ASSESSMENT OF NONPOINT-SOURCE CONTAMINATION OF THE HIGH PLAINS AQUIFER IN SOUTH-CENTRAL KANSAS, 1987

U.S. GEOLOGICAL SURVEY
Open-File Report 91-238

Prepared as part of the
TOXIC WASTE--GROUND-WATER
CONTAMINATION PROGRAM,
U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	square hectometer
square mile (mi^2)	2.590	square kilometer
foot per day (ft/d)	0.3048	meter per day
gallon per minute (gal/min)	0.06309	liter per second
pound (lb)	0.4536	kilogram
barrel (bbl)	0.1590	cubic meter
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

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[1] °C = (°F - 32)/1.8.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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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 were agricultural chemicals, mainly atrazine, and oil-derived hydrocarbons, which might occur in association 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 to 10 square miles. Although true baseline water-quality conditions probably are rare, these baseline conditions are represented most closely by ground water beneath the areas of undeveloped rangeland. The sampling design enabled statistical hypothesis testing of the effects of land use, unsaturated-zone lithology, and type of well sampled. Statistical testing was based on nonparametric procedures.

Results indicate that regional ground-water quality has been affected by prevailing land-use activities, as shown mainly by increased concentrations of several inorganic constituents. Ground water beneath irrigated cropland is characterized by significantly (95-percent confidence level) larger concentrations of hardness, alkalinity, calcium, magnesium, potassium, fluoride, and nitrite plus nitrate than is water beneath undeveloped rangeland. Nondegraded pesticides generally were not detected in the aquifer, probably because of degradation and sorption. Atrazine is present locally in ground water in small concentrations.

Ground water beneath petroleum-production land is characterized by significantly (95-percent confidence level) larger concentrations of hardness, alkalinity, dissolved solids, sodium, and chloride than is water beneath undeveloped rangeland. Nonpoint-source ground-water 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 regional lateral flow and solute transport is sufficiently slow so that the ground-water quality reflects overlying land use in discrete areas of several square miles. Regional flow, however, is sufficiently rapid so that the type of well sampled is not important in regional characterization 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 has directed attention toward the varied and complex aspects of ground-water contamination. Assessing and understanding the effects of human activities on ground-water quality to address effectively the scope of and response to contamination problems has become a matter of national importance.

Study of nonpoint-source contamination is a part of the U.S. Geological Survey's Toxic Waste--Ground-Water Contamination Program. The general objective of the program is to assess the current quality of the Nation's ground-water reserves and the nature and extent of the ground-water contamination problem (Helsel and Ragone, 1984). As part of this effort, seven areas for the study of nonpoint-source contamination were selected to include representative environments in terms of climate, geohydrology, and human activity. The studies were designed to be regional in scope and statistical in approach, and to allow for subsequent work directed toward the extrapolation of results or the focusing on particular aspects important to understanding nonpoint-source ground-water contamination. Three of the seven study areas are in the midwestern United States, and one of these study areas, part of the High Plains aquifer in Kansas, is the subject of this report.

Background

Ground water is a vital resource to the midwestern United States. The most common sources of water supply are shallow, unconfined, unconsolidated aquifers that might be extremely transmissive and have a large storage capacity. The High Plains aquifer is the most areally extensive of these aquifers, but smaller alluvial or glacial-outwash aquifers are present throughout much of the Midwest. These aquifers are readily available sources of water that is needed for public-supply, agricultural, industrial, domestic, and stock purposes. Although contamination of any water resource might 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.

Surficial aquifers with substantial permeability and a shallow water table are especially susceptible to contamination by human activities located at or near the land surface. Possible sources of contamination range from local (point-source) to widespread (nonpoint-source) activities. This study addresses nonpoint-source organic contaminants associated with two activities practiced extensively across much of the Midwest. These activities, agricultural-chemical application and brine disposal associated with petroleum production, pose potential ground-water contamination problems as a result of their widespread practice. Application of agricultural chemicals involves a spreading of the chemicals over the land. These chemicals then have the potential to move down to the water table. Brines produced with oil and oil-derived hydrocarbons, which can occur in association with brines, also might be a problem, particularly as a result of brine-disposal practices prior to regulation. This study also addresses relations among contaminant concentration or detection and two variables--unsaturated-zone lithology and the 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 contribute toward effective monitoring, predictive capability, and ultimate protection of water resources. The contamination problem is complex. The direction and velocity of regional ground-water flow potentially are major factors 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 in evaluating the contamination problem.

The area selected for this study (fig. 1) is a small part of the High Plains aquifer, yet sufficiently large to address the regional scale of the problem. The 5,000-mi^2 area is within the Great Bend Prairie and *Equus* beds areas of south-central Kansas. The study area is a logical unit for investigation of nonpoint-source contaminant distribution in ground water because the area 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 apparently is reflected in large nitrate concentrations in ground water relative to other areas of Kansas (Spruill, 1983).

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; Stullken and others, 1985). The aquifer consists of a

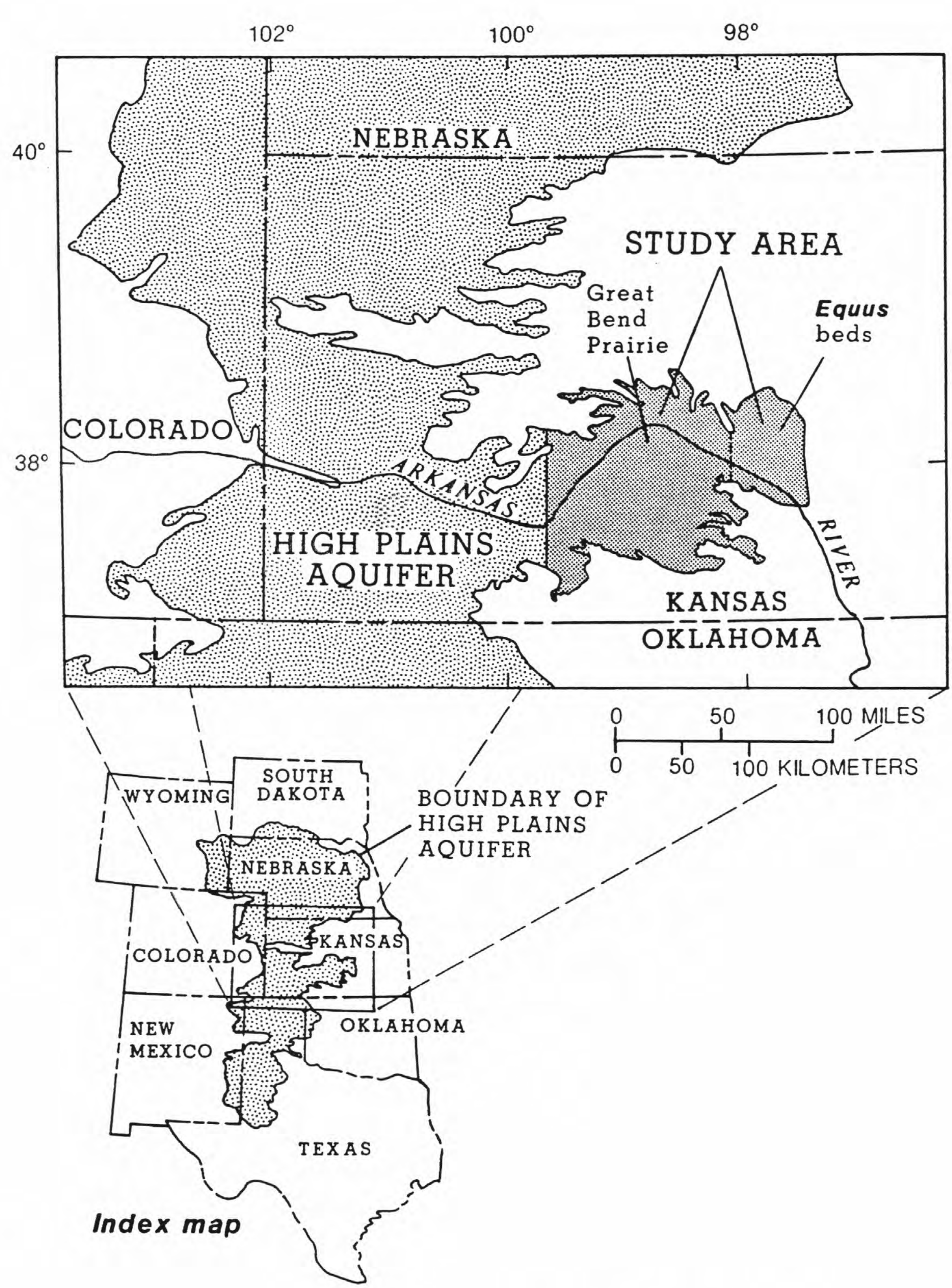


Figure 1. High Plains aquifer and location of study area.

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.

Purpose and Scope

This report characterizes the occurrences of nonpoint-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. Although his report addresses overall ground-water quality, it focuses particularly 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 extensive use and relative persistence or mobility. Specific hydrocarbons are not targeted, however, because potential petroleum-related contaminants include a 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.

DESCRIPTION OF NONPOINT-SOURCE CONTAMINATION PROBLEM AND RELATED STUDIES

Agricultural Land

Land use in Kansas (fig. 2) is typical of much of the Midwest and is largely agricultural. Pesticides (synthetic organic chemicals used principally for weed and insect control) are applied extensively to enhance crop productivity. The distribution of an agricultural chemical in ground water is a result of numerous factors, including source, movement, and fate of the chemical. Applications of pesticides are widespread and many different pesticides are applied, but in most instances application histories are not documented. In addition, timing of applications with respect to natural recharge and irrigation are important factors that affect pesticide infiltration. Other factors include properties of soils and the underlying unsaturated zone, properties of the chemical 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 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 goes to plant uptake, and part might continue percolating through the unsaturated zone. A substantial proportion 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 hydrologic conditions result in serious shortcomings in the ability to predict the effects of pesticides on ground-water quality.

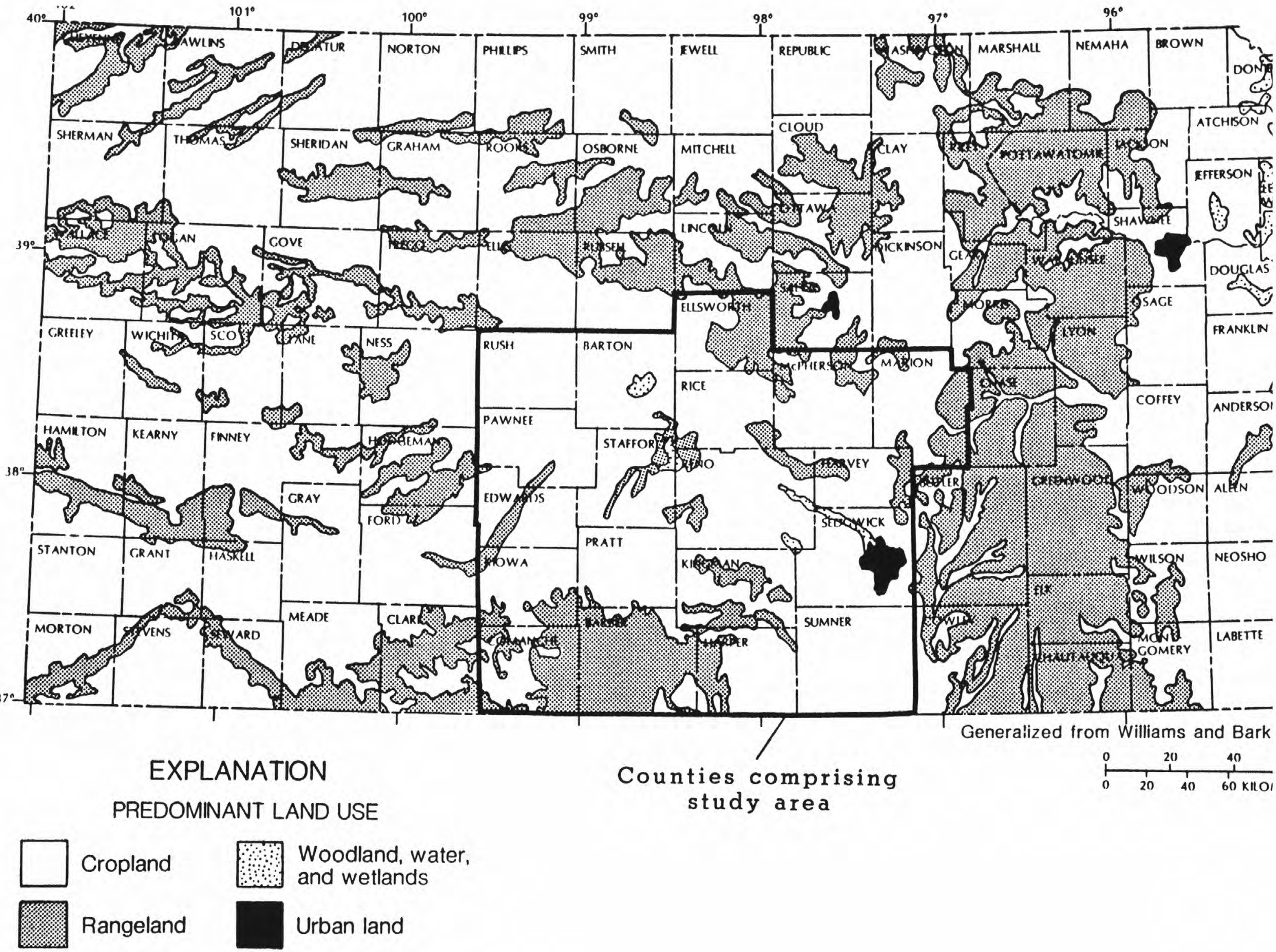


Figure 2. Generalized predominant land use in Kansas.

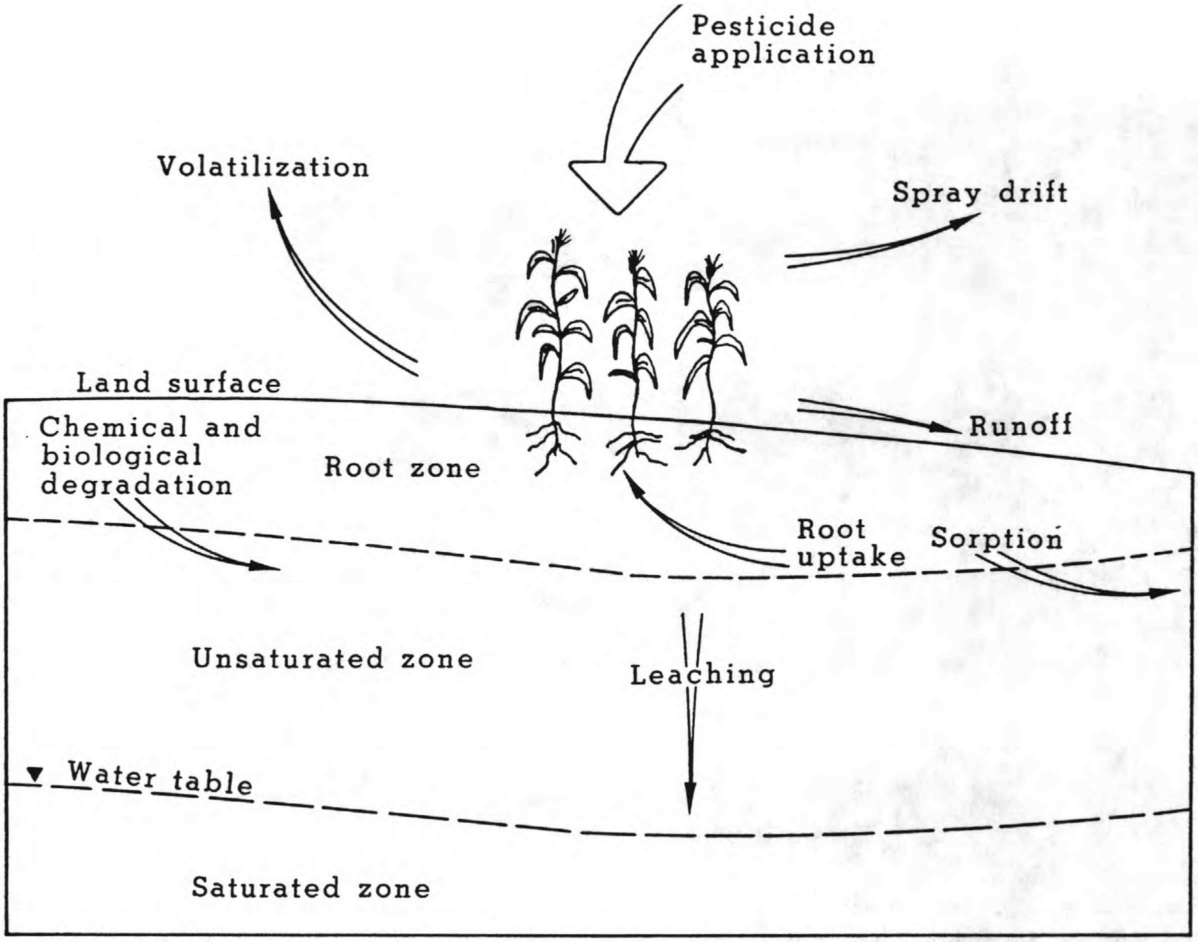


Figure 3. Pathways of pesticide degradation and transport.

Awareness of ground-water contamination by pesticides in the Midwest has increased considerably during the last few years, and 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 from State to State depending on the pesticides in common use. Some of the pesticides typically of concern include alachlor, aldicarb, atrazine, carbofuran, cyanazine, metolachlor, metribuzin, and 2,4-D. The pesticide surveys generally have not systematically evaluated the nonpoint-source contamination problem, but have provided initial indications of pesticide occurrences in ground-water supplies. Some of the largest concentrations detected probably represent localized point-source problems.

The Kansas Department of Health and Environment (Topeka) retrieved U.S. Environmental Protection Agency data in 1984 showing 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 1985-86 random sampling of 103 farmstead wells in 48 counties in Kansas determined that 9 percent had detectable pesticides (Koelliker and others, 1987). Atrazine was the most frequently detected pesticide, 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 was detected at a concentration of 5.6 μg/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 the most frequently detected.

The common practice of irrigation introduces water, supplemental to precipitation, for 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 to 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 such as in many parts of Kansas (Genna Ott, Kansas Department of Health and Environment, written commun., 1984). Direct potential for contamination exists through back-siphoning of chemicals into the supply well if it 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; the chemigation process itself does not appear to result in 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), permitted determinations of 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 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 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 two samples, and propazine was detected in one sample. All concentrations were small, with the largest being 0.20 µg/L for atrazine.

Petroleum-Production Land

Hydrocarbons, a large group of organic compounds consisting of hydrogen and carbon, typically are associated with petroleum and petroleum-related activities. This group includes a variety of compounds with widely varying properties. Virtually no documentation of nonpoint-source hydrocarbon contamination of ground water exists. Recognition of the potential for hydrocarbon contamination on a regional scale is based mainly on conceptual inference in combination with a few instances of reported hydrocarbon occurrence.

The extent of petroleum-production activity 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 of land 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, it was not an uncommon practice to dispose of oil-field wastes (mostly brine) into shallow, unlined pits. The attendant potential contamination problem has been long recognized (Frye and Brazil, 1943).

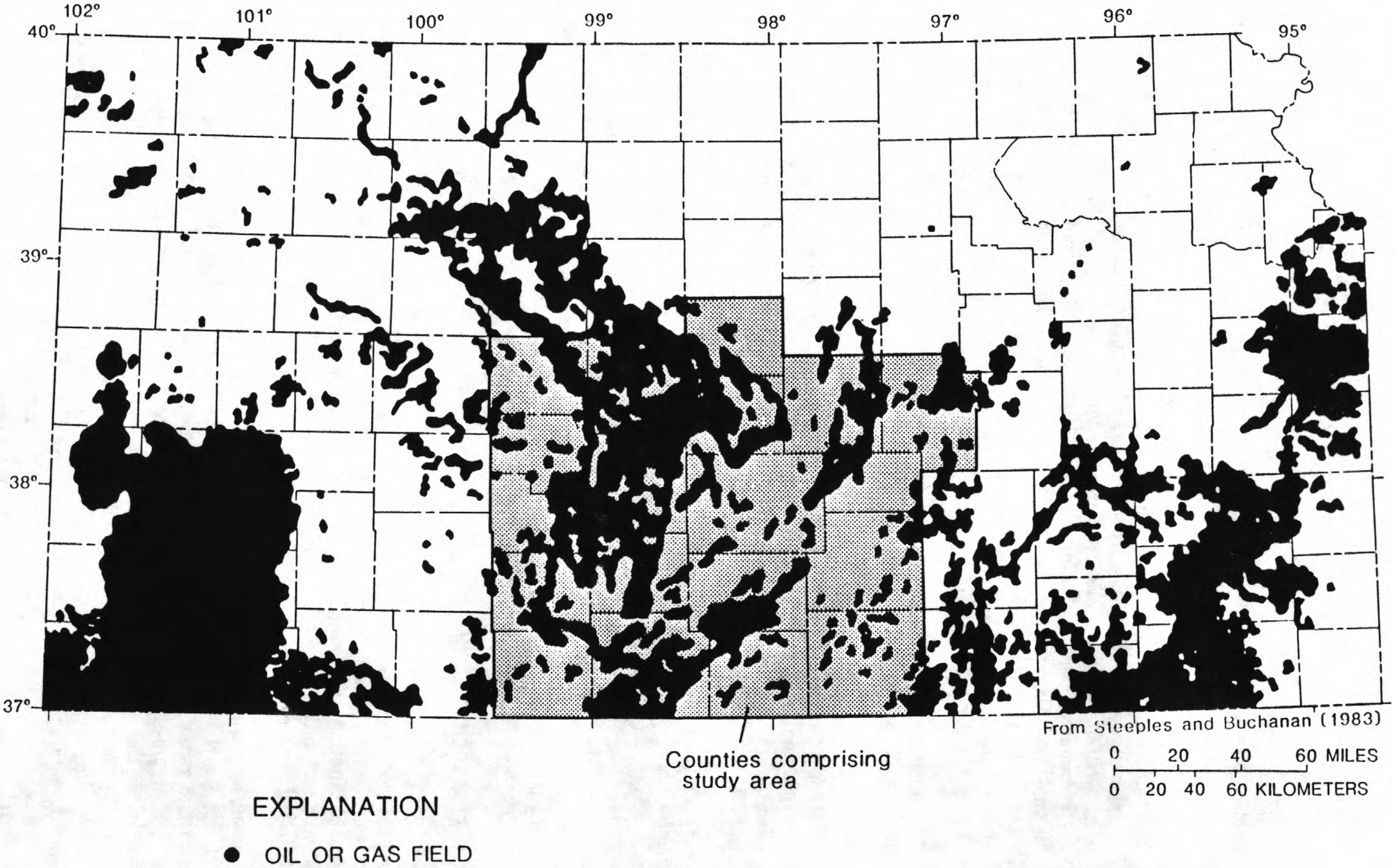


Figure 4. Location of oil and gas fields in Kansas, 1983.

Infiltration of the wastes through the soil and into the freshwater of the underlying aquifer (illustrated schematically in fig. 5) has been documented. Leonard and Berry (1961), for example, described such a contamination problem northwest of the study area in Ellis County. 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 produced with petroleum and is in direct contact with petroleum during production, some hydrocarbons also are associated with 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 previously mentioned 1985-86 sampling of 103 farmstead wells, 2 percent had detectable volatile organic compounds (Koelliker and others, 1987). Many sources for such compounds are possible, but one possibility can be related to oil-production activities. The existence and extent of any such problem currently (1990) is unknown.

STUDY APPROACH AND METHODS

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. Each of these aspects is discussed in the following sections.

Characterization of Contaminant Sources

The two types of organic contaminants of concern in this study have different origins that can be characterized basically in terms of land use. Attention to land use is primary to the study for

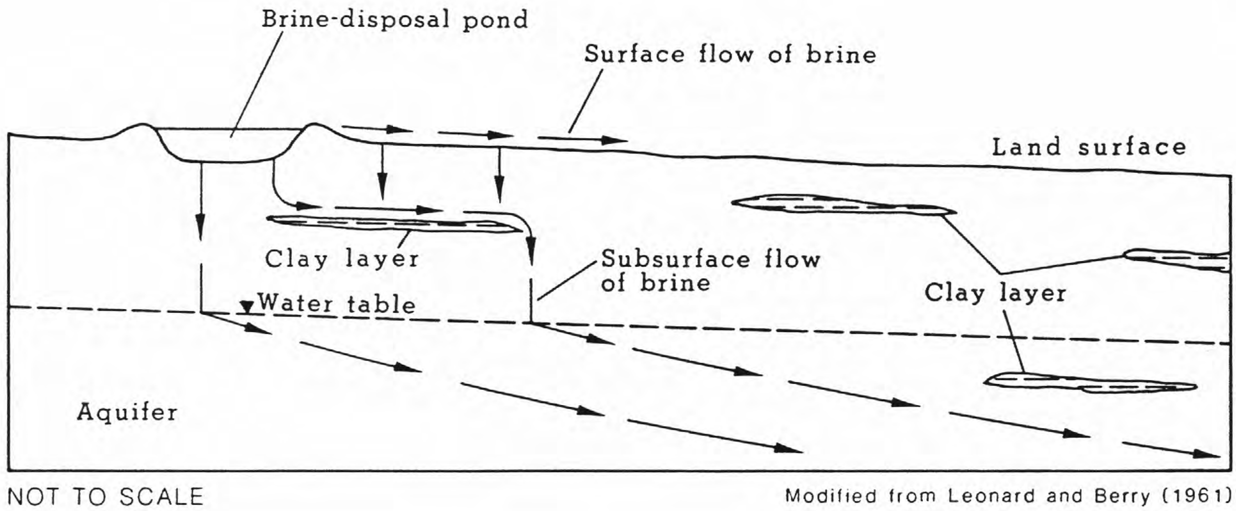


Figure 5. Movement of brine from a brine-disposal pond.

consistency with the overall program emphasis of defining felations 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 oil-derived hydrocarbons on petroleum-production land). However, such data are limited, precluding a quantitative system 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 in the study area. Nearly the entire area is cropland or rangeland; the largest nonagricultural areas are a wildlife refuge and principal communities. Attention was directed to areas of irrigated cropland and rangeland. Although both types of land receive pesticide applications, irrigated cropland receives much more and also receives applications of water, which increase the potential for downward leaching of chemicals.

Some general information about pesticide applications was 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), an area that approximately coincides with the study area. During 1978 in south-central Kansas, 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 seen detected in ground-water samples from the area (Stullken and others, 1987; Bevans, 1989) and are the principal pesticides of concern 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. Oil-derived hydrocarbons might have accompanied brines as they percolated downward from former brine-disposal ponds, as discussed in "Description of Nonpoint-Source Problem and Related Studies." Most oil-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 oil 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 oil-production brines are unknown. Reported rates of brine disposal at pond locations are available and could indicate relative potential for hydrocarbon contamination. Concentrations of oil-derived 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 of and, thus, the assessment of, nonpoint-source contamination. Factors considered particularly important in this study were land use, unsaturated-zone lithology, and type of well sampled.

Land Use

Regional ground-water quality was characterized in relation to associated predominant land-use areas. Contiguous areas of 3 to 10 mi^2 were identified for irrigated cropland, petroleum-production land, and virtually undeveloped rangeland (fig. 6). Such a size was considered

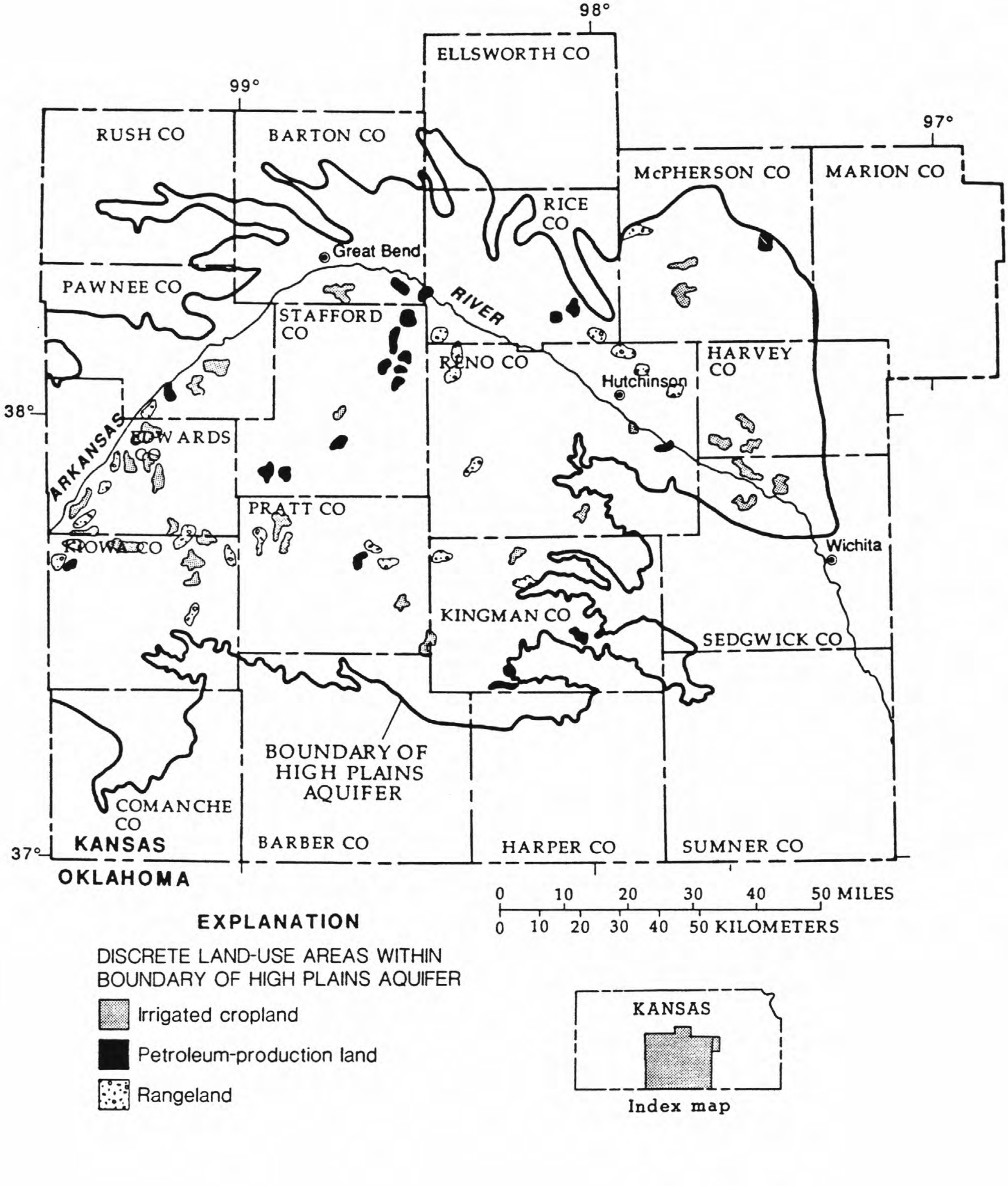


Figure 6. Discrete land-use areas delineated as basis for ground-water sampling.

appropriate for establishing relations 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). Consequently, during the last few decades, when most contamination has occurred, ground water would not have moved much beyond the discrete areas of several square miles; therefore, ground-water quality can be related to general areas of overlying land use. Delineation of areas in narrow, elongate 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 not to overlap and 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, the rangeland is mostly undeveloped and serves as a useful "control" category. "Baseline" conditions might be most closely represented by the areas of rangeland.

Landsat-satellite imagery for late July and early August of 1984 was selected as the primary basis 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 mid-summer development stages. Rangeland was mapped on the basis of textural and tonal qualities of the imagery, with reference to older (1974) land-use maps prepared by the U.S. Geological Survey (1979a, 1979b, 1979c, 1979d). 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 areas of irrigated cropland was not possible, however, because irrigated nd nonirrigated cropland are not differentiated on those maps.

For purposes of this study, areas of petroleum production were defined as areas of collective occurrences of inactive brine ponds. For practical purposes, "inactive" ponds might be considered as those generally of pre-1957 construction from which leakage could be a residual problem and, thus, of concern in this study. "Active" ponds mostly are those installed after regulations requiring proper construction were imposed (1957) and are unlikely to be sources of contamination; active ponds are much fewer, and most are used for temporary storage of brine before subsurface disposal through deep wells. Information was obtained from the Kansas Corporation Commission describing the location of inactive brine-disposal ponds. This information was helpful for this study because pond-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 sections of land containing inactive ponds were noted, and coverage was sufficient to define numerous areas of pond aggregations. Several sections of rangeland containing inactive brine ponds and forming a contiguous 3- to 10-mi^2 area defined an area of petroleum-production land.

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. 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 reportedly 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 based on existing information for the top 20 ft of the unsaturated zone below the soil (this interval comprises most of the unsaturated zone throughout the study area). The interpretation is based on about 80 gamma-ray logs and about 350 descriptive logs available for much of the area. Although reported lithologies were obtained from several different sources, generalized regional patterns of comparative clay thickness were mapped (fig. 7). Because of the scarcity of definitive log data in parts of the area and considerable local lithologic variability, the interpretation is shown as only two categories--"clayey" areas defined arbitrarily as containing at least 25 percent clay in the unsaturated zone, 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 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 stressed 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 High Plains aquifer in Nebraska (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, and a statistical sampling approach is used, as discussed in the "Sampling Design and Procedures" section.

The type of well sampled could be particularly important in areas of irrigated cropland where irrigation water is withdrawn from large-yield wells (generally greater 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 yield 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 of 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.

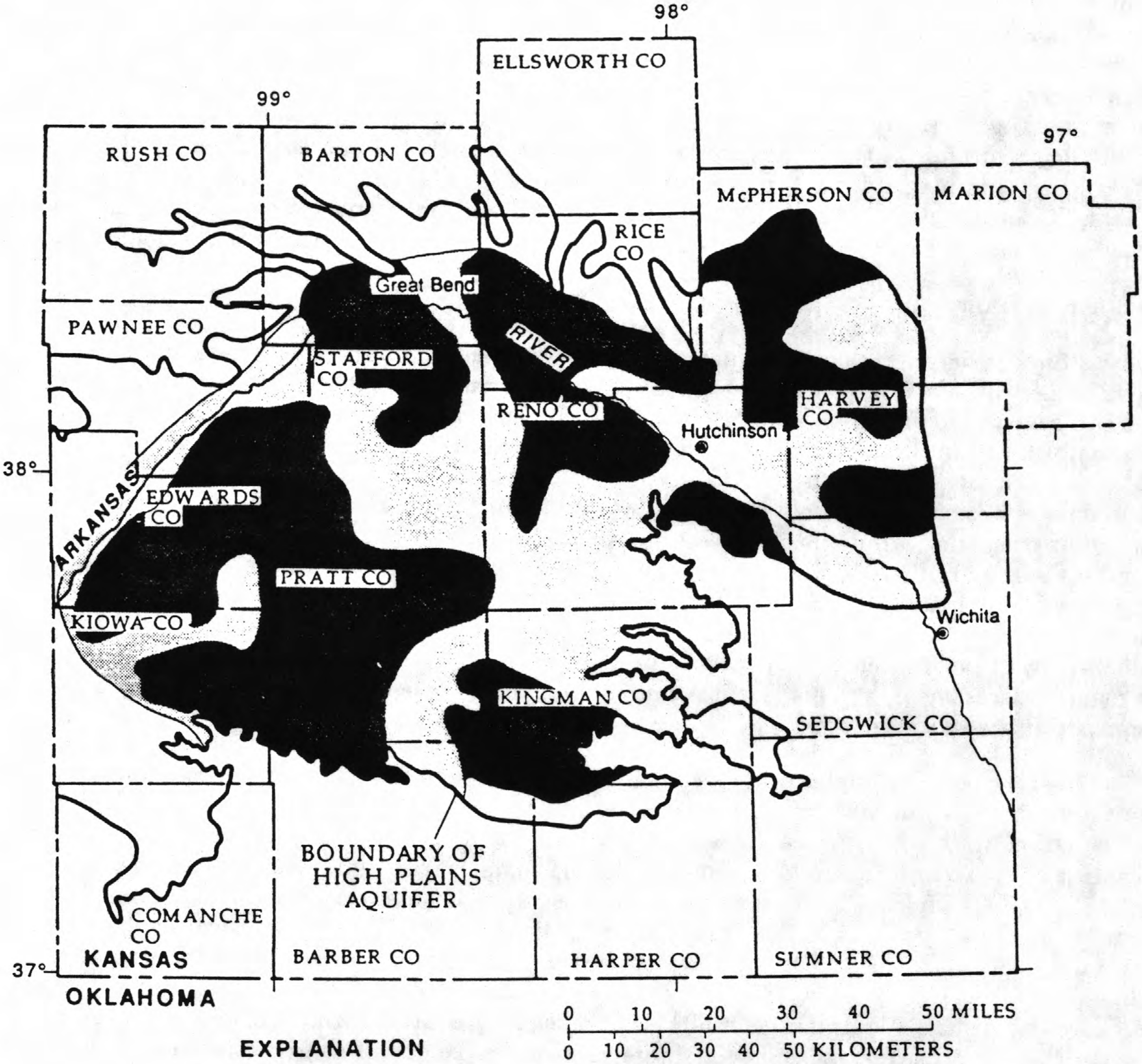
Sampling Design and Procedures

Characterization and evaluation of nonpoint-source contamination in the study area primarily is based on regional sampling of ground water to allow the evaluation of the significance of the selected factors previously discussed. Details of the sampling are described in the following sections.

Sampling Design

The basic framework for sampling consists of the discrete land-use areas shown in figure 6. These areas consist of 30 areas of irrigated cropland, 22 areas of petroleum-production land, and 22 areas of undeveloped rangeland.

The sampling plan was developed to enable several modes of statistical comparison in terms of ground-water quality (fig. 8). The primary comparison was among the three categories of land use.



EXPLANATION

REGIONALIZED UNSATURATED-ZONE LITHOLOGY

- "Clayey" area--More than 25 percent of top 20 feet of unsaturated zone is composed of clay
- "Sandy" area--25 percent or less of top 20 feet of unsaturated zone is composed of clay
- Unmapped area

Figure 7. Regionalized unsaturated-zone lithology.

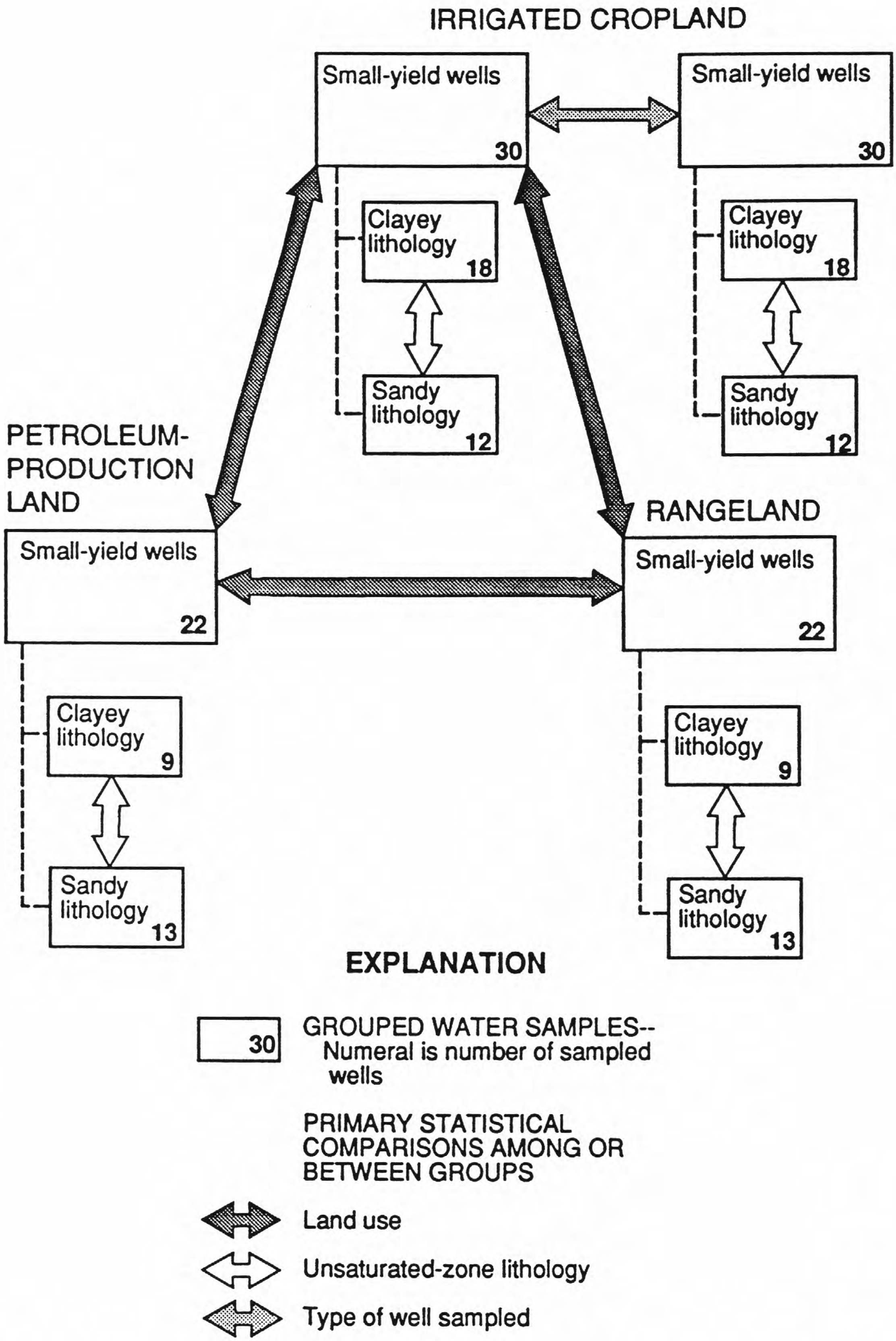


Figure 8. Groupings of water samples for statistical comparisons and number of sampled wells in each group.

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 land were compared with those from undeveloped rangeland for hydrocarbon presence or concentrations. Additionally, comparisons based on unsaturated-zone lithology were included to help recognize its effect on regional ground-water quality. These comparisons, based on land use and unsaturated-zone lithology, were made using samples only from corresponding well types to minimize the effects of well location and yield. 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.

In accordance with the rationale just described, one small-yield well in each of the discrete land-use areas (for all categories of land use) was selected randomly for sampling, and one irrigation well in each area of irrigated cropland was selected randomly for sampling. Statistically, the population from which each well was selected in each discrete land-use area consisted of all wells (small-yield or irrigation, as appropriate) in that area for which information is available. This information consists of driller-submitted records for wells constructed after 1975. The record typically includes location, well depth, construction data, and driller's log. This record enabled verification that a given well was completed in the High Plains aquifer and provided information that could be pertinent to interpreting water-quality results. Although water-quality characteristics could vary with depth of 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 could not be sampled for some other reason, a different well was selected according to the random-number assignment. In some areas having only a few wells with recorded information, inability to sample any of the candidate wells necessitated selecting a well arbitrarily in the field for sampling. 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, and began a few weeks after the irrigation season (normally, June-August) had begun. Each well was sampled once. Samples were collected only from wells that could be pumped long enough to ensure that untreated water was being obtained directly from the aquifer. 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, Colorado, for analysis.

At all sampled wells, onsite determinations were made for specific conductance, pH, water temperature, and alkalinity. Also in all cases, samples were collected for laboratory analyses of the major inorganic ions and other inorganic constituents of interest.

Requested laboratory analyses for organic constituents depended on the land-use area in which the sample was collected. In areas of irrigated cropland and rangeland, samples also were collected for analysis 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 areas of petroleum-production land 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 attempt identification of the organic compounds detected by the GC/FID scan.

Statistical Testing

Data were analyzed by statistical hypothesis tests to identify relations between ground-water quality and land use or other selected factors. Statistical distributions for most chemical constituents were non-normal and positively skewed, and nonparametric procedures were used for statistical testing. The tests applied are described in the following paragraphs.

The two-tailed Wilcoxon-Mann-Whitney rank-sum test (Iman and Conover, 1983) allows statistical comparison of two groups of data. For a given property or constituent, the null hypothesis can be stated that the median values or concentrations of the two groups are equal at a specified confidence level. The alternative hypothesis can be stated that they are not equal. Rank-sum test results, in addition to acceptance or rejection of the null hypothesis at the specified confidence level, indicate at what confidence level the null hypothesis would be rejected. This confidence level provides 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 presented in terms of presence or absence. The null hypothesis for this test can be stated 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 can be stated that there is an association.

RESULTS OF DATA ANALYSIS AND STATISTICAL TESTING

Results of water-quality analyses are given 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. Interpretations of the results are presented in "Discussion of Results."

Inorganic Constituents

Results of the water-quality analyses show that most ground water in the sampled areas contains dissolved solids of about 100 to 600 mg/L (milligrams per liter) and that the water is generally hard to very hard (greater than 120 mg/L as $CaCO_3$). The water is commonly a calcium bicarbonate type, but sodium and chloride are predominant ions in some areas.

Comparisons by Land Use

Examination of some of the statistical data, by land-use area (table 1), indicates that some variation in general ground-water quality might be related to prevailing land use. Boxplots arranged according to land-use area (fig. 9) allow clearer, visual comparisons between medians and overall data distributions. For example, 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 (Wilcoxon-Mann-Whitney) was used to compare each pair of the three land-use areas, in terms of median property values (pH, water temperature, hardness, and alkalinity) and median inorganic-constituent concentrations. The results are illustrated by plotting test confidence levels that exceed 80 percent (fig. 10). For several properties or constituents, these confidence levels exceeded 95 percent, a commonly cited level of confidence that is used in this report

Table 1. *Summary of selected water-quality data grouped according to land-use areas*

[Based on data from small-yield wells; units are in milligram per liter; <, less than]

Property or constituent	Irrigated cropland			Petroleum-production land			Rangeland		
	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median
Hardness, as $CaCO_3$	520	110	180	570	90	190	710	31	130
Alkalinity, total as $CaCO_3$	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

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

Separate comparisons based on unsaturated-zone lithology were made for each land-use category. Because each land-use area is located within a regionally delineated area of either "clayey" or "sandy" unsaturated-zone lithology (as described previously in the "Study Approach and Methods" section), samples from each land-use area were grouped further on this basis. Boxplots of concentrations of major constituents in clayey and sandy areas generally appeared to be similar within any given land-use category. An example set of boxplots is shown for irrigated-cropland data in figure 11.

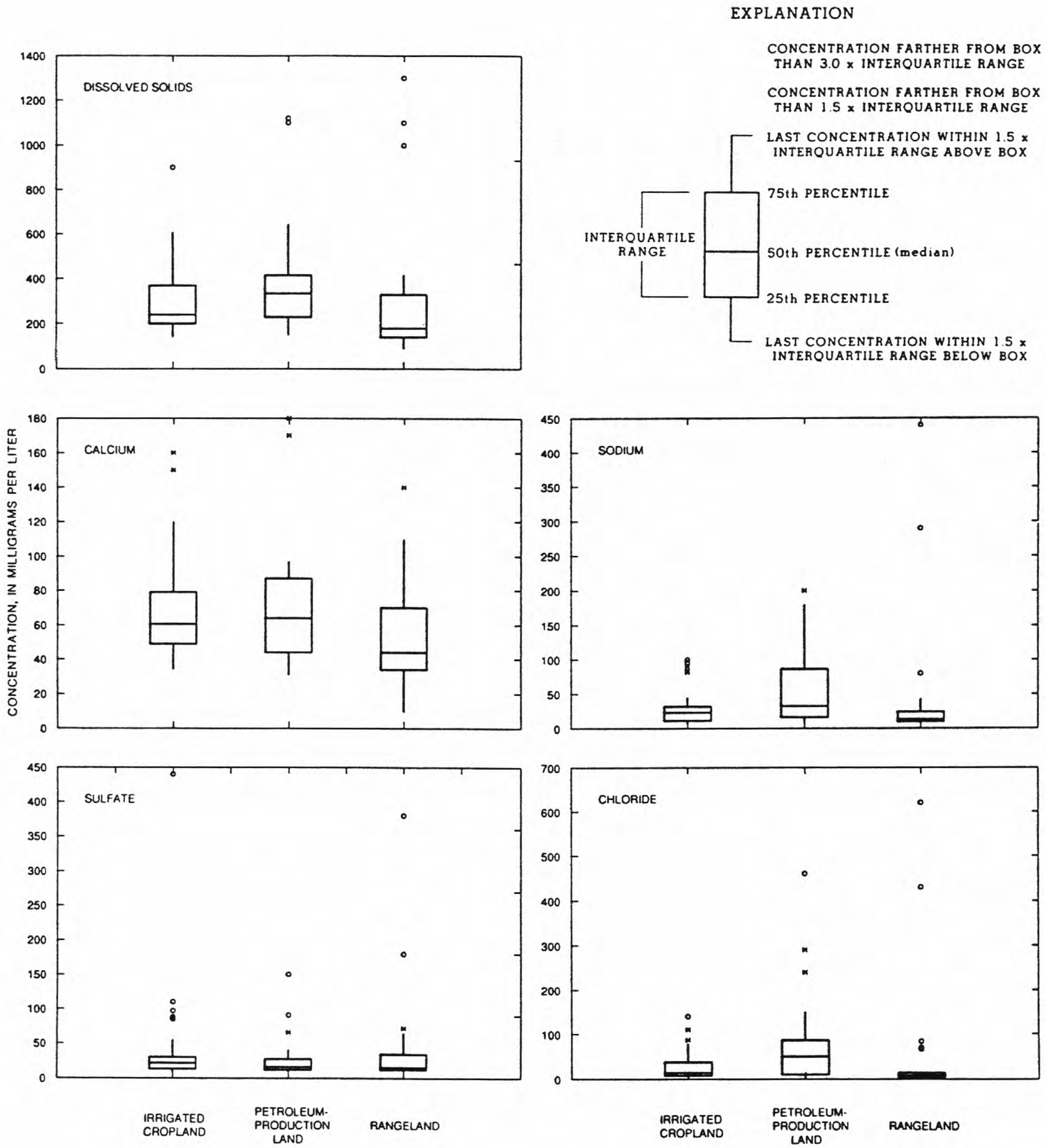


Figure 9. Concentrations of dissolved solids and selected major ions in water samples from small-yield wells grouped according to land-use area (based on 30 irrigated-cropland samples, 22 petroleum-production-land samples, and 22 rangeland samples).

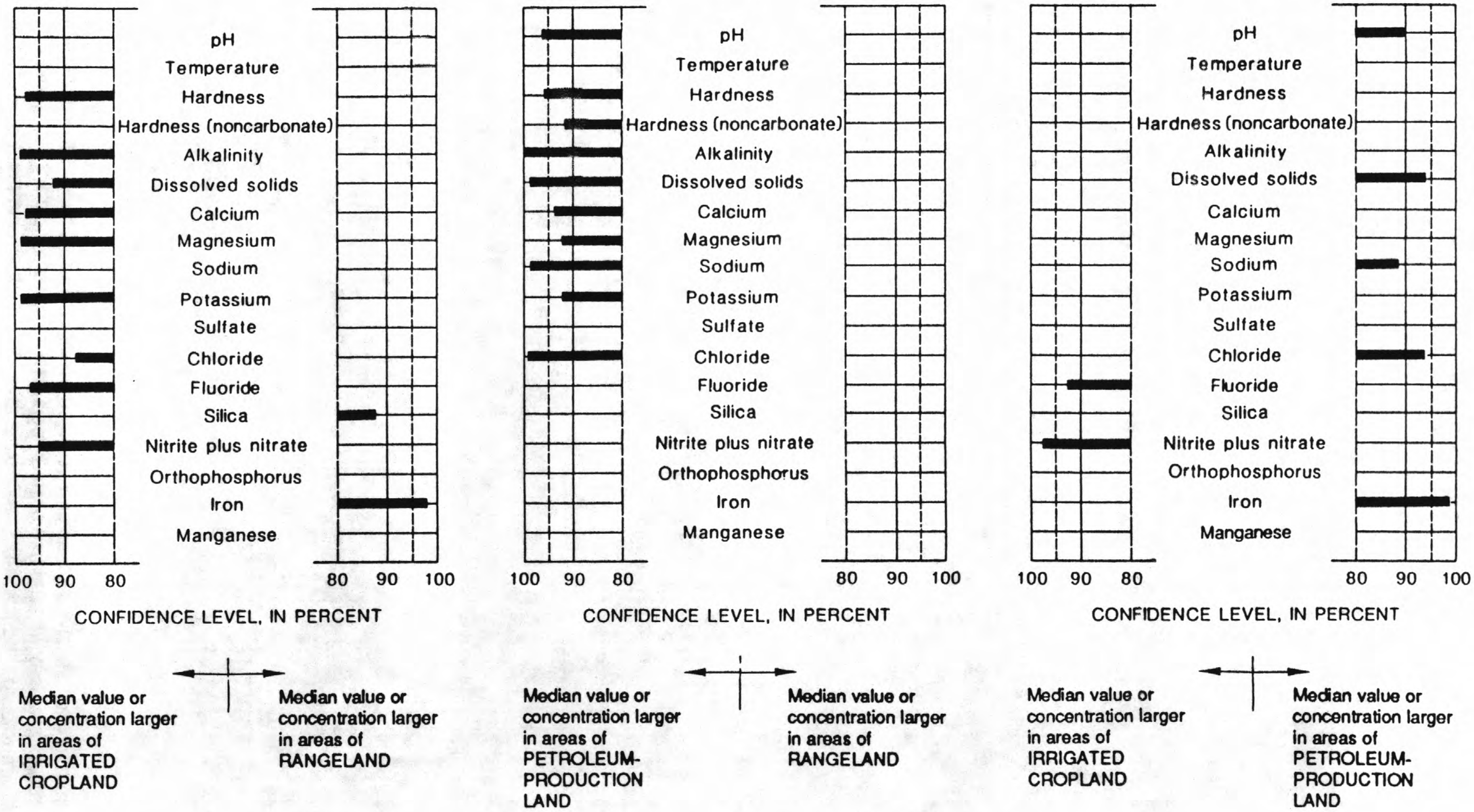


Figure 10. Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in different land-use areas, based two-tailed Wilcoxon-Mann-Whitney rank-sum tests.

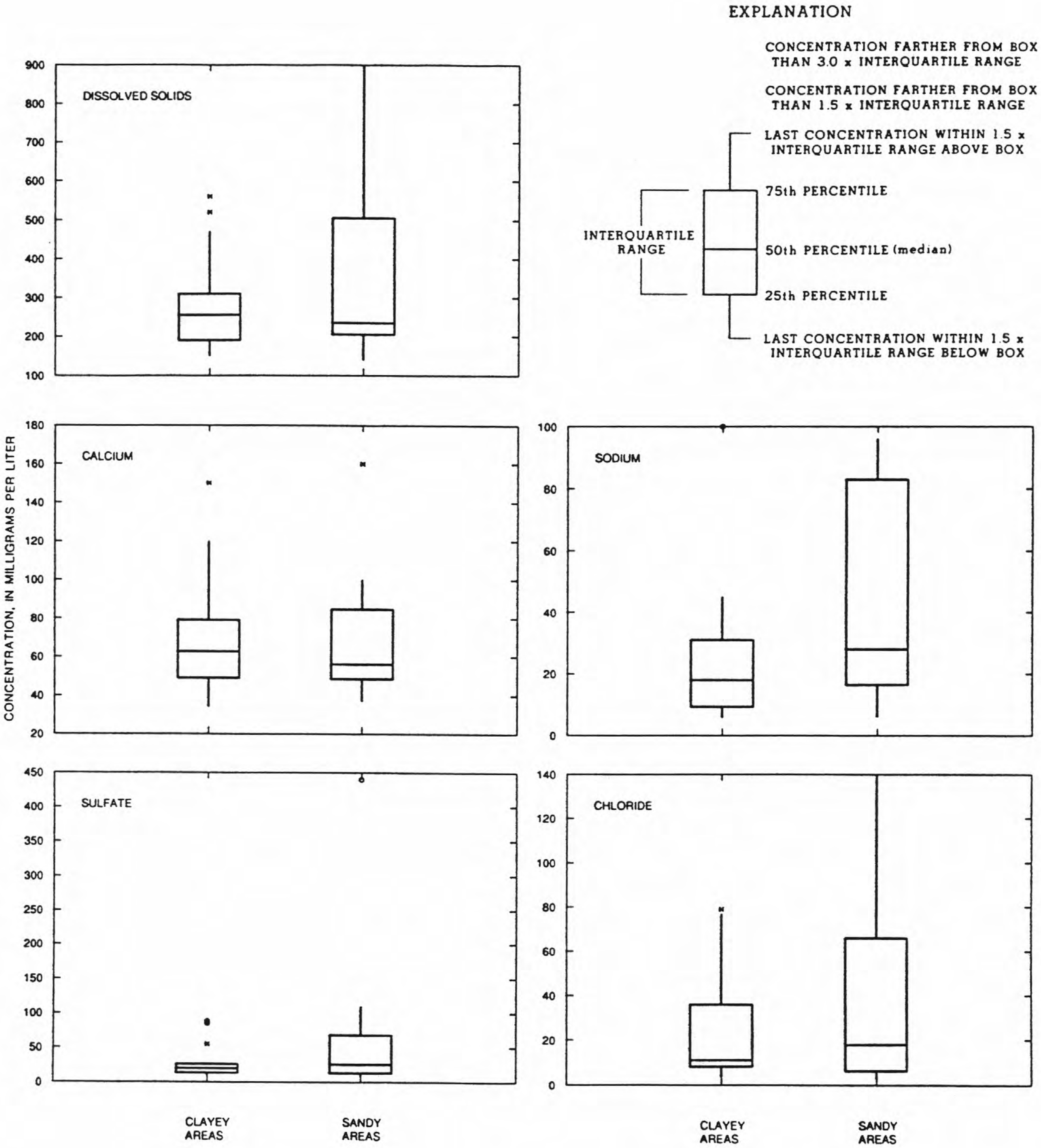


Figure 11. Concentrations of dissolved solids and selected major ions in water samples from small-yield wells in areas of irrigated cropland, grouped according to unsaturated-zone lithology (based on 18 clayey-area samples and 12 sandy-area samples).

The rank-sum test was used to test for equality of individual water-quality characteristics between clayey and sandy unsaturated-zone areas. Results indicated few statistically significant differences (fig. 12), none of those being major constituents. In areas of irrigated cropland, concentrations of silica and orthophosphorus were significantly larger in clayey areas than in sandy areas. In areas of petroleum-production land, no significant differences were evident between clayey and sandy areas. In areas of rangeland, iron concentrations were indicated to be larger in clayey areas than in sandy areas at the 94-percent confidence level.

Testing of the data representing only irrigation wells in the areas of irrigated cropland revealed two significant differences (fig. 13): (1) pH was greater in samples from the 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 according to subdivisions of unsaturated-zone lithology. For the comparison of irrigated-cropland samples with rangeland samples (fig. 10), it was previously noted that concentrations of several major constituents were significantly larger in the irrigated-cropland samples. Rank-sum tests applied only to the data from areas of clayey unsaturated-zone lithology indicate significant differences only for concentrations of nitrite plus nitrate (larger in areas of irrigated cropland) and iron (larger in areas of rangeland) (fig. 14A). Most of the previously noted significant differences, however, remained significant when tests were applied to the data from areas of sandy unsaturated-zone lithology (fig. 14A).

The same procedure was applied for the other two comparisons between land-use areas, petroleum-production land with rangeland, and irrigated cropland with petroleum-production land. As with the comparisons of irrigated cropland with rangeland, most significant differences in the comparisons of petroleum-production land with rangeland were in the areas of sandy unsaturated-zone lithology (fig. 14B). The contrast between areas of clayey and sandy unsaturated-zone lithologies was not evident in the comparisons of irrigated cropland with petroleum-production land (fig. 15). The comparisons of these two land-use areas not divided according to unsaturated-zone lithology (fig. 10) indicated significantly larger concentrations of nitrite plus nitrate in areas of irrigated cropland and significantly larger concentrations of iron in the areas of 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. Boxplots of concentrations of major constituents, grouped according to type of well sampled, show no obvious contrasts between data from small-yield wells and data from irrigation wells (fig. 16).

The rank-sum test was used to compare values and concentrations in samples from small-yield wells to values and concentrations in samples from irrigation wells within the areas of irrigated cropland (fig. 17). Two significant differences are indicated; values for temperature and concentrations of orthophosphorus are significantly larger in the samples from small-yield wells. Significant differences were not indicated for any other constituents.

Pesticides

All samples except those from areas of petroleum-production land were analyzed for pesticides (triazine and other nitrogen-containing herbicides and chlorophenoxy-acid herbicides). Of the 82 samples for which these pesticides were analyzed, 12 samples contained at least one detectable pesticide. The number of detections for each pesticide is shown in table 2, grouped according to land-use area, unsaturated-zone lithology, and type of well sampled. It is apparent from this tabulation that frequency of pesticide detection shows a relation to land use; only one detection is noted for

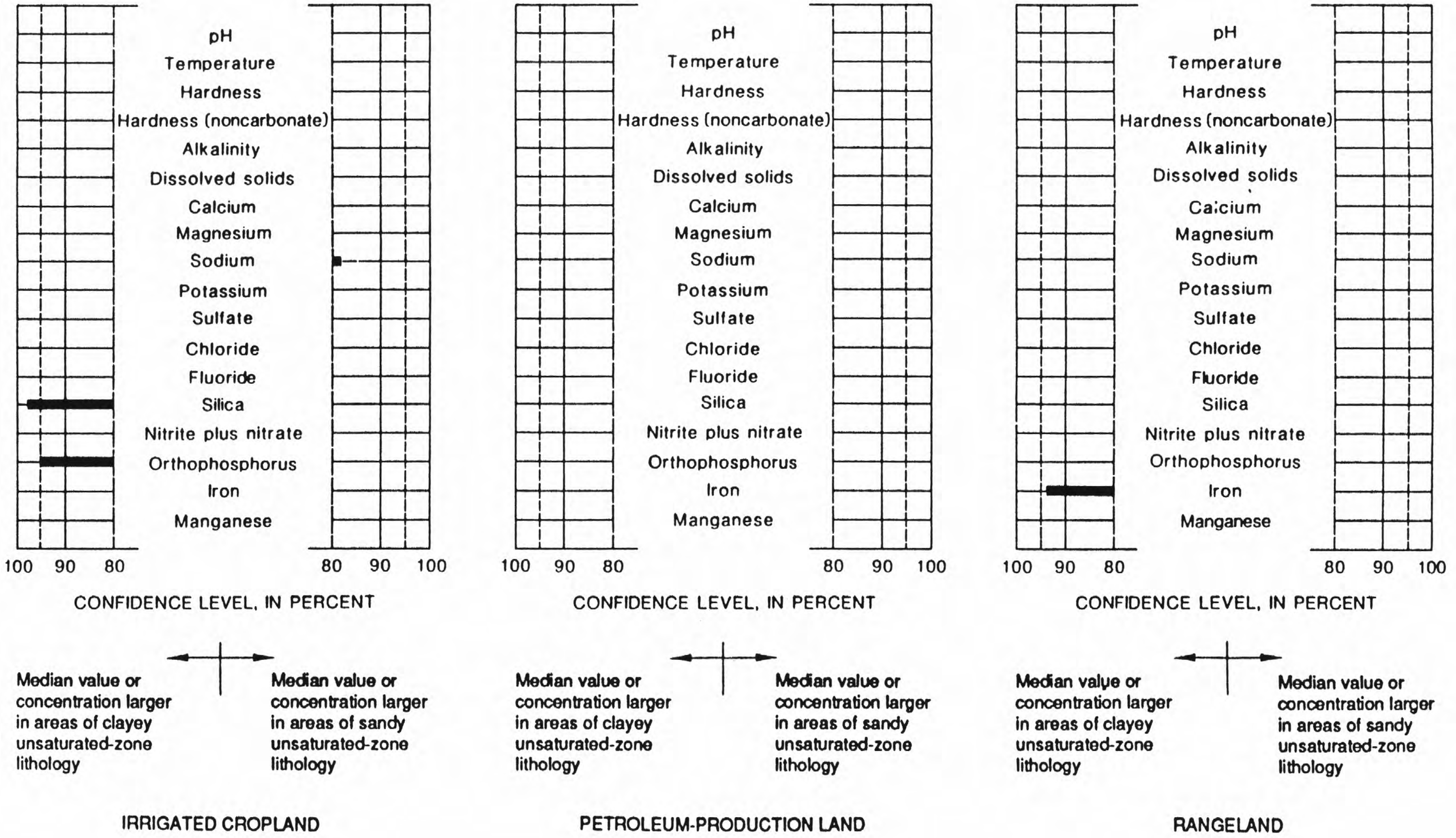


Figure 12. Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in areas of clayey and sandy unsaturated-zone lithology, grouped according to land-use areas and based on two-tailed Wilcoxon-Mann-Whitney rank-sum tests.

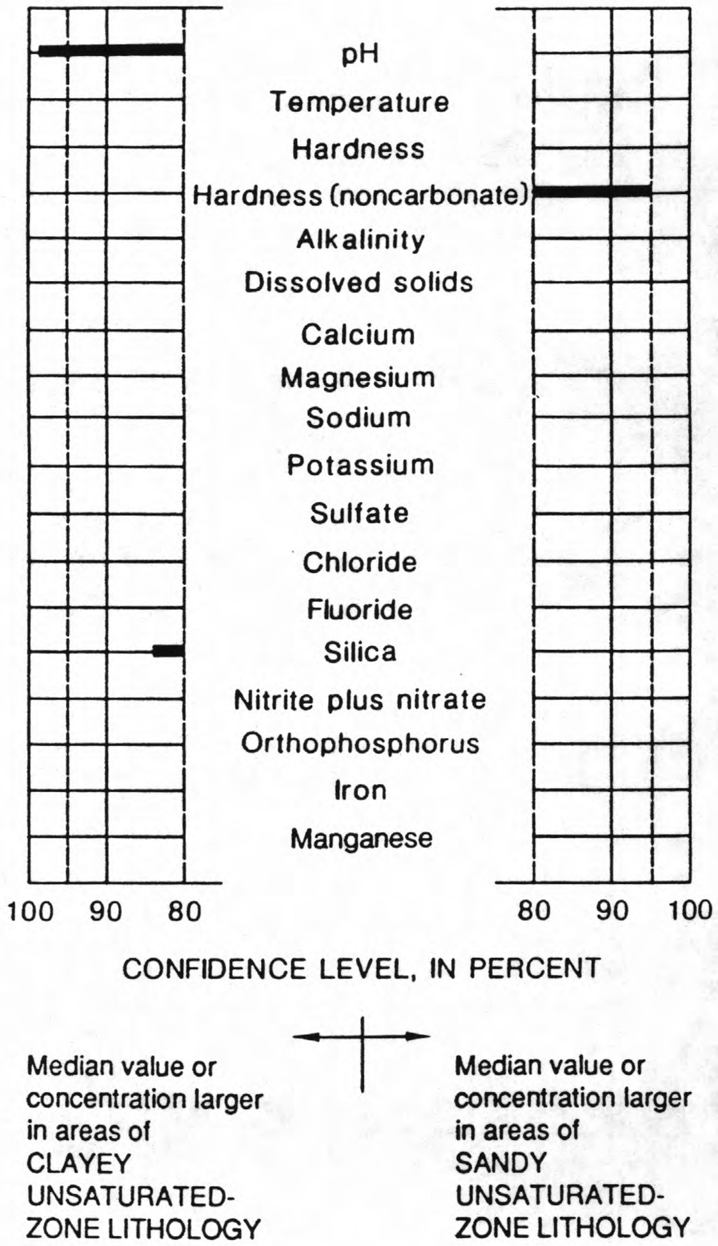
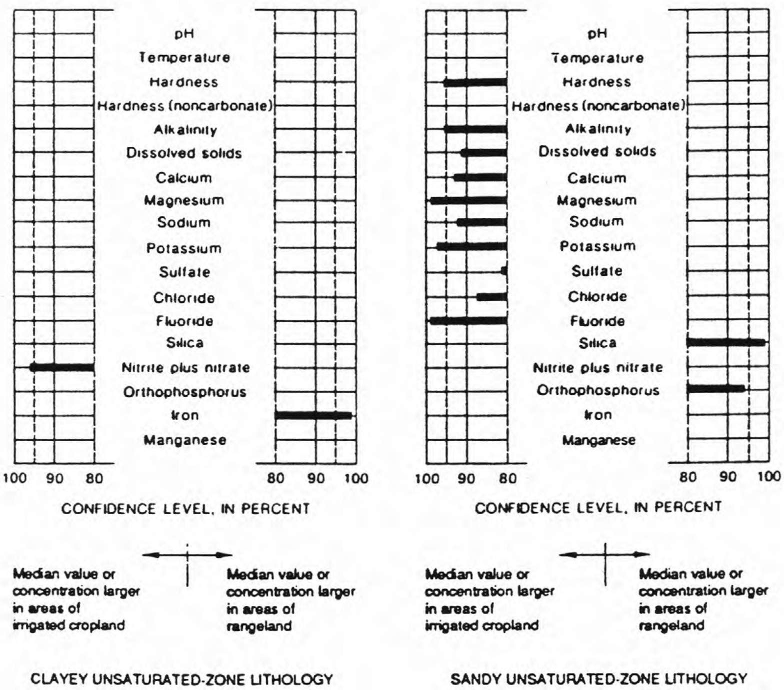


Figure 13. Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from irrigation wells in areas of clayey and sandy unsaturated-zone lithology, based on two-tailed Wilcoxon-Mann-Whitney rank-sum tests.

rangeland samples. However, any association between pesticide detections and either the unsaturated-zone lithology or the type of well sampled is not evident.

The few numbers 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. Atrazine is the only pesticide that was detected more than twice (8 detections) and was present in the largest concentration (3.8 µg/L). The remainder of the "Pesticides" section will be limited to an analysis of atrazine occurrence. The areal distribution of detections and nondetections of atrazine are shown in figure 18.

A. Irrigated cropland and rangeland



B. Petroleum-production land and rangeland

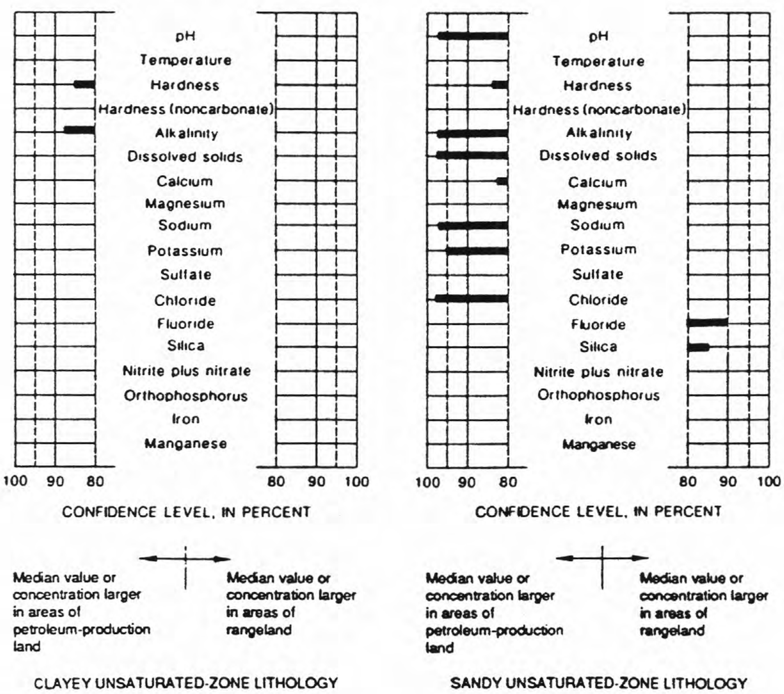


Figure 14. Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in different land-use areas, grouped according to unsaturated-zone lithology and based on two-tailed Wilcoxon-Mann-Whitney rank-sum tests.

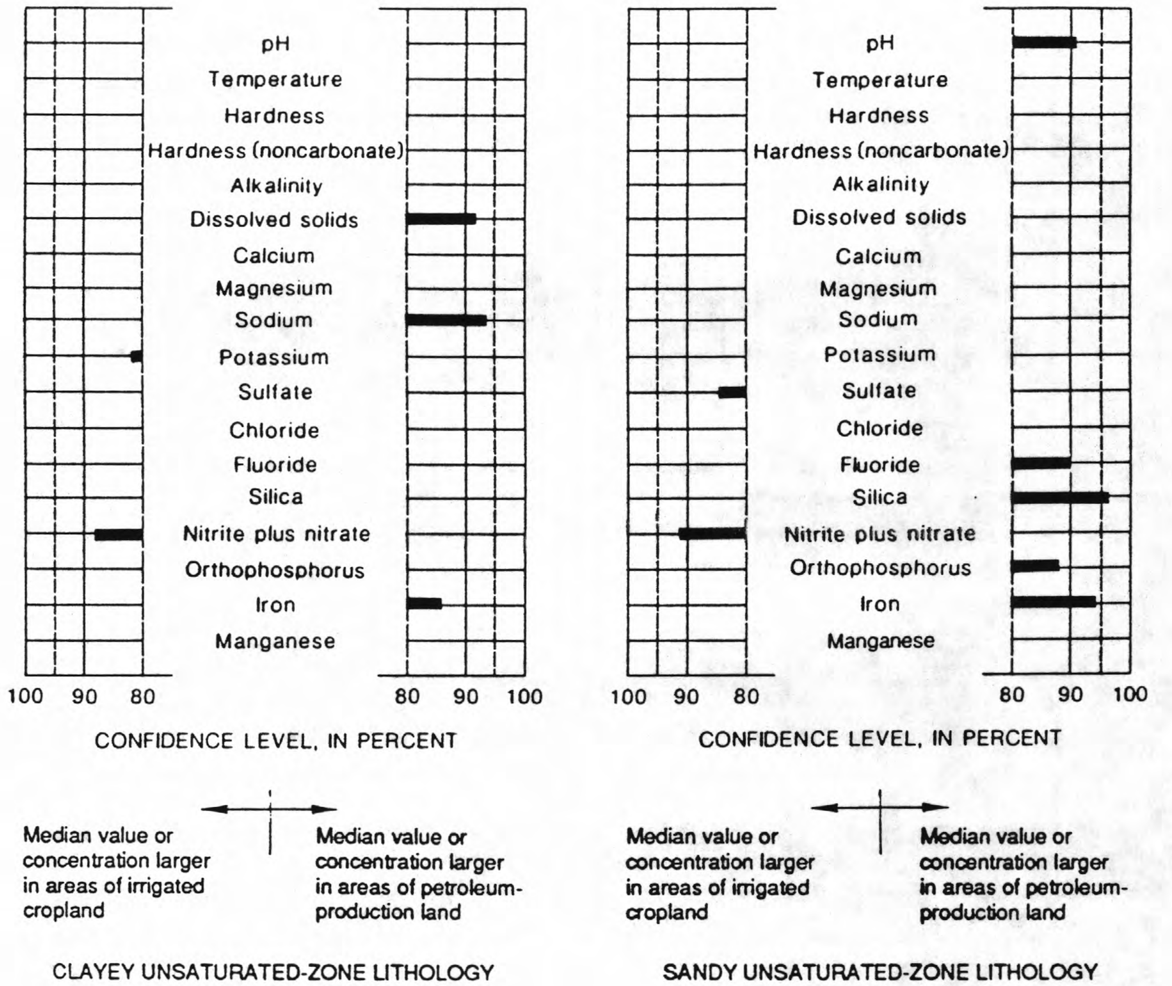


Figure 15. Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells in areas of irrigated cropland and petroleum-production land, grouped according to unsaturated-zone lithology and based on two-tailed Wilcoxon-Mann-Whitney rank-sum tests.

Comparisons by Land Use

The contingency-table test was used to compare the frequency of atrazine detection beneath irrigated cropland (4 out of 30 samples, according to table 2) to the frequency of detection beneath rangeland (1 out of 22 samples). In accordance with the statistical-comparison framework (fig. 8), data from only small-yield wells but from both types of unsaturated-zone lithology were used. The test concluded a 71-percent confidence level, demonstrating no significant association between atrazine occurrence and use.

Comparisons between land-use areas also were made on the same information divided by unsaturated-zone lithology. No significant difference was indicated between land-use areas with a clayey unsaturated-zone lithology. However, a significant difference (95-percent confidence level) was indicated for areas with a sandy unsaturated-zone lithology; atrazine was detected with greater frequency beneath irrigated cropland (3 out of 12 samples) than beneath rangeland (0 out of 13 samples).

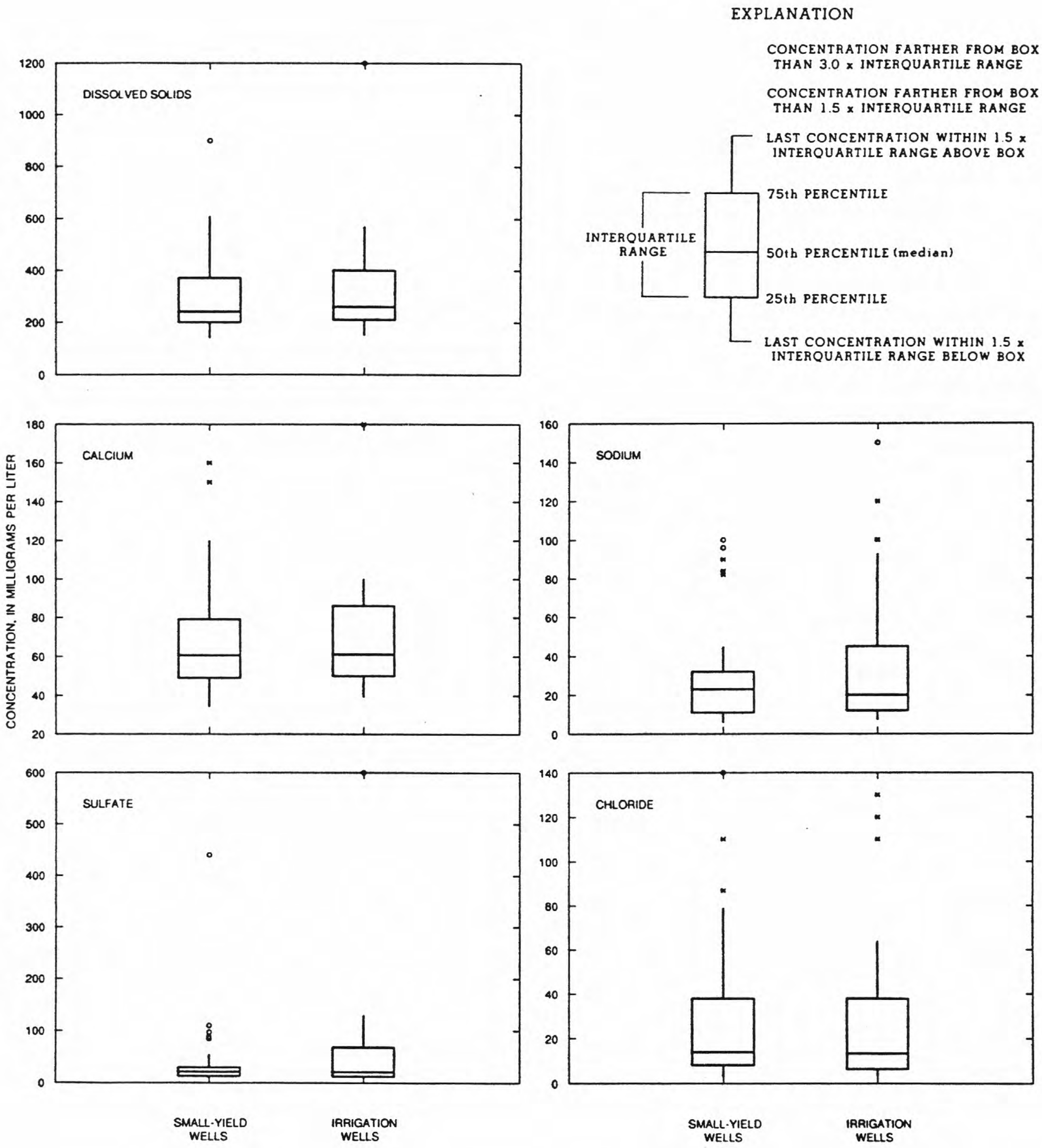


Figure 16. Concentrations of dissolved solids and selected major ions in water samples from wells in areas of irrigated cropland, grouped according to types of well sampled (based on 30 small-yield well samples and 30 irrigation-well samples).

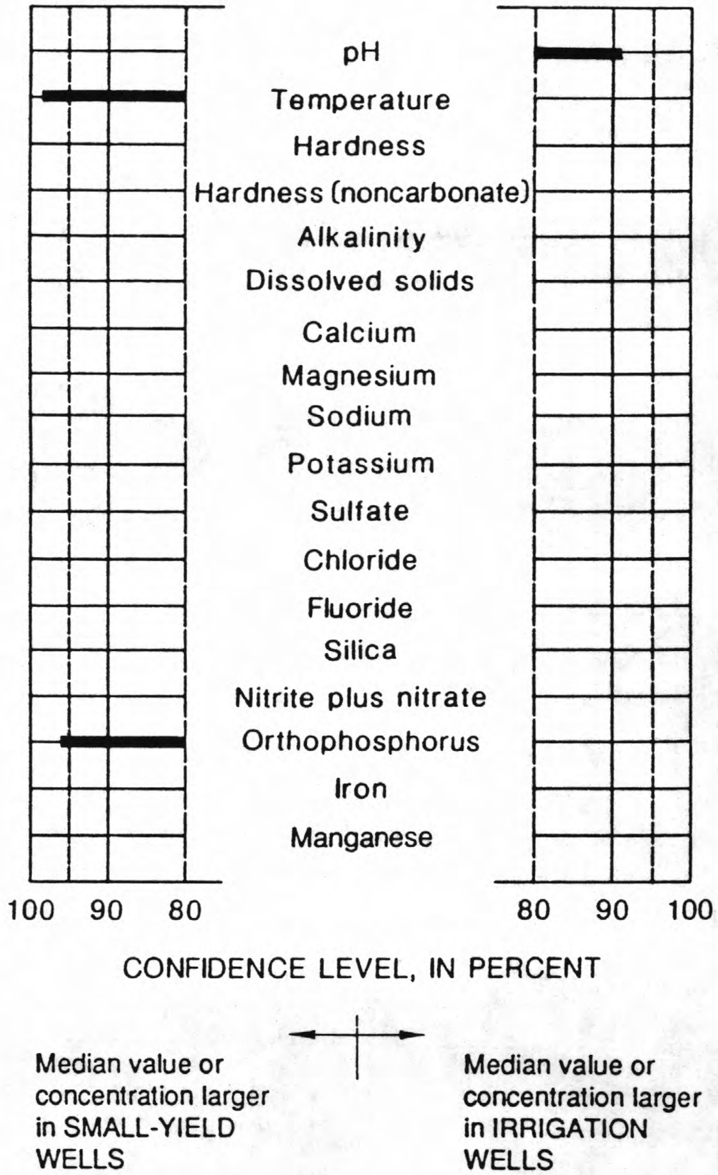


Figure 17. Confidence levels of differences between median property values or inorganic-constituent concentrations in water samples from small-yield wells and irrigation wells in areas of irrigated cropland, based on two-tailed Wilcoxon-Mann-Whitney rank-sum tests.

Comparisons by Unsaturated-Zone Lithology

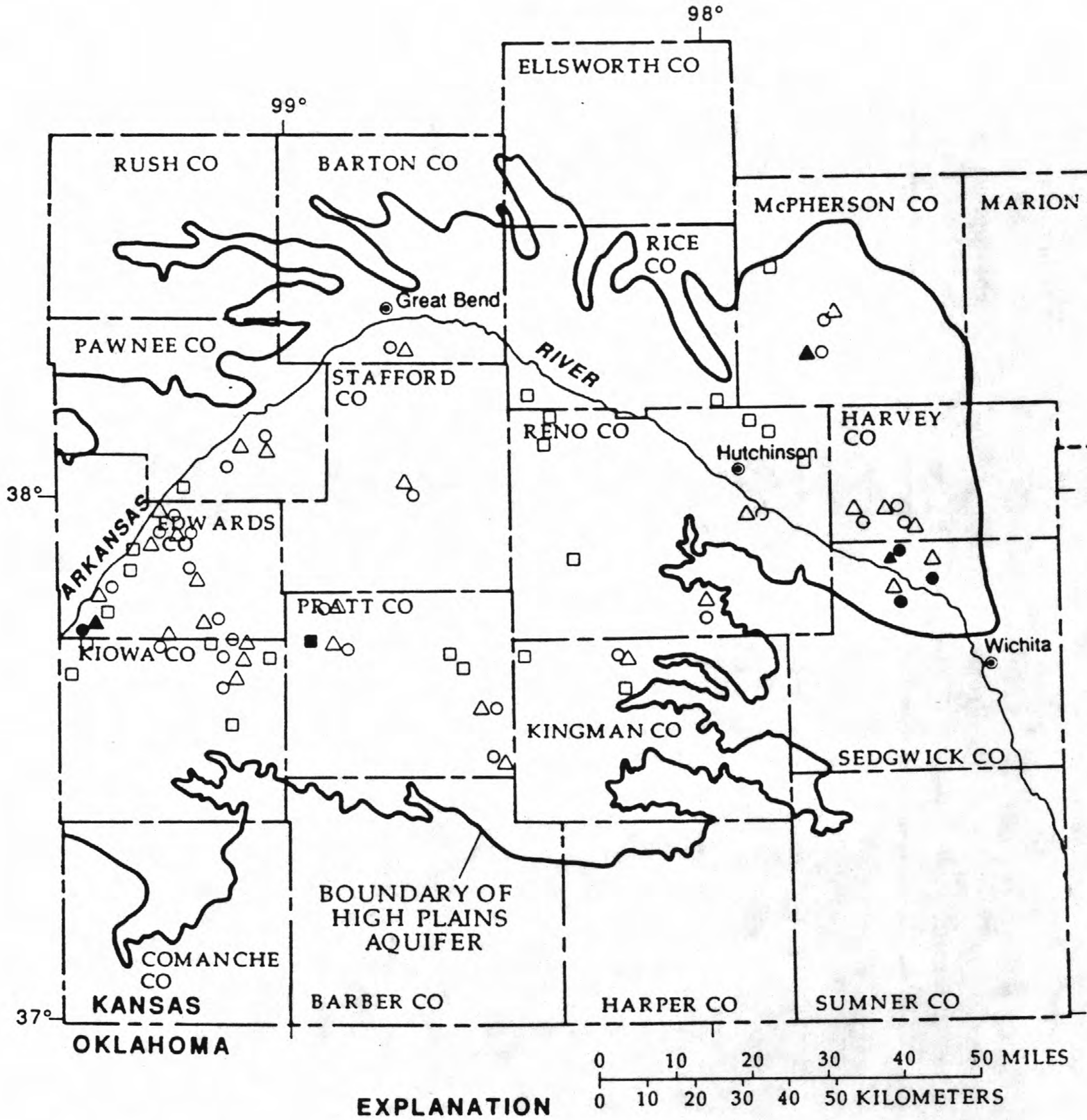
Contingency-table tests were used to make comparisons of the frequencies of atrazine detection in areas of irrigated cropland according to unsaturated-zone lithology. Comparisons indicated no significant associations with this factor. Testing of the results from rangeland for this factor was not appropriate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

Comparisons by Type of Well Sampled

The contingency-table test was used to compare the frequency of atrazine detection in samples from small-yield wells to the frequency of detection in samples from irrigation wells (using results from areas of irrigated cropland). The test concluded a 69-percent confidence level, demonstrating no significant association between atrazine occurrence and type of well sampled. Testing of the data

Table 2. *Frequency of detections of pesticides in ground-water samples grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled*

Land-use area (type of well sampled)	Number of samples	Alachlor	Atrazine	Meto-lachlor	Propa-zine	Triflu-ralin	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



EXPLANATION

● ○ SAMPLE FROM IRRIGATED CROPLAND--Small-yield (domestic or stock) well. Solid circle indicates concentration greater than atrazine detection level; open circle indicates concentration less than atrazine detection level

▲ △ SAMPLE FROM IRRIGATED CROPLAND--Large-yield (irrigation) well. Solid triangle indicates concentration greater than atrazine detection level; open triangle indicates concentration less than atrazine detection level

■ □ SAMPLE FROM RANGELAND--Small-yield (domestic or stock) well. Solid square indicates sample concentration greater than atrazine detection level; open square indicates concentration less than atrazine detection level

(NOTE: Atrazine detection level is 0.10 microgram per liter)

Figure 18. Location of detections and nondetections of atrazine in ground-water samples.

divided according to unsaturated-zone lithology likewise indicated no significant association with type of well sampled for areas of either clayey or sandy unsaturated-zone lithology.

Hydrocarbons

GC/FID scans were made on methylene-chloride extracts of the 22 samples from areas of petroleum-production land and of 23 samples from areas of 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 specification of compounds. Therefore, this effort focused on the output from the GC/FID method, mainly GC/FID chromatograms, which were analyzed in several ways to evaluate hydrocarbon occurrence in ground water in the study area.

Chromatogram Interpretation

An example 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.

Interpretation of GC/FID scan results was based on analysis of the chromatograms themselves and information from the laboratory report. Descriptions of this information are given in the following paragraphs, and comparisons based on the information are discussed in succeeding sections.

Total concentrations of methylene-chloride-extractable compounds in a sample were estimated from the total area under the peaks on a chromatogram (excluding surrogate and internal-standard compounds added to the sample at the laboratory). These estimates (concentrations as perdeuteronaphthalene) were reported by the laboratory and ranged from 3.3 to 14 μg/L in samples from areas of petroleum-production land and from 1.2 to 15 μg/L in samples from areas of rangeland.

Frequencies of occurrence of individual compounds also were studied 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 the laboratory-blank samples (fig. 20). Although arbitrary, this approach was presumed to identify compounds truly present in the collected sample.

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 area under the peaks of the chromatograms. Boxplots (fig. 22) illustrate very similar distributions between total concentrations of organic compounds in samples from areas of petroleum-production land and samples from areas of rangeland, although median and quartile concentrations are larger in the petroleum-production-land samples than in the rangeland samples. The distributions were non-normal and positively skewed; the rank-sum test was applied for statistical testing. The conclusion of equality was accepted at the 95-percent confidence level, the difference being concluded at the 84-percent confidence level.

The frequency of occurrence of individual peaks (specific compounds) also was compared between two land-use areas (fig. 23), and the descriptions reveal only minor differences. The samples

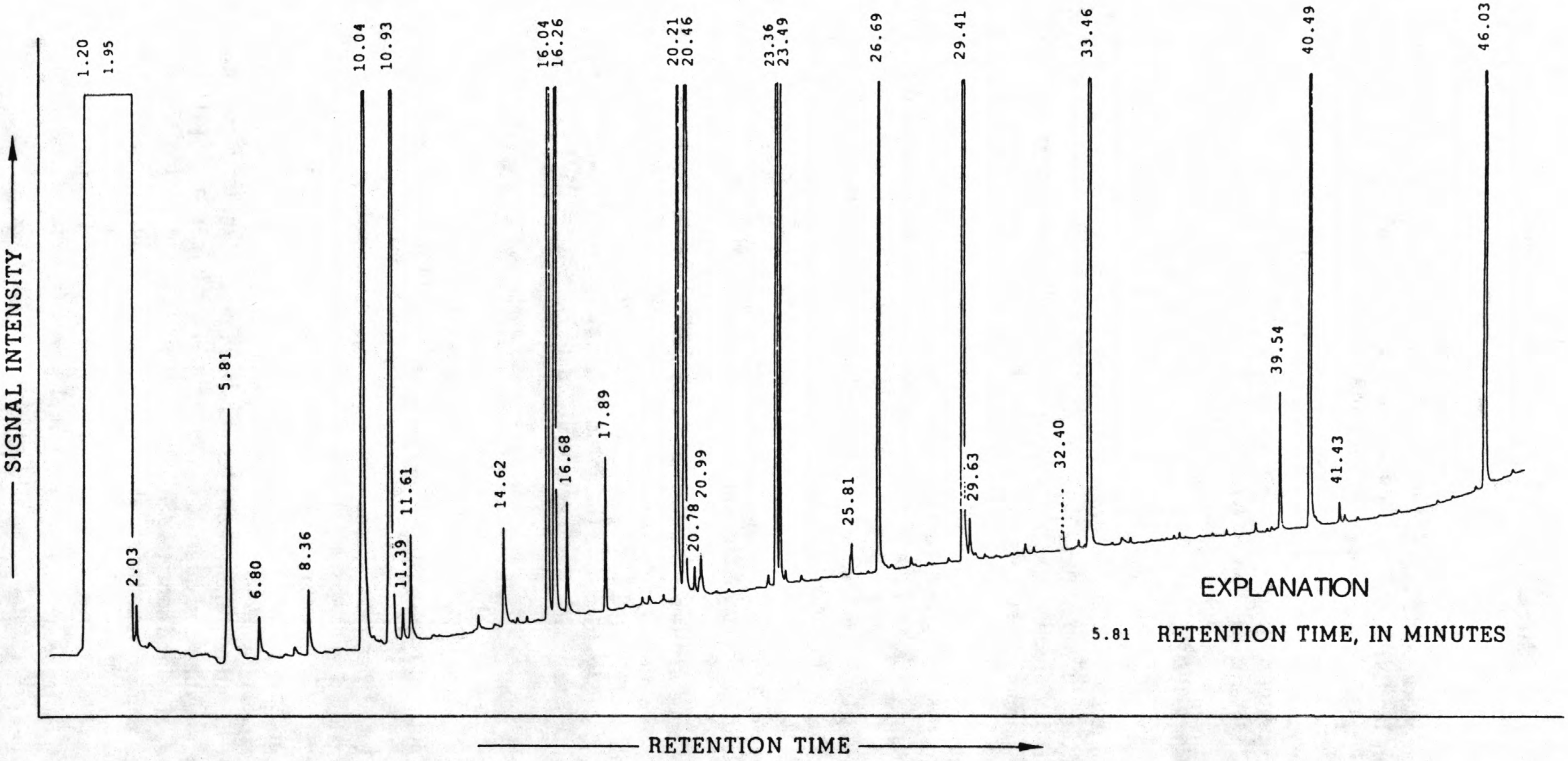


Figure 19. Example of chromatogram produced from analysis of ground-water sample by gas chromatography with flame-ionization detection (GC/FID).

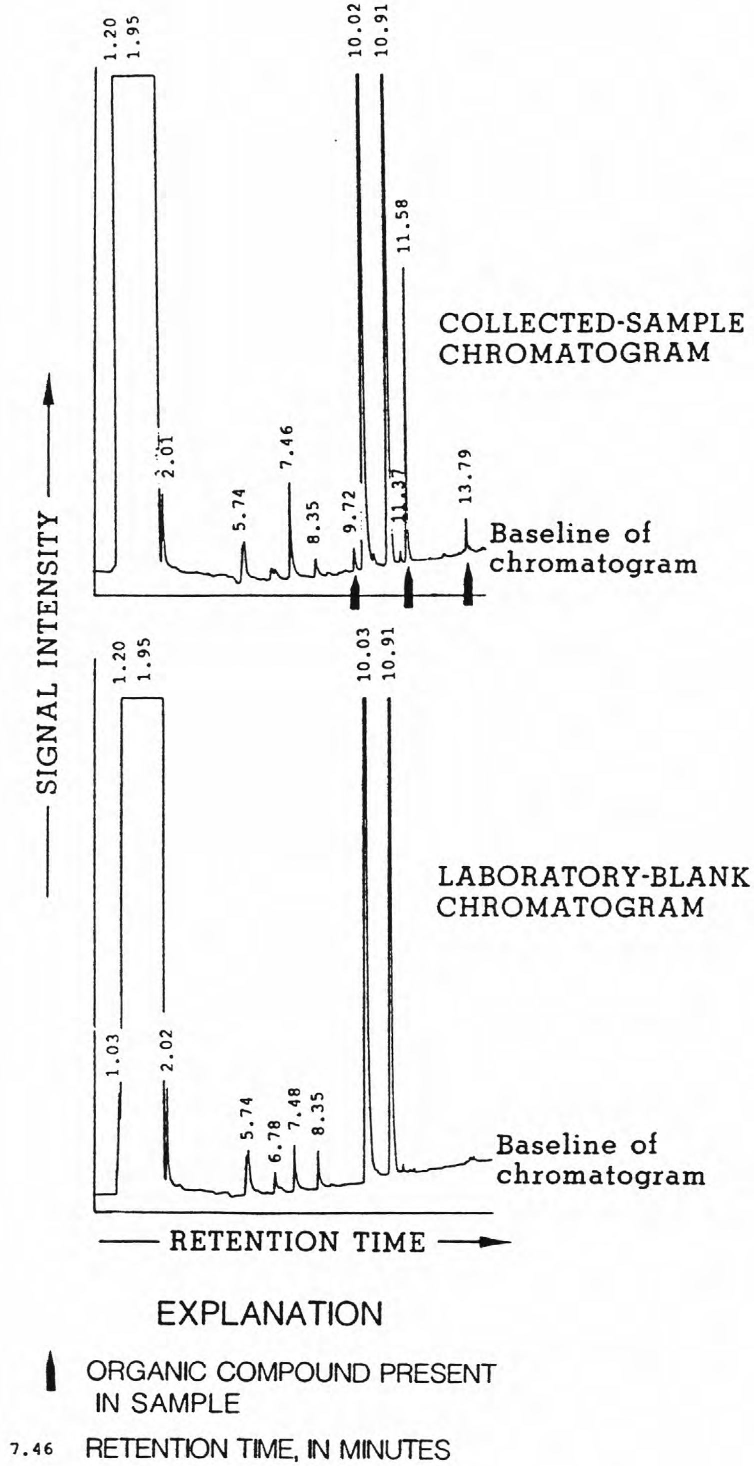


Figure 20. Chromatograms for a collected sample and a laboratory blank that were compared to identify peaks representing organic compounds present in ground water.

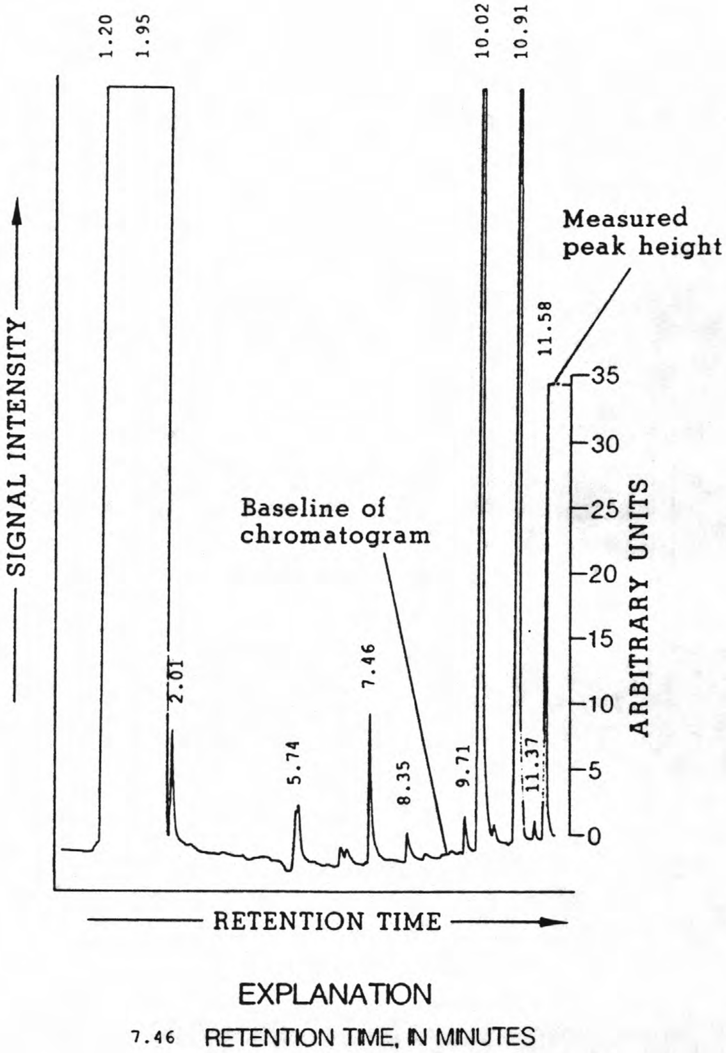


Figure 21. Chromatogram for a collected sample and method of measuring peak height to represent relative concentration of organic compound.

from areas of petroleum-production land 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 areas of rangeland. Contingency-table analyses were used to test for association between land use and presence or absence of individual compounds. Significant associations (95-percent confidence level) were indicated for two specific compounds. The compounds with retention times of 13.79 and 16.68 minutes occurred more frequently in samples from areas of petroleum-production land than in those from areas of rangeland (fig. 23). At the 92-percent confidence level, the compounds with retention times of 19.23, 21.83, and 30.93 minutes occurred more frequently in samples from areas of rangeland than in those from areas of petroleum-production land (fig. 23).

Relative peak heights for specific compounds also provided a means of comparison between land-use areas by using 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 the areas of petroleum-production land than in samples from the areas of rangeland. This compound is one of the two compounds detected with a significantly greater

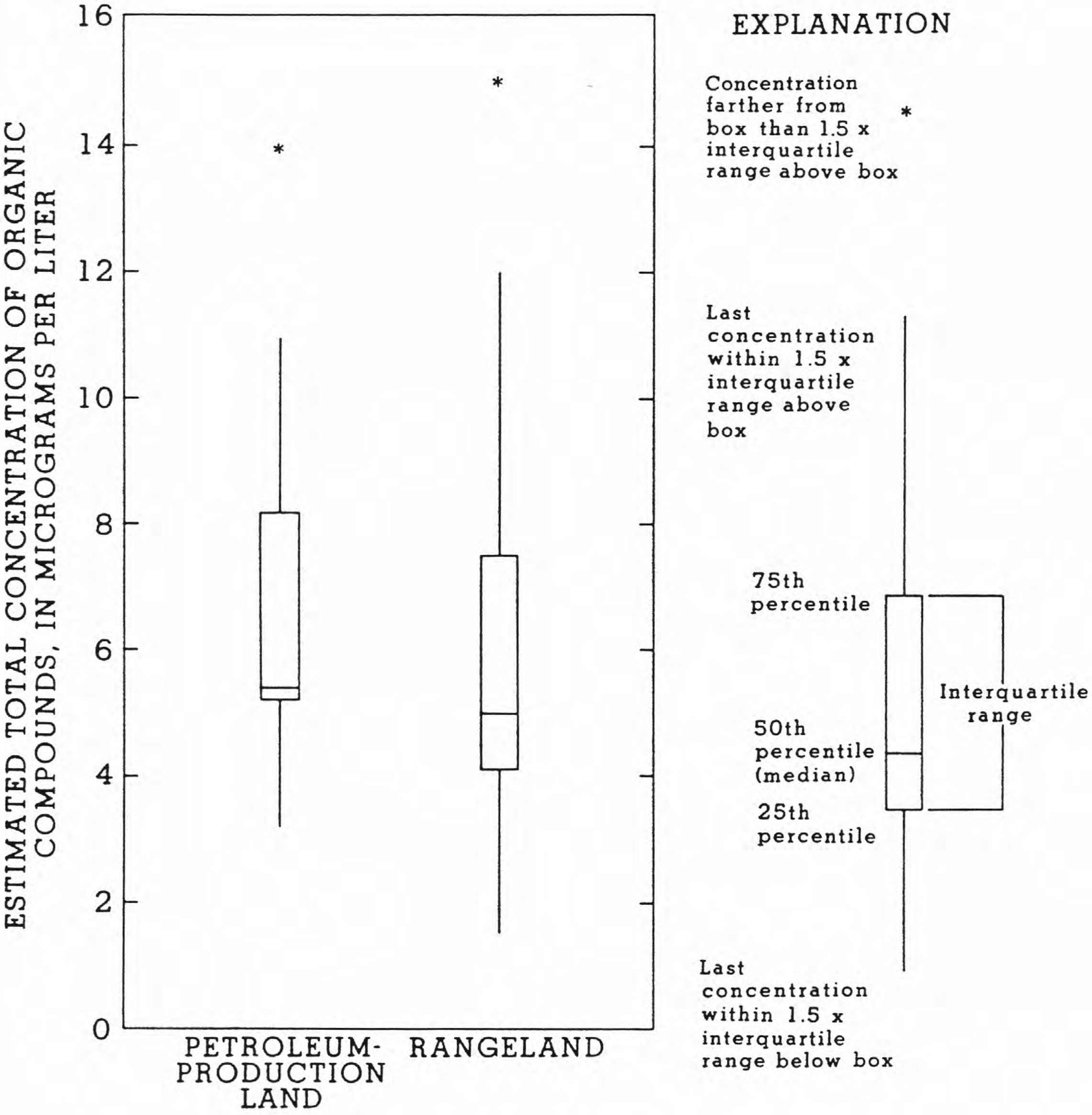


Figure 22. Estimated total concentrations of organic compounds in ground-water samples from areas of petroleum-production land and rangeland (based on 22 petroleum-production-land samples and 23 rangeland samples).

frequency in areas of petroleum-production land according to the contingency-table analysis just described.

Comparisons by Unsaturated-Zone Lithology

Possible relations between hydrocarbon occurrence and unsaturated-zone lithology were considered by dividing data previously compared only by land use. Total organic-compound concentrations (as estimated from total area under peaks) were compared by the rank-sum test between areas of clayey and sandy unsaturated-zone lithologies. Differences were not significant within areas of either petroleum-production land or rangeland. When the land-use comparison (between petroleum-production land and rangeland) was repeated as separate tests for areas of clayey

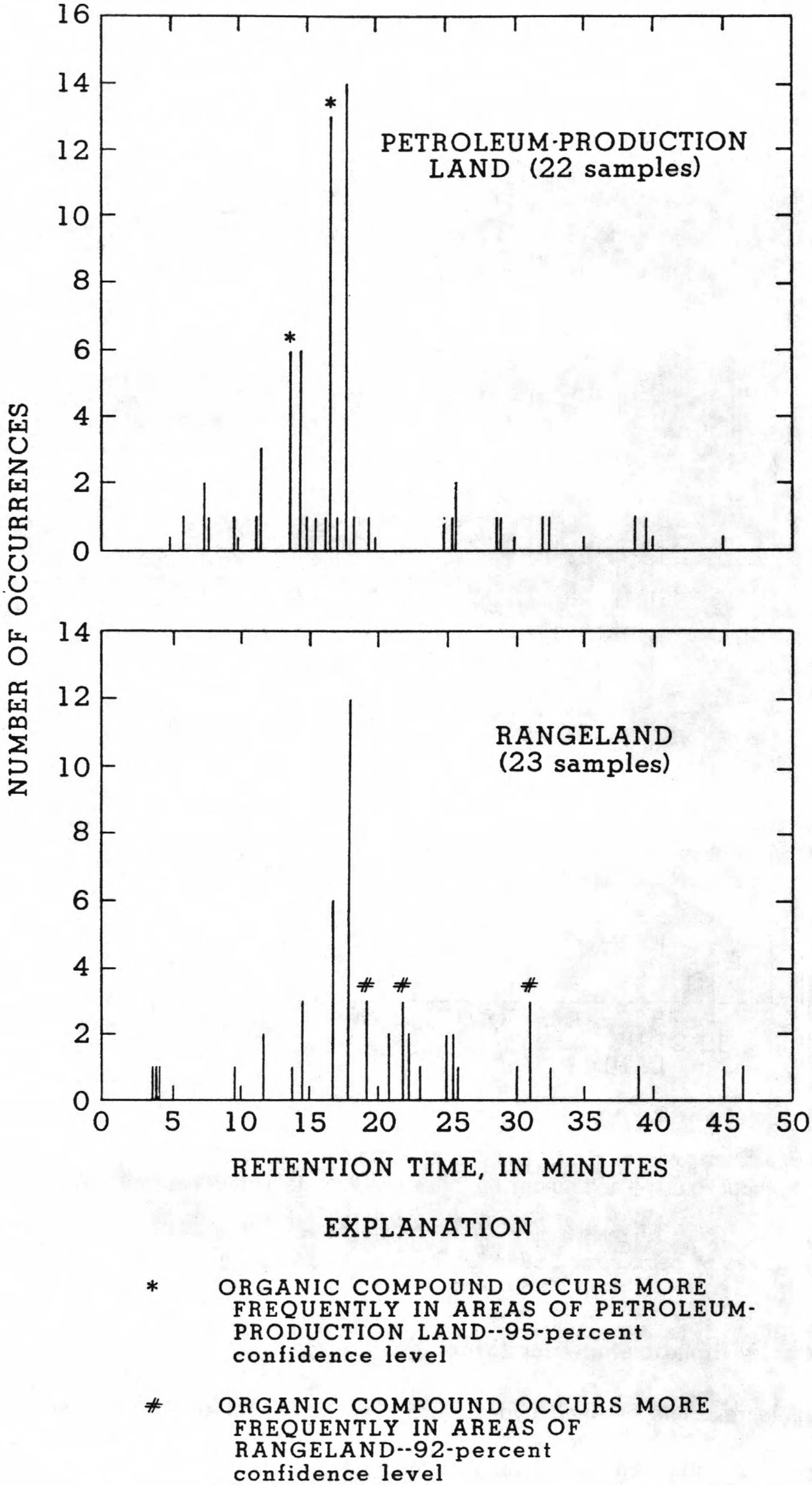


Figure 23. Frequencies of occurrence of individual organic compounds in areas of petroleum-production land and rangeland, based on gas-chromatograph retention time.

and sandy unsaturated-zone lithologies, 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 larger concentrations occurring in the areas of petroleum-production land.

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 category into unsaturated-zone lithology groups. The testing was possible for five peaks on chromatograms for petroleum-production-land samples and one peak on chromatograms for rangeland samples. A significant association was indicated for one peak on chromatograms 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 a 16.68-minute detention time occurred more frequently in areas of petroleum-production land.

Comparisons of individual peak heights, grouped according to unsaturated-zone lithology, were done using the rank-sum test; large numbers of nondetections again weaken the tests. Results indicated no significant differences within a given land-use category. However, land-use comparison tests again were repeated 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 areas of petroleum-production land.

DISCUSSION OF RESULTS

Evaluation of the water-quality data and statistical comparisons from this study allowed some inferences 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. Results are discussed in the following paragraphs according to land-use category. Selected results also have been presented by Helgesen and Thurman (1988) and Helgesen and Rutledge (1989). Summaries of statistical comparisons for inorganic constituents, atrazine, and hydrocarbons are shown in tables 3-5.

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 water and solutes downward from the land surface to the saturated zone. Infiltration and percolation may be expected to be greater on tilled land than on natural rangeland. Furthermore, on irrigated cropland the natural precipitation available for infiltration 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 petroleum-production land or rangeland (table 3) probably result from use of fertilizers. The relatively large fluoride concentrations beneath irrigated cropland might reflect the association of that constituent with a common phosphate-mineral component of fertilizer.

Pesticides were not detected frequently in ground water of the area, even beneath irrigated cropland, where they are commonly applied. The pesticides that were detected, especially atrazine, are relatively soluble and persistent. Although atrazine, where found in this study, 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

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, areas of irrigated cropland; P, areas of petroleum-production land; R, areas of 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 95-percent confidence level]

Property or constituent	Sample group for which property value or constituent concentration is significantly greater at 95-percent confidence level														
	Comparisons by land use only[1]			Comparisons by unsaturated-zone lithology only				Comparisons by land use and unsaturated-zone lithology[2]							Comparisons by type of well sampled only[3]
				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	--	--	--	--	--	--	--
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	R	--	--	--	--	--	R	--	--	--	--	--	--
Manganese	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[1] Small-yield wells; clayey and sandy unsaturated-zone lithologies.
[2] Small-yield wells.
[3] Areas of irrigated cropland; clayey and sandy unsaturated-zone lithologies.

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*

[--, frequencies of detection not significantly different at 95-percent confidence level]

Comparison basis	Sample group for which atrazine was detected with significantly greater frequency at the 95-percent confidence level
By land use only (Irrigated cropland and rangeland; small-yield wells; clayey and sandy unsaturated-zone lithologies)	--
By unsaturated-zone lithology only (Clayey and sandy lithologies; small-yield wells; areas of irrigated cropland)[1]	--
By unsaturated-zone lithology only (Clayey and sandy lithologies; 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 lithologies)	--

[1] Statistical test for areas of rangeland not possible because of insufficient number of atrazine detections.

separately as discussed later in this section.

Concentrations of most inorganic constituents beneath areas of irrigated cropland showed no significant association with regionally delineated unsaturated-zone lithology. Concentrations of silica and orthophosphorus were significantly larger in areas of clayey as compared to sandy unsaturated-zone lithology; explanations for those differences are not evident. Although no other differences can be related directly to unsaturated-zone lithology, some significant differences between areas of irrigated cropland and rangeland are indicated if only the samples from sandy unsaturated-zone lithology in each land-use area are compared. These significant differences exist for several properties and inorganic constituents (hardness, alkalinity, magnesium, potassium, and fluoride) and for atrazine (table 4).

Conclusions regarding the effects of unsaturated-zone lithology thus appear to depend on whether the lithology groups within areas of 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

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*

[--, frequencies of detection not significantly different at 95-percent confidence level]

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

[1] Based on contigency-table testing.
[2] Based on rank-sum testing.

unsaturated-zone lithology. Nitrite-plus-nitrate concentrations were significantly larger beneath irrigated cropland than beneath rangeland based on data from 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 (particularly in organic-rich zones) within this study area (Rutledge and Helgesen, 1990) and near Topeka, Kansas (C.A. Perry, U.S. Geological

Survey, written commun., 1989). Larger atrazine concentrations in soils tend to be associated with horizons richer 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 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 feet below land 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 the area of 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 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 sufficiently slow to allow identification of some relations between water quality and prevailing land use in discrete areas of several square miles, it apparently is sufficiently rapid so that water quality within these discrete 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 are related to 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 comparable increases of that constituent, ascribed to animal wastes at the farmsteads and fertilizers in the fields.

Petroleum-Production Land

In areas of petroleum-production land containing aggregations of former brine-disposal ponds, the inorganic quality of underlying ground water generally is affected, whereas no general effect on organic water quality is apparent. In areas of petroleum-production land, pH 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 the 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 greater than 85-percent confidence level) of dissolved solids, sodium, and chloride beneath petroleum-production land (fig. 10) indicate that brine wastes might have a greater effect on inorganic ground-water quality than irrigated-cropland practices.

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 (total concentrations of as large as 15 μg/L, fig. 22). The characteristics of occurrence of these organic compounds associated with these two land-use categories are not statistically different in terms of total concentration, frequency of occurrence of most specific compounds, or concentration (peak height) of most specific compounds. The few significant differences related to specific organic compounds indicate more frequent detection of relatively lighter weight compounds in the areas of petroleum-production land.

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 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 probably is rare.

Concentrations of dissolved solids and some major 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, which probably accompanied lateral ground-water flow from beneath a nearby area of cropland. That sample also contained a relatively large concentration of nitrite plus nitrate, probably 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 areas of 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 beneath irrigated cropland) out of 82 samples, although none of the wells sampled in 1984 were resampled in 1987. This ratio (1 out of 82) does not confirm a conclusion of extensive occurrence of 2,4-D in the ground water of the study area, and the initially reported 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, atrazine, 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 part of the High Plains aquifer in about 5,000 mi^2 of 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 oil-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 produced in association with oil and formerly were 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 to 10 mi^2 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. 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 based upon prevailing land use, unsaturated-zone lithology (clayey compared to sandy), and type of well sampled (irrigation compared to small yield). 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 other nitrogen-containing herbicides, 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 were non-normal 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 quantities 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 subsoil and chemicals applied as fertilizer, and transports these solutes 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 former brine-disposal ponds exhibits significantly larger values of pH, and concentrations of hardness, alkalinity, 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. Statistical differences (at greater than 85-percent confidence level) between several constituents indicate that former brine-disposal activities might have more of an effect than agricultural practices 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 oil-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 organic compounds are naturally occurring and probably dissolved from soil or aquifer materials.

Mixed results concerning the effects of unsaturated-zone lithology probably relate to small sample size when testing within a single land-use area and to the arbitrary nature of defining regional "clayey" and "sandy" lithologies. The unsaturated zone is lithologically heterogeneous and contains substantial clay that inhibits the downward movement of water and solutes. Movement of percolating water through the unsaturated zone might require 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 infrequent detection of atrazine in the ground water.

Within the aquifer, the rate of regional lateral flow and solute transport is sufficiently slow so that the ground-water quality reflects, to some extent, 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.

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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: µS/cm, microsiemens per centimeter at 25 degrees Celsius; deg C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. <, less than; --, no analysis]

Well number (latitude, longitude sequence number)	County	Date of collection (month-day-year)	Specific conductance (µS/cm)	pH (standard units)	Temperature, water (deg C)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Alkalinity, (mg/L as $CaCO_3$)	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

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

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_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)
					Areas of irrigated cropland (small-yield wells)--Continued					
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
374311098530901	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

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

Well number (latitude, longitude, sequence number)	County	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Alachlor, total (µg/L)	Ametryne, total (µg/L)	Atrazine, total (µg/L)	Cyanazine, total (µg/L)	Metolachlor, total (µg/L)	Metribuzin, total (µg/L)	Prometone, total, (µg/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
375208099152801	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
375859097332001	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			
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
374209098123001	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

Table 6. *Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled--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 irrigated cropland (small-yield wells)--Continued						
CLAYEY LITHOLOGY										
381755098462201	Barton	<0.1	<0.10	<0.01	<0.10	<0.1	<0.10	<0.01	<0.01	<0.01
375841099164201	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375531099155302	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
375029099260101	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
374629098024001	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*

Well number (latitude, longitude, sequence number)	County	Date of collection (month-day-year)	Specific conductance μS/cm)	pH (standard units)	Temperature, water (deg C)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Alkalinity, (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Calcium, dissolved (mg/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
373826099080401	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	150	260	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

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

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_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, NO_2+NO_3, 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
375521099165501	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*

Well number (latitude, longitude, sequence number)	County	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Alachlor, total (µg/L)	Ametryne, total (µg/L)	Atrazine, total (µg/L)	Cyanazine, total (µg/L)	Metolachlor, total (µg/L)	Metribuzin, total (µg/L)	Prometone, total (µg/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
375758099193901	Edwards	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375521099165501	Edwards	5	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375057099141201	Edwards	<3	3	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374434099115601	Edwards	<3	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374416099275101	Edwards	<3	2	<.10	<.10	1.4	<.10	.1	<.1	<.1
375843097334001	Harvey	1,900	280	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375616097314901	Harvey	4	210	<.10	<.10	<.10	<.10	<.1	<.1	<.1
373826099080401	Kiowa	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
382106097415501	McPherson	8	5	<.10	<.10	<.10	<.10	<.1	<.1	<.1
381620097444101	McPherson	9	2	<.10	<.10	.10	<.10	<.1	<.1	<.1
380612099043601	Pawnee	29	56	<.10	<.10	<.10	<.10	<.1	<.1	<.1
380549099074101	Pawnee	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374648098540701	Pratt	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374324098534201	Pratt	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
373509098333401	Pratt	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
372922098292501	Pratt	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375810097534001	Reno	<3	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
SANDY LITHOLOGY										
375336099204501	Edwards	4	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374909099274901	Edwards	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375735097382401	Harvey	460	300	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374209098122101	Kingman	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374311099190101	Kiowa	8	5	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374018099070301	Kiowa	<3	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374316099070401	Kiowa	31	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374729098014301	Reno	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375256097333801	Sedgwick	<3	2	.10	<.10	.30	<.10	1.0	<.1	<.1
375223097275401	Sedgwick	110	120	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374843097323401	Sedgwick	<3	5	<.10	<.10	<.10	<.10	<.1	<.1	<.1
380127098435601	Stafford	6	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1

Table 6. *Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled--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 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	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375521099165501	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375057099141201	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374434099115601	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374416099275101	Edwards	<.1	.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375843097334001	Harvey	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375616097314901	Harvey	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
373826099080401	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
382106097415501	McPherson	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
381620097444101	McPherson	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380612099043601	Pawnee	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380549099074101	Pawnee	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
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	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375810097534001	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
SANDY LITHOLOGY										
375336099204501	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374909099274901	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375735097382401	Harvey	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374209098122101	Kingman	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374311099190101	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374018099070301	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374316099070401	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374729098014301	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375256097333801	Sedgwick	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375223097275401	Sedgwick	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374843097323401	Sedgwick	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380127098435601	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*

Well number (latitude, longitude, sequence number)	County	Date of collection (month-day-year)	Specific conductance (µS/cm)	pH (standard units)	Temperature, water (deg C)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Alkalinity, (mg/L as as $CaCO_3$)	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	2,360	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	180	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

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

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_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, NO_2+NO_3, 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
374021099304901	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
380731098315101	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*

Well number (latitude, longitude, sequence number)	County	Date of collection (month-day-year)	Specific conductance (µS/cm)	pH (standard units)	Temperature, water (deg C)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)
Areas of rangeland										
CLAYEY LITHOLOGY										
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
SANDY LITHOLOGY										
375345099223201	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	93	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
380845097545101	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

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

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_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, NO_2+NO_3, 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*

Well number (latitude, longitude, (sequence number)	County	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Alachlor, total (µg/L)	Ametryne, total (µg/L)	Atrazine, total (µg/L)	Cyanazine, total (µgL)	Metolachlor, total (µg/L)	Metribuzin, total (µg/L)	Prometone, total (µg/L)
					Areas of rangeland--Continued					
CLAYEY LITHOLOGY										
375204099232501	Edwards	14	<1	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<0.1
374708099263501	Edwards	26	1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374251099283901	Kiowa	24	1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
373343099075501	Kiowa	13	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374338099102901	Kiowa	21	1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
382624097505801	McPherson	8	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374314098581201	Pratt	28	2	<.10	<.10	.10	<.10	<.1	<.1	<.1
380955098234101	Reno	28	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
381029097591901	Rice	12	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
SANDY LITHOLOGY										
375345099223201	Edwards	6	1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374215098262101	Kingman	<3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
373923099325901	Kiowa	3	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374116099022501	Kiowa	5	3	<.10	<.10	<.10	<.10	<.1	<.1	<.1
380151099162601	Pawnee	25	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
374220098384201	Pratt	<3	1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375646098381001	Pratt	210	3	<.10	<.10	<.10	<.10	<.1	<.1	<.1
380845097545101	Reno	<3	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
380746097514802	Reno	<3	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1
380350097463301	Reno	12	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
375327098193401	Reno	17	<1	<.10	<.10	<.10	<.10	<.1	<.1	<.1
380632098231401	Reno	80	10	<.10	<.10	<.10	<.10	<.1	<.1	<.1
381159098262101	Rice	5	2	<.10	<.10	<.10	<.10	<.1	<.1	<.1

Table 6. *Results of water-quality analyses, grouped according to land-use areas, unsaturated-zone lithology, and type of well sampled--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	<.01	<.10	<.1	<.10	<.01	<.01	<.01
373343099075501	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374338099102901	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
382624097505801	McPherson	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374314098581201	Pratt	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380955098234101	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
381029097591901	Rice	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
SANDY LITHOLOGY										
375345099223201	Edwards	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374215098262101	Kingman	<.1	<.10	--	<.10	<.1	<.10	--	--	--
373923099325901	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374116099022501	Kiowa	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380151099162601	Pawnee	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
374220098384201	Pratt	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375646098381001	Pratt	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380845097545101	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380746097514802	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380350097463301	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
375327098193401	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
380632098231401	Reno	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01
381159098262101	Rice	<.1	<.10	<.01	<.10	<.1	<.10	<.01	<.01	<.01