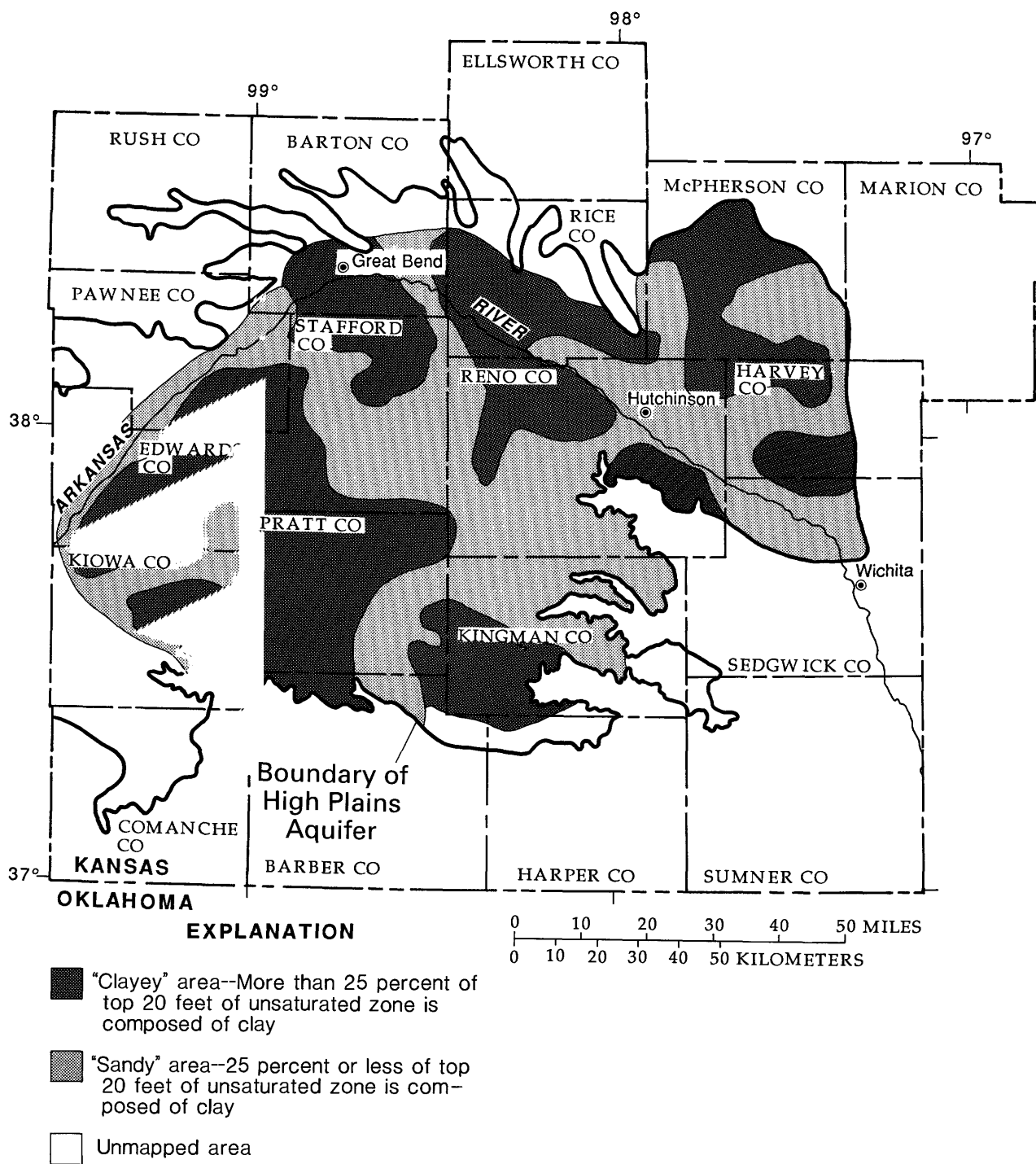
The type of well sampled could be particularly important in areas where irrigation water is withdrawn from large-yield wells (those yielding more than 500 gal/min). Samples from irrigation wells, which typically are located within the irrigated fields, potentially contain larger concentrations of an agricultural contaminant than do samples from small-yield wells (normally those that are drilled for domestic or stock use and yielding less than 30 gal/min) located away from the fields. Irrigation wells develop cones of depression directly beneath the areas of chemical application and potentially cause local recirculation of water and contaminants. In the initial reconnaissance by Stullken and others (1987), the only irrigation well sampled yielded water containing the largest pesticide concentration. Well yield generally is not relevant to characterization of ground-water quality beneath rangeland because of a lack of large-yield wells. Nonpoint-source contaminants beneath rangeland, whether agriculture or petroleum related, are less likely to be diverted from natural regional ground-water flow patterns.

## **Sampling Design and Procedures**

Characterization and evaluation of nonpoint-source contamination based on regional sampling of ground water allows an evaluation of the significance of the selected factors previously discussed.

### **Sampling Design**

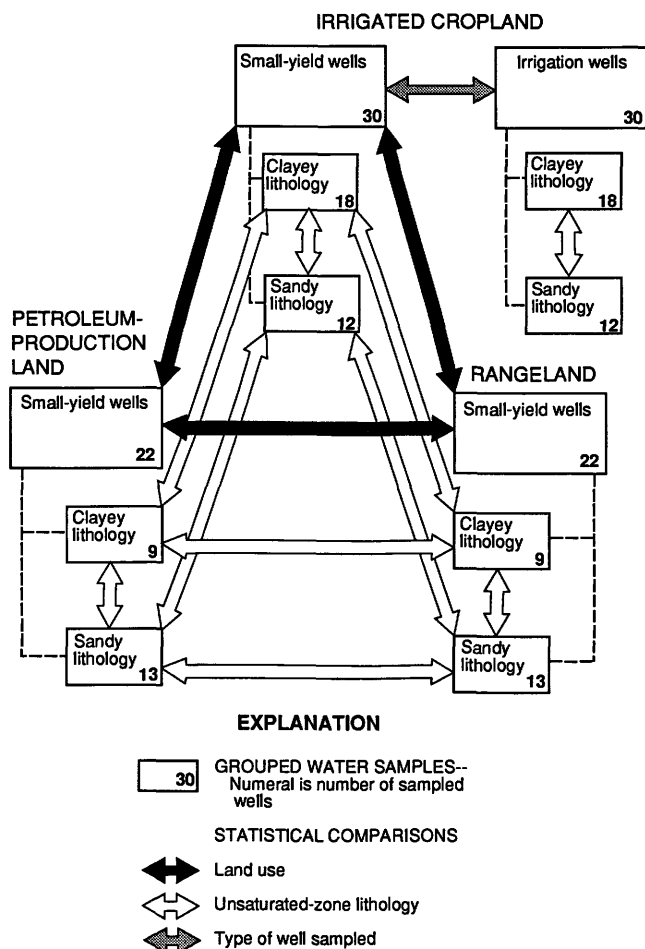
The basic framework for sampling consists of the three discrete types of land use (fig. 6). These consist of 30 areas of irrigated cropland, 22 petroleum-production areas, and 22 areas of undeveloped rangeland. The sampling plan was developed to enable the use of several modes of statistical comparison in terms of ground-water quality (fig. 8). The primary comparisons were among the three categories of land use. With regard to organic compounds, samples from irrigated cropland were compared with those from undeveloped rangeland for pesticide presence or concentrations, and samples from petroleum-production areas were compared with those from



**Figure 7.** Generalized unsaturated-zone lithology.

undeveloped rangeland for hydrocarbon presence or concentrations. All three types of areas were compared in terms of inorganic constituents. Additionally, comparisons based on unsaturated-zone lithology were included to help recognize its effect on regional ground-water quality. All of these

comparisons were made using samples only from small-yield wells to minimize the effects of different well locations and yields. The effect of the type of well sampled was evaluated by comparing results from small-yield wells with those from irrigation wells in the areas of irrigated cropland.



**Figure 8.** Testing framework for statistical comparisons among various sampling factors.

Accordingly, one small-yield well in each land-use area, and one irrigation well in each area of irrigated cropland, was selected randomly for sampling. Statistically, the population from which each well was selected contained all similar wells (small-yield or irrigation, as appropriate) in that land-use area for which information is available. This information consists of driller-submitted records for wells constructed after 1975. These records typically include location, well depth, construction data, and driller's log. The records verify that a given well was completed in the High Plains aquifer and provide information that could be pertinent to interpreting water-quality results. Although water-quality characteristics could vary with the depth of the well sampled, well depths in an area tend to be similar and results are assumed to be representative.

Random-number generation was used to select wells for sampling. If, for a particular land-use area, the well could not be located or sampled for any

reason, a different well was selected according to the random-number assignment. In areas having only a few wells with recorded information, inability to sample any of the candidate wells necessitated selecting an alternate well arbitrarily in the field. This entailed recording as much information about the well as possible based on an interview with the well user.

## Sampling Procedures

Sampling was conducted during July 1987, a few weeks after the irrigation season (normally June to August) had begun. Each well was sampled once. Samples were taken only from wells that could be pumped long enough to ensure that untreated water was being obtained directly from the aquifer. Onsite determinations were made for specific conductance, pH, water temperature, and alkalinity. Samples were collected and prepared according to standard procedures developed by Skougstad and others (1979) and sent to the U.S. Geological Survey Water Quality Laboratory in Arvada, Colo., for analysis.

In all cases, samples were to be analyzed for the presence of major inorganic ions and other inorganic constituents. Requested analyses for organic constituents, however, depended on the land-use area in which the sample was collected. In areas of irrigated cropland and rangeland, samples also were collected for analyses of triazine and other nitrogen-containing herbicides, and chlorophenoxy-acid herbicides. These classes of pesticides contain the chemicals most commonly applied and were the only pesticides detected during the 1984 reconnaissance sampling (Stullken and others, 1987).

In petroleum-production areas and rangeland, samples were collected for analysis by gas chromatography with flame-ionization detection (GC/FID scan). Descriptions of this procedure are given by Feltz and others (1986) and Stullken and others (1987). Without targeting specific organic compounds, the GC/FID scan is used as a screening procedure capable of detecting a variety of organic compounds and is particularly suitable for detection of hydrocarbons. Results provided by the GC/FID scans are only semiquantitative and nonspecific (specific compounds are not identified). Subsequently, gas chromatography with mass spectrometry (GC/MS) was performed on selected samples to identify the organic compounds detected by the GC/FID scan.

**Table 1.** Summary of selected water-quality data grouped according to land-use areas.  
[Based on data from small-yield wells. Units are in milligrams per liter. (<), less than]

Property or constituent	Irrigated cropland			Petroieum-production land			Rangeland		
	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median
Hardness, as CaCO <sub>3</sub>	520	110	180	570	90	190	710	31	130
Alkalinity, total as CaCO <sub>3</sub>	300	40	150	420	77	160	420	28	100
Dissolved solids	900	140	240	1,120	149	335	1,300	88	180
Calcium	160	34	60	180	31	64	140	9.5	44
Magnesium	30	3.2	7.1	35	2.5	6.6	88	1.8	4.0
Sodium	100	5.8	23	200	8.5	32	440	6.8	13
Potassium	5	1	3	9	1	2	6	.9	2
Sulfate	440	7.8	22	150	9.1	16	380	10	15
Chloride	140	2.9	14	460	3.2	50	620	2.7	7.9
Nitrite plus nitrate	18	<.10	6.8	23	.46	3.6	36	1.1	3.4
Orthophosphorus	.13	.01	.05	.14	.01	.06	.49	.01	.07

## Statistical Testing

Data were analyzed by statistical hypothesis tests to identify associations between ground-water quality and land use or other selected factors. Statistical distributions for most chemical constituents were nonnormal and positively skewed, and nonparametric procedures were used for statistical testing. The two-tailed Wilcoxon-Mann-Whitney rank-sum test (Iman and Conover, 1983) is used for statistical comparison of two groups of data. For a given property or constituent, the null hypothesis is that the median values or concentrations of the two groups are equal at a specified confidence level. The alternative hypothesis is that they are not equal. Rank-sum test results indicate at what confidence level the null hypothesis would be rejected, thus providing a measure of similarity or dissimilarity between the two groups. In cases of strong dissimilarity, the group with the larger median value or concentration can be identified by the statistics of the distributions.

Contingency-table analysis is used to help evaluate data that are classified by two criteria (Iman and Conover, 1983). This method is applicable for trace organic constituents in this study because these data are analyzed in terms of their presence or absence. The null hypothesis for this test is that there is no association between a particular factor of interest and

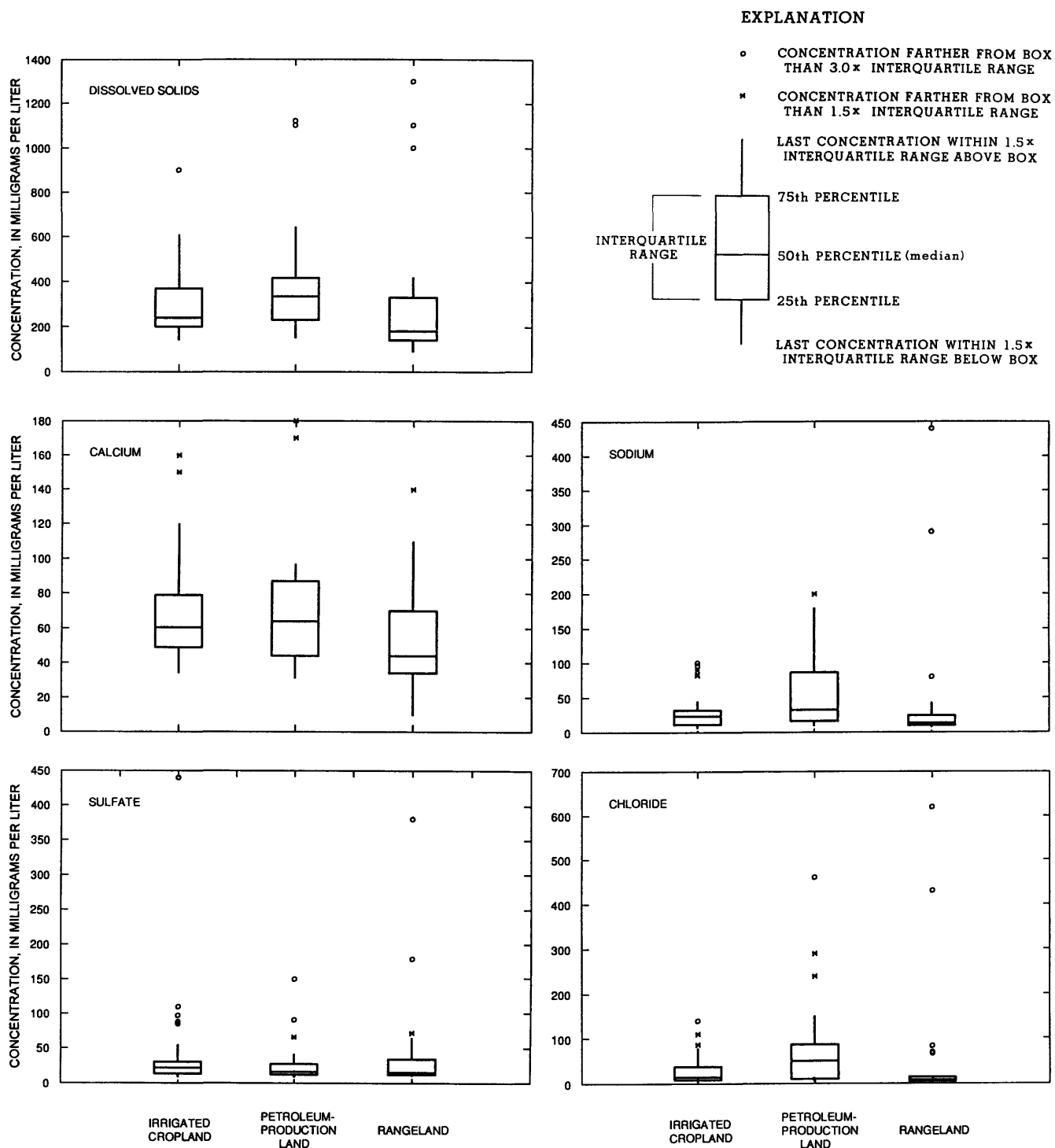
the presence or absence of a particular constituent in the ground water at a specified confidence level. The alternative hypothesis is that there is an association.

## RESULTS OF DATA ANALYSIS AND STATISTICAL TESTING

Results of water-sample analyses are presented in table 6 at the end of this report and are grouped according to the factors considered—land use, unsaturated-zone lithology, and type of well sampled. Data analyses for inorganic constituents, pesticides, and hydrocarbons are considered separately according to the appropriate statistical-testing procedures.

### Inorganic Constituents

Results of the water-quality analyses show that most ground water in the sampled areas contains about 100–600 mg/L (milligrams per liter) of dissolved solids and that the water is generally hard to very hard (greater than 120 mg/L as CaCO<sub>3</sub>). The water is commonly a calcium bicarbonate type, but sodium and chloride are predominant ions in some areas.

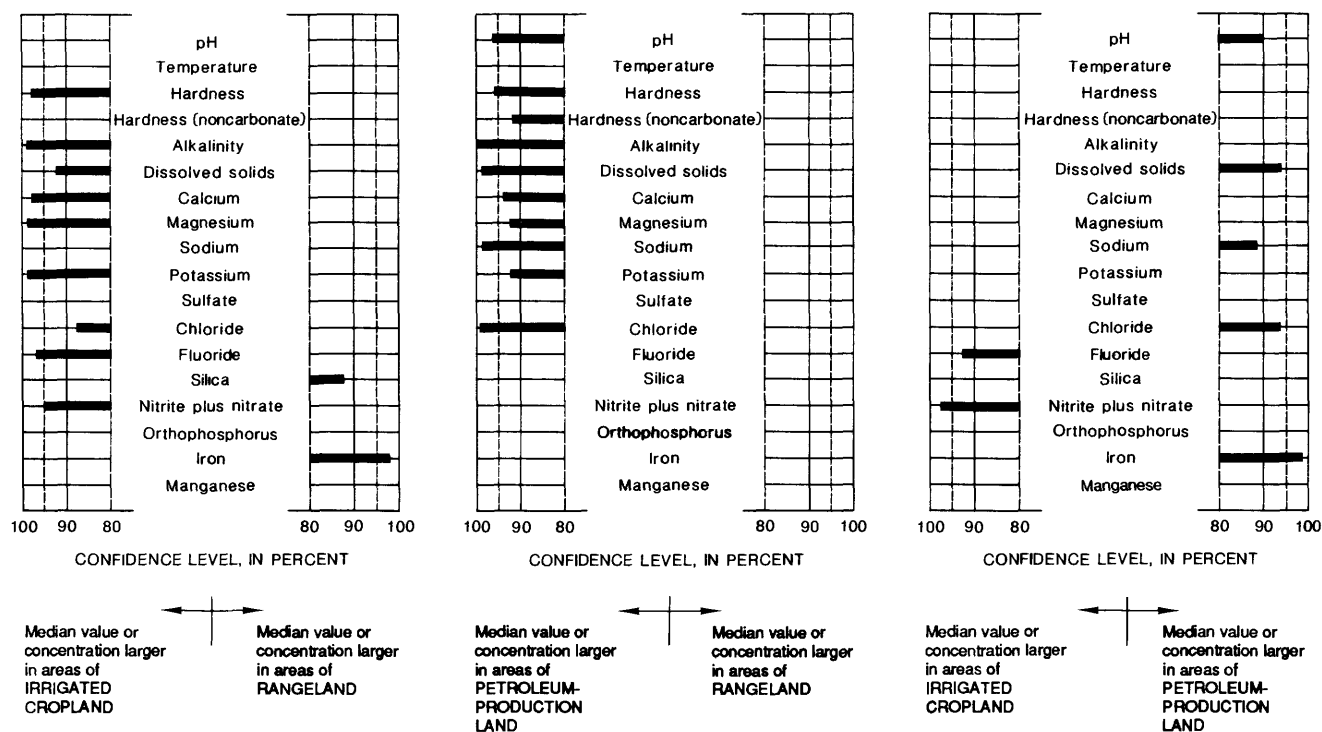


**Figure 9.** Concentrations of dissolved solids and selected major ions in water samples from small-yield wells, grouped according to land-use area (based on 30 irrigated-cropland samples, 22 petroleum-production-land samples, and 22 rangeland samples).

### Comparisons by Land Use

Examination of some of the statistical data (table 1) indicates that some variation in general

ground-water quality might be related to prevailing land use. Box plots arranged according to land use (fig. 9) allow clearer visual comparisons between medians and overall data distributions. For example,



**Figure 10.** Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in different land-use areas.

it is apparent that ground-water samples from petroleum-production land exhibit larger median concentrations of dissolved solids, calcium, sodium, and chloride than do samples from irrigated cropland or rangeland. Samples from rangeland exhibit smaller median concentrations of dissolved solids, calcium, sodium, and chloride than do samples from the other two land-use areas.

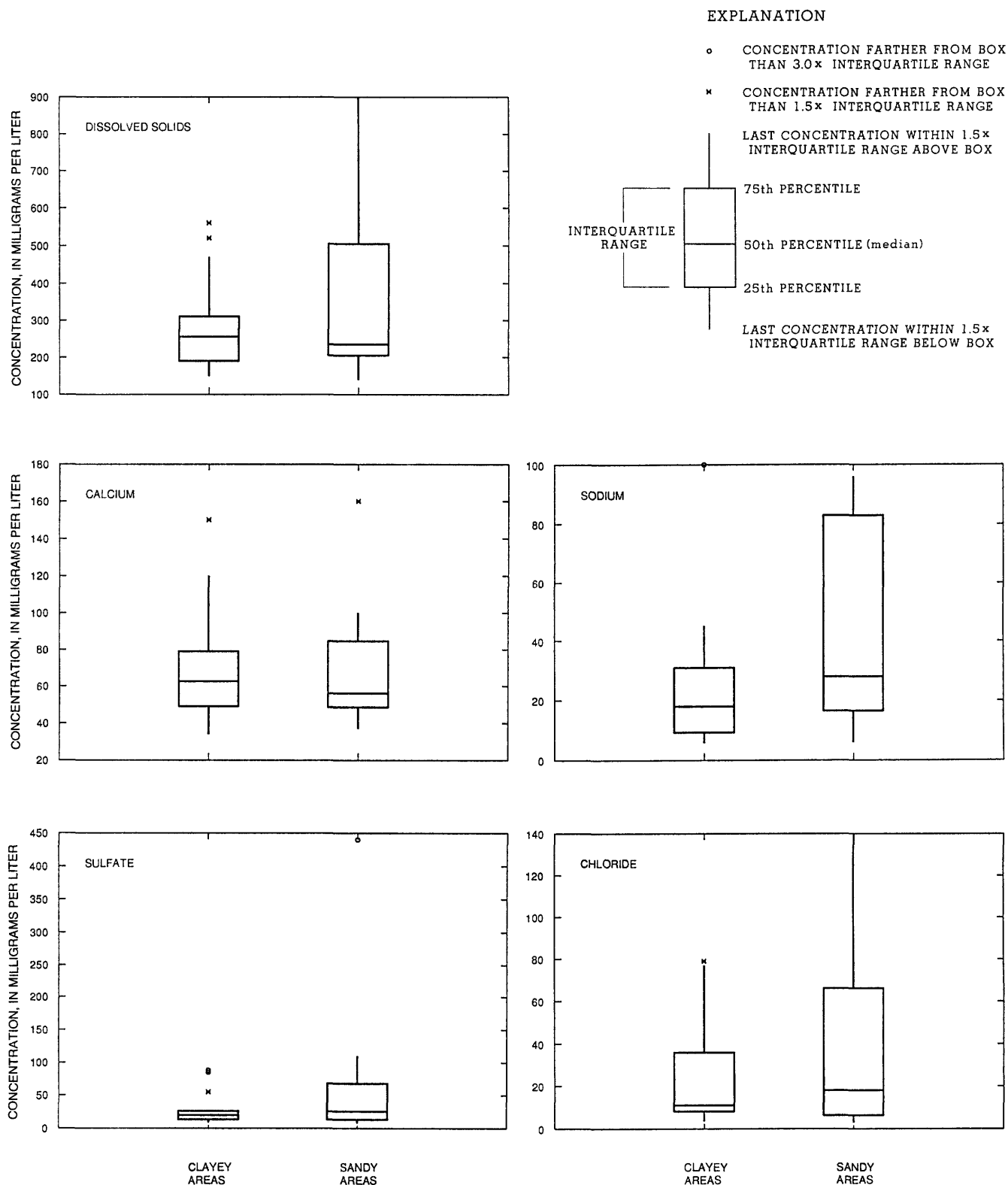
The rank-sum test was used to compare each pair of the three land-use areas in terms of median values for properties (pH, water temperature, hardness, and alkalinity) and inorganic-constituent concentrations. The results are illustrated by plotting test confidence levels that exceed 80 percent (fig. 10). For several properties and constituents, these confidence levels exceed 95 percent, a commonly cited level that is used in this report to define statistically "significant" differences between groups. At that confidence level, concentrations of hardness, alkalinity, calcium, magnesium, potassium, fluoride, and nitrite plus nitrate are significantly larger beneath areas of irrigated cropland than beneath areas of rangeland. Iron concentrations are significantly larger beneath rangeland than beneath irrigated cropland. Values of pH, and concentrations of hardness, alkalinity, dissolved solids,

sodium, and chloride are significantly larger beneath petroleum-production land than beneath rangeland. Concentrations of nitrite plus nitrate are larger beneath irrigated cropland than beneath petroleum-production land. Concentrations of iron are significantly larger beneath petroleum-production land than beneath irrigated cropland.

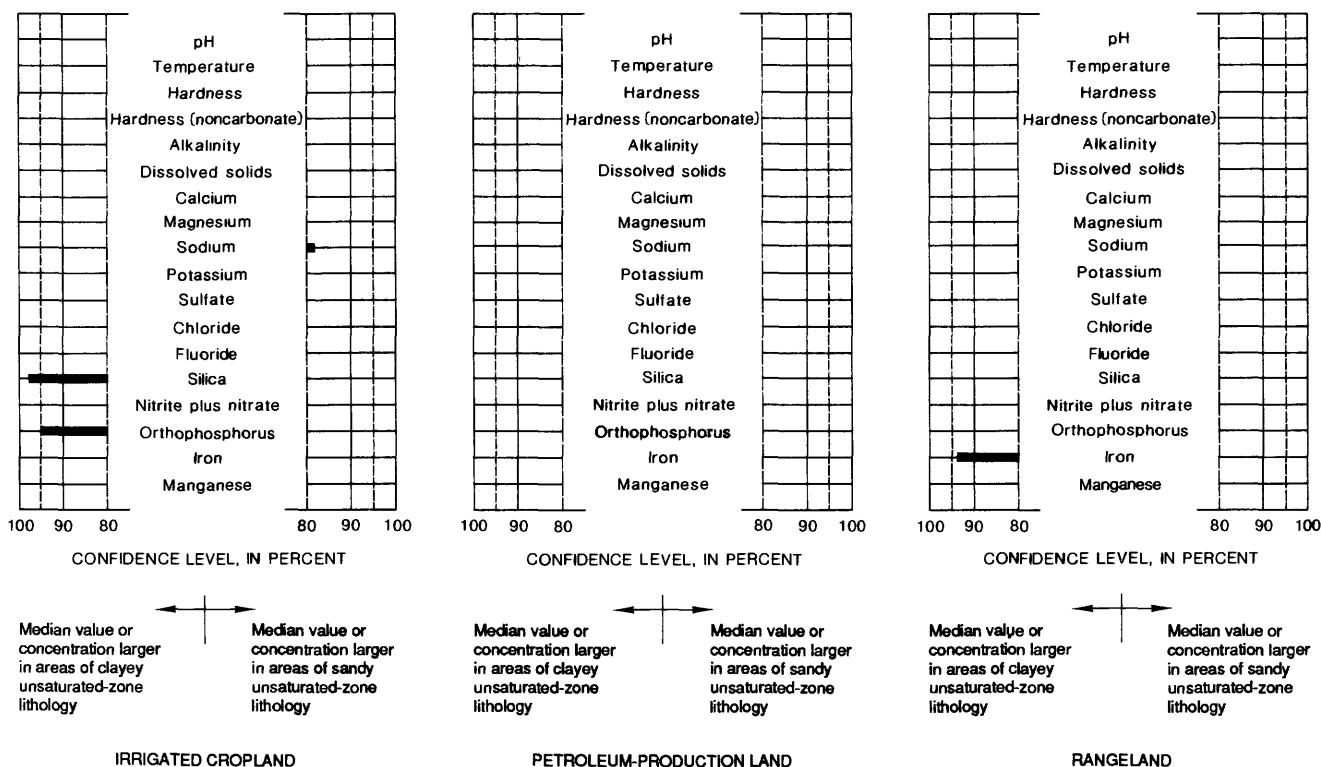
### Comparisons by Unsaturated-Zone Lithology

Comparisons of samples grouped on the basis of clayey or sandy unsaturated-zone lithology were made for each land-use area. Box plots of concentrations of major inorganic constituents in clayey and sandy areas generally show similarities within any given land-use area. An example set of box plots is shown for irrigated-cropland data in figure 11.

The rank-sum test was used to test individual water-quality characteristics between clayey and sandy unsaturated-zone areas. Results indicated few statistically significant differences (fig. 12), none of which involved major constituents. In irrigated cropland, concentrations of silica and orthophosphorus were significantly larger in clayey areas than in sandy areas. In petroleum-production land, no significant



**Figure 11.** Concentrations of dissolved solids and selected major ions in water samples from small-yield wells in areas of irrigated cropland, grouped according to unsaturated-zone lithology (based on 18 clayey-area samples and 12 sandy-area samples).



**Figure 12.** Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in areas of clayey and sandy unsaturated-zone lithology, grouped according to land-use areas.

differences were evident between clayey and sandy areas. In rangeland, iron concentrations were larger in clayey areas than in sandy areas at the 94-percent confidence level.

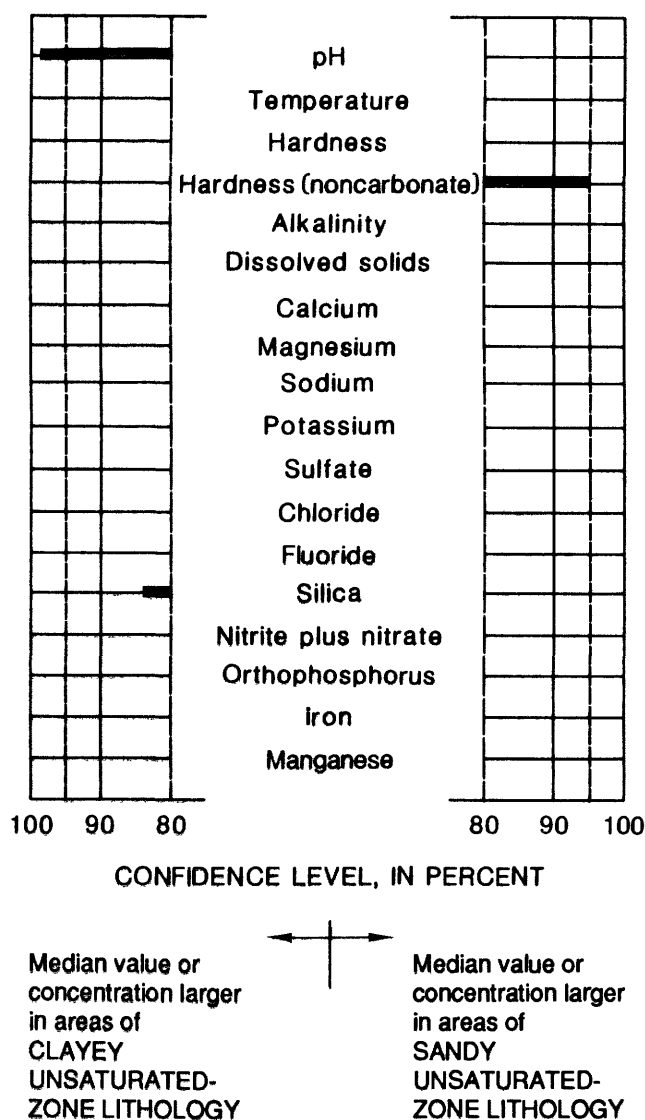
Testing of the data representing only irrigation wells in irrigated cropland (fig. 13) revealed two significant differences: (1) pH was greater in samples from areas of clayey unsaturated-zone lithology, and (2) noncarbonate hardness was greater in samples from areas of sandy unsaturated-zone lithology.

The lithology factor also was assessed by repeating comparisons between land-use areas, but this time according to subdivisions of unsaturated-zone lithology. In comparing irrigated-cropland samples with rangeland samples, it was previously noted that concentrations of several major constituents were significantly larger in the irrigated-cropland samples (fig. 10). Rank-sum tests applied only to the data from areas of clayey unsaturated-zone lithology indicated significant differences only for concentrations of nitrite plus nitrate (larger in irrigated cropland) and iron (larger in rangeland) (fig. 14A). Previous trends were repeated, however, when tests were applied to the data from areas of sandy unsaturated-zone lithology.

The same procedure was applied to the other two land-use comparisons. As with the comparisons of irrigated cropland with rangeland, most significant differences in the comparisons of petroleum-production land with rangeland were in areas of sandy unsaturated-zone lithology (fig. 14B). However, the contrast between areas of clayey and sandy unsaturated-zone lithology was not evident in the comparisons of irrigated cropland with petroleum-production land (fig. 15). The undifferentiated comparisons of these two land-use areas (fig. 10) indicated significantly larger concentrations of nitrite plus nitrate in irrigated cropland and significantly larger concentrations of iron in petroleum-production land.

### Comparisons by Type of Well Sampled

Testing for differences in inorganic ground-water quality according to type of well sampled was limited to the areas of irrigated cropland. Box plots of concentrations of major constituents show no obvious contrasts between data from small-yield wells and data from irrigation wells (fig. 16). The rank-sum test, however, indicated two significant



**Figure 13.** Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from irrigation wells in areas of clayey and sandy unsaturated-zone lithology.

differences: temperature and concentrations of orthophosphorous are significantly larger in the samples from small-yield wells (fig. 17).

## Pesticides

All samples except those from petroleum-production areas were analyzed for triazine and other nitrogen-containing herbicides, and chlorophenoxy-acid herbicides. Of the 82 samples analyzed, 12 contained at least 1 detectable pesticide. From the results, which are summarized in table 2, it is apparent that

frequency of pesticide occurrence is related to land use; only one detection is noted for rangeland samples. However, any association between pesticide detection and either unsaturated-zone lithology or type of well sampled is not evident.

The small number of detections made value-based statistical comparisons of pesticides meaningless. Therefore, contingency-table analysis was used for statistical testing. Even when detected, pesticides were present only in trace amounts. Because atrazine is the only pesticide that was detected more than twice (eight detections) and was present in the largest concentrations (up to 3.8 µg/L), the remainder of this section will be limited to an analysis of atrazine occurrence. The areal distribution of detections of atrazine is shown in figure 18.

## Comparisons by Land Use

In accordance with the statistical-comparison framework (fig. 8), only data from small-yield wells (but from both types of unsaturated-zone lithology) were used for land-use comparisons. The contingency-table test was used to compare the frequency of atrazine detection beneath irrigated cropland (4 out of 30 samples) to the frequency of detection beneath rangeland (1 out of 22 samples). The test determined a 71-percent confidence level, demonstrating no significant association between atrazine occurrence and land use.

Comparisons between land-use areas also were made on the basis of unsaturated-zone lithology. No significant difference was indicated between land-use areas with a clayey unsaturated-zone lithology. However, a significant difference was indicated for areas with a sandy unsaturated-zone lithology: atrazine was detected beneath irrigated cropland in 3 out of 12 samples, but was not detected beneath rangeland.

## Comparisons by Unsaturated-Zone Lithology

Contingency-table tests used to make comparisons of the frequency of atrazine detection in areas of irrigated cropland according to unsaturated-zone lithology indicated no significant associations with this factor. Testing of the data from rangeland samples was not appropriate because of an insufficient number of atrazine detections.

**Table 2.** Frequency of detections of pesticides in ground-water samples from irrigated cropland and rangeland, grouped according to unsaturated-zone lithology and type of well sampled.

Land-use area (type of well sampled)	Number of samples	Alachlor	Atrazine	Metolachlor	Propazine	Trifluralin	2,4-D	Other triazine and chlorophenoxy- acid herbicides
All data								
Irrigated cropland:								
Small-yield wells	30	0	4	0	1	1	1	0
Irrigation wells	30	1	3	2	1	1	0	0
Rangeland	22	0	1	0	0	0	0	0
Clayey unsaturated- zone lithology								
Irrigated cropland:								
Small-yield wells	18	0	1	0	1	0	1	0
Irrigation wells	18	0	2	1	1	1	0	0
Rangeland	9	0	1	0	0	0	0	0
Sandy unsaturated- zone lithology								
Irrigated cropland:								
Small-yield wells	12	0	3	0	0	1	0	0
Irrigation wells	12	1	1	1	0	0	0	0
Rangeland	13	0	0	0	0	0	0	0

## Comparisons by Type of Well Sampled

The contingency-table test determined a 69-percent confidence level when comparing atrazine in samples from small-yield wells to samples from irrigation wells using data from irrigated cropland, demonstrating no significant association between atrazine occurrence and type of well sampled. Testing of the data according to clayey or sandy unsaturated-zone lithology likewise indicated no significant association with type of well sampled.

## Hydrocarbons

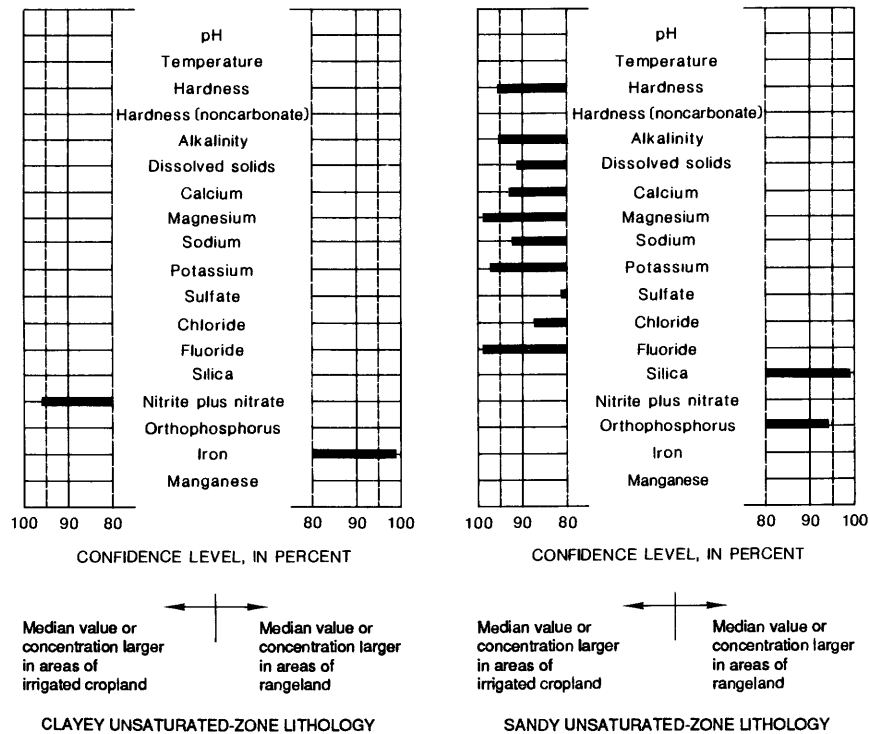
GC/FID scans were made on methylene-chloride extracts of the 22 samples from petroleum-production areas and 23 samples from rangeland (one additional rangeland sample was analyzed by GC/FID, as compared with analyses for inorganic constituents and pesticides). Selected samples were analyzed by GC/MS; however, the very small concentrations

prevented identification of compounds. Therefore, this effort focused mainly on the output from GC/FID chromatograms and associated information from laboratory reports, which were analyzed in several ways to evaluate hydrocarbon occurrence.

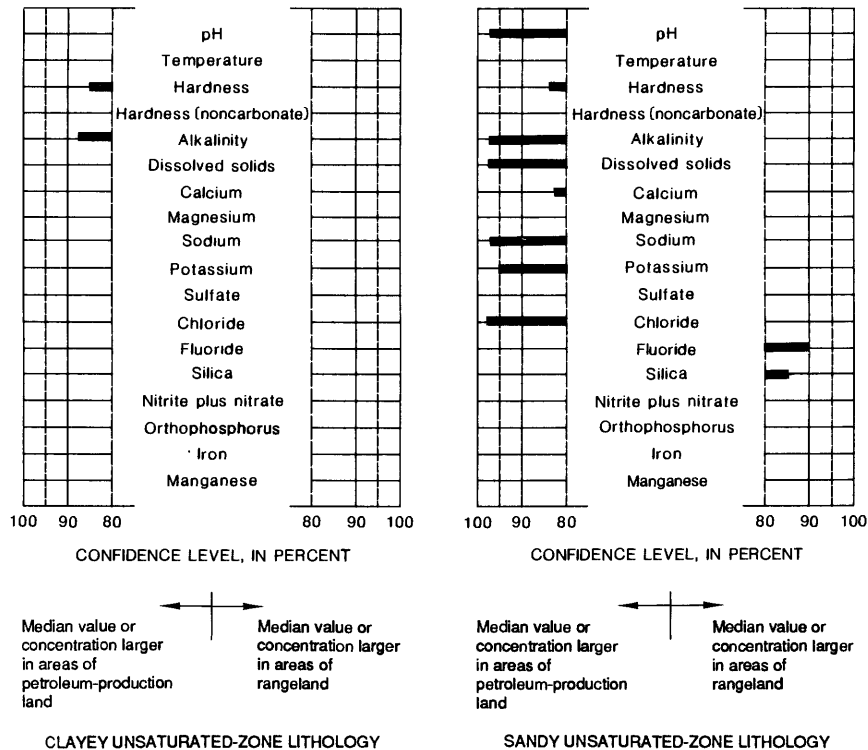
## Chromatogram Interpretation

A chromatogram for one of the samples is shown in figure 19. The horizontal axis represents retention time of elution (heavier compounds, those with greater molecular weight, generally elute later than lighter compounds). Each peak represents an individual compound. The area under a peak (and, for practical purposes, vertical height of the peak) is proportional to the concentration of the compound represented by the peak. This method was used to estimate total concentrations of methylene-chloride-extractable compounds (excluding surrogate and internal-standard compounds added to the sample at the laboratory). These estimates (concentrations as perdeuterionaphthalene) were reported by the laboratory as ranging

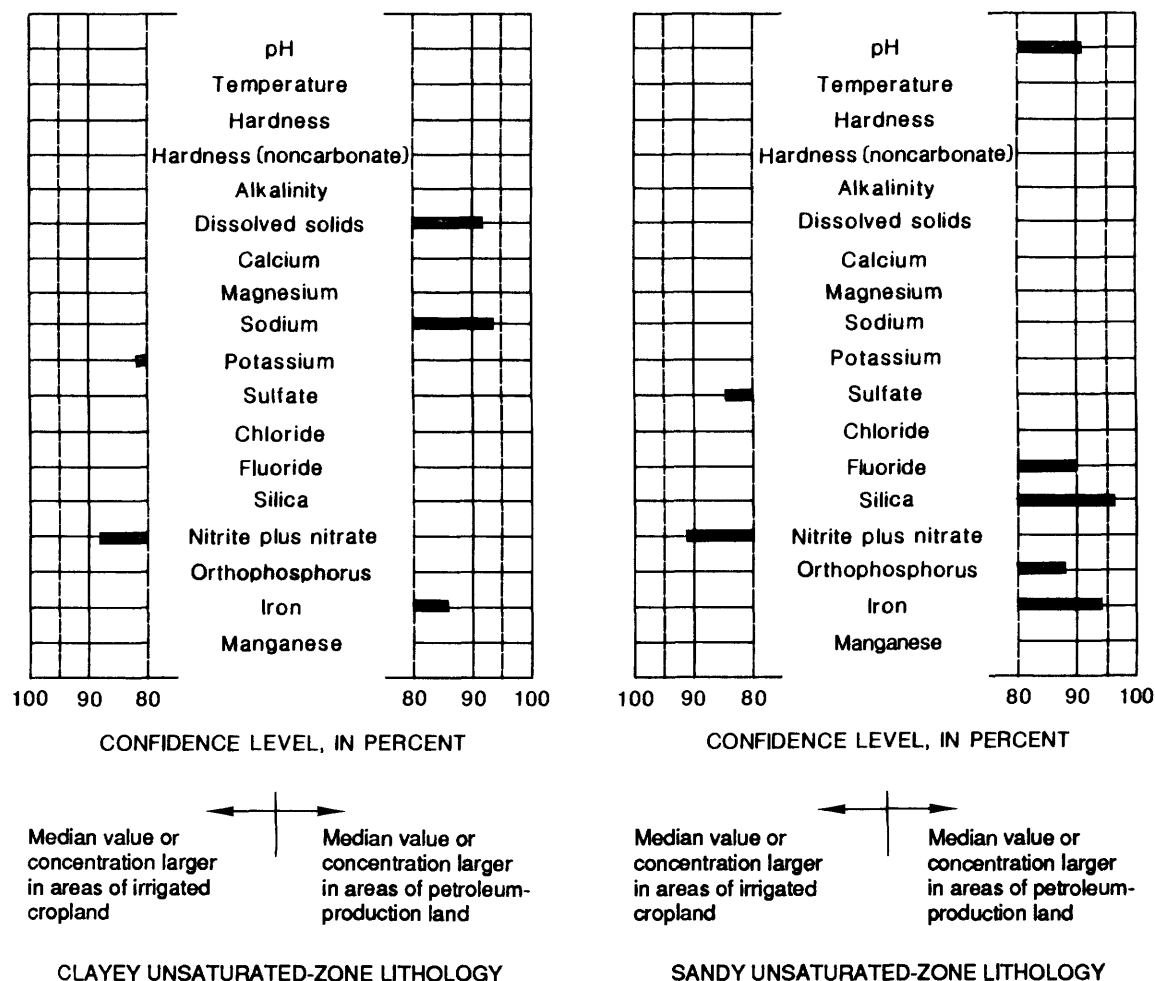
### A. Irrigated cropland and rangeland



### B. Petroleum-production land and rangeland



**Figure 14.** Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in different land-use areas, grouped according to unsaturated-zone lithology.



**Figure 15.** Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in areas of irrigated cropland and petroleum-production land, grouped according to unsaturated-zone lithology.

from 3.3 to 14  $\mu\text{g/L}$  in samples from petroleum-production areas and from 1.2 to 15  $\mu\text{g/L}$  in samples from rangeland.

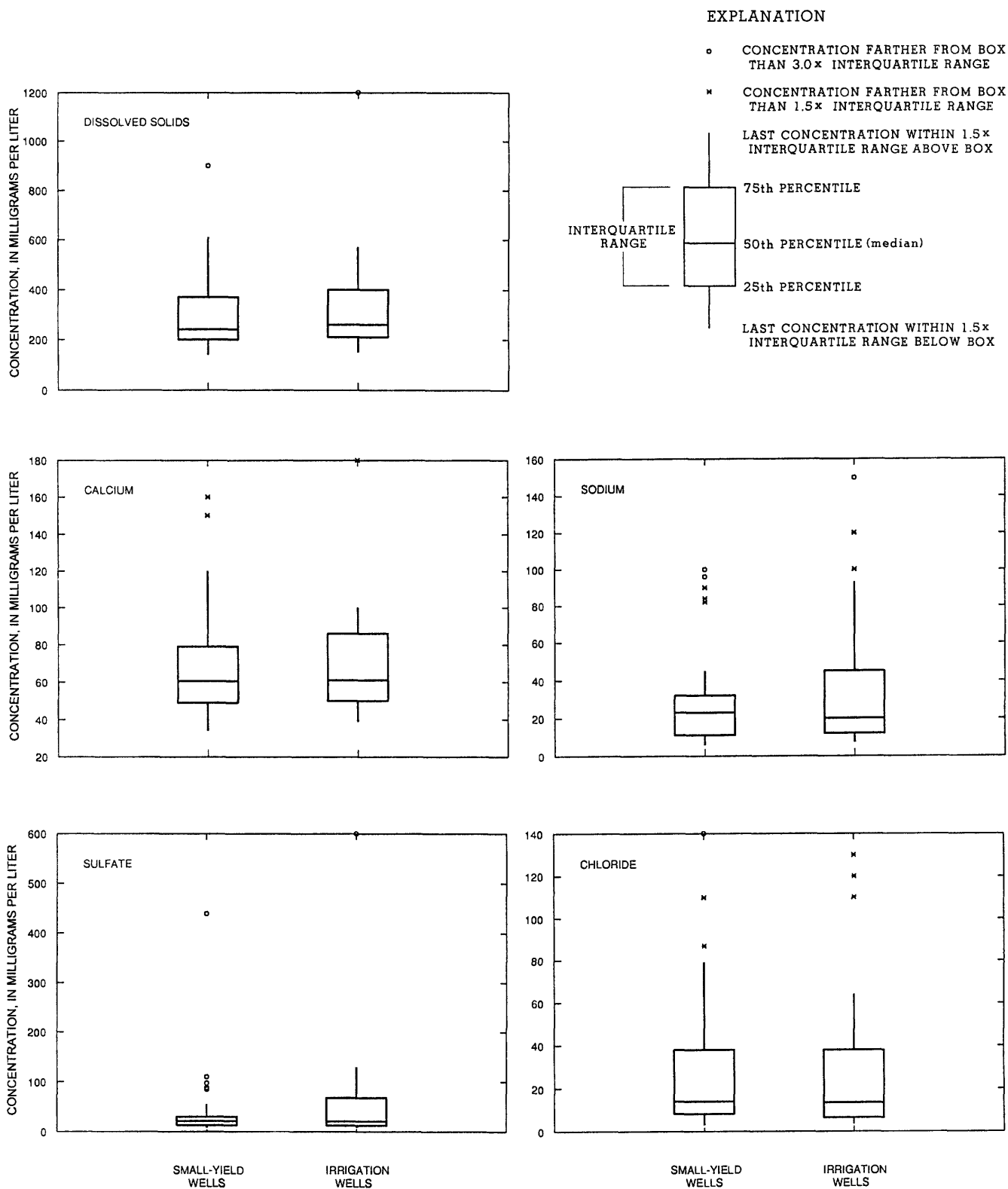
Frequencies of occurrence of individual compounds were determined by assuming that each peak at a particular retention time represented the same compound. Presence of a specific compound in a collected sample was defined by whether its peak height was at least three times the height of corresponding peaks, if they existed, in the chromatograms of laboratory-blank samples (fig. 20).

Data describing relative heights of individual peaks on chromatograms also were compiled and analyzed as being representative of relative concentrations in the water. Peak heights were measured above the baseline of the chromatogram with the use of an arbitrary, but consistent, scale (fig. 21).

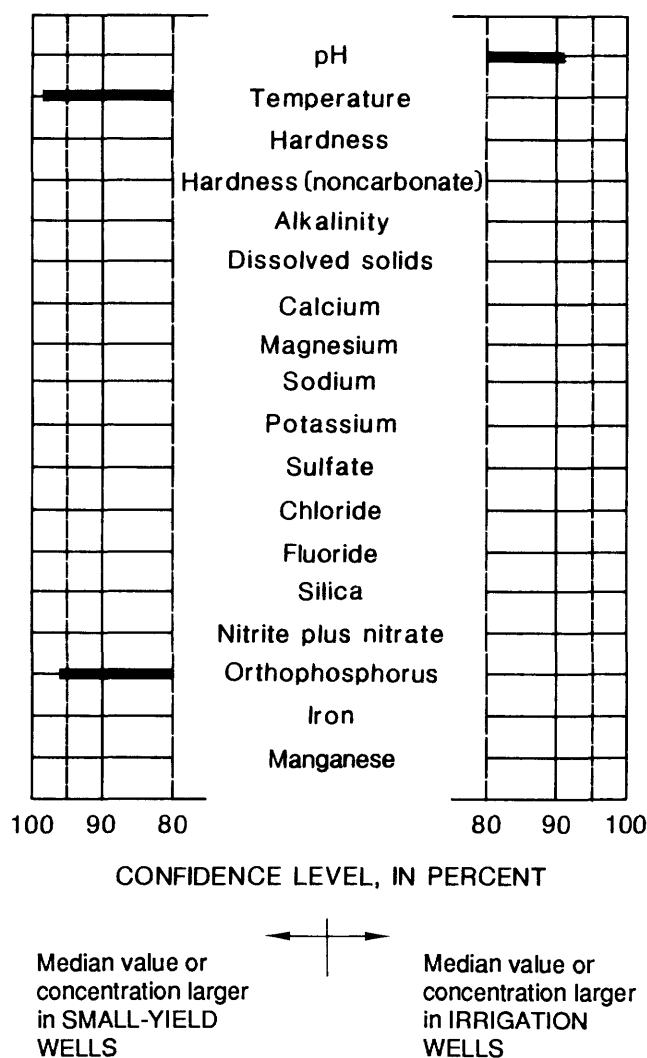
### Comparisons by Land Use

The occurrence of hydrocarbons in relation to land use was evaluated first in terms of total concentrations of organic compounds as estimated based on total areas under the peaks of the chromatograms. Box plots (fig. 22) illustrate very similar distributions between estimated total concentrations of organic compounds in samples from petroleum-production areas and samples from rangeland, although median and quartile concentrations are larger in the samples from petroleum-production areas. The distributions were nonnormal and positively skewed. The rank-sum test for equality was rejected at the 84-percent confidence level.

Comparisons of the frequency of occurrence of specific compounds (fig. 23) revealed only minor



**Figure 16.** Concentrations of dissolved solids and selected major ions in water samples from areas of irrigated cropland, grouped according to type of well sampled (based on 30 small-yield well samples and 30 irrigation-well samples).



**Figure 17.** Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells and irrigation wells in areas of irrigated cropland.

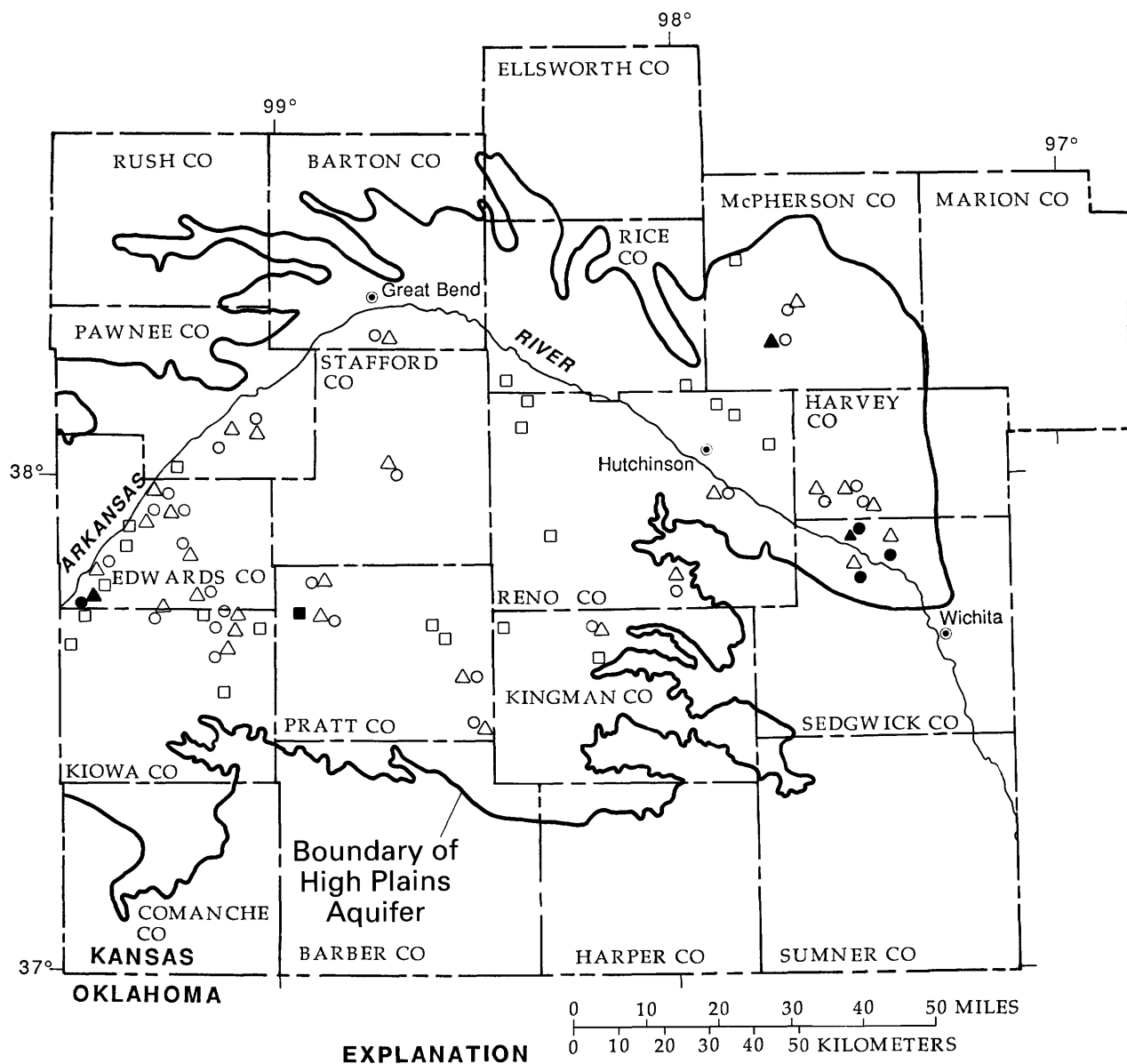
differences. The samples from petroleum-production areas showed a slightly smaller range of retention times and perhaps more of a tendency toward the presence of lighter compounds (smaller retention times) than the samples from rangeland. Contingency-table analyses indicated that two specific compounds with retention times of 13.79 and 16.68 minutes significantly occurred more frequently in samples from petroleum-production areas than in those from rangeland. At the 92-percent confidence level, the compounds with retention times of 19.23, 21.83, and 30.93 occurred more frequently in samples from rangeland than from petroleum-production areas.

Relative peak heights for specific compounds also provided a means of comparison between land-use areas through the use of the rank-sum test. Although a large number of nondetections of most compounds limits the strength of the tests, a significant difference in peak height was indicated for one compound. This compound, with a retention time of 16.68 minutes, had higher peak heights (larger concentrations) in samples from petroleum-production areas than in samples from rangeland. This compound is one of the two compounds detected with a significantly greater frequency in petroleum-production areas according to the contingency-table analysis just described.

### Comparisons by Unsaturated-Zone Lithology

Possible associations between hydrocarbon occurrence and unsaturated-zone lithology were considered by dividing data previously compared only by land use. Total organic-compound concentrations were compared using the rank-sum test between areas of clayey and sandy unsaturated-zone lithology. Differences were not significant within areas of either petroleum-production land or rangeland. When the land-use comparison was repeated as separate tests for areas of clayey and sandy unsaturated-zone lithology, notably different results were produced. The test for equality was rejected at only the 14-percent confidence level for clayey lithology, but at the 92-percent confidence level for sandy lithology, with the larger concentrations occurring in petroleum-production areas.

The frequency of occurrence of individual peaks was compared by contingency-table testing in cases where the number of occurrences remained sufficient for valid results after dividing the data for each land-use area into unsaturated-zone lithology groups. The testing was possible for five peaks on chromatograms for petroleum-production-land samples and one peak for rangeland samples. A significant association was indicated for one peak for petroleum-production-land samples; the compound with an 11.60-minute retention time occurred more frequently in clayey unsaturated-zone lithology. When data were divided into unsaturated-zone lithology groups and then compared by land use, a significant association was indicated for one compound; in the sandy unsaturated-zone lithology, the compound with



**Figure 18.** Locations of wells from which water samples were tested for atrazine. Solid symbols indicate samples with detectable concentrations of atrazine (greater than 0.10 µg/L).

a 16.68-minute retention time occurred more frequently in petroleum-production areas.

Rank-sum-test comparisons of individual peak heights were done according to unsaturated-zone

lithology, but large numbers of nondetections again weakened the tests. Results indicated no significant differences within a given land-use category. However, land-use comparison tests again were repeated

**Table 3.** Summary of statistical comparisons of median property values and inorganic-constituent concentrations in ground-water samples, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled.

[I, irrigated cropland; P, petroleum-production land; R, rangeland; C, clayey unsaturated-zone lithology; S, sandy unsaturated-zone lithology; SW, small-yield wells; IW, irrigation wells; (--), median values or concentrations not significantly different at the 95-percent confidence level]

Sample group for which property value or constituent concentration is significantly greater at the 95-percent confidence level

Property or constituent	Comparison by land use only <sup>1</sup>			Comparison by unsaturated-zone lithology only				Comparison by land use and unsaturated-zone lithology <sup>2</sup>						Comparison by type of well sampled only <sup>3</sup>
				SW			IW							
				I	P	R	I	C			S			
	I and R	P and R	I and P	C and S	C and S	C and S	C and S	I and R	P and R	I and P	I and R	P and R	I and P	SW and IW
pH	--	P	--	--	--	--	C	--	--	--	--	P	--	--
Temperature	--	--	--	--	--	--	--	--	--	--	--	--	--	SW
Hardness	I	P	--	--	--	--	--	--	--	--	I	--	--	--
Hardness (noncarbonate)	--	--	--	--	--	--	S	--	--	--	--	--	--	--
Alkalinity	I	P	--	--	--	--	--	--	--	--	I	P	--	--
Dissolved solids	--	P	--	--	--	--	--	--	--	--	--	P	--	--
Calcium	I	--	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium	I	--	--	--	--	--	--	--	--	--	I	--	--	--
Sodium	--	P	--	--	--	--	--	--	--	--	--	P	--	--
Potassium	I	--	--	--	--	--	--	--	--	--	I	--	--	--
Sulfate	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chloride	--	P	--	--	--	--	--	--	--	--	--	P	--	--
Fluoride	I	--	--	--	--	--	--	--	--	--	I	--	--	--
Silica	--	--	--	C	--	--	--	--	--	--	R	--	P	--
Nitrite plus nitrate	I	--	I	--	--	--	--	I	--	--	--	--	--	--
Orthophosphorus	--	--	--	C	--	--	--	--	--	--	--	--	--	SW
Iron	R	--	P	--	--	--	--	R	--	--	--	--	--	--
Manganese	--	--	--	--	--	--	--	--	--	--	--	--	--	--

<sup>1</sup> Small-yield wells; clayey and sandy unsaturated-zone lithology.

<sup>2</sup> Small-yield wells.

<sup>3</sup> Irrigated cropland; clayey and sandy unsaturated-zone lithology.

**Table 4.** Summary of statistical comparisons of atrazine detections in ground-water samples, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled.  
[Leaders (--), frequencies of detection not significantly different at the 95-percent confidence level]

Comparison basis	Sample group for which atrazine was detected with significantly <u>greater</u> frequency at the 95-percent confidence level
By land use only (Irrigated cropland and rangeland; small-yield wells; clayey and sandy unsaturated-zone lithology)	--
By unsaturated-zone lithology only (Clayey and sandy lithology; small-yield wells; areas of irrigated cropland) <sup>1</sup>	--
By unsaturated-zone lithology only (Clayey and sandy lithology; irrigation wells; areas of irrigated cropland)	--
By land use and unsaturated-zone lithology (Irrigated cropland and rangeland; clayey unsaturated-zone lithology)	--
By land use and unsaturated-zone lithology (Irrigated cropland and rangeland; sandy unsaturated-zone lithology)	Irrigated cropland
By type of well sampled only (Small-yield wells and irrigation wells; areas of irrigated cropland; clayey and sandy unsaturated-zone lithology)	--

<sup>1</sup> Statistical test for areas of rangeland not possible because of insufficient number of atrazine detections.

as separate tests for clayey and sandy unsaturated-zone lithology. Results for the compound with a 17.89-minute retention time showed only a 24-percent confidence level for rejection of equality in clayey lithology, but a 94-percent confidence level in sandy lithology, with larger concentrations in petroleum-production areas.

## DISCUSSION OF RESULTS

Evaluation of the water-quality data and statistical comparisons allowed some inferences to be made with regard to the effects of prevailing land use on ground-water quality, the extent or scale of the effects, and the importance of unsaturated-zone lithology and type of well sampled as related to the occurrence of contaminants. Summaries of statistical comparisons for inorganic constituents, atrazine, and hydrocarbons are presented in tables 3–5, and results are discussed below according to land-use category. Selected results

also have been presented by Helgesen and Thurman (1988) and Helgesen and Rutledge (1989).

### Irrigated Cropland

The quality of ground water beneath areas of irrigated cropland showed discernable effects of this land use. Relative to rangeland, larger concentrations of hardness, alkalinity, calcium, magnesium, potassium, fluoride, and nitrite plus nitrate (table 3) reflect the movement of greater quantities of solutes downward from the land surface to the saturated zone. Infiltration and percolation are expected to be greater on tilled land than on natural rangeland. Natural precipitation is supplemented by irrigation, which uses more mineralized water pumped from the High Plains aquifer. Evapotranspiration at the land surface and in the root zone further concentrates solutes in the water that leaches through the soil.

Larger concentrations of nitrite plus nitrate beneath irrigated cropland than beneath the other land uses

**Table 5.** Summary of statistical comparisons of hydrocarbon-compound detections and relative concentrations in ground-water samples, grouped according to land-use areas and unsaturated-zone lithology.

[Leaders (--), frequency of detection not significantly different at the 95-percent confidence level]

Sample group for which hydrocarbon-compound detection frequency <sup>1</sup> or concentration <sup>2</sup> is significantly <u>greater</u> at the 95-percent confidence level					
Comparison	Comparison by land use only (petroleum-production land and rangeland)	Comparison by unsaturated-zone lithology only (clayey and sandy lithology)		Comparison by land use (petroleum-production land and rangeland) and unsaturated-zone lithology	
		Petroleum-production land	Rangeland	Clayey lithology	Sandy lithology
Total organic-compound concentration <sup>2</sup>	--	--	--	--	--
Frequency of detection of specific compounds <sup>1</sup>	Petroleum-production land (2 compounds)	Clayey lithology (1 compound)	--	--	Petroleum-production land (1 compound)
Relative concentrations of specific compounds <sup>2</sup>	Petroleum-production land (1 compound)	--	--	--	--

<sup>1</sup> Based on contingency-table testing.

<sup>2</sup> Based on rank-sum testing.

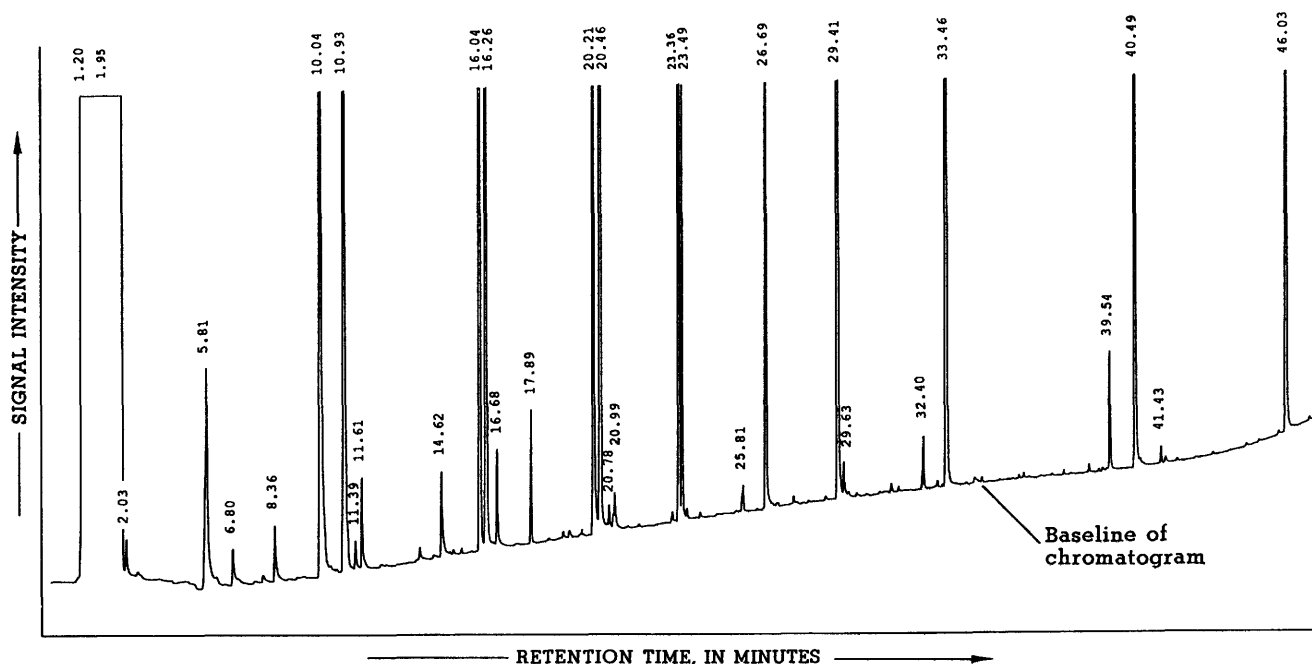
(table 3) probably result from the use of fertilizers. Relatively large fluoride concentrations might reflect the association of that constituent with a common phosphate-mineral component of fertilizer.

Pesticides, although commonly applied, were not detected frequently in ground water beneath irrigated cropland. The pesticides that were detected, especially atrazine, are relatively soluble and persistent. Although atrazine, when found, was nearly always beneath areas of irrigated cropland, differences in occurrence between land-use areas were not statistically significant except when data from areas of sandy unsaturated-zone lithology were tested separately (table 4).

Concentrations of most inorganic constituents beneath irrigated cropland showed no significant associations with regionally delineated unsaturated-zone lithology. Concentrations of silica and orthophosphorus were significantly larger in clayey areas as compared to sandy areas; explanations for those differences are not evident. Although no other differences

can be related uniquely to unsaturated-zone lithology, some significant differences between irrigated cropland and rangeland are indicated if only the samples from sandy unsaturated-zone lithology in each land-use area are compared. These differences exist for hardness, alkalinity, magnesium, potassium, and fluoride and also for atrazine.

Conclusions regarding the effects of unsaturated-zone lithology thus appear to depend on whether the lithology groups within irrigated cropland are being compared or irrigated cropland is being compared with rangeland using only sandy lithology. Reasons for these mixed results are unclear but could relate to the smaller sample size for the single land-use test and to the arbitrary nature of defining regional areas of clayey and sandy unsaturated-zone lithology. These considerations also may be factors relevant to nitrite-plus-nitrate and iron results from the clayey unsaturated-zone lithology. Nitrite-plus-nitrate concentrations were significantly larger beneath irrigated cropland than beneath rangeland based on data from



**Figure 19.** Example of a chromatogram produced from analysis of a ground-water sample by gas chromatography with flame-ionization detection (GC/FID). Numbers are elution times for individual compounds.

clayey lithology but not sandy lithology. Iron concentrations were significantly larger beneath rangeland based on data from clayey lithology.

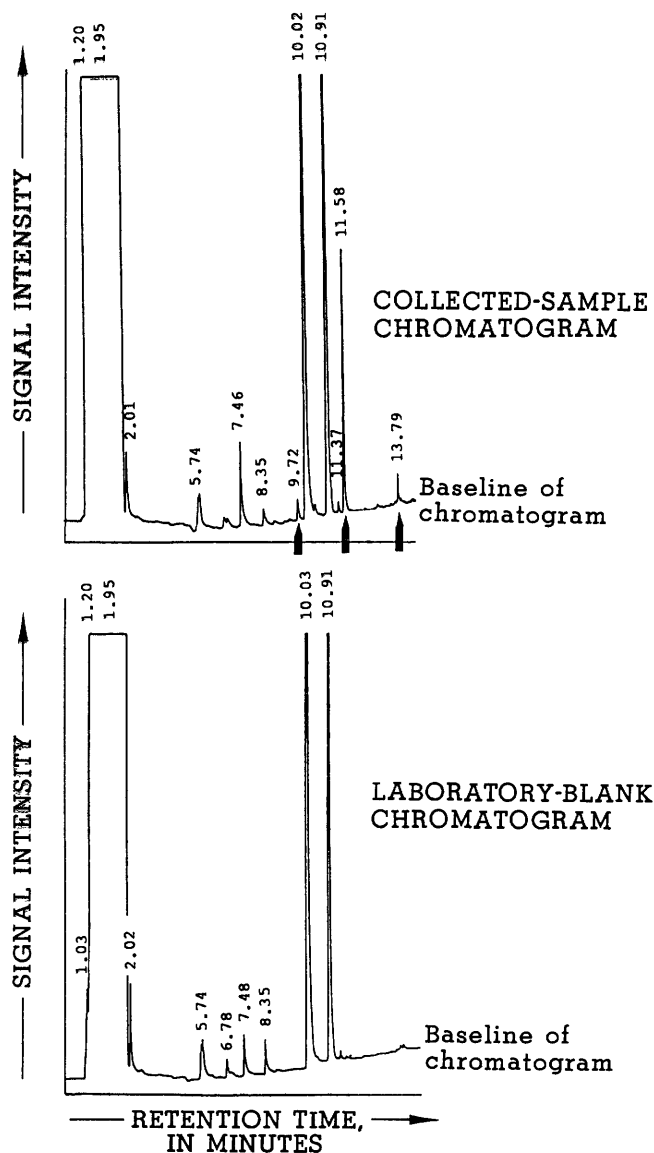
Despite its small-scale heterogeneity, lithology of the unsaturated zone is a factor to consider when assessing contamination. Easier downward movement of water and solutes is favored in areas of sandy unsaturated-zone lithology; the sandier material probably also makes atrazine less susceptible to sorption.

Processes of degradation and sorption probably are important in preventing most pesticides from reaching the saturated zone. At the time of the 1987 sampling, procedures were not available for analyzing degradation products of atrazine. Recently, degradation products of atrazine produced by bacterial action have been identified in samples from sites within this study area and elsewhere in Kansas (E.M. Thurman, U.S. Geological Survey, written commun., 1989) and in Nebraska (A.D. Druliner, U.S. Geological Survey, written commun., 1989). Sorption apparently is an important factor affecting the distribution of pesticides in soil profiles within this study area (Rutledge and Helgesen, 1990) and near Topeka, Kansas (Perry, 1991). Large atrazine concentrations in soils tend to be associated with horizons particularly rich in organic materials. Huang and others (1984) report

that even nonorganic and nonclay fractions of a soil may be significant in atrazine adsorption.

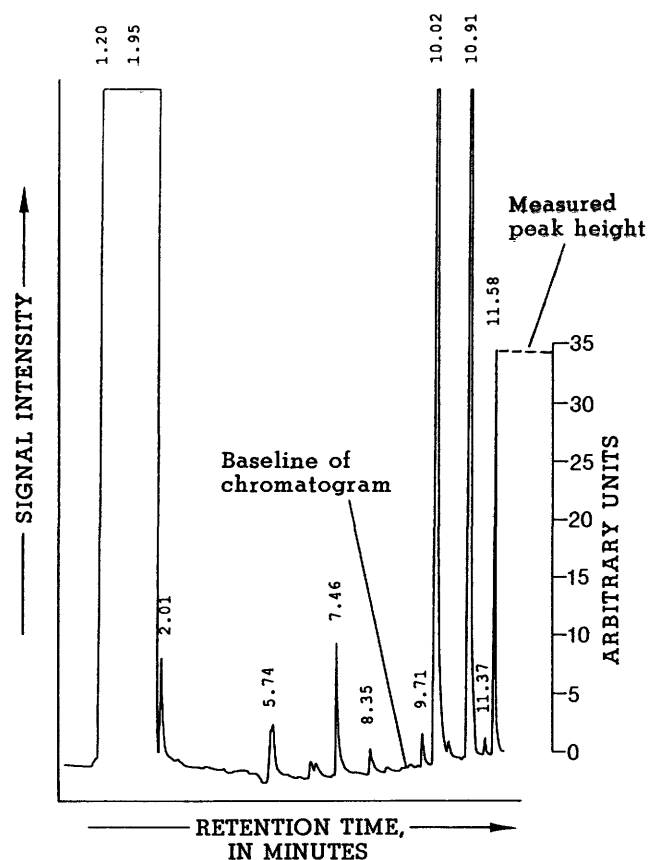
Application of a simple mathematical model (Rutledge and Helgesen, 1989) demonstrates the importance of degradation and sorption on the transport and fate of pesticides in the unsaturated zone. The model calculates pesticide residence time and also the fraction of pesticide remaining in solution as a function of depth. Results of simulations using data representative of the study area indicate that several years are required for movement of relatively mobile pesticides such as atrazine and 2,4-D through the unsaturated zone, and that the fractions remaining in solution at 20 or 30 ft below the surface (typical depths to the water table in the study area) are very small. These results are consistent with the observed infrequency of detection of nondegraded pesticides in the ground water of the study area.

Concentrations of inorganic constituents and atrazine were similar between ground water beneath irrigated fields (collected from large-yield irrigation wells) and ground water away from the fields but still within areas defined as irrigated cropland (collected from small-yield domestic or stock wells). This similarity indicates a predominance of regional flow over the process of recirculation of water (and



**Figure 20.** Chromatograms for a collected ground-water sample and a laboratory blank that were compared to identify peaks representing organic compounds present in the sample. The three black markers in the top chromatogram indicate compounds found in the ground-water sample. Numbers are elution times for individual compounds.

solutes) within cones of depression beneath irrigated fields. Seasonal development of individual cones of depression generally do not maintain enough of a continuous diversion of water away from the regional flow pattern to establish isolated areas of anomalous water quality around irrigation wells. Regionally, although lateral solute transport is slow enough to allow identification of some associations between water quality and prevailing land use in discrete areas of several square miles, it apparently is



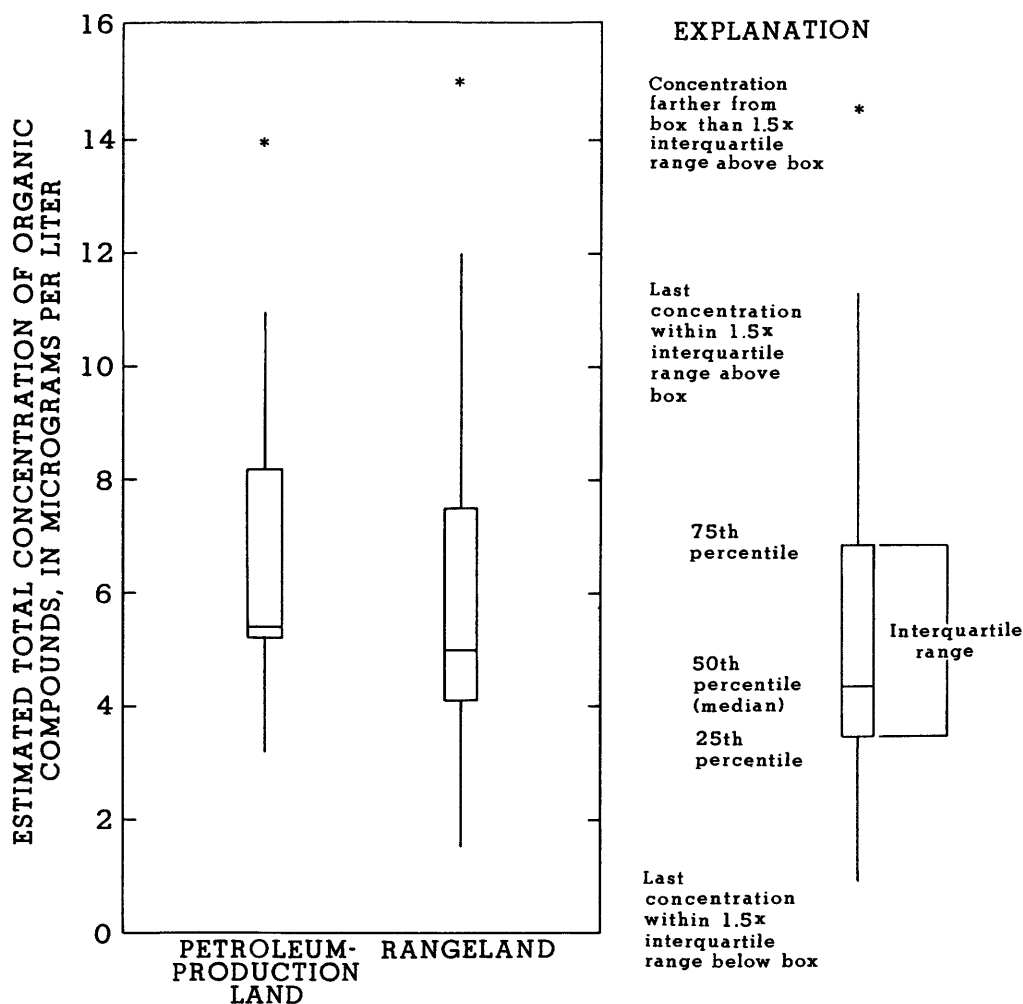
**Figure 21.** Measuring peak height to determine relative concentration of an organic compound in a ground-water sample. Numbers are elution times for individual compounds.

sufficiently rapid so that water quality within these areas is relatively homogeneous.

Water temperatures and orthophosphorus concentrations both were significantly larger in samples from small-yield wells than from irrigation wells (table 3). The higher water temperatures probably were related to the collection point; samples commonly were collected from taps within farmstead pipe systems where some warming occurred. The orthophosphorus concentrations might be attributable to animal wastes associated with the farmsteads. Lack of a significant difference between concentrations of nitrite plus nitrate in samples from small-yield and irrigation wells might reflect parallel increases due to animal wastes at the farmsteads and fertilizers in the fields.

### Petroleum-Production Land

In petroleum-production areas containing aggregations of former brine-disposal ponds, the quality of



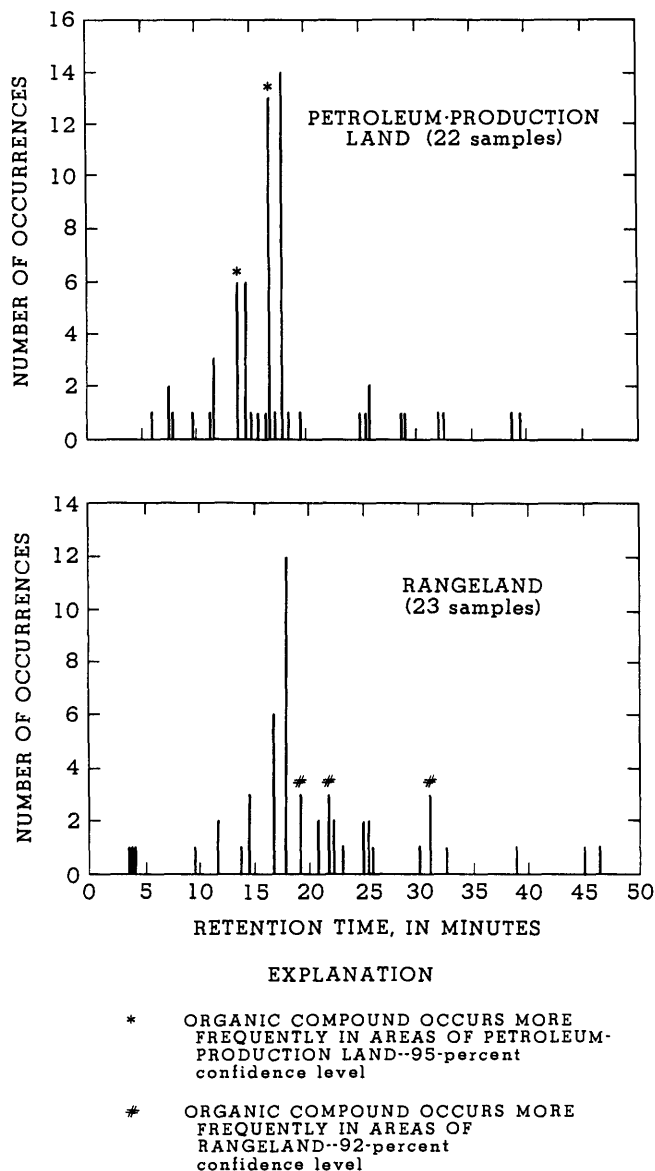
**Figure 22.** Estimated total concentrations of organic compounds in ground-water samples from small-yield wells in petroleum-production areas and rangeland (based on 22 petroleum-production-land samples and 23 rangeland samples).

underlying ground water generally appears to be affected only by inorganic constituents. The pH level, and concentrations of hardness, alkalinity, dissolved solids, sodium, and chloride significantly exceeded concentrations representative of ground water beneath rangeland (table 3). These differences probably reflect the percolation of brines from leaky disposal ponds downward to the aquifer. As generally was the case with irrigated cropland, significant ground-water-quality characteristics associated with petroleum-production land are recognizable in sandy unsaturated-zone lithology but not in clayey unsaturated-zone lithology.

Comparison of ground-water quality beneath petroleum-production land with that beneath irrigated cropland indicates few statistically significant differences at the 95-percent confidence level. However,

larger concentrations (at a greater than 85-percent confidence level) of dissolved solids, sodium, and chloride beneath petroleum-production land (fig. 10) might indicate that brine wastes have a greater effect than irrigated-crop production on inorganic ground-water quality.

Organic compounds detected by GC/FID scans generally are present in ground water beneath petroleum-production land at trace concentrations comparable to those beneath undeveloped rangeland, with total concentrations as large as 15 µg/L (fig. 22). The characteristics of occurrence of organic compounds associated with these two land-use categories are not very different in terms of total concentration, frequency of occurrence of most specific compounds, or relative concentration of most specific compounds (table 5). The few significant differences related to



**Figure 23.** Frequencies of occurrence of individual organic compounds in petroleum-production areas and rangeland, based on gas-chromatograph retention time.

specific organic compounds indicate more frequent detection of relatively lighter weight compounds in petroleum-production areas.

Hydrocarbons have not been introduced into the ground-water system in any way that constitutes identifiable nonpoint-source contamination. Either negligible amounts of oil-derived hydrocarbons are associated with the formerly disposed brines or, more likely, these compounds are attenuated by sorption and microbial digestion in the unsaturated and saturated zones.

## Rangeland

Ground-water quality beneath most rangeland areas of sufficiently large extent (several square miles) probably approaches baseline (or predevelopment) conditions for the study area. However, large contiguous areas of rangeland, or any other land use, are rare; land use in much of this region is quite intermixed, so that the presence of true baseline conditions might be rare.

Concentrations of dissolved solids and some major inorganic constituents were significantly smaller beneath areas of rangeland than beneath areas of irrigated cropland or petroleum-production land. No major-ion concentrations were significantly larger beneath rangeland than beneath other land-use areas. Increased concentrations of dissolved solids or major inorganic constituents that occurred at particular locations beneath rangeland probably can be attributed to lateral flow into the area from nearby areas of cropland or petroleum-production land.

Although pesticides are applied on some rangeland, there was only one pesticide detection in the July 1987 sampling of water from rangeland wells. That compound was atrazine, and it probably accompanied lateral ground-water flow from a nearby area of cropland, because the sample also contained a relatively large concentration of nitrite plus nitrate, which probably was related to fertilizer application. In the initial reconnaissance of 1984, the herbicide 2,4-D was reported in 23 out of the 27 samples collected from rangeland and irrigated cropland (Stullken and others, 1987). The expanded sampling of 1987 resulted in only 1 detection of 2,4-D (in a sample from irrigated cropland) out of 82 samples, although none of the wells sampled in 1984 were resampled in 1987. This ratio indicates a general absence of 2,4-D in the ground water of the study area, and the 1984 survey results are considered questionable.

Trace concentrations of many organic compounds are present in the ground water beneath rangeland, as inferred from results of the GC/FID scans. Concentrations were too small to allow compound identification, but their general occurrence suggests that they are naturally occurring organic compounds dissolved from the soil or aquifer materials through which the water has moved. Although the primary purpose of the GC/FID scans was to identify possible petroleum-related hydrocarbons, three specific (relatively heavier weight) compounds occurred more frequently

(at the 92-percent confidence level) beneath rangeland than beneath petroleum-production land.

The effect of regionally delineated unsaturated-zone lithology was not evident in ground water beneath rangeland in terms of major inorganic constituents, pesticides, or hydrocarbons. This could be due, at least partly, to the fact that the rangeland is undeveloped and poses relatively minor contamination potential at or near the land surface. In areas of clayey unsaturated-zone lithology, relatively large concentrations of iron were detected in rangeland samples; no explanation for this condition is apparent.

## SUMMARY AND CONCLUSIONS

Nonpoint-source contamination of a 5,000-mi<sup>2</sup> area of the High Plains aquifer in south-central Kansas was assessed as part of the U.S. Geological Survey's Toxic Waste—Ground-Water Contamination Program. Typical of much of the Midwest, the study area is dominated by agricultural land use and also supports petroleum-production activities. Pesticides and petroleum-derived hydrocarbons—organic contaminants that pose potential ground-water contamination problems—were of particular interest to this study. Pesticide application is a common agricultural practice. Hydrocarbons might occur with brines formerly produced with oil and disposed into unlined ponds. The study area contains permeable soils and a generally shallow water table, making ground water particularly susceptible to contamination.

The delineation and understanding of regional nonpoint-source contamination is a complex undertaking. Relating ground-water quality to overlying land use was the basic approach used. Discrete land-use areas (irrigated cropland, petroleum-production land containing former brine-disposal ponds, and undeveloped rangeland) of 3–10 mi<sup>2</sup> were identified. One small-yield well in each area was selected randomly for sampling and analysis on the assumption that the results would characterize ground-water quality associated with that land-use area. In addition to land use, two other factors thought to be potentially important in this regional evaluation were addressed. The effect of unsaturated-zone lithology on ground-water contamination was evaluated by categorizing each land-use area as having either a clayey or sandy unsaturated zone, as interpreted by regionalized mapping. Clay within the unsaturated

zone possibly inhibits downward movement of water and chemicals to the water table. The effect of the type of well sampled was evaluated by also sampling a randomly selected irrigation well in each area of irrigated cropland. This approach allowed testing of the hypothesis that samples from irrigation wells, drawing water from directly beneath fields receiving irrigation water and agricultural chemicals, will indicate water of different quality than that from small-yield wells away from the fields.

The sampling design thus enabled comparisons to be made based upon prevailing land use, unsaturated-zone lithology, and type of well sampled. Although true baseline water-quality conditions probably are rare in the study area, these conditions might be represented most closely by ground water beneath the areas of undeveloped rangeland, which is a useful “control” against which to compare water quality in the developed areas. All samples collected were analyzed for major inorganic ions and other inorganic constituents commonly of interest. Samples from areas of irrigated cropland and rangeland also were analyzed for triazine and chlorophenoxy-acid herbicides. Samples from areas of petroleum-production land and rangeland were analyzed for hydrocarbons using GC/FID scans.

Most data distributions for chemical properties and constituents in collected samples are nonnormal and positively skewed. Statistical testing thus was based on nonparametric procedures—the two-tailed Wilcoxon-Mann-Whitney rank-sum test and contingency-table analysis. GC/FID scans revealed only trace concentrations of organic compounds that were not identifiable, although comparative analysis was done through chromatogram interpretation.

Results of this study indicate that regional water quality of the High Plains aquifer of south-central Kansas has been affected by prevailing land-use activities. The effects are principally in the form of increased concentrations of inorganic, rather than organic, constituents.

Ground water beneath areas of irrigated cropland is characterized by significantly (95-percent confidence level) larger concentrations of hardness, alkalinity, calcium, magnesium, potassium, fluoride, and nitrite plus nitrate than water beneath undeveloped rangeland. These effects are attributed to relatively large rates of infiltration and percolation through the tilled soil and unsaturated zone, a substantial part of which consists of applied irrigation water that has

been concentrated by evapotranspiration. The water dissolves minerals from the soil and chemicals applied as fertilizer and transports them down to the aquifer. Nondegraded pesticides were detected infrequently in the aquifer. Recent identification of degradation products of atrazine at some sites warrants further study to define their extent. Atrazine itself appears to be present only locally in the ground water beneath areas of irrigated cropland. Concentrations generally are less than a few micrograms per liter. Other pesticides were detected even less frequently.

Ground-water quality beneath petroleum-production land containing older brine-disposal ponds exhibits significantly larger values of pH, hardness, and alkalinity, and larger concentrations of dissolved solids, sodium, and chloride as compared to water beneath undeveloped rangeland. These differences probably reflect the downward percolation of brines from leaky disposal ponds in those areas. Differences between several constituents indicate that former brine-disposal activities might have more of an effect than irrigated-crop production on ground-water quality in the study area, except for the increased concentrations of nitrite plus nitrate demonstrated in the areas of irrigated cropland. Nonpoint-source contamination by petroleum-derived hydrocarbons was not discernible in areas of petroleum-production land. Occurrences of trace organic compounds were similar between areas of petroleum-production land and undeveloped rangeland, which indicates that most or all of these compounds are naturally occurring and probably dissolved from soil or aquifer materials.

Mixed results concerning the effects of unsaturated-zone lithology probably relate to the small sample size when testing within a single land-use area and to the arbitrary nature of defining regional clayey and sandy lithology. The unsaturated zone is lithologically heterogeneous and contains substantial clay that inhibits the downward movement of water and solutes. Water percolating through the unsaturated zone might require from several months to several years to reach the water table. Atrazine in the study area is believed to be concentrated mostly in the soil zone, and degradation and sorption probably account for the infrequent detection of atrazine in the ground water.

Within the aquifer, the rate of lateral regional flow and solute transport is slow enough so that the ground-water quality reflects prevailing overlying land use in discrete areas of several square miles. Regional flow is sufficiently rapid, however, so that

the type of well sampled is not important in regional characterization of the water quality beneath areas of irrigated cropland; the seasonal pumping of irrigation wells does not appear to divert regional flow enough to cause discernible local anomalies of more mineralized ground water.

## REFERENCES CITED

- Bevans, H.E., 1989, Water resources of Sedgwick County, Kansas: U.S. Geological Survey Water-Resources Investigations Report 88-4225, 119 p.
- Burrton Task Force, 1984, Report of the Burrton Task Force to the Chief Engineer-Director of the Kansas State Board of Agriculture, Division of Water Resources, concerning the Proposed Burrton Intensive Ground-Water Use Control Area: Topeka, Kansas Water Agencies, 103 p.
- Chen, H.H., and Druliner, A.D., 1987, Nonpoint-source agricultural chemicals in ground water in Nebraska—Preliminary results for six areas of the High Plains aquifer: U.S. Geological Survey Water-Resources Investigations Report 86-4338, 68 p.
- Cheng, H.H., and Koskinen, W.C., 1986, Processes and factors affecting transport of pesticides to ground water, in Garner, W.Y., Honeycutt, R.C., and Nigg, H.N., eds., Evaluation of pesticides in ground water: Washington, D.C., American Chemical Society, p. 3-13.
- Cobb, P.M., Colarullo, S.J., and Heidari, Manoucher, 1983, A ground-water flow model for the Great Bend aquifer, south-central Kansas: Kansas Geological Survey Open-File Report 83-20, 220 p.
- Druliner, A.D., 1989, Overview of the relations of nonpoint-source agricultural chemical contamination to local hydrogeologic, soil, land-use, and hydrochemical characteristics of the High Plains aquifer of Nebraska, in Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 411-435.
- Fader, S.W., and Stullken, L.E., 1978, Geohydrology of the Great Bend Prairie, south-central Kansas: Kansas Geological Survey Irrigation Series 4, 19 p.
- Feltz, H.R., Lewis, J.A., and Cardinali, F.L., 1986, Application of the gas chromatographic/flame ionization detector analysis, in Ragone, S.E., ed., U.S. Geological Survey Program on Toxic Waste—Ground-Water Contamination; Proceedings of the Second Technical Meeting, Cape Cod, Massachusetts, October 21-25, 1985: U.S. Geological Survey Open-File Report 86-481, p. F11-F15.
- Frye, J.C., and Brazil, J.J., 1943, Ground water in the oil-field areas of Ellis and Russell Counties, Kansas: Kansas Geological Survey Bulletin 50, 104 p.

- Hathaway, L.R., Galle, O.K., Waugh, T.C., and Dickey, H.P., 1978, Chemical quality of irrigation waters in Ford County and the Great Bend Prairie of Kansas: Kansas Geological Survey Chemical Quality Series 7, 41 p.
- Hathaway, L.R., Waugh, T.C., Galle, O.K., and Dickey, H.P., 1981, Chemical quality of irrigation water in the *Equus* beds area, south-central Kansas: Kansas Geological Survey Chemical Quality Series 10, 45 p.
- Helgesen, J.O., and Rutledge, A.T., 1989, Relations between land use and water quality in the High Plains aquifer of south-central Kansas, in Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Phoenix, Arizona, September 26–30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88–4220, p. 437–443.
- Helgesen, J.O., and Thurman, E.M., 1988, Trace organic compounds in ground water in south-central Kansas as inferred from gas chromatography with flame-ionization detection: Washington, D.C., American Chemical Society, Division of Environmental Chemistry, v. 28, no. 2, p. 9–12.
- Helsel, D.R., and Ragone, S.E., 1984, Evaluation of regional ground-water quality in relation to land use—U.S. Geological Survey Toxic Waste—Ground-Water Contamination Program: U.S. Geological Survey Water-Resources Investigations Report 84–4217, 33 p.
- Huang, P.M., Grover, R., and McKercher, R.B., 1984, Components and particle size fractions involved in atrazine adsorption by soils, in Saltzman, Sarina, and Yaron, Bruno, eds., Pesticides in soil: New York, Van Nostrand Reinhold Co., p. 33–37.
- Huntzinger, T.L., and Stullken, L.E., 1988, An experiment in representative ground-water sampling for water-quality analysis: U.S. Geological Survey Water-Resources Investigations Report 88–4178, 12 p.
- Iman, R.L., and Conover, W.J., 1983, A modern approach to statistics: New York, John Wiley and Sons, 497 p.
- Kansas Department of Health and Environment, 1982, Groundwater quality management plan for the State of Kansas: Kansas Department of Health and Environment Bulletin 3–4, 76 p.
- Koelliker, J.K., Steiken, J.M., Yearout, R.D., Heiman, A.T., and Grosh, D.L., 1987, Identification of factors affecting farmstead well water quality: Manhattan, Kansas Water Resources Research Institute Report No. G1226–02, 50 p.
- Leonard, A.R., and Berry, D.W., 1961, Geology and ground-water resources of southern Ellis County and parts of Trego and Rush Counties: Kansas Geological Survey Bulletin 149, 156 p.
- Luckey, R.R., Gutentag, E.D., Heimes, F.J., and Weeks, J.B., 1986, Digital simulation of ground-water flow in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–D, 57 p.
- Nilson, E.B., and Johnson, M.E., 1980, Kansas 1978 pesticide usage: Manhattan, Kansas Crop and Livestock Reporting Service and Kansas State University Cooperative Extension Service, 36 p.
- Perry, C.A., 1990, Source, extent, and degradation of herbicides in a shallow aquifer near Hesston, Kansas: U.S. Geological Survey Water-Resources Investigations Report 90–4019, 24 p.
- 1991, Observed and simulated distribution of selected herbicides in silty loam, sandy loam, and clay soil profiles near Topeka, Kansas, 1986–88: U.S. Geological Survey Water-Resources Investigations Report 91–4017, 61 p.
- Perry, C.A., and Anderson, M.R., 1991, Statistical comparison of selected chemical constituents in water from chemigation and conventional irrigation wells in Kansas, 1987: U.S. Geological Survey Water-Resources Investigations Report 91–4049, 1 sheet.
- Perry, C.A., Robbins, F.V., and Barnes, P.L., 1988, Factors affecting leaching in agricultural areas and an assessment of agricultural chemicals in the ground water of Kansas: U.S. Geological Survey Water-Resources Investigations Report 88–4104, 55 p.
- Power, James, 1982, A plan for protection of Kansas ground-water resources from pollution, in Nielson, D.M., ed., Sixth National Groundwater Quality Symposium: Worthington, Ohio, National Water Well Association, 318 p.
- Rutledge, A.T., and Helgesen, J.O., 1989, Use of a simplified transport model for pesticides in the unsaturated zone, in Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Phoenix, Arizona, September 26–30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88–4220, p. 523–530.
- 1990, Characterization of ground-water flow and chemical transport beneath two irrigated fields in south-central Kansas, 1988: U.S. Geological Survey Water-Resources Investigations Report 90–4065, 37 p.
- Severn, D.J., 1987, Pesticides and the ground water connection, in Pesticides and groundwater—A health concern for the Midwest; Proceedings of Conference, St. Paul, Minnesota, October 16–17, 1986: Navarre, Minnesota, Freshwater Foundation, p. 29–44.
- Skougstad, M.W., Fishman, M.J., Friedman, L.C., Erdmann, D.E., and Duncan, S.S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.
- Sophocleous, M.A., 1983, Water-quality modeling of the *Equus*-beds aquifer in south-central Kansas: Kansas Geological Survey Open-File Report 83–1, 75 p.
- Sophocleous, M.A., and Perry, C.A., 1987, Measuring and computing natural ground-water recharge at sites in south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 87–4097, 48 p.
- Spinazola, J.M., Gillespie, J.B., and Hart, R.J., 1985, Ground-water flow and solute transport in the *Equus*

- beds area, south-central Kansas, 1940–79: U.S. Geological Survey Water-Resources Investigations Report 85–4336, 68 p.
- Spruill, T.B., 1983, Statistical summaries of selected chemical constituents in Kansas ground-water supplies, 1976–81: U.S. Geological Survey Open-File Report 83–263, 29 p.
- Steeple, D.W., and Buchanan, R.C., 1983, Kansas geo-maps: Kansas Geological Survey Educational Series 4, 30 p.
- Stramel, G.J., 1956, Progress report on the ground-water hydrology of the *Equus* beds area, Kansas: Kansas Geological Survey Bulletin 119, part 1, 59 p.
- 1967, Progress report on the ground-water hydrology of the *Equus* beds area, Kansas, 1966: Kansas Geological Survey Bulletin 187, part 2, 25 p.
- Stullken, L.E., and Fader, S.W., 1976, Hydrogeologic data from the Great Bend Prairie, south-central Kansas: Kansas Geological Survey Basic Data Series, Ground-Water Release 5, 50 p.
- Stullken, L.E., Stamer, J.K., and Carr, J.E., 1987, Reconnaissance of water quality in the High Plains aquifer beneath agricultural lands, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 87–4003, 25 p.
- Stullken, L.E., Watts, K.R., and Lindgren, R.J., 1985, Geohydrology of the High Plains aquifer, western Kansas: U.S. Geological Survey Water-Resources Investigations Report 85–4198, 86 p.
- U.S. Geological Survey, 1979a, Land use and land cover, 1974, Great Bend, Kansas: U.S. Geological Survey Map L–21, 1 sheet, scale 1:250,000.
- 1979b, Land use and land cover, 1974, Hutchinson, Kansas: U.S. Geological Survey Map L–23, 1 sheet, scale 1:250,000.
- 1979c, Land use and land cover, 1974, Pratt, Kansas: U.S. Geological Survey Map L–28, 1 sheet, scale 1:250,000.
- 1979d, Land use and land cover, 1974, Wichita, Kansas: U.S. Geological Survey Map L–30, 1 sheet, scale 1:250,000.
- Williams, D.L., and Barker, B.L., 1974, Kansas land-use patterns, summer 1973 (map): Lawrence, Space Technology Laboratories, University of Kansas, 1 sheet, scale 1:1,000,000.
- Williams, C.C., and Lohman, S.W., 1949, Geology and ground-water resources of a part of south-central Kansas, with specific reference to the Wichita municipal water supply: Kansas Geological Survey Bulletin 79, 455 p.

---

---

## TABLE 6

---

---

**Table 6.** Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled.

[Analyses by U.S. Geological Survey. Units of measurement:  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter. (<), less than; (—), no analysis]

Well number (latitude, longitude sequence number)	County	Date of collection (month-day-year)	Specific conductance ( $\mu\text{S}/\text{cm}$ )	pH (standard units)	Temperature, water (deg C)	Hardness, total (mg/L as $\text{CaCO}_3$ )	Hardness, noncarbonate (mg/L as $\text{CaCO}_3$ )	Alkalinity (mg/L as $\text{CaCO}_3$ )	Solids, sum of constituents, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)
Areas of irrigated cropland (small-yield wells)										
CLAYEY LITHOLOGY										
381755098462201	Barton	07-21-87	576	7.2	16.0	220	16	200	331	72
375841099164201	Edwards	07-09-87	357	7.2	16.0	180	25	160	259	60
375531099155302	Edwards	07-14-87	420	7.2	15.0	180	13	170	258	60
375208099152801	Edwards	07-30-87	353	7.2	14.5	150	42	110	228	50
374457099113501	Edwards	07-30-87	370	6.5	15.0	130	38	96	220	46
374409099280701	Edwards	07-27-87	506	6.6	17.0	200	160	40	348	61
375859097332001	Harvey	07-20-87	323	7.0	16.0	110	0	140	208	34
375632097320101	Harvey	07-20-87	848	7.2	16.5	250	0	270	556	79
373819099081301	Kiowa	07-29-87	253	6.9	15.0	120	34	86	192	41
382050097424801	McPherson	07-14-87	951	7.4	16.0	430	130	300	568	150
381734097433801	McPherson	07-14-87	836	7.3	16.0	350	70	280	486	120
380635099043201	Pawnee	07-08-87	475	7.3	15.5	190	0	200	295	64
380414099091601	Pawnee	07-08-87	541	7.2	15.0	210	0	220	333	71
374638098551301	Pratt	07-20-87	285	7.6	15.5	120	17	100	181	42
374311098530901	Pratt	07-22-87	346	7.5	18.0	140	40	97	203	49
373510098313701	Pratt	07-21-87	399	7.5	16.0	180	32	150	237	65
372909098291701	Pratt	07-22-87	534	7.3	15.5	260	35	220	323	92
375817097530701	Reno	07-27-87	591	7.2	16.0	250	1	250	404	87
SANDY LITHOLOGY										
375445099194301	Edwards	07-15-87	335	7.3	17.0	150	23	130	209	49
375026099260101	Edwards	07-23-87	1,410	7.4	15.5	520	340	180	934	160
375718097381101	Harvey	07-20-87	988	7.3	16.0	320	58	270	614	100
374209098123001	Kingman	07-23-87	462	7.5	16.0	170	34	140	290	60
374301099191401	Kiowa	07-22-87	302	7.3	15.0	210	88	130	284	74
374113099094801	Kiowa	07-21-87	314	7.1	15.5	130	21	110	209	47
374330099072101	Kiowa	07-29-87	247	7.1	16.0	110	19	89	159	37
374629098024001	Reno	07-23-87	424	6.9	17.0	150	26	120	264	48
375348097325801	Sedgwick	07-22-87	478	6.9	16.5	160	3	150	277	49
375019097274501	Sedgwick	07-22-87	941	6.4	16.5	230	120	110	535	71
374751097320902	Sedgwick	07-21-87	957	7.1	16.0	320	38	290	558	95
380022098434001	Stafford	07-15-87	389	7.5	15.0	150	0	160	239	52

Well number (latitude, longitude, sequence number)	County	Magnesium dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO <sub>4</sub> )	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO <sub>2</sub> )	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> , dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)
CLAYEY LITHOLOGY										
381755098462201	Barton	8.9	30	3	22	38	0.5	19	3.7	0.03
375841099164201	Edwards	7.4	17	3	16	11	.5	22	6.6	.03
375531099155302	Edwards	7.4	16	2	20	6.2	.5	22	5.2	.04
375208099152801	Edwards	5.6	11	2	24	8.2	.3	27	8.1	.08
374457099113501	Edwards	4.7	12	3	21	11	.3	28	8.3	.12
374409099280701	Edwards	11	19	3	88	36	.1	27	18	.05
375859097332001	Harvey	5.6	32	2	14	11	.5	21	<.10	.12
375632097320101	Harvey	12	100	4	85	77	.5	34	<.10	.05
373819099081301	Kiowa	4.2	9.3	3	11	5.1	.3	29	8.6	.13
382050097424801	McPherson	13	32	3	26	79	.2	31	12	.06
381734097433801	McPherson	13	28	2	55	52	.3	30	3.4	.05
380635099043201	Pawnee	6.5	27	3	17	11	.4	23	4.6	.05
380414099091601	Pawnee	8.0	31	3	19	17	.6	20	7.4	.08
374638098551301	Pratt	3.2	5.8	2	8.8	5.8	.3	26	6.0	.09
374311098530801	Pratt	3.5	8.5	3	9.6	21	.3	22	6.4	.05
373510098313701	Pratt	4.2	7.5	1	13	9.6	.2	18	6.6	.05
372909098291701	Pratt	6.8	7.6	1	9.5	3.6	.4	20	11	.01
375817097530701	Reno	8.1	45	3	26	30	.2	24	7.0	.12
SANDY LITHOLOGY										
375445099194301	Edwards	6.9	11	2	24	4.5	.5	21	3.2	.02
375029099260101	Edwards	30	90	4	440	45	.6	19	7.8	.01
375718097381101	Harvey	18	96	3	110	110	.6	16	<.10	.02
374209098123001	Kingman	5.1	24	2	15	17	.2	23	14	.07
374301099191401	Kiowa	6.9	35	5	30	35	.4	14	1.9	.01
374113099094801	Kiowa	4.1	10	3	11	4.0	.4	25	8.3	.09
374330099072101	Kiowa	3.8	5.9	2	7.8	2.9	.4	23	5.1	.03
374629098024001	Reno	7.3	22	2	26	8.2	.4	23	12	.08
375348097325801	Sedgwick	8.2	32	3	25	19	.4	17	7.2	.03
375019097274501	Sedgwick	14	84	3	97	140	.3	15	10	.02
374751097320902	Sedgwick	21	82	2	39	87	.4	21	8.8	.11
380022098434001	Stafford	5.3	22	2	11	11	.3	21	4.3	.03

Areas of irrigated cropland (small-yield wells)--Continued

**Table 6. Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled—Continued**

[Analyses by U.S. Geological Survey. Units of measurement:  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter. (<), less than; (--), no analysis]

Well number (latitude, longitude, sequence number)	County	Iron, dissolved ( $\mu\text{g}/\text{L}$ as Fe)	Manganese, dissolved ( $\mu\text{g}/\text{L}$ as Mn)	Alachlor, total ( $\mu\text{g}/\text{L}$ )	Ametrine, total ( $\mu\text{g}/\text{L}$ )	Atrazine, total ( $\mu\text{g}/\text{L}$ )	Cyanazine, total ( $\mu\text{g}/\text{L}$ )	Metolachlor, total ( $\mu\text{g}/\text{L}$ )	Metribuzin, total ( $\mu\text{g}/\text{L}$ )	Prometone, total, ( $\mu\text{g}/\text{L}$ )
Areas of irrigated cropland (small-yield wells)—Continued										
CLAYEY LITHOLOGY										
381755098462201	Barton	<3	9	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375841099164201	Edwards	<3	2	<10	<10	<10	<10	<1	<1	<1
375531099155302	Edwards	<3	<1	<10	<10	<10	<10	<1	<1	<1
375209099152801	Edwards	10	5	<10	<10	<10	<10	<1	<1	<1
374457099113501	Edwards	20	3	<10	<10	3.8	<10	<1	<1	<1
374409099280701	Edwards	7	<1	<10	<10	<10	<10	<1	<1	<1
375659097332001	Harvey	870	270	<10	<10	<10	<10	<1	<1	<1
375632097320101	Harvey	420	460	<10	<10	<10	<10	<1	<1	<1
373819099081301	Kiowa	<3	1	<10	<10	<10	<10	<1	<1	<1
382050097424801	McPherson	6	1	<10	<10	<10	<10	<1	<1	<1
381734097433801	McPherson	5	<1	<10	<10	<10	<10	<1	<1	<1
380635099043201	Pawnee	4	1	<10	<10	<10	<10	<1	<1	<1
380414099091601	Pawnee	<3	<1	<10	<10	<10	<10	<1	<1	<1
374638098551301	Pratt	<3	<1	<10	<10	<10	<10	<1	<1	<1
374311098530901	Pratt	10	3	<10	<10	<10	<10	<1	<1	<1
373510098313701	Pratt	<3	<1	<10	<10	<10	<10	<1	<1	<1
372909098291701	Pratt	<3	<1	<10	<10	<10	<10	<1	<1	<1
375817097530701	Reno	5	1	<10	<10	<10	<10	<1	<1	<1
SANDY LITHOLOGY										
375445099194301	Edwards	10	7	<10	<10	<10	<10	<1	<1	<1
375029099260101	Edwards	3	2	<10	<10	<10	<10	<1	<1	<1
375718097381101	Harvey	300	180	<10	<10	<10	<10	<1	<1	<1
374209099123001	Kingman	3	<1	<10	<10	<10	<10	<1	<1	<1
374301099191401	Kiowa	4	30	<10	<10	<10	<10	<1	<1	<1
374113099094801	Kiowa	<3	<1	<10	<10	<10	<10	<1	<1	<1
374330099072101	Kiowa	<3	<1	<10	<10	<10	<10	<1	<1	<1
374629098024001	Reno	9	2	<10	<10	<10	<10	<1	<1	<1
375348097325801	Sedgwick	5	13	<10	<10	<10	.10	<1	<1	<1
375019097274501	Sedgwick	4	3	<10	<10	<10	.30	<1	<1	<1
374751097320902	Sedgwick	<3	2	<10	<10	<10	.90	<1	<1	<1
380022098434001	Stafford	<3	<1	<10	<10	<10	<10	<1	<1	<1

Well number (latitude, longitude, sequence number)	County	Prometryne, total (µg/L)	Propazine, total (µg/L)	Silvex, total (µg/L)	Simazine, total (µg/L)	Simetryne, total (µg/L)	Trifluralin, total (µg/L)	2,4-D, total (µg/L)	2,4-DP, total (µg/L)	2,4,5-T, total (µg/L)
Areas of irrigated cropland (irrigation wells)--Continued										
CLAYEY LITHOLOGY										
381715098443501	Barton	<0.1	<0.10	<0.01	<0.10	<0.1	<0.10	<0.01	<0.01	<0.01
375758099193901	Edwards	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375521099165501	Edwards	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375057099141201	Edwards	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374434099115601	Edwards	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374416099275101	Edwards	<1	.10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375843097334001	Harvey	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375616097314901	Harvey	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
373826099080401	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
382106097415501	McPherson	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
381620097444101	McPherson	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380612099043601	Pawnee	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380549099074101	Pawnee	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374648098540701	Pratt	<1	<10	--	<10	<1	.10	--	--	--
374324098534201	Pratt	<1	<10	--	<10	<1	<10	--	--	--
373509098333401	Pratt	<1	<10	--	<10	<1	<10	--	--	--
372922098292501	Pratt	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375810097534001	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
SANDY LITHOLOGY										
375336099204501	Edwards	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374909099274901	Edwards	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375735097382401	Harvey	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374209098122101	Kingman	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374311099190101	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374018099070301	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374316099070401	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374729098014301	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375256097333801	Sedgwick	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375223097275401	Sedgwick	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374843097323401	Sedgwick	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380127098435601	Stafford	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1

**Table 6. Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled—Continued**

[Analyses by U.S. Geological Survey. Units of measurement:  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius;  $\text{mg}/\text{L}$ , milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter. (<), less than; (—), no analysis]

Well number (latitude, longitude, sequence number)	County	Date of collection (month-day-year)	Specific conductance $\mu\text{S}/\text{cm}$	pH (standard units)	Temperature, water (deg C)	Hardness, total ( $\text{mg}/\text{L}$ as $\text{CaCO}_3$ )	Hardness, noncarbonate ( $\text{mg}/\text{L}$ as $\text{CaCO}_3$ )	Alkalinity, ( $\text{mg}/\text{L}$ as $\text{CaCO}_3$ ) dissolved	Solids, sum of constituents, dissolved ( $\text{mg}/\text{L}$ as Ca)	Calcium, dissolved ( $\text{mg}/\text{L}$ as Ca)
Areas of irrigated cropland (irrigation wells)										
CLAYEY LITHOLOGY										
381715098443501	Barton	07-21-87	538	7.5	14.5	150	0	210	268	52
375758099193901	Edwards	07-15-87	332	7.2	15.0	170	27	140	221	58
375521099165501	Edwards	07-15-87	447	7.4	15.0	200	15	190	290	67
375057099141201	Edwards	07-22-87	420	7.6	15.0	190	30	160	288	63
374434099115601	Edwards	07-22-87	404	7.4	14.5	170	32	140	207	59
374416099275101	Edwards	07-27-87	620	7.4	15.5	220	140	83	393	71
375843097334001	Harvey	07-22-87	478	6.7	16.0	160	39	120	301	49
375616097314901	Harvey	07-20-87	719	7.6	17.5	190	25	160	397	58
373826098080401	Kiowa	07-22-87	310	7.1	15.0	130	18	120	206	46
382106097415501	McPherson	07-21-87	582	7.3	16.5	270	23	240	345	92
381620097444101	McPherson	07-14-87	845	7.4	15.0	330	28	300	495	99
380612099043601	Pawnee	07-20-87	561	7.5	16.0	170	10	160	324	50
380549099074101	Pawnee	07-14-87	420	7.3	14.0	200	35	160	308	67
374648098540701	Pratt	07-20-87	421	7.7	14.5	180	30	160	280	65
374324098534201	Pratt	07-21-87	306	7.4	15.0	120	12	110	191	43
373509098333401	Pratt	07-21-87	431	7.7	16.0	170	0	170	258	59
372922098292501	Pratt	07-22-87	524	7.5	15.0	260	42	220	327	92
375810097534001	Reno	07-22-87	607	7.2	16.5	220	0	230	359	74
SANDY LITHOLOGY										
375336099204501	Edwards	07-15-87	360	7.3	14.5	170	38	130	236	56
374909099274901	Edwards	07-23-87	1,700	7.3	15.0	650	430	220	1,220	180
375735097382401	Harvey	07-20-87	1,000	7.6	15.5	320	150	170	569	97
374209098122101	Kingman	07-23-87	450	7.4	15.0	180	44	140	284	66
374311099190101	Kiowa	07-22-87	266	7.3	15.0	150	18	130	207	50
374018099070301	Kiowa	07-21-87	340	7.0	15.0	140	8	130	223	47
374316099070401	Kiowa	07-22-87	289	7.0	15.0	110	17	98	172	39
374729098014301	Reno	07-27-87	315	7.1	15.5	130	60	68	235	41
375256097333801	Sedgwick	07-22-87	1,040	6.9	15.5	330	130	200	600	100
375223097275401	Sedgwick	07-22-87	710	6.9	15.5	280	54	230	434	91
374843097323401	Sedgwick	07-21-87	916	7.1	15.0	170	0	180	541	53
380127098435601	Stafford	07-15-87	832	7.3	14.5	260	68	200	474	86

Well number (latitude, longitude) sequence number	County	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO <sub>4</sub> )	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO <sub>2</sub> )	Nitrogen, NO <sub>2</sub> -NO <sub>3</sub> , dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)
Areas of irrigated cropland (irrigation wells)--Continued										
CLAYEY LITHOLOGY										
381715098443501	Barton	5.2	9.2	3	14	6.4	0.4	23	7.2	0.07
375758099193901	Edwards	6.4	7.3	1	16	5.0	.3	26	3.2	.05
375621099165501	Edwards	8.5	19	2	20	8.1	.5	23	6.7	.05
375057099141201	Edwards	7.6	19	3	27	11	.6	20	9.3	.04
374434099115601	Edwards	5.7	12	3	13	7.1	.5	22	.43	.02
374416099275101	Edwards	11	27	2	130	22	.3	23	13	.03
375843097334001	Harvey	8.4	32	3	100	13	.4	22	<.10	.01
375616097314901	Harvey	10	93	3	68	44	.4	24	<.10	.03
373826099080401	Kiowa	4.8	12	3	11	5.6	.3	26	6.2	.06
382106097415501	McPherson	9.0	18	2	22	21	.3	31	.74	.02
381620097444101	McPherson	19	49	2	56	41	.3	23	6.0	.02
380612099043601	Pawnee	10	45	3	76	26	.8	19	<.10	.02
380549099074101	Pawnee	7.7	22	3	19	17	.5	21	12	.04
374648098540701	Pratt	4.6	10	3	11	9.0	.3	25	9.3	.08
374324098534201	Pratt	3.3	8.5	3	9.4	4.1	.3	23	7	.07
373509098333401	Pratt	6.0	25	3	10	16	.3	23	2.9	.02
372922098292501	Pratt	7.2	12	2	9.6	7.6	.4	22	10	<.01
375810097534001	Reno	8.1	40	3	24	14	.3	22	7.8	.06
SANDY LITHOLOGY										
375336099204501	Edwards	6.6	12	1	30	4.7	.4	24	5.4	.04
374909099274901	Edwards	48	150	5	600	64	1.0	16	4.8	.01
375735097382401	Harvey	18	100	3	110	120	.7	17	.15	.01
374209098122101	Kingman	4.8	21	1	13	18	.2	22	12	.05
374311099190101	Kiowa	5.0	11	3	11	5.9	.5	21	5.3	.04
374018099070301	Kiowa	4.6	10	3	12	6.2	.4	25	8.4	.07
374316099070401	Kiowa	4.2	7.6	2	9.4	3.4	.3	25	5.0	.03
374729098014301	Reno	6.2	19	2	19	11	.2	25	16	.11
375256097333801	Sedgwick	20	76	4	100	110	.5	18	12	.02
375223097275401	Sedgwick	13	39	3	96	38	.5	15	.58	.01
374843097323401	Sedgwick	9.8	120	3	60	130	.6	19	8.6	.04
380127098435601	Stafford	12	59	3	24	110	.3	23	8.8	.03

**Table 6. Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled—Continued**

[Analyses by U.S. Geological Survey. Units of measurement:  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter. (<), less than; (—), no analysis]

Well number (latitude, longitude, sequence number)	County	Iron, dissolved ( $\mu\text{g}/\text{L}$ as Fe)	Manganese, dissolved ( $\mu\text{g}/\text{L}$ as Mn)	Alachlor, total ( $\mu\text{g}/\text{L}$ )	Ametryne, total ( $\mu\text{g}/\text{L}$ )	Atrazine, total ( $\mu\text{g}/\text{L}$ )	Cyanazine, total ( $\mu\text{g}/\text{L}$ )	Metolachlor, total ( $\mu\text{g}/\text{L}$ )	Metribuzin, total ( $\mu\text{g}/\text{L}$ )	Prometon, total ( $\mu\text{g}/\text{L}$ )
Areas of irrigated cropland (irrigation wells)—Continued										
CLAYEY LITHOLOGY										
381715098443501	Barton	10	6	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375758099198901	Edwards	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375521098165501	Edwards	5	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375057099141201	Edwards	<3	3	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374434099115601	Edwards	<3	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374416099275101	Edwards	<3	2	<0.10	<0.10	1.4	<0.10	.1	<0.1	<0.1
375843097334001	Harvey	1,900	280	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375616097314901	Harvey	4	210	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
373826099080401	Kiowa	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
382106097415501	McPherson	8	5	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
381620097444101	McPherson	9	2	<0.10	<0.10	.10	<0.10	<0.1	<0.1	<0.1
380612099043601	Pawnee	29	56	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380549098074101	Pawnee	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374649098540701	Pratt	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374324098534201	Pratt	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
373509098333401	Pratt	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
372922098292501	Pratt	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375810097534001	Reno	<3	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
SANDY LITHOLOGY										
375336099204501	Edwards	4	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374909099274901	Edwards	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375735097382401	Harvey	460	300	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374209098122101	Kingman	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374311099190101	Kiowa	8	5	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374018099070301	Kiowa	<3	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374316099070401	Kiowa	31	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374729098014301	Reno	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
37525609733801	Sedgwick	<3	2	.10	<0.10	.30	<0.10	1.0	<0.1	<0.1
375223097275401	Sedgwick	110	120	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374843097323401	Sedgwick	<3	5	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380127098435601	Stafford	6	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1

Well number (latitude, longitude, sequence number)	County	Prometryne, total (µg/L)	Propazine, total (µg/L)	Silvex, total (µg/L)	Simazine, total (µg/L)	Simeetryne, total (µg/L)	Trifluralin, total (µg/L)	2,4-D, total (µg/L)	2,4-DP, total (µg/L)	2,4,5-T, total (µg/L)
Areas of irrigated cropland (small-yield wells)-Continued										
CLAYEY LITHOLOGY										
381756098462201	Barton	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375841098164201	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375631099155302	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375208099152801	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374457099113501	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374409099280701	Edwards	<.1	.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375859097332001	Harvey	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375632097320101	Harvey	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
373819099081301	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
382050097424801	McPherson	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
381734097433801	McPherson	<.1	<.10	<.01	<.10	<.1	<.10	.01	<.01	<.01
380635099043201	Pawnee	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380414099091601	Pawnee	<.1	<.10	--	<.10	<.1	<.10	--	--	--
374638098551301	Pratt	<.1	<.10	<.01	<.10	<.1	.10	<.01	<.01	<.01
374311098530901	Pratt	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
373510098313701	Pratt	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
372909098291701	Pratt	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375817097530701	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
SANDY LITHOLOGY										
375445099194301	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375028099280101	Edwards	<.1	<.10	<.01	<.10	<.1	.40	<.01	<.01	<.01
375718097381101	Harvey	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374209098123001	Kingman	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374301099191401	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374113099094801	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374330099072101	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374628098024001	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375348097325801	Sedgwick	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375019097274501	Sedgwick	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374751097320902	Sedgwick	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380022098434001	Stafford	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01

**Table 6. Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled—Continued**

[Analyses by U.S. Geological Survey. Units of measurement:  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter. (<), less than; (--), no analysis]

Well number (latitude, longitude, sequence number)	County	Date of collection (month-day-year)	Specific conductance ( $\mu\text{S}/\text{cm}$ )	pH (standard units)	Temperature, water (deg C)	Hardness, total (mg/L as $\text{CaCO}_3$ )	Hardness, noncarbonate (mg/L as $\text{CaCO}_3$ )	Alkalinity, (mg/L as as $\text{CaCO}_3$ )	Solids, sum of constituents, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Areas of petroleum-production land											
CLAYEY LITHOLOGY											
372553098133701	Kingman	07-29-87	2,380	6.6	20.0	570	470	100	1,100	170	35
372302098143601	Kingman	07-29-87	677	7.1	16.0	260	46	210	383	93	6.6
374021099304901	Kiowa	07-28-87	295	7.3	15.0	120	6	110	187	40	4.9
382425097290101	McPherson	07-13-87	481	7.0	17.0	190	0	220	294	64	6.6
375619097494101	Reno	07-28-87	754	7.4	16.0	290	10	280	412	97	11
381358098045301	Rice	07-08-87	824	7.3	16.0	230	0	240	481	37	34
381629098023601	Rice	07-14-87	503	7.3	14.0	220	39	190	317	78	7.2
381140098345101	Stafford	07-09-87	557	7.5	18.5	190	0	190	329	66	5.4
375231098561901	Stafford	07-30-87	134	7.7	15.0	160	22	130	223	55	4.5
SANDY LITHOLOGY											
381819098330101	Barton	07-07-87	1,470	7.4	15.0	540	130	420	1,120	180	23
381707098290901	Barton	07-08-87	935	7.2	17.0	290	150	140	520	96	11
373124097591201	Kingman	07-29-87	485	7.0	27.0	180	53	120	280	54	9.9
373048098015401	Kingman	07-29-87	373	7.1	16.0	120	1	120	196	41	5.3
380249099133401	Pawnee	07-09-87	625	7.3	15.0	260	120	140	375	86	11
374207098394801	Pratt	07-30-87	645	7.8	17.0	200	47	160	341	73	5.5
381411098311901	Stafford	07-08-87	560	7.5	15.0	140	3	180	343	64	4.9
380916098315101	Stafford	07-13-87	743	7.7	14.5	140	0	220	416	44	6.8
380731098315101	Stafford	07-14-87	229	6.8	14.0	90	13	77	149	31	3.0
380631098361401	Stafford	07-14-87	392	7.6	14.5	160	0	160	229	58	2.5
380553098341801	Stafford	07-14-87	1,190	7.9	14.5	95	0	190	646	33	3.1
375625098444601	Stafford	07-15-87	359	7.5	17.0	150	19	130	224	54	3.7
375310098523701	Stafford	07-16-87	587	7.2	15.5	250	84	160	329	87	7.6

Well number (latitude, longitude, sequence number)	County	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO <sub>4</sub> )	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO <sub>2</sub> )	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> , dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
Areas of petroleum-production land--Continued											
CLAYEY LITHOLOGY											
372553098133701	Kingman	180	2	66	460	0.3	21	23	<0.01	40	<10
372302098143601	Kingman	34	2	27	45	.2	24	5.3	.03	130	2
374021098304901	Kiowa	14	2	15	9.2	.3	25	2.0	.08	<3	<1
382425097290101	McPherson	31	3	21	10	.4	21	1.6	.09	49	7
375619097494101	Reno	36	2	15	33	.2	25	6.0	.04	9	1
381358098045301	Rice	100	3	91	63	.3	2.8	1.6	.14	6	250
381629098023601	Rice	18	1	39	13	.2	28	4.7	.07	5	<1
381140098345101	Stafford	37	3	9.4	55	.4	23	3.6	.05	8	<1
375231098561901	Stafford	9.6	3	12	7.6	.3	26	5.6	.09	5	<1
SANDY LITHOLOGY											
381819098330101	Barton	180	8	150	290	.4	24	2.5	.02	34	380
381707098290901	Barton	86	4	41	150	.4	22	6.1	.04	10	<1
373124097591201	Kingman	18	1	21	10	.2	25	15	.08	77	5
373048098015401	Kingman	17	1	9.1	16	.2	25	1.4	.09	570	18
380249099133401	Pawnee	22	3	21	91	.4	24	7.1	.05	<3	1
374207098394801	Pratt	38	2	14	78	.3	20	3.4	.03	85	4
381411098311901	Stafford	40	4	9.8	77	.3	22	3.3	.07	8	<1
380916098315101	Stafford	110	2	12	86	.4	23	.46	.03	3	2
380781098315101	Stafford	8.5	1	13	3.2	.3	27	3.6	.09	8	<1
380631098361401	Stafford	16	9	17	10	.3	16	.91	.05	640	110
380553098341801	Stafford	200	2	22	240	.4	21	2.5	.10	10	<1
375625098444601	Stafford	13	2	12	7.9	.4	22	6.8	.06	<3	<1
375310098523701	Stafford	16	3	10	64	.3	25	3.7	.06	6	<1

**Table 6. Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled—Continued**

[Analyses by U.S. Geological Survey. Units of measurement:  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter. (<), less than; (--), no analysis]

Well number (latitude, longitude, sequence number)	County	Date of collection (month-day-year)	Specific conductance ( $\mu\text{S}/\text{cm}$ )	pH (standard units)	Temperature, water (deg C)	Hardness, total (mg/L as $\text{CaCO}_3$ )	Hardness, noncarbonate as $\text{CaCO}_3$	Alkalinity (mg/L as $\text{CaCO}_3$ )	Solids, sum of constituents, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)
<b>Areas of rangeland</b>										
<b>CLAYEY LITHOLOGY</b>										
375204099232501	Edwards	07-28-87	335	7.4	17.0	130	21	110	193	45
374708099263501	Edwards	07-28-87	585	7.5	15.5	220	100	120	429	73
374251099283901	Kiowa	07-28-87	290	6.8	15.0	89	33	56	197	28
373343099075501	Kiowa	07-29-87	365	6.9	15.5	190	12	180	252	66
374338099102901	Kiowa	07-29-87	250	6.9	15.0	110	23	86	169	37
382624097505801	McPherson	07-13-87	1,600	7.2	16.5	710	300	420	1,030	140
374314098581201	Pratt	07-30-87	268	7.5	16.0	100	31	71	183	35
380955098234101	Reno	07-16-87	1,990	7.0	16.0	240	0	250	1,070	77
381029097591901	Rice	07-09-87	176	6.0	16.0	53	10	43	135	16
<b>SANDY LITHOLOGY</b>										
37534509923201	Edwards	07-28-87	316	6.0	15.5	140	34	110	201	51
374215098262101	Kingman	07-24-87	297	7.0	15.5	130	33	96	194	45
373923099325901	Kiowa	07-28-87	219	7.3	16.0	99	6	153	153	34
374116099022501	Kiowa	07-29-87	248	6.9	15.0	100	22	81	173	35
380151099162601	Pawnee	07-15-87	465	7.5	18.0	210	23	190	286	70
374220098384201	Pratt	07-30-87	703	7.8	16.0	310	110	200	415	110
375646098381001	Pratt	07-30-87	456	7.5	16.0	190	35	160	269	70
380845097645101	Reno	07-28-87	223	6.9	16.0	76	0	76	146	24
380746097514802	Reno	07-28-87	280	7.7	16.0	110	6	110	178	40
380350097463301	Reno	07-29-87	156	6.4	16.0	31	3	28	100	9.5
375327098193401	Reno	07-15-87	865	6.7	14.5	320	250	69	500	110
380632098231401	Reno	07-15-87	1,960	7.0	19.0	130	0	160	1,320	43
381159098262101	Rice	07-16-87	188	6.2	15.0	49	3	46	127	15

Well number (latitude, longitude, sequence number)	County	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO <sub>4</sub> )	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO <sub>2</sub> )	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> , dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)
Areas of rangeland--Continued										
CLAYEY LITHOLOGY										
375204099232501	Edwards	3.6	14	0.9	28	7.9	0.4	19	2.5	0.03
374708099263501	Edwards	9.2	43	2	180	14	.4	23	2.9	.04
374251099283901	Kiowa	4.6	23	1	54	14	.2	25	3.0	.10
373343099075501	Kiowa	5.6	13	2	11	13	.3	23	2.7	.02
374338099102901	Kiowa	3.9	7.6	2	12	4.6	.3	27	5.0	.17
382624097505801	McPherson	88	80	6	380	67	.4	14	1.0	<.01
374314098581201	Pratt	3.4	9.5	3	12	4.8	.3	28	10	.07
380955098234101	Reno	11	290	3	72	430	.4	20	3.8	.10
381029097591901	Rice	3.2	13	1	13	4.8	.2	39	3.9	.43
SANDY LITHOLOGY										
375345099223201	Edwards	3.1	7.5	1	24	8.0	.3	18	5.5	.06
374215098262101	Kingman	4.1	8.6	1	16	2.7	.2	25	7.6	.09
373923099325901	Kiowa	3.5	6.8	2	12	3.1	.3	26	2.2	.14
374116099022501	Kiowa	3.7	9.6	3	10	3.7	.3	27	7.4	.07
380151099162601	Pawnee	8.6	15	2	32	7.9	.6	23	3.1	.03
374220098384201	Pratt	7.4	25	3	19	70	.3	23	8.6	.04
375646098381001	Pratt	4.5	13	2	14	7.3	.2	21	9.6	.04
380845097545101	Reno	3.8	13	1	14	4.1	.2	31	2.0	.12
380746097514802	Reno	3.5	11	1	10	3.5	.2	32	2.6	.07
380350097463301	Reno	1.8	11	3	11	3.2	.2	30	2.7	.49
375327098193401	Reno	11	24	2	34	84	.2	22	39	.06
380632098231401	Reno	5.6	440	2	65	620	.4	22	5.8	<.01
381159098262101	Rice	2.8	16	1	13	11	.3	29	2.5	10

**Table 6. Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled—Continued**

[Analyses by U.S. Geological Survey. Units of measurement:  $\mu\text{S/cm}$ , microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g/L}$ , micrograms per liter. (<), less than; (—), no analysis]

Well number (latitude, longitude, sequence number)	County	Iron, dissolved ( $\mu\text{g/L}$ as Fe)	Manganese, dissolved ( $\mu\text{g/L}$ as Mn)	Alachlor, total ( $\mu\text{g/L}$ )	Ametrine, total ( $\mu\text{g/L}$ )	Atrazine, total ( $\mu\text{g/L}$ )	Cyanazine, total ( $\mu\text{g/L}$ )	Metolachlor, total ( $\mu\text{g/L}$ )	Metribuzin, total ( $\mu\text{g/L}$ )	Prometon, total ( $\mu\text{g/L}$ )
CLAYEY LITHOLOGY										
375204099232501	Edwards	14	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374708099263501	Edwards	26	1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374251099283901	Kiowa	24	1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
373343099075501	Kiowa	13	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374338099102901	Kiowa	21	1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
382624097505801	McPherson	8	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374314098581201	Pratt	28	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380955098234101	Reno	28	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
381029097591901	Rice	12	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
SANDY LITHOLOGY										
375345099232301	Edwards	6	1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374215098262101	Kingman	<3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
373923098325901	Kiowa	3	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374116099022501	Kiowa	5	3	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380151099162601	Pawnee	25	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374220098384201	Pratt	<3	1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375646098381001	Pratt	210	3	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380845097545101	Reno	<3	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380746097514802	Reno	<3	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380350097463301	Reno	12	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
375327098193401	Reno	17	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
380632098231401	Reno	80	10	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
381159098262101	Rice	5	2	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1

Areas of rangeland—Continued

Well number (latitude, longitude, sequence number)	County	Prometryne, total (µg/L)	Propazine, total (µg/L)	Silvex, total (µg/L)	Simazine, total (µg/L)	Simetryne, total (µg/L)	Trifluralin, total (µg/L)	2,4-D, total (µg/L)	2,4-DP, total (µg/L)	2,4,5-T, total (µg/L)
Areas of rangeland--Continued										
CLAYEY LITHOLOGY										
375204099232501	Edwards	<0.1	<0.10	<0.01	<0.10	<0.1	<0.10	<0.01	<0.01	<0.01
374708099263501	Edwards	<1	<10	--	<10	<1	<10	--	--	--
374251099283901	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
373343099075501	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374338099102901	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
382624097505801	McPherson	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374314098581201	Pratt	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380955098234101	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
381029097591901	Rice	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
SANDY LITHOLOGY										
375345099223201	Edwards	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374215098262101	Kingman	<1	<10	--	<10	<1	<10	--	--	--
373923099325901	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374116099022501	Kiowa	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380151099162601	Pawnee	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
374220098384201	Pratt	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375646098381001	Pratt	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380845097545101	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380746097514802	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380350097463301	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
375327098193401	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
380632098231401	Reno	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1
381159098262101	Rice	<1	<10	<0.1	<10	<1	<10	<0.1	<0.1	<0.1