RECONNAISSANCE OF WATER QUALITY IN THE HIGH PLAINS AQUIFER

BENEATH AGRICULTURAL LANDS, SOUTH-CENTRAL KANSAS

By Lloyd E. Stullken, John K. Stamer, and Jerry E. Carr

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CONVERSION FACTORS

The inch-pound units of measurement given in this report may be converted to the International System (SI) of Units by using the following conversion factors:

Inch-pound unit	Multiply by	SI unit
inch (in.)	25.4	millimeter
foot (ft)	0.305	meter
mile (mi)	1.609	kilometer
acre	0.4047	square hectometer
square mile (mi^2)	2.59	square kilometer
gallon (gal)	3.785	liter
inch per year (in/yr)	25.4	millimeter per year
foot per day (ft/d)	0.305	meter per day
foot per year (ft/yr)	0.305	meter per year
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon per minute (gal/min)	0.06309	liter per second
pound (lb)	0.4535	kilogram
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

[1] °C = (°F - 32)/1.8.

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

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ABSTRACT

The High Plains of western Kansas was one of 14 areas selected for preliminary ground-water-quality reconnaissance by the U.S. Geological Survey's Toxic Waste—Ground-Water Contamination Program. The specific objective was to evaluate the effects of land used for agriculture (irrigated cropland and nonirrigated rangeland) on the quality of water in the High Plains aquifer.

Conceptual inferences, based on the information available, would lead one to expect ground water beneath irrigated cropland to contain larger concentrations of sodium, sulfate, chloride, nitrite plus nitrate, and some water-soluble pesticides than water beneath nonirrigated land (rangeland).

The central part of the Great Bend Prairie, an area of about 1,800 square miles overlying the High Plains aquifer in south-central Kansas, was selected for the study of agricultural land use because it has sandy soils, a shallow water table, relatively large annual precipitation, and includes large areas that are exclusively irrigated cropland or nonirrigated rangeland.

As determined by a two-tailed Wilcoxon rank-sum test, concentrations of sodium and alkalinity were significantly larger at the 95-percent confidence level for water samples from beneath irrigated cropland than from beneath rangeland. No statistically significant difference in concentrations of sulfate, chloride, nitrite plus nitrate, and ammonia, was detected. Concentrations of 2,4-D found in water samples from beneath rangeland were larger at the 99-percent confidence level as compared to concentrations of 2,4-D in samples from beneath irrigated cropland. Larger concentrations of sodium and alkalinity were found in water beneath irrigated cropland, and the largest concentration of the pesticide atrazine (triazines were found in three samples) was found in water from the only irrigation well sampled. The sodium and atrazine concentrations found in water from the irrigation well support the premise that water-level drawdown develops under irrigated fields, diverting the natural ground-water flow patterns, and that pumpage may cause recycling and subsequent concentration of leachates from the land surface.

INTRODUCTION

Background

Ground-water-quality appraisals presently (1986) are being conducted as part of the U.S. Geological Survey's Toxic Waste--Ground-Water Contamination Program. A primary objective of the program is to evaluate methods to determine the quality of the Nation's ground-water reserves and to determine the extent and nature of ground-water contamination with emphasis on the occurrence of trace organic substances and metals. A second objective is to evaluate the effects of land use on ground-water quality (Helsel and Ragone, 1984). The High Plains of western Kansas was one of 14 areas selected for preliminary ground-water-quality reconnaissance, as shown in table 1.

The High Plains aquifer underlies about 174,000 mi^2 in parts of eight states in the High Plains physiographic subdivision (Gutentag and others, 1984). It is the principal water resource for the High Plains region, which is one of the Nation's major agricultural areas. Application of fertilizers and pesticides to agricultural land throughout the High Plains creates a potential for adverse effects on the water quality of the High Plains aquifer. Descriptive data on the possible occurrence and extent of organic compounds in water from the High Plains aquifer and their relation to land use are lacking.

Purpose and Scope

This report describes the results of the High Plains ground-water-quality reconnaissance study in Kansas to evaluate the effects of land used for agriculture on ground-water quality. The design of the Kansas study paralleled that of the National program in that conceptual inferences of the contaminant flow system were developed, a data-collection plan was formulated, and data were collected and analyzed according to that plan. The central part of the Great Bend Prairie was selected to evaluate the possible effects of agriculture on ground-water quality of the High Plains aquifer (fig. 1).

Relation of Land Use and Ground-Water Quality

This study was predicated on the concept that chemical compounds applied to the land surface, generally as a result of human activity, are subject to mobilization by precipitation and irrigation water and may be transported through the soil zone to the water table along with that water. This concept recognizes that: (1) The compound must have a finite water solubility to be transported or have mobility of its own; (2) the compound must persist long enough to reach the water table; (3) the intervening materials between the land surface and the aquifer must be permeable enough to allow movement of fluids; and (4) the compound, or its degradation products, must be detectable as chemical constituents in the ground water. Detection of these constituents at the water table would be expected to be greater if the travel path from the land surface to the water table was short (shallow water table). Finally, the implication of these concepts is that chemical constituents in water beneath a particular land use, in some way, represent or indicate that overlying land use.

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Table 1.--*Ground-water-quality appraisals as part of the U.S. Geological Survey's Toxic Waste-- Ground-Water Contamination Program*

Gulf Coastal Plain, Louisiana and Mississippi
Long Island, New York
Philadelphia area, Pennsylvania
Potomac-Raritan-Magothy outcrop area, New Jersey
Houston area, Texas
Floridan aquifer, Florida
Edwards aquifer, Texas
Combined regolith, North Carolina
San Joaquin Valley, California
Arkansas River valley, Colorado
Albuquerque-Belen basin, New Mexico
High Plains aquifer, western Kansas
High Plains aquifer, Nebraska
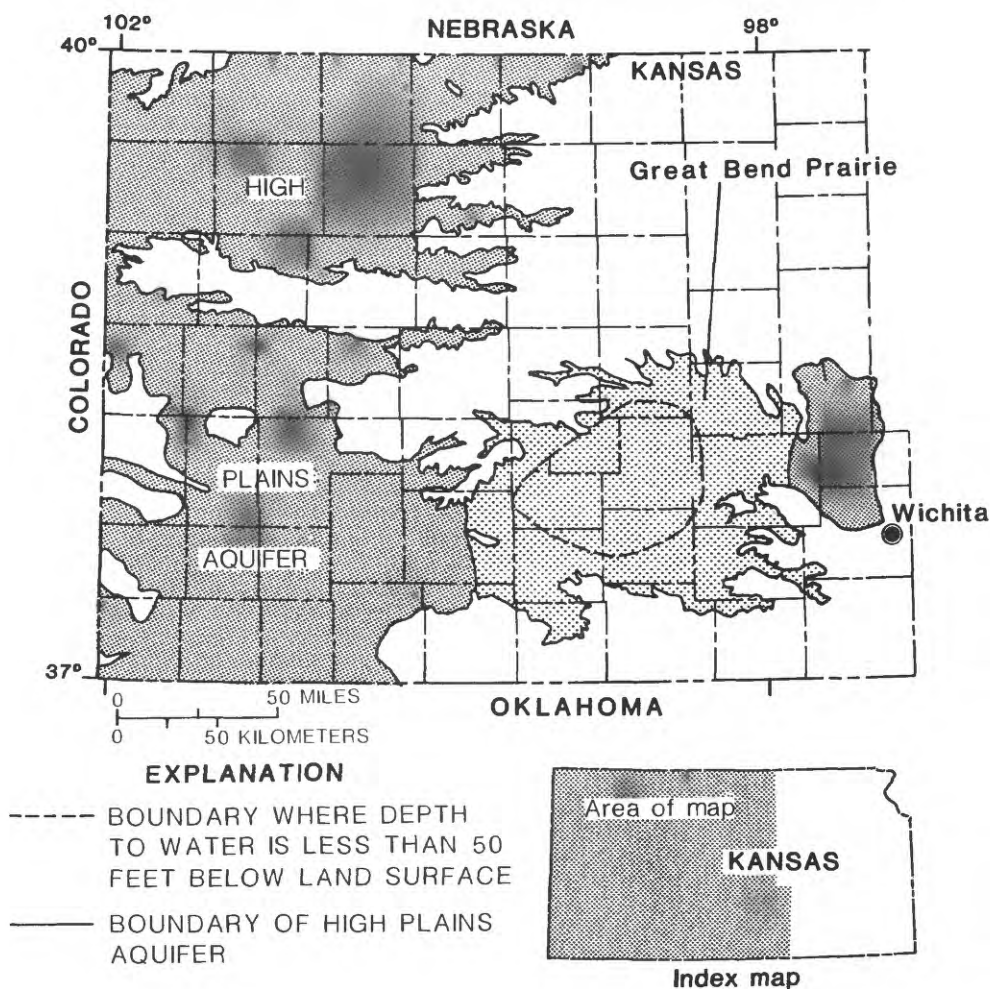Connecticut River valley, Connecticut

EXPLANATION

----- BOUNDARY WHERE DEPTH TO WATER IS LESS THAN 50 FEET BELOW LAND SURFACE

——— BOUNDARY OF HIGH PLAINS AQUIFER

Figure 1.--Location of High Plains aquifer and Great Bend Prairie.

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Underneath irrigated cropland, the most likely chemical constituents to be found in water as indicators of the overlying land use are associated with the application of agricultural fertilizers, herbicides, and insecticides. Therefore, one might expect ground water beneath irrigated cropland to contain larger concentrations of sodium, sulfate, chloride, nitrite plus nitrate, and some water-soluble pesticides than water beneath rangeland (nonirrigated land). Moreover, any apparent increase of nitrite plus nitrate in ground water might indicate that recharge water containing water-soluble pesticides, which have a persistence in the soil of several months, could infiltrate to the aquifer and increase pesticide concentrations to significantly larger than the present levels of detection.

Potential effects of nonirrigated land on ground water, which in the central part of the Great Bend Prairie is predominantly rangeland, would be expected to be minimal. Hem (1985) suggests that few natural waters are pristine; that is, unaffected by human activity. In nonirrigated rangeland areas, the principal source of water that is available to the land surface is precipitation, thus greatly limiting the amount of water available for infiltration to the aquifer in these areas. Also, fewer agricultural chemicals are applied to rangeland. The combination of these two conditions could result in smaller concentrations of major cations, major anions, and nitrite plus nitrate.

GROUND-WATER QUALITY IN AGRICULTURAL LANDS

Selection and Description of Study Area

The central part of the Great Bend Prairie, an area of about 1,800 mi^2 (fig. 1), was chosen for study of the effects of agriculture on ground-water quality because it has sandy soils, a shallow water table, relatively large annual precipitation, and includes some large areas that are exclusively irrigated cropland or nonirrigated rangeland. Also, these characteristics may allow for a greater potential for ground-water contamination than may be found in the High Plains aquifer as a whole.

The geohydrologic characteristics of the High Plains aquifer in the Great Bend Prairie have been reported in previous studies by Fader and Stullken (1978) and Cobb and others (1982). Spruill (1983) found that the Great Bend Prairie had the largest median concentration of nitrate in ground water of the 14 ground-water regions in Kansas. The median concentration of nitrate in the region was 5.6 mg/L (milligrams per liter), while the next largest median value was 4.5 mg/L in the northwestern and west-central parts of the State. Permeable soils, shallow depth to water, increasing irrigation, and application of fertilizers in the Great Bend Prairie may be contributing factors responsible for the large observed concentrations of nitrate. Increased nitrate concentrations also have been noted under irrigated ground in the High Plains of Nebraska by Chen and Druliner (1987).

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Throughout the central part of the Great Bend Prairie the land sur-
face is poorly drained and traversed by only a few streams. Almost
one-half of the area has no external drainage. The land surface varies
from flat, where the soil often is a silty loam, to undulating, where
the soil is predominantly an eolian sand. Recharge to the High Plains
aquifer is by infiltration of direct precipitation and by irrigation
return flow. Average annual precipitation on the Great Bend Prairie is
about 25 in. Natural-recharge values used in a ground-water flow model
of the High Plains aquifer in the Great Bend Prairie (Cobb and others,
1982) averaged 0.75 in/yr. By comparison, recharge rates used by Stullken
and others (1985) in modeling the High Plains aquifer in northwestern
and southwestern Kansas were 0.20 and 0.25 in/yr, respectively. The
much greater recharge rate in the Great Bend Prairie accrues from both a
greater soil permeability and larger amounts of precipitation (about 25
in/yr or 5 to 10 in. greater than for western Kansas).

The principal water-bearing materials underlying the central part of
the Great Bend Prairie are unconsolidated deposits of clay, silt, sand,
and gravel with some layers of loosely cemented sand and caliche. These
deposits, which reach a maximum thickness of 360 ft, comprise a part of
the High Plains aquifer and were laid down by aggrading, eastward-flowing
streams carrying sediments derived from the Rocky Mountains in Colorado.
The aquifer immediately underlies the soil zone, and depths to water range
from a few feet to generally less than 50 ft (fig. 2). Clay lenses
generally are not of sufficient extent to cause perching or separation of
the aquifer into different units. Therefore, the entire thickness of the
High Plains aquifer was involved in this study.
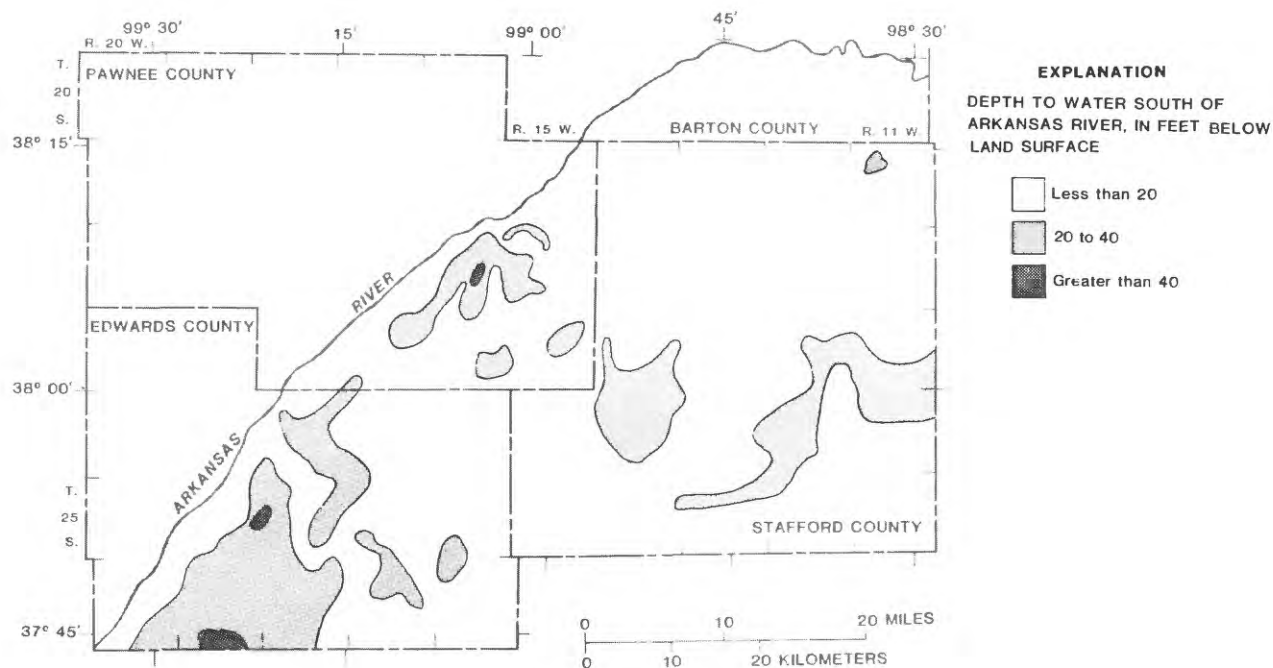
Figure 2.--Depth to water in central part of Great
Bend Prairie, January 1980.

Ground-water flow in the saturated part of the High Plains aquifer is generally from west to east at a regional gradient of about 8 ft/mi (fig. 3). The Great Bend Prairie model of Cobb and others (1982) used a hydraulic conductivity of 85 ft/d. Using Darcy's law and a porosity of 0.17 (dimensionless), water in the aquifer flows at a rate of about 276 ft/yr (about 1 mile in 19 years) under natural gradients. Contact time of recharge water with potential leachates in the soil may range from several months during winter periods (September through April) when no recharge is occurring to relatively short periods of time during summer months (May to August) of intense precipitation or irrigation.

The Great Bend Prairie contains large areas of irrigated cropland and nonirrigated rangeland as shown in figure 4. The undesignated areas shown in figure 4 are predominantly nonirrigated cropland, although smaller areas of both irrigated cropland and rangeland are scattered throughout. Areas of irrigated cropland and nonirrigated rangeland were determined by visual inspection of aerial photographs and maps at county offices of the Soil Conservation Service, U.S. Department of Agriculture. The aerial photographs were taken during 1980. The irrigated areas were defined further by onsite reconnaissance during 1985. Figure 4 also shows the location of irrigation wells during 1980 as a further illustration of the distribution of irrigation throughout the area. Collectively, the individual areas selected to represent irrigated cropland totaled 91 mi^2, and those selected to represent nonirrigated rangeland totaled 93 mi^2.
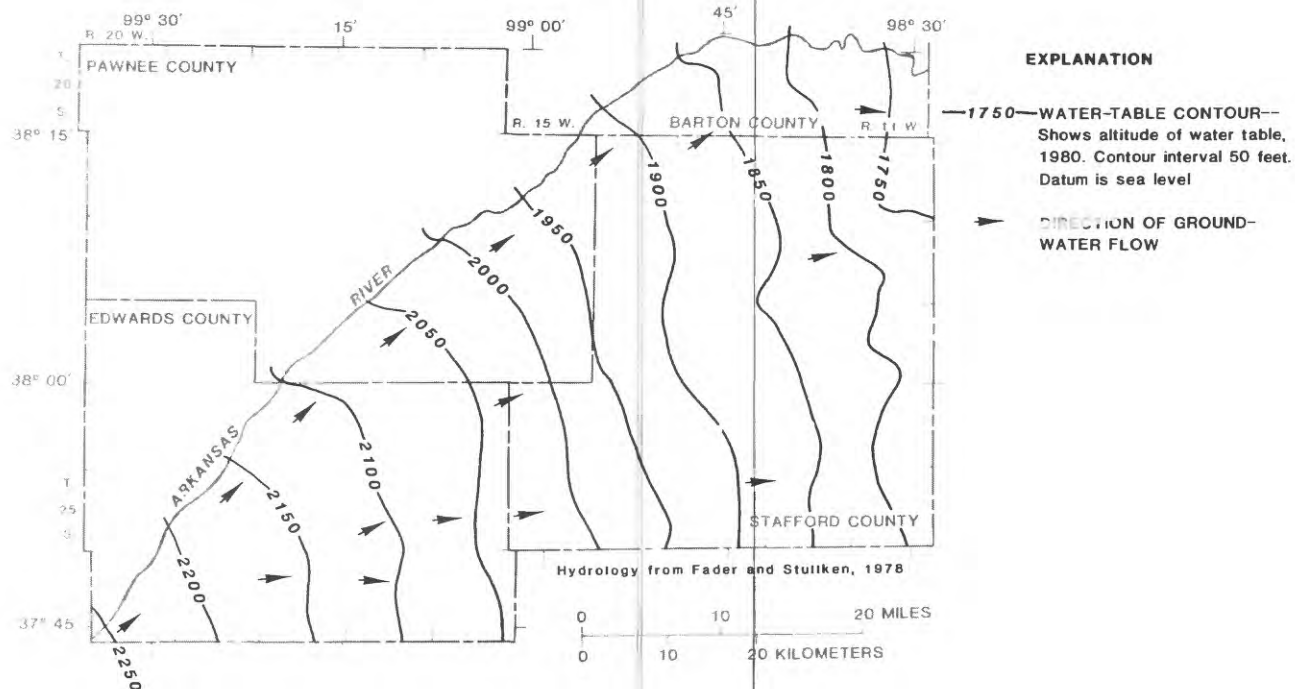
Figure 3.--Altitude of water table in the High Plains aquifer in central part of Great Bend Prairie, January 1980, and direction of ground-water flow.

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Within the irrigated areas, the major crops were wheat, grain sorghum, corn, soybeans, and alfalfa (Kansas Crop and Livestock Reporting Service, 1983). In addition to the use of fertilizers to increase crop growth, other agricultural chemicals, namely pesticides, have been used to reduce the competitive or destructive action of weeds and insects. The principal classes of pesticides used in the Great Bend Prairie area include carbamate insecticides, chlorophenoxy acid herbicides, organochlorine insecticides, organophosphate insecticides, and triazine herbicides. Pesticides applied in the Great Bend Prairie area during 1978 are listed in table 2. As noted in the table, the principal herbicides used were atrazine, propazine, 2,4-D, propachlor, alachlor, or some combination of the above. The principal insecticides used in 1978 were toxaphene, heptachlor, carbofuran, carbaryl, and phorate (table 2). Within the nonirrigated rangeland, water-soluble chlorophenoxy herbicides, such as 2,4-D and 2,4,5-T, typically are applied to reduce unwanted vegetation (Ohlenbusch, 1984).

Data Collection

The data-collection network in the Great Bend Prairie study consisted of 27 wells in Barton, Edwards, Pawnee, and Stafford Counties (fig. 5). Of the 27 wells from which water samples were collected in August and September 1984, 13 were located on irrigated cropland, and the remaining 14 were located on nonirrigated rangeland. Factors that were considered in the selection of wells on irrigated and nonirrigated land were that there be no obvious point-source contamination and that the sampled well be surrounded by sufficient land of the same use to ensure that the water quality in the aquifer be representative of the overlying land use (optimally, at least a 1-mi radius).
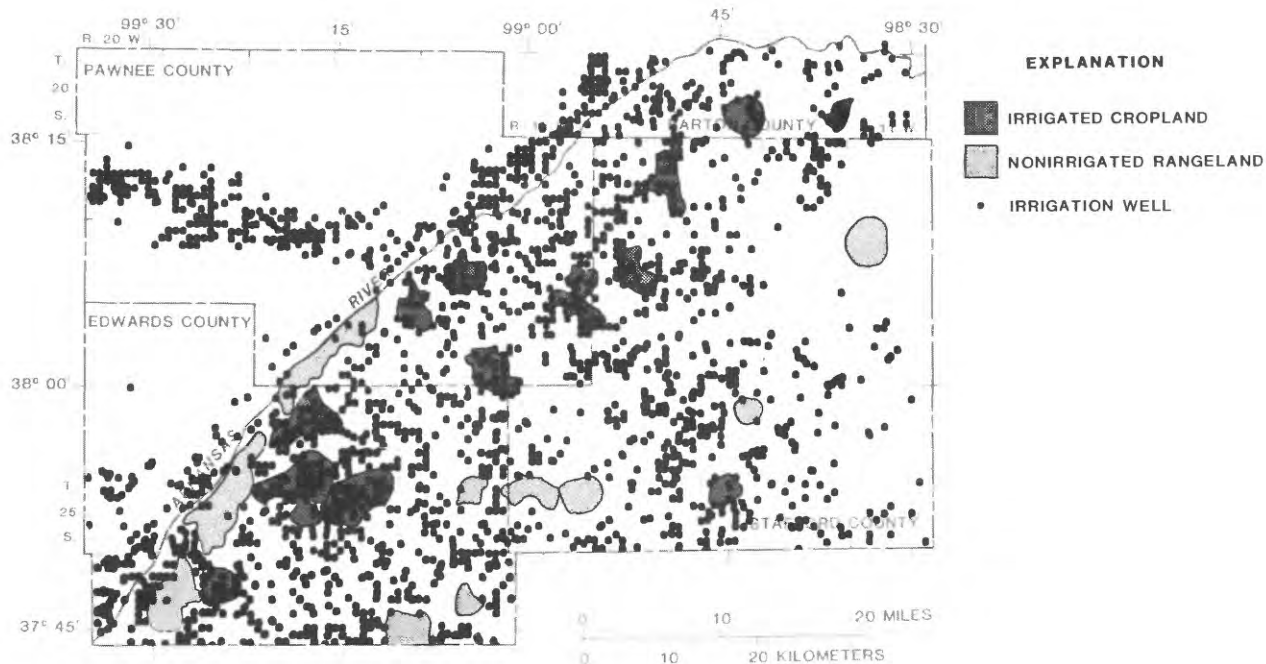
Figure 4.--Selected areas of irrigated cropland, nonirrigated rangeland, and distribution of irrigation wells, 1980.

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Table 2.—*Specific pesticides applied to crops in south-central Kansas, 1978*

Herbicides[1]	Corn	Grain sorghum	Wheat	Soybeans	Alfalfa	Pounds[2]
2,4-D Amine	*	*	*			91,400
2,4-D Ester	*	*	*			59,100
2,4-DB Amine					*	200
Alachlor (Lasso)	*		*			28,300
Alachlor plus atrazine	*					183,000
Alachlor plus cyanazine	*					1,300
Atrazine	*	*				177,000
Benefin (Balan)					*	900
Bentazon (Basagran)	*		*			4,000
Bifenox plus alachlor				*		3,900
Bromoxynil (Brominal) plus 2,4-D			*			4,000
Butylate plus antidote (Sutan+)	*					22,100
Butylate plus antidote plus atrazine	*					65,000
Cyanazine (Bladex)	*					1,700
Cyanazine plus atrazine	*					6,700
Cyanazine plus propachlor		*				16,500
Cyanazine plus propazine		*				2,400
Dicamba (Banvel)	*	*	*			7,900
EPTC (Eradicane)	*					12,800
EPTC plus atrazine	*					15,900
EPTC plus cyanazine	*					--
Glyphosate (Roundup)	*	*		*		5,500
Metolachlor (Dual) plus atrazine	*					2,100
Metribuzin (Lexone/Sencor)				*		400
Metribuzin plus alachlor				*		600

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Table 2.—*Specific pesticides applied to crops in south-central Kansas, 1978* —Continued

Herbicides[1]	Corn	Grain sorghum	Wheat	Soybeans	Alfalfa	Pounds[2]
Metribuzin plus trifluralin				*		400
Pendimethalin (Prowl)	*		*			2,100
Pendimethalin plus atrazine	*					1,400
Propachlor (Ramrod)		*				113,900
Propachlor plus atrazine	*	*				239,800
Propachlor plus propazine		*				78,900
Propazine		*				122,400
Propham (Chem-Hoe)					*	21,000
Simazine (Princep)					*	8,000
Terbacil (Sinbar)					*	800
Terbutryn (Igran)		*				16,800
Terbutryn plus atrazine		*				23,200
Terbutryn plus propazine		*				109,600
Trifluralin (Treflan)				*		65,200

Insecticides[1]

	Corn	Grain sorghum	Wheat	Soybeans	Alfalfa	Pounds
Azinphosmethyl (Guthion)					*	1,000
Carbaryl (Sevin)	*	*	*	*	*	31,900
Carbofuran (Furadan)	*	*			*	42,900
Carbophenothion (Trithion)	*					100
Chlorpyrifos (Lorsban)	*					——
Demeton (Synstox)		*				100
Diazinon	*				*	7,200
Dimethoate (Cygon, Defend)	*	*	*	*	*	1,300
Dimethoate plus propargite	*					3,800
Disulfoton (Di-Syston)	*	*				23,200

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Table 2.--*Specific pesticides applied to crops in south-central Kansas, 1978*--Continued

Insecticides[1]	Corn	Grain sorghum	Wheat	Soybeans	Alfalfa	Pounds[2]
Endosulfan (Thiodan)			*			1,700
Endrin	*		*			100
EPN	*					2,400
Ethion	*					600
Ethyl parathion	*	*	*	*		20,200
Fonofos (Dyfonate)	*					18,200
Heptachlor	*	*	*			56,300
Lindane		*	*			1,700
Malathion	*	*	*	*	*	9,800
Methidathion (Supracide)					*	1,200
Methoxychlor					*	100
Methyl parathion					*	1,400
Oxydemetonmethyl (Meta-Systox)	*	*				2,100
Phorate (Thimet)	*	*				28,000
Phosmet (Imadan)					*	600
Propargite (Comite)	*					1,700
Terbufos (Counter)	*					1,900
Toxaphene	*	*	*	*		85,800
Trichlorfon (Dylox)					*	200

[1] Generic names are listed first followed by a trade name in parenthesis to help identify pesticides. No endorsement is intended nor is any criticism implied of similar products not mentioned.

[2] Estimated quantity applied in south-central Kansas based on data from the Kansas Crop and Livestock Reporting Service (1978, 1980).

Water samples were collected from wells that provided stock, irrigation, public, and domestic supplies. Prior to sample collection and onsite measurements, at least two well volumes of water were pumped. Onsite measurements consisted of specific conductance, pH, water temperature, and alkalinity (based on titration to a pH of 4.5). Table 3 lists the location of sampled wells (by latitude, longitude, and sequence number), the water use, and the data collected. Water samples were collected and preserved using U.S. Geological Survey standard procedures (Skougstad and others, 1979). Four gas-chromatography detectors and high-performance liquid chromatography were used to analyze pesticide
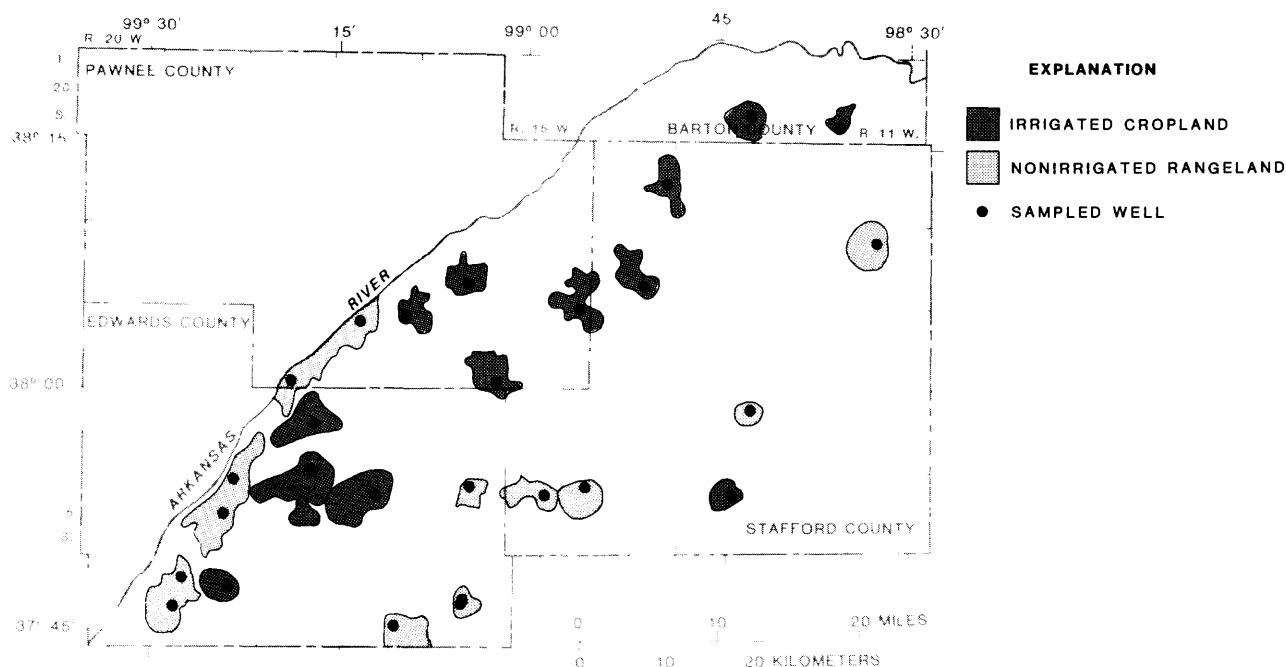
Figure 5.--Location of sampled wells and selected areas of land use.

concentrations as indicated in table 4. The list of pesticides in table 4 is extensive because this study was a reconnaissance and, as such, had a broad overview. Also, there was no previous organic-water-quality information on which to base restrictions. In addition to the pesticide determinations, concentrations of dissolved sodium, sulfate, chloride, nitrite plus nitrate, and ammonia were determined.

Organic-compound scans for all 27 sampling sites were determined on a gas chromatograph equipped with a flame-ionization detector (GC/FID scan-- see section on "Gas-Chromatograph Analysis" for an expanded description of this procedure). The scans are best suited for detecting hydrocarbons but also can detect numerous other organic compounds if present in large concentrations.

Data Analysis

Concentrations of sodium, sulfate, chloride, nitrite plus nitrate, ammonia, and pesticides that exceeded the present level of laboratory detection are listed in table 5. In the table, wells are grouped by their location on irrigated cropland and nonirrigated rangeland. Of the 42 organic compounds for which analyses were made (table 4), only 2,4-D, atrazine, and propazine were detected.

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Table 3.--*Data-collection sites and selected data from the Great Bend Prairie area*

[Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; temperature in degrees Celsius; and alkalinity as CaCO$_3$, in milligrams per liter]

Well number (latitude, longitude, sequence number)	County	Date (month/ day/ year)	Time (24- hour)	Specific conduct- ance	pH	Tem- per- ature	Alka- lin- ity	Water use
Wells in irrigated cropland								
381629098352901	Barton	08/29/84	0930	755	7.7	17.0	178	Domestic
381718098422601	Barton	08/29/84	1040	590	7.6	17.0	211	Do.
381335098492401	Stafford	08/29/84	1320	485	7.4	18.0	203	Do.
380621098502901	Stafford	08/29/84	1435	620	7.6	18.0	194	Do.
380513098555401	Pawnee	08/29/84	1540	440	7.7	18.0	184	Do.
380635099043201	Pawnee	08/30/84	1130	445	7.7	17.0	207	Do.
380005099021402	Pawnee	09/05/84	1245	540	7.5	16.0	219	Do.
380421099095001	Pawnee	08/30/84	1010	400	7.7	17.5	158	Do.
375729099164201	Edwards	09/05/84	1000	455	7.6	15.5	178	Do.
375254098434001	Stafford	08/30/84	1730	700	7.1	15.0	198	Irrigation
375318099111101	Edwards	08/30/84	1220	650	7.4	15.0	203	Stock
375333099185401	Edwards	08/30/84	1100	370	7.6	17.0	138	Domestic
374711099230501	Edwards	08/31/84	1020	555	7.3	16.0	413	Do.
Wells in nonirrigated rangeland								
380929098323201	Stafford	08/28/84	1935	270	7.7	13.5	97	Public
380424099124901	Pawnee	08/20/84	1400	870	7.7	19.0	101	Stock
380105099174802	Pawnee	09/05/84	0840	500	7.7	18.5	194	Do.
375843098421701	Stafford	08/30/84	1615	405	6.9	16.0	183	Do.
375447099222701	Edwards	09/04/84	1815	350	7.6	16.0	117	Do.
375409098523701	Stafford	08/30/84	1500	450	7.3	16.0	190	Do.
375317098575601	Stafford	08/30/84	1415	545	7.3	16.0	166	Do.
375337099040801	Edwards	08/30/84	1320	545	7.2	16.0	227	Do.
375155099174001	Edwards	08/30/84	1140	420	7.4	17.0	174	Do.
375204099231701	Edwards	09/04/84	1700	300	7.4	16.5	93.2	Do.
374705099043801	Edwards	08/28/84	1535	420	7.4	15.0	170	Do.
374516099095701	Edwards	08/28/84	1450	310	7.4	16.0	101	Do.
374812099263101	Edwards	08/28/84	1200	585	7.3	16.0	122	Do.
374606099271101	Edwards	08/28/84	1325	710	7.5	16.0	117	Do.

Table 4.--*Pesticides analyzed by class, detector, detection limit, and frequency of detections*

Pesticide	Lowest detectable concentration (micrograms per liter)	Number of samples in which the pesticide was detected (27 samples analyzed)
Carbamate insecticides analyzed using high-performance liquid chromatography		
Carbofuran	2.0	0
Chlorophenoxy acid herbicides analyzed using gas chromatography with dual-electron-capture detector		
2,4-D	0.01	23
2,4-DP	.01	0
2,4,5-T	.01	0
silvex	.01	0
Organochlorine insecticides analyzed using gas chromatography with electron-capture detector		
Aldrin	0.01	0
Chlordane	.1	0
DDD	.01	0
DDE	.01	0
DDT	.01	0
Dieldrin	.01	0
Endosulfan	.01	0
Endrin	.01	0
Heptachlor	.01	0
Heptachlor epoxide	.01	0
Lindane	.01	0
Methoxychlor	.01	0
Mirex	.01	0
Perthane	.1	0
Toxaphene	1.0	0
Organophosphate insecticides analyzed using gas chromatography with flame photometric detector		
Diazinon	0.01	0
Ethion	.01	0
Fonofos	.01	0
Malathion	.01	0
Methyl parathion	.01	0
Methyl trithion	.01	0
Parathion	.01	0
Phorate	.01	0
Trithion	.01	0

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Table 4.--*Pesticides analyzed by class, detector, detection limit, and frequency of detection*--Continued

Pesticide	Lowest detectable concentration (micrograms per liter)	Number of samples in which the pesticide was detected (27 samples analyzed)
Triazine herbicides analyzed using gas chromatography with alkalai flame-ionization detector		
Alachlor	0.1	0
Ametryn	.1	0
Atratone	.1	0
Atrazine	.1	2
Cyanazine	.1	0
Cyprazine	.1	0
Prometon	.1	0
Prometryn	.1	0
Propazine	.1	1
Simazine	.1	0
Simetone	.1	0
Simetryn	.1	0
Trifluralin	.1	0

Onsite measurements (table 3) and chemical-constituent samples (table 5) from wells in irrigated cropland and nonirrigated rangeland were analyzed statistically to determine if differences in water quality occurred between the measurements of samples. A statistical summary of the onsite measurements and chemical-constituent samples is shown in table 6. The table includes the 25th, 50th (median), and 75th percentiles for each onsite measurement and chemical constituent for which statistical analyses could be made. The median value was selected as a single estimator of the central tendency of water quality because the median is not sensitive to outlier values as compared to the mean of the data. For example, the mean concentrations of nitrite plus nitrate as nitrogen for water samples from irrigated and nonirrigated areas were 6.8 and 4.7 mg/L, respectively, while the median values (table 6) were 5.5 and 4.8 mg/L, respectively. The mean concentration of nitrite plus nitrate as nitrogen from the irrigated areas was influenced greatly by the two extreme values of 12 and 16 mg/L.

The 25th and 75th percentiles of the data are shown as a measure of the range of the data. For example, the interquartile range (75th percentile minus the 25th percentile) for concentrations of sodium is approximately the same for irrigated and nonirrigated samples; compare 16 to 15 mg/L (table 6). However, the median concentrations of sodium from

Table 5.—*Summary of selected chemical constituents in ground water from central part of Great Bend Prairie*

[Concentrations of sodium, sulfate, chloride, nitrite plus nitrate as nitrogen, and ammonia as nitrogen, are in milligrams per liter. Concentrations of 2,4-D, atrazine, and propazine, are given in microgams per liter]

Well number (Latitude, longitude, sequence number)	County	Sodium	Sulfate	Chloride	Nitrite plus nitrate	Ammonia as nitrogen	2,4-D	Atrazine	Propazine
				Wells in irrigated land					
381629098352901	Barton	39	26	99	12	0.02	0.01	<0.1	<0.1
381718098422601	Barton	40	26	48	2.6	<.01	.01	< 1	<.1
381335098492401	Stafford	34	24	12	5.5	<.01	.08	.1	<.1
380621098502901	Stafford	36	10	59	7.3	<.01	.01	<.1	<.1
380513098555401	Pawnee	27	19	13	7.0	<.01	.02	<.1	<.1
380635099043201	Pawnee	29	17	10	3.9	<.01	<.01	<.1	<.1
380005099021402	Pawnee	30	19	17	5.0	<.01	<.01	<.1	<.1
380421099095001	Pawnee	18	19	11	9.5	<.01	<.01	<.1	<.1
375729099164201	Edwards	21	22	11	5.3	<.01	.01	<.1	<.1
375254098434001	Stafford	72	22	71	5.4	.02	.01	.2	<.1
375318099111101	Edwards	37	31	4.0	16	.04	.04	<.1	<.1
375333099185401	Edwards	15	24	6.8	2.8	<.01	<.01	<.1	<.1
374711099230501	Edwards	24	34	9.1	5.5	.07	.01	<.1	.1
				Wells in nonirrigated land					
380929098323201	Stafford	16	7.3	15	1.1	<0.01	0.04	<0.1	<0.1
380424099124901	Pawnee	86	22	250	7.4	.10	.04	<.1	<.1
380105099174802	Pawnee	18	31	9.0	6.0	.01	.03	<.1	<.1
375843098421701	Stafford	18	15	5.3	4.9	.01	.04	<.1	<.1
375447099222701	Edwards	21	18	20	2.1	<.01	.04	<.1	<.1
375409098523701	Stafford	6.5	7.8	11	4.6	.02	.04	<.1	<.1
375317098575601	Stafford	5.9	8.5	4.0	3.5	<.01	.04	<.1	<.1
375337099040801	Edwards	20	17	11	4.9	.01	.04	<.1	<.1
375155099174001	Edwards	21	23	8.5	8.2	<.01	.03	<.1	<.1
375204099231701	Edwards	11	31	10	3.3	<.01	.04	<.1	<.1
374705099043801	Edwards	17	19	5.3	5.4	<.01	.03	<.1	<.1
374516099095701	Edwards	11	17	3.3	8.1	<.01	.05	<.1	<.1
374812099263101	Edwards	39	140	11	3.3	.01	.05	<.1	<.1
374606099271101	Edwards	51	200	17	3.2	.02	.04	<.1	<.1

irrigated and nonirrigated areas are 30 and 18 mg/L, respectively. The median value of specific conductance for irrigated areas is 105 S/cm (microsiemens per centimeter) at 25 ℃ larger than for nonirrigated areas. The difference supports the concept that ground water beneath nonirrigated land is affected less by the overlying land use than ground water beneath irrigated land because specific conductance is a good measure of the amount of dissolved-solids concentrations in water. Except for 2,4-D and ammonia (table 6), median values for chemical constituents from the irrigated areas generally exceeded those from nonirrigated areas.

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Table 6.—*Statistical summary of selected onsite measurements and chemical-constituent samples from wells on irrigated and nonirrigated land in central part of Great Bend Prairie*

[Specific conductance is in microsiemens per centimeter at 25 degrees Celsius; pH is in standard units; water temperature is in degrees Celsius. Concentrations of sodium, alkalinity as calcium carbonate (CaCO3), sulfate, chloride, nitrite plus nitrate as nitrogen, and ammonia as nitrogen are in milligrams per liter. Concentrations of 2,4-D are in micrograms per liter]

	Specific conductance		pH		Water temperature		Sodium		Alkalinity as CaCO3		Sulfate		Chloride		Nitrite plus nitrate as nitrogen		Ammonia as nitrogen		2,4-D	
	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated
25th percentile	442	340	7.4	7.3	15.8	16.0	22	11	168	101	19	13	9.6	5.3	4.5	3.3	<0.01	<0.01	<0.01	0.04
Median (50th percentile)	540	435	7.6	7.4	17.0	16.0	30	18	194	144	22	18	12	10.5	5.5	4.8	<.01	.01	.01	.04
75th percentile	635	555	7.7	7.6	17.8	16.6	38	26	205	191	26	31	53	15.5	8.4	6.4	.02	.01	.02	.04
Two-tailed Wilcoxon rank-sum test	NSD1/		NSD		NSD		*(2)		*(2)		NSD		NSD		NSD		NSD		**(3)	

1 NSD, distributions are not significantly different at the 95-percent confidence level.

2 *, Distributions are significantly different at the 95-percent confidence level.

3 **, Distributions are significantly different at the 99-percent confidence level.

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To statistically evaluate potential differences in water quality between samples in irrigated and nonirrigated areas, a two-tailed Wilcoxon rank-sum test (Conover, 1980), also called the Wilcoxon-Mann-Whitney rank-sum test (Iman and Conover, 1983), was used. The 95-percent confidence level was specified as the minimum criterion to test for significant differences in water quality between onsite measurements and chemical-constituent concentrations in the two areas. Results of the two-tailed Wilcoxon rank-sum test shown in table 6 indicate that only concentrations of sodium and alkalinity were significantly larger at the 95-percent confidence level for samples beneath irrigated cropland as compared to nonirrigated rangeland. Conversely, concentrations of 2,4-D in samples from nonirrigated rangeland were larger at the 99-percent confidence level compared to those from irrigated cropland. While 2,4-D is used on both irrigated and nonirrigated land, the data may indicate that it is used in greater quantities on nonirrigated rangeland. On irrigated cropland, some farmers may use 2,4-D to eliminate unwanted vegetation prior to planting and then reapply it to control undesirable vegetation that emerges after planting. On nonirrigated rangeland, 2,4-D is used in apparently larger amounts to remove vegetation that is not wanted for grazing.

No statistically significant difference in values of specific conductance, pH, water temperature, sulfate, chloride, nitrite plus nitrate, and ammonia was detected using the two-tailed Wilcoxon rank-sum test. While no statistically significant differences were detected for the onsite measurements or laboratory analyses listed above, it is noteworthy that the median values for specific conductance, pH, water temperature, sulfate, chloride, and nitrite plus nitrate are larger for samples of ground water beneath irrigated as compared to nonirrigated areas. The larger median values of these physical and chemical properties may indicate that continued irrigation may result in significantly larger values of these constituents. The increase in the quantity of water moving down through the soil transports material applied to the land surface and leaches materials from the soil. This can cause the ground water beneath irrigated areas to increase in dissolved-solids content and possible pesticide residues. Evapotranspiration also can increase concentrations of dissolved solids in ground water in the irrigated areas, particularly where corn is grown.

In addition to the larger concentrations of sodium and alkalinity in water under irrigated cropland, the largest concentration of atrazine (0.2 µg/L) was found in water from the only irrigation well sampled (375254098434001, table 5). Water from the irrigation well also contained the largest sodium concentration (72 mg/L) and the second largest chloride concentration (71 mg/L) of wells located in the irrigated areas (table 5). This could suggest that water from the smaller domestic-supply wells, located on the fringe of irrigated fields, may represent a different quality of water within the aquifer than does water from the irrigation well. The sodium and atrazine concentrations found in water from the irrigation well support the premise that water-level drawdown develops under the irrigated fields, diverting the natural ground-water-flow patterns, and that pumpage may cause recycling and subsequent concentration of leachates from the land surface.

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IMPLICATIONS FOR FURTHER STUDY

The objective of this study was to evaluate the effects of land used for agriculture on ground-water quality in the High Plains aquifer in Kansas. An objective for further study would be to relate ground-water quality under similar land uses in other areas of the High Plains to that already found in this reconnaissance study. In the course of conducting this reconnaissance study, setting up analysis procedures, analyzing the results, and preparing for additional sampling for further statistical work, several adjustments to the initial study procedures appear to warrant further consideration:

(1) In sampling other areas to compare with reconnaissance results, water samples from large-capacity (irrigation) wells withdrawing water from directly beneath irrigated fields might be used to detect the maximum effects of larger recharge rates occurring where irrigation is practiced. Domestic wells sampled on the fringe of these fields during the reconnaissance study showed some effects of irrigation, but they may not be truly indicative of the potential problem of pesticide contamination.

(2) Analyses for carbamate insecticides, organochlorine insecticides, and organophosphate insecticides could be discontinued because no concentration of these compounds was measured above the present levels of detection during the reconnaissance study.

(3) The principal degradation products of the most commonly used pesticides need to be analyzed. For example, a principal degradation product of atrazine is hydroxyatrazine, which is far more water soluble than atrazine, thus increasing the likelihood that this degradation product could reach the water table. Several of the chlorophenoxy herbicides degrade to trichlorophenol (TCP), which can through a process of bimolecular condensation form paradioxin or dibenzofuran (Thomas Steinheimer, U.S. Geological Survey, oral commun., 1985).

(4) Data-collection procedures need to be reviewed to determine what is happening to the herbicide alachlor. Alachlor is the second most extensively used herbicide in Kansas and has a solubility of 220 mg/L, which is about about seven times the solubility of atrazine (33 mg/L) (McNeely and others, 1979). While it is true that the persistence of alachlor is not as long as that of atrazine, the combination of its extensive use and relatively large solubility suggests that alachlor or perhaps its principal degradation product(s) may be present in ground water. One factor to be considered is that alachlor was part of the triazine-herbicide determination in the reconnaissance study. The alkalai flame-ionization detector used to identify hydrocarbons is specific for nitrogen and phosphorus. Alachlor has only about 16 percent of the nitrogen content of atrazine. Thus, alachlor would have to be present in about six times the concentration of atrazine to be detected.

(5) Data-collection procedures also may need to be modified to determine why trifluralin, like alachlor, was not detected in the water-quality analyses, even though it has had extensive application in Kansas for the

last 20 years. Trifluralin (Treflan) has a reported solubility of about 24 mg/L (McNeely and others, 1979), which makes it moderately soluble when compared to other triazine herbicides. Fluorine is more electronegative than chlorine, which suggests that trifluralin could form a more tightly bonded compound than other triazine compounds. Thus, trifluralin may tend to persist longer in the environment than some of the other triazine compounds. The combination of moderate solubility and persistence, therefore, would suggest that, in time, trifluralin could reach the water table.

(6) Although organophosphate insecticides have been applied to irrigated cropland for many years, they were not detected in any of the ground-water samples during the reconnaissance study. Photolysis is the principal means by which these insecticides degrade on the land surface or in surface water, but they are not subject to photolysis in the soil where it is dark. An investigative procedure needs to be implemented to explain their movement if these compounds are detected in the ground water at some later time.

(7) The organochlorine insecticides that were used extensively in Kansas until the mid-1970's are most likely somewhere in the soil column, although not detected in the ground-water samples. These insecticides are very resistant to biodegradation and may have a longer half-life in the soil as compared to their residency in streambed sediments. These compounds are sparingly soluble in water and, thus, tend to adsorb onto soil particles; however, in the Great Bend Prairie and other areas of Kansas, the soil is quite sandy, and the amount of adsorption may not be great. The possibility that these compounds could eventually leach down into the ground water needs to be evaluated.

(8) Implications 2, 4, 5, 6, and 7 suggest that a study be conducted in the unsaturated zones in the Great Bend Prairie area to determine the presence or absence of the parent pesticide compounds that either were not detected or were detected at or near the detection level in the ground water. This could be accomplished by a combination of coring the soil profile and analyzing slices in the vertical and by analyzing the soil moisture collected from a series of suction lysimeters placed in the soil at different depths below land surface. If the presence of the parent pesticide compounds is detected, then studies to determine the distribution and migration of these compounds could be conducted.

Such a study, as briefly outlined above, is important in view of the fact that the nondetection of the compounds that can potentially migrate into the ground water in any 1 year does not preclude their presence in the future. The recent pesticide contamination of ground water by ethylene dibromide (EDB) in Arizona, California, Connecticut, Florida, Georgia, South Carolina, Massachusetts, and Washington and by dibromochloropropane (DBCP) in Arizona, California, Hawaii, Maryland, and South Carolina, as documented by the U.S. Environmental Protection Agency (Cohen and others, 1986), serves as an example of the apparent unpredictability of pesticide contamination.

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(9) The representativeness of water quality from the shallow wells
in the irrigated areas needs to be investigated. An experiment could be
designed to test the hypothesis that the water quality from a shallow
well located in an irrigated quarter-section is representative of water
quality from an adjacent irrigation well. Water-quality samples from six
shallow wells and six irrigation wells would constitute a sufficiently
large sample to test the hypothesis. A nonparametric paired test, such
as the exact median test as described by Iman and Conover (1983), could
be used to test the hypothesis. If the water quality of samples of
ground water from the shallow and irrigation wells is not statistically
different at the 95-percent confidence level, then deep wells could be
drilled, sampled, and their water quality compared to that of the irri-
gation wells.

SUMMARY

The High Plains of western Kansas is one of 14 areas selected for
preliminary ground-water-quality appraisal by the U.S. Geological Survey's
Toxic Waste--Ground-Water Contamination Program. The specific objective
of the reconnaissance study, reported herein, was to evaluate the effects
of land used for agriculture (irrigated cropland and nonirrigated range-
land) on water quality of the High Plains aquifer.

Conceptual inferences, based on the information available, would
expect ground water beneath irrigated cropland to contain larger con-
centrations of sodium, sulfate, chloride, nitrite plus nitrate, and some
water-soluble pesticides than water beneath rangeland (nonirrigated land).

The central part of the Great Bend Prairie, an area of about 1,800
mi^2, was selected for the study of agricultural land use because it has
sandy soils, a shallow water table, relatively large annual precipitation,
and includes large areas that are exclusively irrigated cropland or non-
irrigated rangeland. Within the irrigated areas, the major crops are
corn, grain sorghum, wheat, soybeans, and alfalfa. In addition to the use
of fertilizers to increase crop growth, carbamate insecticides, chloro-
phenoxy acid herbicides, organochlorine insecticides, organophosphate in-
secticides, and triazine herbicides have been used to reduce the competi-
tive or destructive action of weeds and insects. Within nonirrigated
rangeland areas, water-soluble chlorophenoxy herbicides typically are ap-
plied to reduce unwanted vegetation.

As determined by the two-tailed Wilcoxon rank-sum test, concentra-
tions of sodium and alkalinity were significantly larger at the 95-percent
confidence level for water samples from beneath irrigated cropland as
compared to rangeland. Concentrations of 2,4-D found in the water samples
from beneath rangeland were larger at the 99-percent confidence level as
compared to concentrations of 2,4-D in samples from beneath irrigated crop-
land. In addition to the significantly larger concentrations of sodium and
alkalinity in water beneath irrigated cropland, the largest concentration
of atrazine was found in water from the only irrigation well sampled. No
statistically significant difference, at the 95-percent confidence level,
was found for specific conductance, pH, water temperature, sulfate, chlo-
ride, nitrite plus nitrate, and ammonia.

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GAS-CHROMATOGRAPH ANALYSIS

Detecting the presence of organic substances with a gas chromatograph equipped with a flame-ionization detector generally is referred to as a GC/FID scan. In the method, a sample of water is made acidic and then extracted with an organic solvent such as methylene chloride. The sample of water then is made alkaline and extracted again with the same solvent. The two extracts are combined, reduced in volume, and injected into a gas chromatograph equipped with a flame-ionization detector. As the compounds that have been extracted elute from the gas chromatograph, the flame causes the compounds to ionize, which in turn causes an electrical current to flow that is proportional to the concentration present. The current is amplified and recorded on a strip chart using elapsed time since injection as the abscissa. The recording is called a chromatogram.

The chromatogram provides a semiquantitative and semiqualitative analysis. It is semiquantitative in the sense that if organic compound "xyz" is present in a larger concentration than compound "abc," and given that both contain the same proportion of carbon and hydrogen to their total molecular weight, then the concentration of "xyz" will be reported to be larger than that of "abc." Internal standards are added to the sample to provide a basis for the semiquantification of the unknowns. The scan is also semiqualitative in the sense that lighter molecular-weight compounds will elute earlier than heavier ones. Thus, benzene will be displayed on the chromatogram with a retention time that is less than that of pentachlorophenol, although from a visual inspection of the chromatogram one would not know necessarily where benzene or pentachlorophenol was on the chromatogram.

Flame-ionization detectors are designed to measure organic compounds that are composed mostly of carbon and hydrogen. Compounds that fall within this category are oil-derived substances such as gasoline, other fuels, and many organic solvents. The present level of detection of an organic compound that is composed of only carbon and hydrogen is about 0.2 µg/L. GC/FID scans are not particularly useful for finding various pesticide residues, such as organochlorine and organophosphorus insecticides or the triazine herbicides, unless the water is grossly contaminated with these substances. For example, the herbicide atrazine is by molecular weight composed of 51.09-percent carbon and hydrogen. Thus, for the GC/FID scan to detect atrazine in a water sample, about 0.4 µg/L of atrazine would have to be present. Another example is the detection of phorate, which is an extensively used organophosphate insecticide. Phorate is 38.8 percent carbon and hydrogen by molecular weight. For a GC/FID scan to detect the presence of phorate, at least 0.52 µg/L would have to be present given a detection level of 0.2 µg/L for a compound that is composed of only carbon and hydrogen. An analysis of the pesticides that commonly are used today indicates that they are on the average composed of about 50 percent carbon and hydrogen by molecular weight. Thus, under ideal conditions, no less than about 0.4 µg/L of a pesticide would need to be present to be detected.

The GC/FID scan was used because of its ability to detect numerous compounds. That is, if some particular unrecognized agricultural activity resulted in contributing large concentrations of organic compounds other than pesticides to the ground-water system, the GC/FID scan could detect this. Additionally, if the ground water was grossly contaminated with pesticides, the GC/FID scan could detect their presence, although in either case an observation of the chromatogram would not discern the difference between the presence of a pesticide or some other organic compound. If the GC/FID scan did detect the presence of one or more compounds in several of the samples, these extracts then could be injected into a gas chromatograph/mass spectrograph for identification.