NONPOINT-SOURCE AGRICULTURAL CHEMICALS IN GROUND WATER IN NEBRASKA--PRELIMINARY RESULTS FOR SIX AREAS OF THE HIGH PLAINS AQUIFER

By Hsiu-Hsiung Chen and A. Douglas Druliner

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DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas S. Peck, Director

For additional information
write to:
District Chief
U.S. Geological Survey
406 Federal Building
100 Centennial Mall, North
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CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer metric system, the conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
acre	0.004047	square kilometer
bushel	0.0352	cubic meter
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
foot per mile	0.0189	meter per kilometer
gallon per minute	0.0038	cubic meter per minute
inch	25.4	millimeter
inch per year	25.4	millimeter per year
million gallons per day	3,785	cubic meter per day
mile	1.609	kilometer
mile per year	1.609	kilometer per year
pound	0.4536	kilogram
pound per acre	1.120	kilogram per hectare
square mile	2,590	square kilometer

DEFINITION OF VERTICAL DATUM

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

This report describes the reconnaissance phase of a study to determine the occurrence of agricultural chemicals from nonpoint sources in ground water in six areas, which are representative of the major provinces of the High Plains aquifer in Nebraska. Nitrate and triazine-herbicide concentrations in ground water were assessed to establish preliminary relations between these constituents and selected hydrogeologic, climatic, and land-use variables.

In 1984, water from 82 wells in the 6 study areas was analyzed for nitrate, and water from 57 of the 82 wells was analysed for triazine herbicides. Data for 9 of the 21 independent variables suspected of affecting concentrations of nitrate and triazine herbicides in ground water were compiled from the 82 well sites. The variables and their ranges are: hydraulic gradient (X1), 0.0006-0.0053; hydraulic conductivity (X2), 5-149 feet per day; specific discharge (X3), 0.0128-0.2998 foot per day; depth to water (X4), 3-239 feet; well depth (X5), 40-550 feet; annual precipitation (X6), 12.0-39.3 inches; soil permeability (X7), 0.76-9.0 inches; irrigation-well density (X8), 0-8 irrigation wells per square mile; and annual nitrogen fertilizer use (X9), 0-260 pounds of nitrogen per acre.

Nitrate concentrations ranged from less than 0.1 to 45 milligrams per liter as nitrogen. Triazine-herbicide concentrations were detected in samples from five of the six study areas in concentrations ranging from less than 0.1 to 2.3 micrograms per liter. Statistical tests indicated that there were significant differences in nitrate concentrations among the six study areas, while no significant differences in triazine-herbicide concentrations were found.

Concentrations of nitrate and triazine herbicide were determined, by use of nonparametric statistics, to be significantly larger in more intensively irrigated areas than in less intensively irrigated areas. Preliminary correlations with the independent variables and nitrate concentrations indicated significant relations at the 95-percent confidence level with variables X2, X5, and X8. Correlations with triazine-herbicide concentrations indicated significant relations with variables X2, X3, X5, X6 and X8, and with nitrate concentrations (X10). By use of a simple multiple-regression technique, variables X5, X8, and X9 explained about 51 percent of the variation in nitrate concentrations. Variables X3 and X5 explained about 60 percent of the variation in triazine-herbicide concentrations. With the addition of nitrate concentration as an independent variable, two variables, X10 and X3, explained 84 percent of the total variation in triazine-herbicide concentrations.

INTRODUCTION

In 1984, the U.S. Geological Survey began an appraisal of the Nation's ground-water quality under the Toxic Waste/Ground-Water Contamination Program. Fourteen study areas throughout the United States were selected to include a variety of hydrologic, climatic, soil, and land-use environments. The studies are intended to develop methods useful for systematic evaluation of the extent of ground-water contamination and for determination of the effects of human activities and local hydrology on ground-water quality (Helsel and Ragone, 1984).

Nebraska was selected as one of the 14 initial study areas because much of the State is underlain by the High Plains aquifer, which is the primary ground-water source for eight States in the High Plains, and because large quantities of agricultural fertilizers and pesticides are applied annually in the State. Nebraska is typical of many High Plains States in which agriculture has become dependent on fertilizers and pesticides to sustain production. Agricultural-chemical use in Nebraska has been increasing substantially since the early 1970's. During 1985 an estimated 200 million pounds of fertilizer and 30 million pounds of pesticides (active ingredients) were applied in Nebraska (Powers, 1985).

Agricultural chemicals have been detected in the ground water in some locations in Nebraska. Nitrate contamination of ground water, which results primarily from fertilizer application (Gormly and Spalding, 1979), has been detected in intensively farmed areas of Nebraska for several years. Similarly, pesticide contamination of ground water has been detected in some areas of the State (Spalding and others, 1978).

To date (1984) only a few studies of the High Plains aquifer have been made to determine the magnitude and extent of ground-water contamination that results from the nonpoint application of pesticides. Also, little is known about the variables that control the access of these chemicals to the aquifer and the relative importance of the variables.

Purpose and Scope

The objectives of the overall study are to: (1) Determine the extent of ground-water contamination by selected agricultural chemicals applied in six study areas in Nebraska that are underlain by the High Plains aquifer, and (2) relate the distribution of these ground-water contaminants to the major variables that may affect ground-water quality in the six areas through a series of mathematical or statistical equations. These equations may be used as predictive tools to identify areas of potential ground-water contamination in agricultural chemicals in other areas of the High Plains aquifer. This study consists of two phases—a reconnaissance and preliminary evaluation phase (described in this report) and a detailed evaluation phase.

The purposes of this reconnaissance phase of the study were to: (1) provide information on ground-water contamination by agricultural chemicals with emphasis on nitrogen fertilizers and triazine herbicides, (2) establish tentative relations between some hydrogeologic, climatic, soil, and land-use variables and ground-water contamination caused by agricultural chemicals, and (3) provide a preliminary evaluation of the use of multiple regression and other statistical techniques to assess the relative importance of selected variables in affecting ground-water contamination by agricultural chemicals.

The reconnaissance phase of the study included the evaluation of hydrogeologic, climatic, soils, land-use, and water-quality data from several State and Federal agencies. The water-quality data were used to identify areas of probable nonpoint-source contamination and to examine contamination trends. The absence of pesticide data for most areas of the High Plains aquifer in Nebraska prompted new sampling of 82 wells in 6 areas of the State. This report presents preliminary evaluation of the relations of selected variables to nitrate and triazine-herbicide concentrations in ground water in the six areas.

Acknowledgments

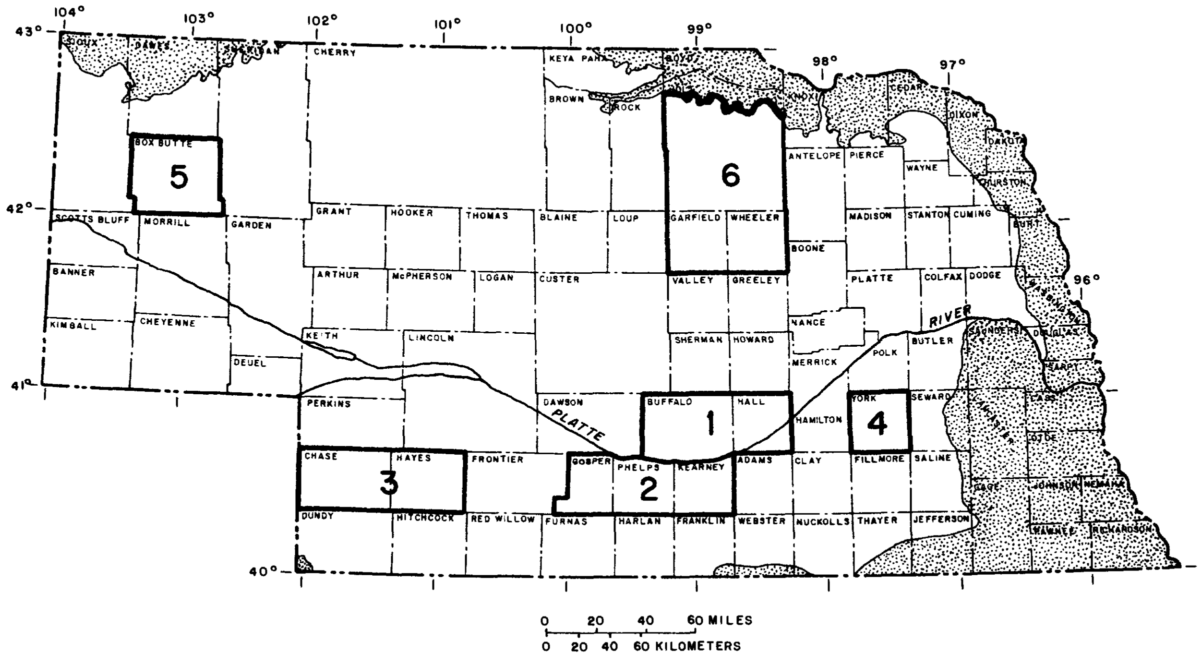
The authors are grateful to numerous individuals and organizations who facilitated the data collection. We acknowledge helpful discussions with Dr. Gerald Kutih, statistical consultant, University of Nebraska, Dr. Bruce Johnson, Agricultural Economics, University of Nebraska, and Dr. Shripat Kumble, Environmental Programs, University of Nebraska; the release of water-quality data by Dr. Roy Spalding, Conservation and Survey Division, University of Nebraska; and numerous landowners or tenants who permitted access to their wells.

DESCRIPTION OF THE SIX STUDY AREAS

Six areas in Nebraska (fig. 1) that are underlain by the High Plains aquifer were selected for study based on the diversity and availability of hydrogeologic, climatic, soils, and land-use data. These areas are representative of major ground-water provinces and principal land uses in Nebraska. The six areas also are characterized by either existing or potential ground-water contamination by nitrate resulting from intensive application of agricultural chemicals.

Physical Description of the High Plains Aquifer

The High Plains aquifer extends from South Dakota to Texas and underlies parts of eight states; the aquifer underlies about 65,000 square miles (37 percent) in Nebraska. The aquifer is unconfined and predominately consists of the Ogallala Formation of Tertiary age. Locally, hydraulically connected sand and gravel in younger or older formations are part of the aquifer. The



EXPLANATION

HIGH PLAINS AQUIFER

HIGH PLAINS AQUIFER NOT PRESENT

1 BUFFALO AND HALL COUNTIES

2 GOSPER, PHELPS, AND KEARNEY COUNTIES

3 CHASE AND HAYES COUNTIES

4 YORK COUNTY

5 BOX BUTTE COUNTY

6 GARFIELD AND WHEELER COUNTIES AND PART OF HOLT COUNTY

Figure 1.--Extent of High Plains aquifer and location of the six study areas.

Ogallala Formation is of fluvial origin and is comprised of semiconsolidated calcareous silt, sand, and sandstone, with some zones of coarse sand and gravel. The Ogallala and the overlying Pleistocene units generally are hydraulically connected, although clay lenses separate them in some places. The base of the aquifer consists of Cretaceous shale and chalk deposits in all study areas except area 5 and parts of area 6, which are underlain by older Tertiary clay, silt, and some basal sand.

The saturated thickness of the High Plains aquifer in Nebraska ranges from less than 1 foot to more than 1,000 feet. In areas 1, 2, and 4, the saturated thickness ranges from 200 to 400 feet; in area 3 it ranges from 100 to 400 feet; in area 5 it ranges from 200 to 600 feet; and in area 6 it ranges from 0 to 800 feet (Pettijohn and Chen, 1983).

The average hydraulic conductivity of the High Plains aquifer in the six study areas ranges from less than 10 feet per day in parts of area 5 to 200 feet per day in parts of areas 1 and 3 (Pettijohn and Chen, 1984b). Large parts of the study area have average hydraulic-conductivity values between 10 and 50 feet per day.

Depth to water, based on spring 1984 water-level measurements, ranges from 5 to 30 feet in the southern part of area 1 and the northern part of area 2, both of which border the Platte River. Depth to water exceeds 250 feet in the eastern one-half of area 3. In most upland areas, depth to water ranges from 100 to 250 feet below land surface (Pettijohn and Chen, 1983).

Specific yield, an estimate of effective porosity, ranges from less than 0.10 in parts of areas 1, 2, and 6 to more than 0.25 in areas 2 and 3 (Pettijohn and Chen, 1983).

The ground-water flow system is controlled principally by topography. During spring 1984, the potentiometric surface of the High Plains aquifer ranged from an altitude[1] of 5,250 feet above National Geodetic Vertical Datum of 1929 (NGVD of 1929) in western Nebraska to 1,100 feet about 350 miles to the east, indicating an eastward direction of ground-water flow and an average hydraulic gradient of about 12 feet per mile. The direction of flow in the six study areas also is predominantly to the east, with some minor flow to the northeast and southeast (figs. 2-4).

Estimates for the rate of ground-water flow in the six study areas have been made by dividing the specific-discharge values by porosity estimates for the aquifer materials. Using an approximate porosity of 20 percent, ground-water flow rates in the six study areas range from 0.06 to 1.50 feet per day and average about 0.38 foot per day (0.026 mile per year). Thus, an average of about 38 years is needed for ground water to travel 1 mile. In areas affected by pumpage from large-volume production wells, the gradient will be increased near the well, thus increasing the rate of flow toward the well.

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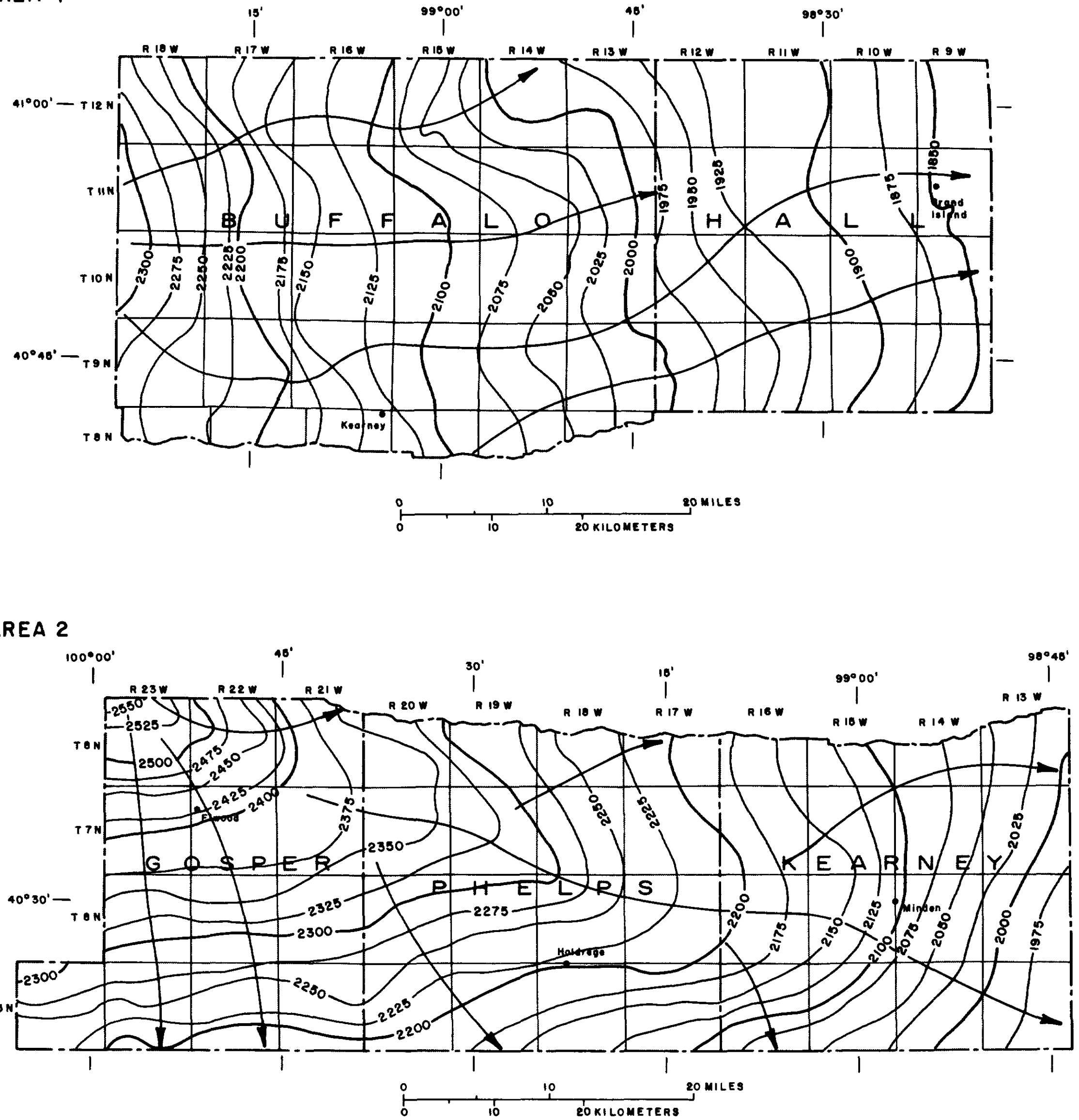
[1] Altitude, as used in this report, refers to distance above or below the NGVD of 1929.

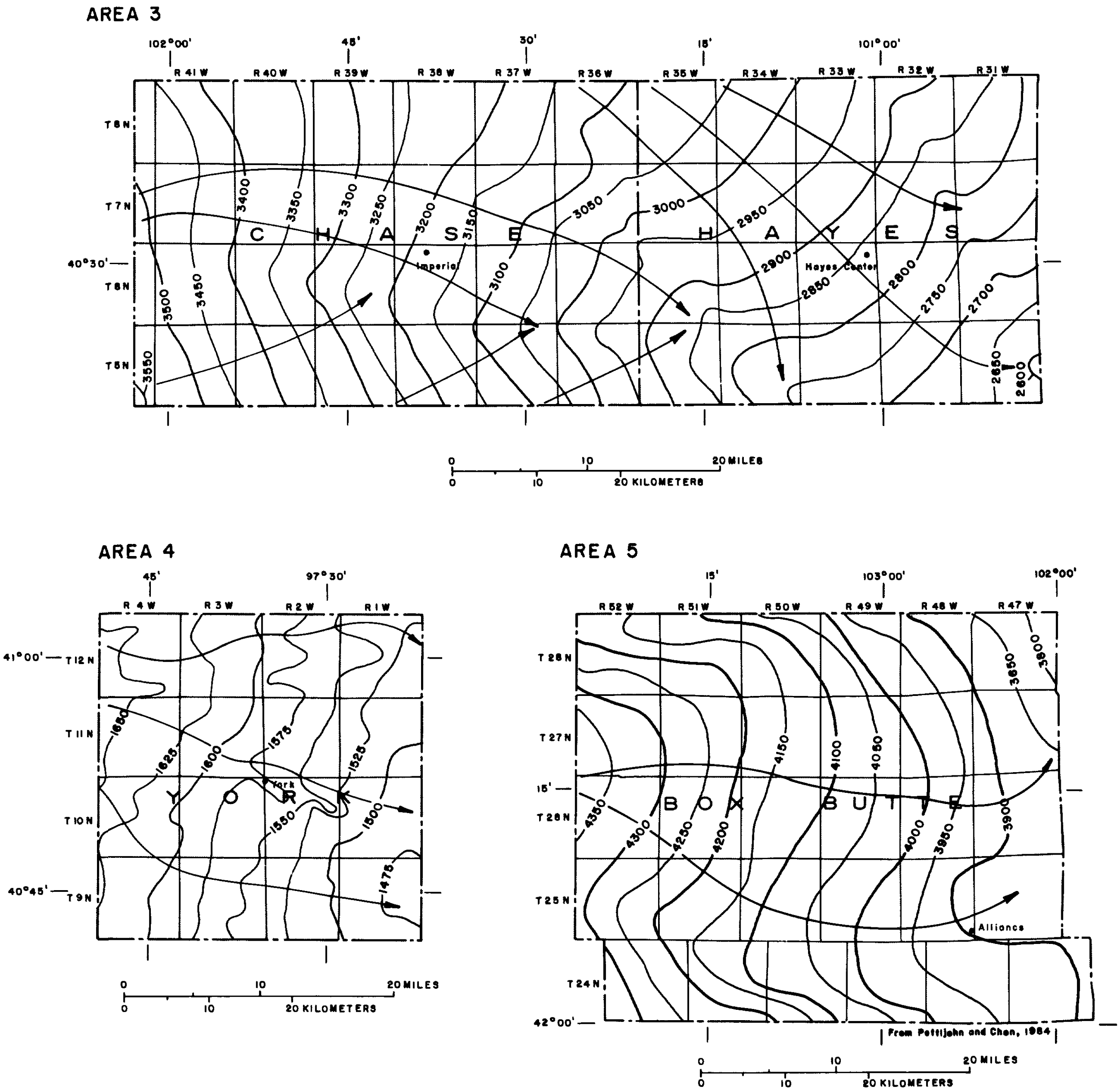


EXPLANATION

—2100— POTENTIOMETRIC CONTOUR--Shows altitude of potentiometric surface. Contour interval 25 feet. Datum is NGVD of 1929

⟶ DIRECTION OF GROUND-WATER FLOW

Figure 2.--Potentiometric surface of the High Plains aquifer in areas 1 and 2, spring 1984.



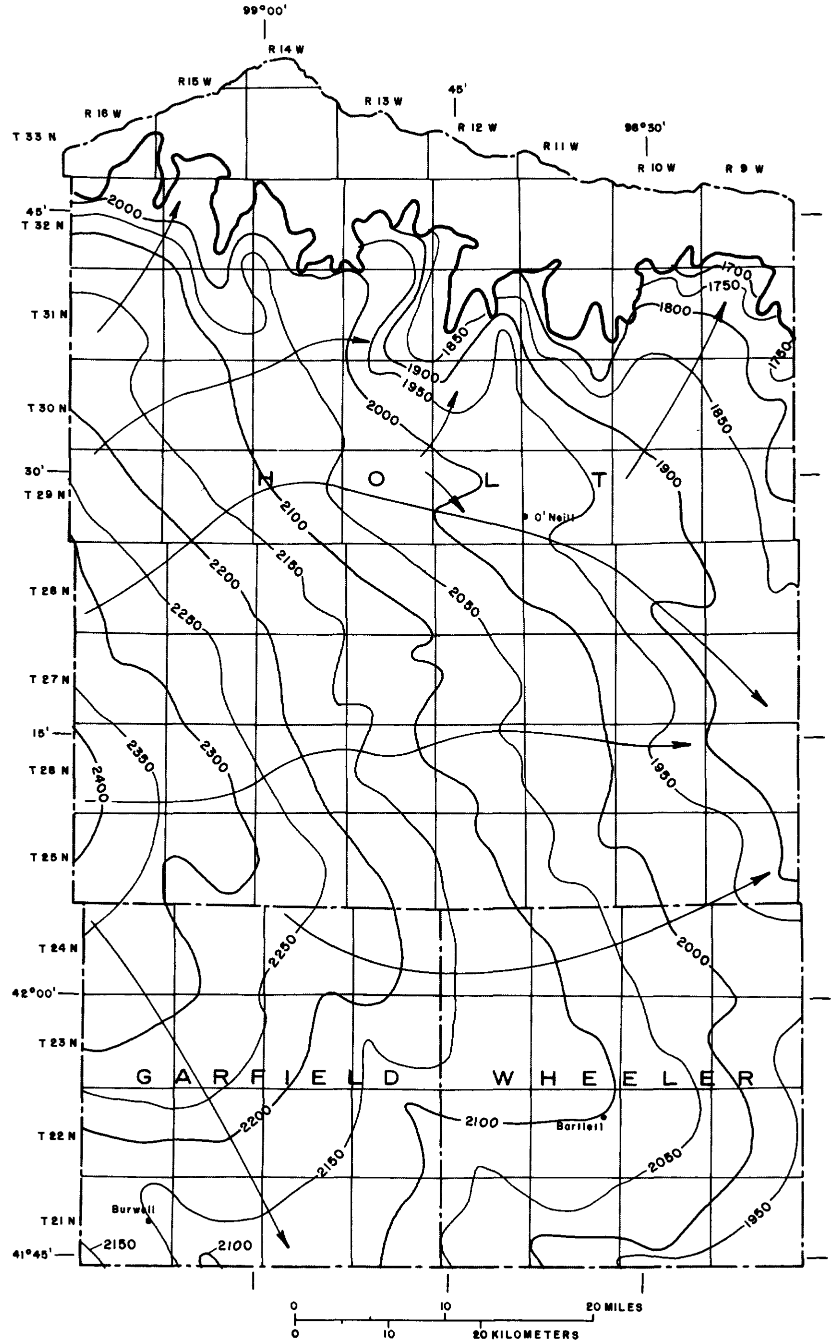
EXPLANATION

—— 1600 —— POTENTIOMETRIC CONTOUR--Shows altitude of potentiometric surface. Contour interval 25 and 50 feet. Datum is NGVD of 1929

——→ DIRECTION OF GROUND-WATER FLOW

Figure 3.--Potentiometric surface of the High Plains aquifer in areas 3, 4, and 5, spring 1984.

AREA 6



EXPLANATION

—2100— POTENTIOMETRIC CONTOUR--Shows altitude of potentiometric surface. Contour interval 50 feet. Datum is NGVD of 1929

→ DIRECTION OF GROUND-WATER FLOW

▬ NORTHERN BOUNDARY OF HIGH PLAINS AQUIFER

Figure 4.--Potentiometric surface of the High Plains aquifer in area 6, spring 1984.

Recharge to and Discharge from the High Plains Aquifer

In the six study areas, recharge from deep percolation of precipitation primarily occurs in upland areas. This is supplemented by irigation return flows, seasonal river and stream recharge, and canal leakage. Mean annual precipitation for the six study areas ranges from 17 inches in area 5 to 27 inches in area 4. Mean annual recharge in area 5 was estimated by Pettijohn and Chen (1984a) to range from 0.5 to 3.0 inches per year.

In the six study areas, discharge occurs principally as irrigation-well pumpage. Evapotranspiration and seepage into streams and creeks during periods of low flow occur in lowland areas such as stream valleys, lakes, and wet meadows.

Development of the High Plains Aquifer

Ninety-four percent of the ground water pumped in the State is used for irrigation, 5 percent is used for domestic purposes, and 1 percent is used for other purposes. The number of registered irrigation wells in the 6 study areas in 1984 ranged from 886 in area 5 to 6,407 in area 1 (table 1). The greatest concentrations of irrigation wells are in areas 1, 2, and 4; the wells are developed in Quaternary alluvial deposits. Estimates of annual ground-water pumpage during 1980 ranged from 108,400 acre-feet in area 5 to 608,700 acre-feet in area 1 (table 1).

The effects of intensive irrigation development on water levels in the High Plains aquifer are indicated by the water-level declines from predevelopment levels (figs. 5, 6, and 7). Declines of more than 30 feet have occurred in areas 3 and 5, less than 25 feet in area 6, and less than 20 feet in area 1 (Ellis and Pederson, 1985). In contrast, water levels have risen by more than 50 feet in much of area 2 as a result of a surface-water diversion project.

Susceptibility of the High Plains Aquifer to Contamination

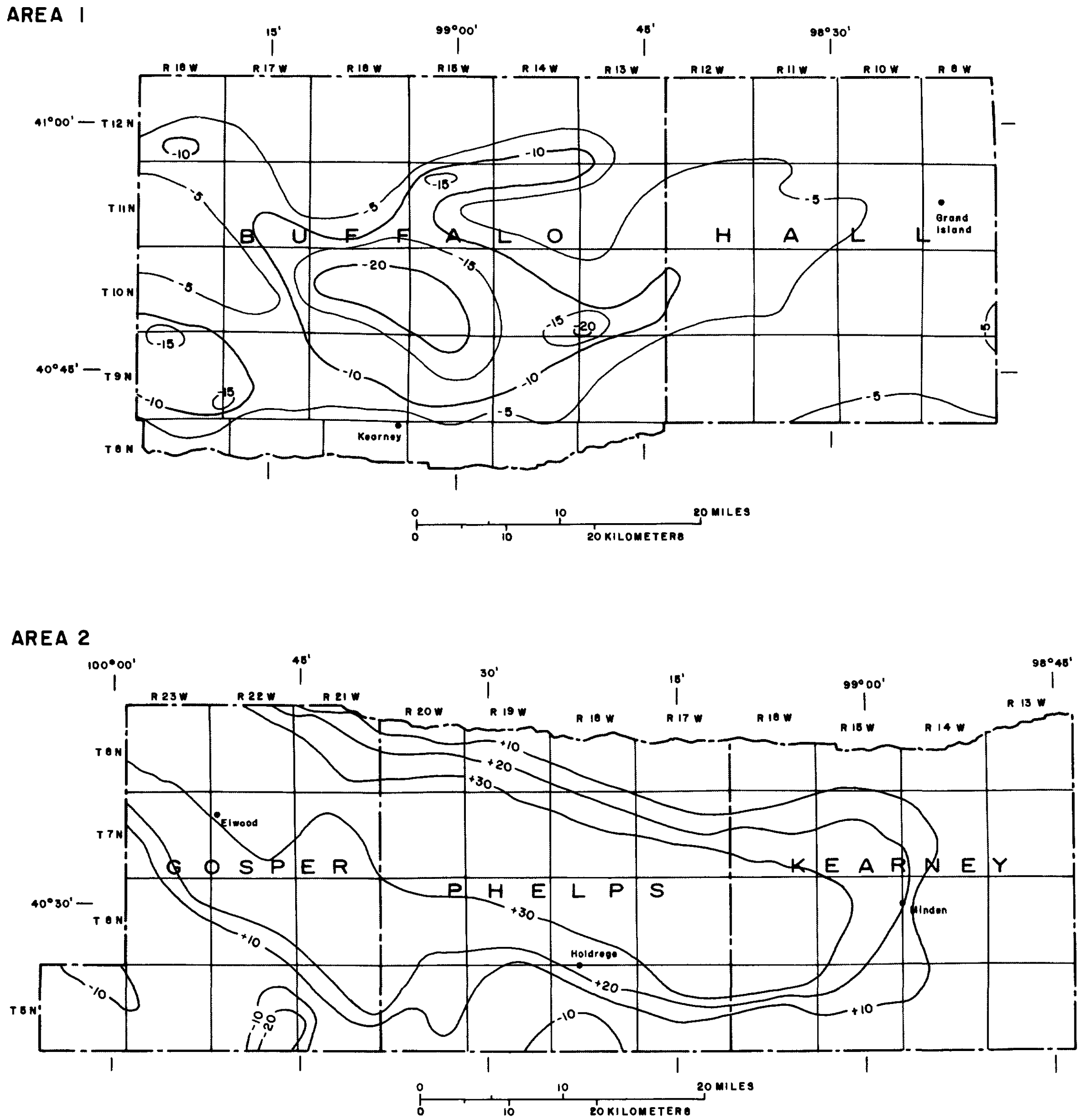
Little work has been done in estimating ground-water residence times in the High Plains aquifer in Nebraska. Based on the recharge pattern, the age of the water in the aquifer is assumed to be relatively young.

The likelihood of finding leachable agricultural chemicals in ground water beneath the six study areas is possible, based on the hydrogeologic considerations discussed above. The relatively young age of the water and its slow rate of flow, the locally shallow depths to water, and the moderate to substantial permeability of the sediments should allow the detection of contaminants reaching the water table from the unsaturated zone.

Table 1.--Agricultural land-use and irrigation data for the six study areas (Nebraska Department of Agriculture, 1984)

Study area	Land area (acres)	Farmland (percent)	Irrigated farmland (percent)	Number of registered irrigation wells1/	Estimated irrigation water used during 1980 (acre-feet)2/	Major crops grown in 1984	Estimated area where ground-water nitrate concentrations exceed 10 milli-grams per liter (square mile)3/
1	948,594	95.3	49	6,407	608,700	Corn, alfalfa, wheat, soybeans	4/ 156
2	972,325	93.6	50	3,872	474,800	Corn, sorghum, soybeans, wheat	5/ 83
3	1,028,371	97.6	21	1,648	180,300	Corn, wheat, sorghum	4/< 1
4	368,486	94.9	63	2,583	268,400	Corn, sorghum, soybeans	4/< 1
5	689,280	96.6	19	886	108,400	Wheat, corn, alfalfa, edible beans	4/ 59
6	2,272,748	88.7	15	2,866	408,600	Corn, alfalfa	4/ 226

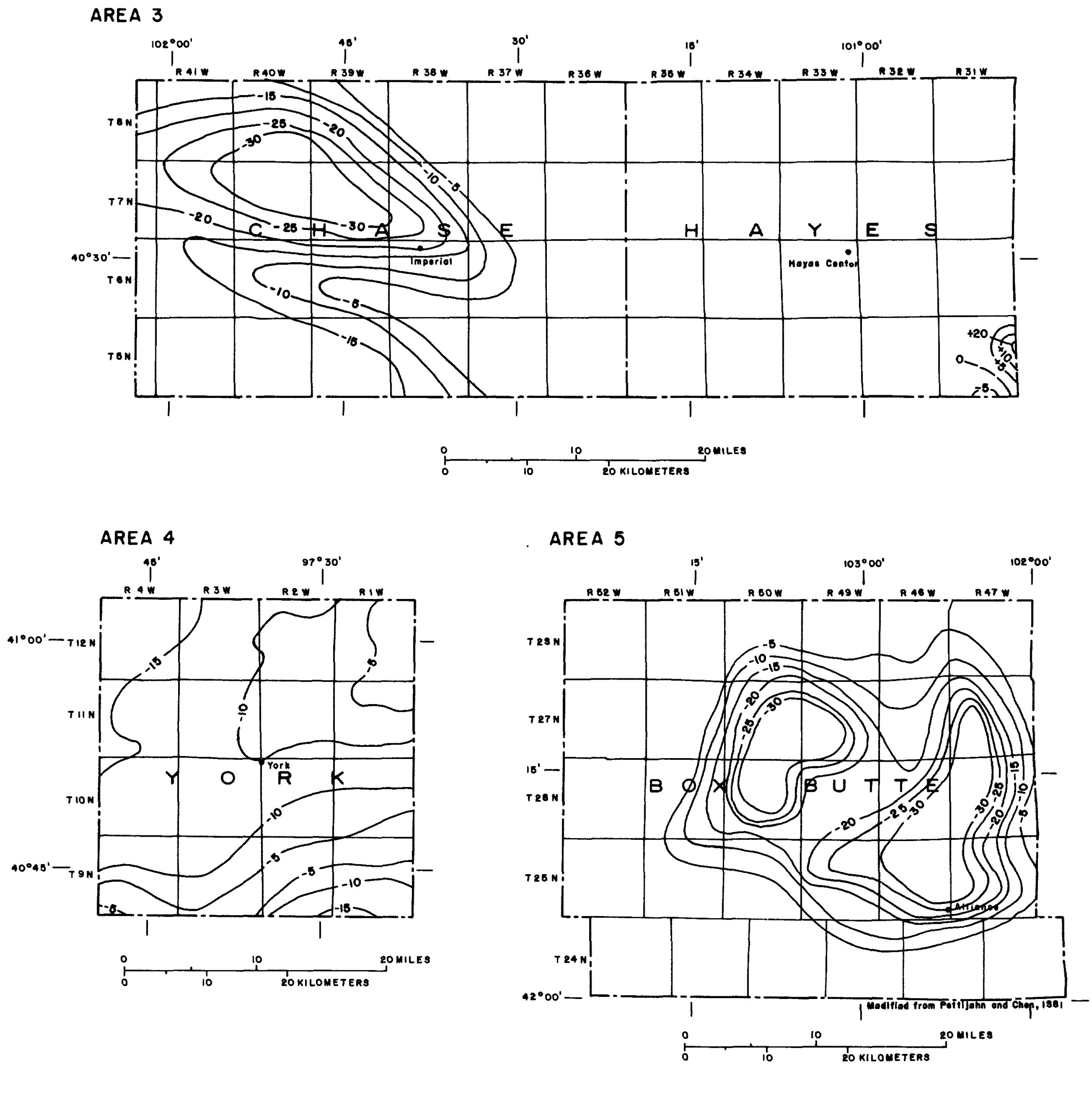
1/ From Ellis and Pederson (1985).
2/ From E.K. Steele, Jr., (U.S. Geological Survey, written commun., 1984).
3/ From Exner and Spalding (1979), Gormly and Spalding (1979), and Spalding (1975, 1981).
4/ Period used, 1975-79.
5/ Period used, 1978-79.



EXPLANATION

——+10—— LINE OF EQUAL WATER-LEVEL RISE (+) OR DECLINE (-)--Interval 5 and 10 feet

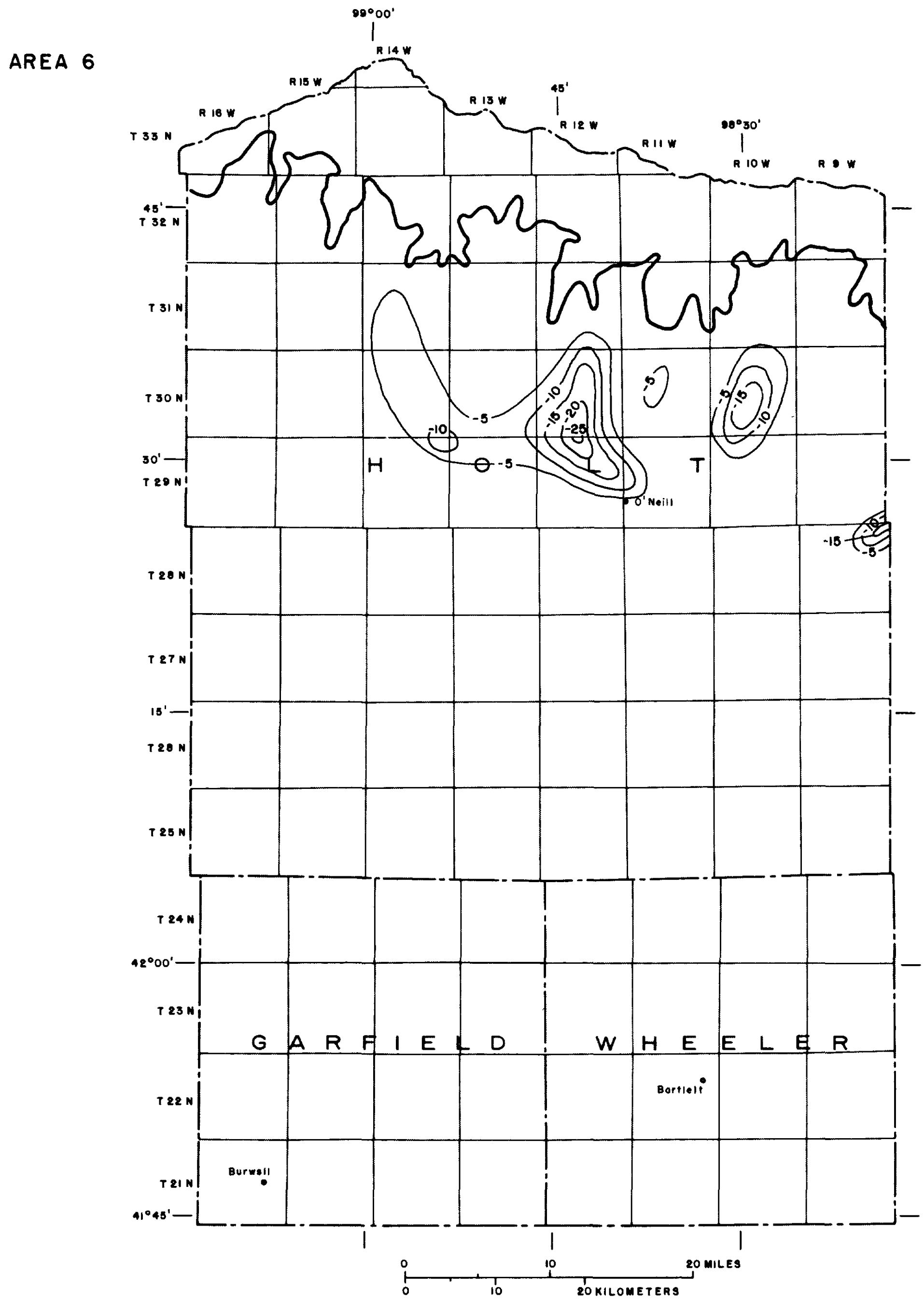
Figure 5.--Rises and declines in ground-water levels in areas 1 and 2, predevelopment through 1984.



EXPLANATION

——— -5 ——— LINE OF EQUAL WATER-LEVEL RISE (+) OR DECLINE (-)--Interval, 5 and 10 feet

Figure 6.--Rises and declines in ground-water levels in areas 3, 4, and 5, predevelopment through 1984.



EXPLANATION

—— -5 —— LINE OF EQUAL GROUND-LEVEL DECLINE--
Interval 5 feet

———— NORTHERN BOUNDARY OF HIGH PLAINS AQUIFER

Figure 7.--Declines in ground-water levels in area 6, predevelopment through 1984.

Land Use in the Six Study Areas

The six study areas consist of 12 counties constituting 13 percent of the State. An average of 94 percent of the six study areas is used for agriculture, with corn as the dominant crop in all but area 5. The study areas in the western part of the State tend to be drier and support fewer acres of row crops. Irrigated cropland accounts for about 50 percent of the total farmland in the southeastern study areas (areas 1, 2, and 4), and about 20 percent in the western and northeastern study areas (areas 3, 5, and 6). Agricultural land-use and irrigation data for the six study areas are tabulated in table 1. A summary of crops grown in the six study areas during 1984 is presented in table 2.

Current corn-production techniques require large quantities of nitrogen fertilizers and pesticides. The Cooperative Extension Service of the University of Nebraska recommends a total-nitrogen content in the soil of 270 pounds per acre to produce 200 bushels of corn per acre (University of Nebraska, 1979). Farmers commonly apply from 80 to 250 pounds of total nitrogen per acre, mostly as anhydrous ammonia to supplement residual nitrogen in the soil. Most of the applied nitrogen not used by crops is oxidized to nitrate in the soil. Nitrate is water soluble and extremely mobile. Thus, under oxidizing conditions in shallow and moderately permeable aquifers, nitrate can contaminate the ground water and migrate down gradient from application areas.

During 1978 and 1982, an estimated 24.5 and 29.6 million pounds of pesticides (active ingredients) were applied on agricultural lands in Nebraska (Johnson and Byers, 1979, and Johnson and Kamble, 1984). Quantities of principal herbicides used in Nebraska during 1978 and 1982 and the crops to which they were applied are summarized in table 3; similar data for insecticides are summarized in table 4. Herbicides accounted for 18.8 million pounds in 1978 (77 percent) and 24.3 million pounds in 1982 (80 percent), and insecticides accounted for 5.7 million pounds in 1978 and 5.3 million pounds in 1982. Most of these chemicals were applied to corn. The application rates of many of the more commonly used herbicides range from 1 to 2 pounds per acre; insecticide rates range from 4 to 8 pounds per acre. The solubility, half-life in soil and water, and mobility of some of these pesticides are such that significant ground-water contamination may occur in moderately permeable sediments (table 5).

Table 2.--Total acreage of crops (upper number) and percentage of total area planted in crops (lower number) in the six study areas, 1984
[*, less than 100 acres planted; ---, less than 1 percent of total area]

Area	Row crops			Small-grain crops			Other crops	
	Corn	Sorghum	Soybeans	Wheat	Oats	Barley	Alfalfa	Hay
1	372,000 39	19,900 2	45,000 5	49,000 5	5,700 1	800 *	54,500 6	69,000 7
2	401,000 41	56,000 6	53,000 5	89,000 9	4,700 *	300 *	28,000 3	41,000 4
3	167,000 16	40,000 4	11,800 1	143,000 14	4,700 *	1,600 *	13,900 1	29,000 3
4	180,000 49	71,000 19	47,000 13	16,000 4	700 *	--- *	6,700 2	9,000 2
5	35,000 5	900 *	32,000 5	115,000 17	11,500 2	10,900 2	12,400 2	26,000 4
6	304,000 15	8,400 *	11,800 1	6,800 *	11,000 *	200 *	57,700 3	374,000 16

Table 3.--Herbicide use on agricultural land in Nebraska, 1978 and 1982

[From Johnson and Byers, 1979; Johnson and Kamble, 1984. Dashes indicate no reported information]

Herbicide (common or trade name)	Thousands of pounds (active ingredients)									
	Corn		Sorghum		Soybeans		Other crops		Total	
	1978	1982	1978	1982	1978	1982	1978	1982	1978	1982
Atrazine	5,703	5,808	1,368	1,340	---	---	15	---	7,086	7,148
Alachlor (Lasso)	3,565	4,001	---	---	698	1,025	---	---	4,263	5,026
Butylate (Sutan)	1,850	5,156	---	---	---	---	---	---	1,850	5,156
Cyanazine (Bladex)	1,023	1,333	31	40	---	---	---	---	1,054	1,373
2, 4-D	270	274	140	95	---	---	160	648	570	1,017
EPTC (Eradicane)	770	364	---	---	---	---	---	---	770	364
Metolachlor (Dual)	101	240	---	150	---	---	---	---	101	390
Metribuzin (Sencor, Lexone)	---	---	---	---	139	330	---	---	139	330
Propachlor (Ramrod)	76	90	1,547	1,777	---	---	---	---	1,623	1,867
Trifluralin (Treflan)	---	---	---	---	258	955	---	---	258	955
Others	708	38	9	131	353	361	17	153	1,087	683
Total	14,066	17,304	3,095	3,533	1,448	2,671	192	801	18,801	24,309

Table 4.--Insecticide use on agricultural land in Nebraska, 1978 and 1982
[From Johnson and Byers, 1979; Johnson and Kamble, 1984. Dashes indicate no reported information]

Insecticide (common or trade name)	Thousands of pounds (active ingredients)									
	Corn		Sorghum		Soybeans		Other crops		Total	
	1978	1982	1978	1982	1978	1982	1978	1982	1978	1982
Carbaryl (Sevin)	172	28	13	9	19	---	33	---	237	37
Carbofuran (Furadan)	1,089	670	52	90	13	---	18	---	1,172	760
Chlorpyrifos (Lorsban)	83	483	---	---	---	---	---	---	83	483
Diazinon	21	47	---	---	---	---	---	---	21	47
Dimethoate (Cygon, Defend)	30	24	10	2	---	---	2	---	42	26
Disultoton (Di-Syston)	11	---	116	2	---	---	---	---	127	2
Ethoprop (Mocap)	139	94	---	---	---	---	---	---	139	94
Fonofos (Dyfonate)	1,071	1,552	---	---	---	---	---	---	1,071	1,552
Isofenphos (Amaze)	---	104	---	---	---	---	---	---	---	104
Malathion	7	4	3	---	---	---	190	44	200	48
Parathion	131	282	82	152	---	---	70	---	283	434
Permethrin (Ambush, Pounce)	---	20	---	---	---	---	---	---	---	20
Phorate (Thimet)	999	412	90	21	---	---	7	---	1,096	433
Terbofos (Counter)	1,145	1,263	---	---	---	---	---	---	1,145	1,263
Toxaphene	39	9	---	---	---	---	37	---	76	9
Other	18	---	5	---	---	---	---	---	23	---
Total	4,955	4,992	371	276	32	---	357	44	5,715	5,312

Table 5.--Chemical characteristics of pesticides commonly used in Nebraska
[Dashes indicate no reported information]

Pesticide	Recommended application rate (pounds per acre)1/	Solubility in water (milligrams per liter)2/	Half-life in soil (weeks)3/	Half-life in water (weeks)4/	Mobility5/
Herbicide					
Alachlor	1-4	242	1-10	---	0.6-8.1
Atrazine	2-4	33	4-57	10-106	0.4-8.0
Butylate	3-4	45	1.5-3	---	1.4-8.9
Cyanazine	1-2.5	171	1-5	---	3.4-4.6
2, 4-D	0.25-0.4	900	1-4	---	---
Propachlor	2-4	700	1-4	---	0.3-5.4
Insecticide					
Carbofuran	1	700	1-37	2.50	0.25-8.7
Chlorpyrifos	1	2	1-17	4-5	49.5-99.7
Fonofos	1	<1	3->24	---	---
Terbifos	1	15	---	---	---

1/ Pounds of active ingredients per acre (Weed Science Society of America, 1979).

2/ At 25 °Celsius (Cohen and others, 1984; Weed Science Society of America, 1979).

3/ Cohen and others (1984); Weed Science Society of America (1979).

4/ At ambient pH and temperature (Cohen and others, 1984; Meikle and Youngson, 1977).

5/ Soil-water distribution coefficient or adsorption constant. Values less than 5 are considered moderately mobile; values of 1-2 are more mobile (Cohen and others, 1984).

VARIABLES AFFECTING GROUND-WATER QUALITY

The potential for ground-water contamination with agricultural chemicals may be related to a variety of hydrogeologic, climatic, soil, and land-use variables. To identify those variables that affect ground water by agricultural chemicals in the six study areas, 21 independent variables were selected for evaluation in the overall study (table 6). Nine of these variables were selected for evaluation in this preliminary report based on present availability of data.

Descriptive statistics and frequency data for these nine variables are given in table 7. These data are based on conditions at 82 well sites in the six study areas where water samples were collected in 1984. Maximum and minimum values in table 7 define the overall range of the variables, but 90th and 10th percentiles in table 7 generally define a more effective range for general examination of the variables. Values greater than the 90th percentile or less than the 10th percentile are considered outliers that may represent anomalous data or random errors in the data base. Because of the skewed nature of the data, the median (50th percentile) may be more representative than the mean, because the mean may be affected unduly by the outliers, whereas the median is not.

Hydrogeologic Variables

The hydrogeologic characteristics of an aquifer system are among the most important categories of independent variables that may affect ground-water contamination. Contaminants dissolved in water enter ground-water systems in recharge areas and move through the system to discharge areas as dictated by the hydraulic gradient and hydraulic conductivity. Hydrogeologic variables control the direction and rate of contamination transport, the rate of contaminant attenuation, and the degree of dissipation by hydrodynamic dispersion within the aquifer system.

Hydraulic Gradient

The hydraulic gradient of the potentiometric surface determines the direction and, to some extent, the rate at which ground water moves; therefore, the hydraulic gradient affects the direction and maximum velocity of ground-water contaminant transport.

Hydraulic gradients were determined for each of the 82 sites sampled in 1984 by measuring the distance between contours on the spring 1984 potentiometric-surface maps (figs. 2-4), which were constructed from water levels measured in observation wells. The gradients for the 82 sample sites in the six study areas ranged from 0.0006 (3 feet per mile) to 0.0053 (26 feet per mile) and have an overall median of 0.0020 (10.0 feet per mile (table 7). Areas 1, 4, and 6 had the lowest median gradients, whereas the remaining areas had steeper median gradients (fig. 8A).

Table 6.--Variables that may affect nitrate and pesticide concentrations in ground water

Hydrogeologic	Soil
Hydraulic gradient 1/	Permeability 1/
Hydraulic conductivity 1/	Average water capacity
Specific discharge 1/	Percent surface slope
Depth to water 1/	
Well depth 1/	**Land Use**
Specific yield	
Rate of flow	Irrigation-well density 1/
Precipitation recharge	Nitrogen-fertilizer use 1/
	Percent irrigated land
Climatic	Pesticide use
	Human-caused rises and declines in the water level
Annual precipitation 1/	
Annual evapotranspiration	
Mean annual temperature	**Geomorphic**
	Drainage area
	Drainage density

1/ Indicates variables that have been preliminarily investigated and are related by statistical analyses to nitrate and triazine-herbicide concentrations in this study.

Table 7.--Descriptive statistics and frequency data for independent variables at the 82 sites in the six study areas, 1984

[Units: ft/d, feet per day; ft, feet; in, inches; in/h, inches per hour; lb/acre, pounds per acre; wells/mi^2, wells per square mile]

Independent variable	Unit	Descriptive statistics				Percent of sites at which values were equal to or less than those shown				
		Maximum	Minimum	Mean	Standard deviation	90	75	50	25	10
HYDROGEOLOGIC										
Hydraulic gradient (X1)	----	0.0053	0.0006	0.0023	0.0011	0.0038	0.0029	0.0020	0.0014	0.0011
Hydraulic conductivity (X2)	ft/d	149	5	52	36	106	78	40	23	11
Specific discharge (X3)	ft/d	0.2998	0.0128	0.0759	0.0576	0.1425	0.0931	0.0565	0.0418	0.0253
Depth to water (X4)	ft	239	3	73	60	165	88	47	30	16
Well depth (X5)	ft	550	40	199	109	341	275	180	100	75
CLIMATIC										
Annual precipitation (X6)	in	39.3	12.0	25.2	6.5	32.0	29.2	26.2	20.5	15.7
SOIL										
Soil permeability (X7)	in/h	9.0	0.76	2.46	2.12	6.63	2.54	1.30	1.17	0.74
LAND USE										
Irrigation-well density (X8)	wells/mi^2	8	0	3.1	2.2	5.4	4.1	2.6	0.68	0
Nitrogen-fertilizer use (X9)	lb/acre	260	0	124.8	81.6	210	188.6	147.3	30	----

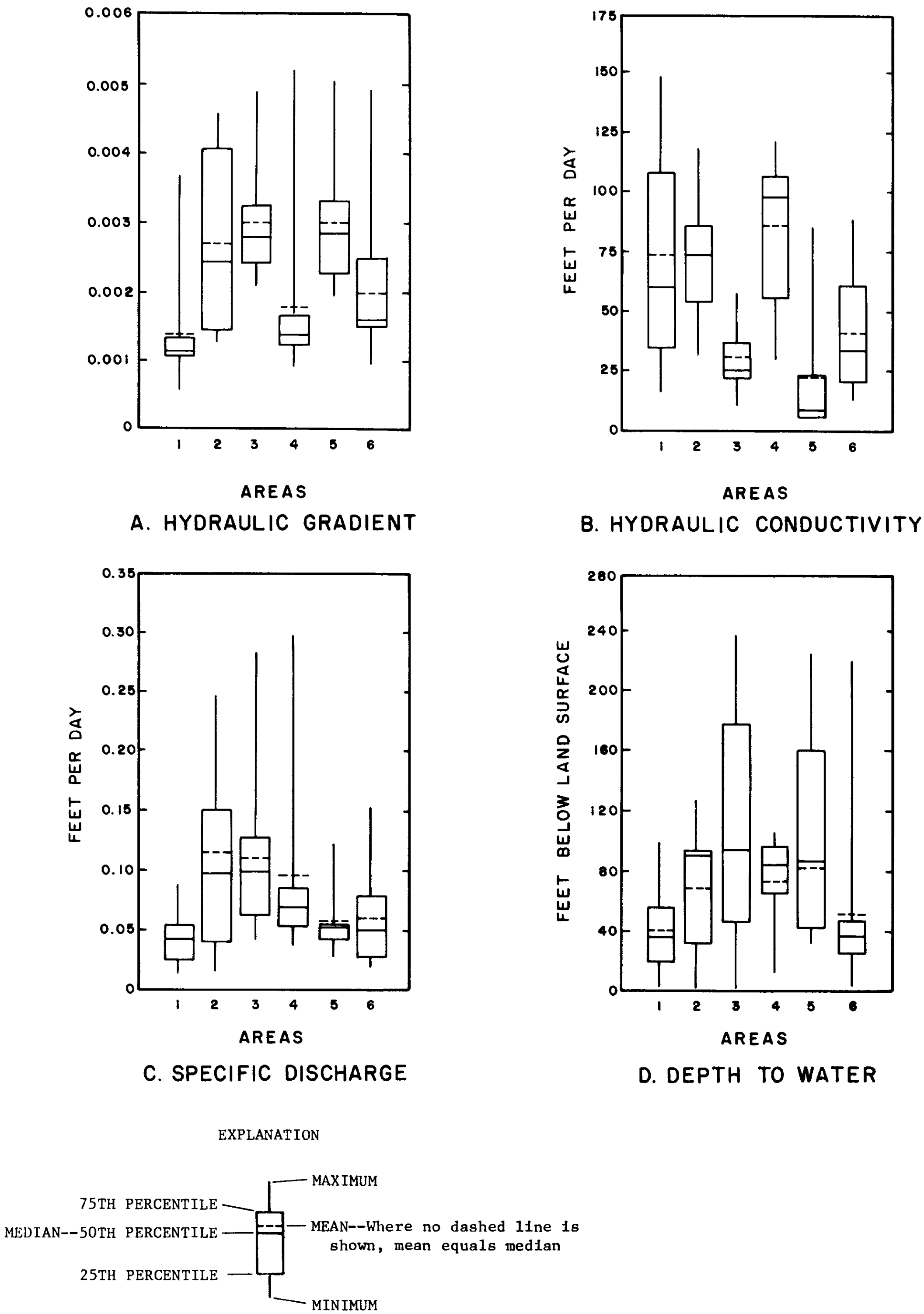
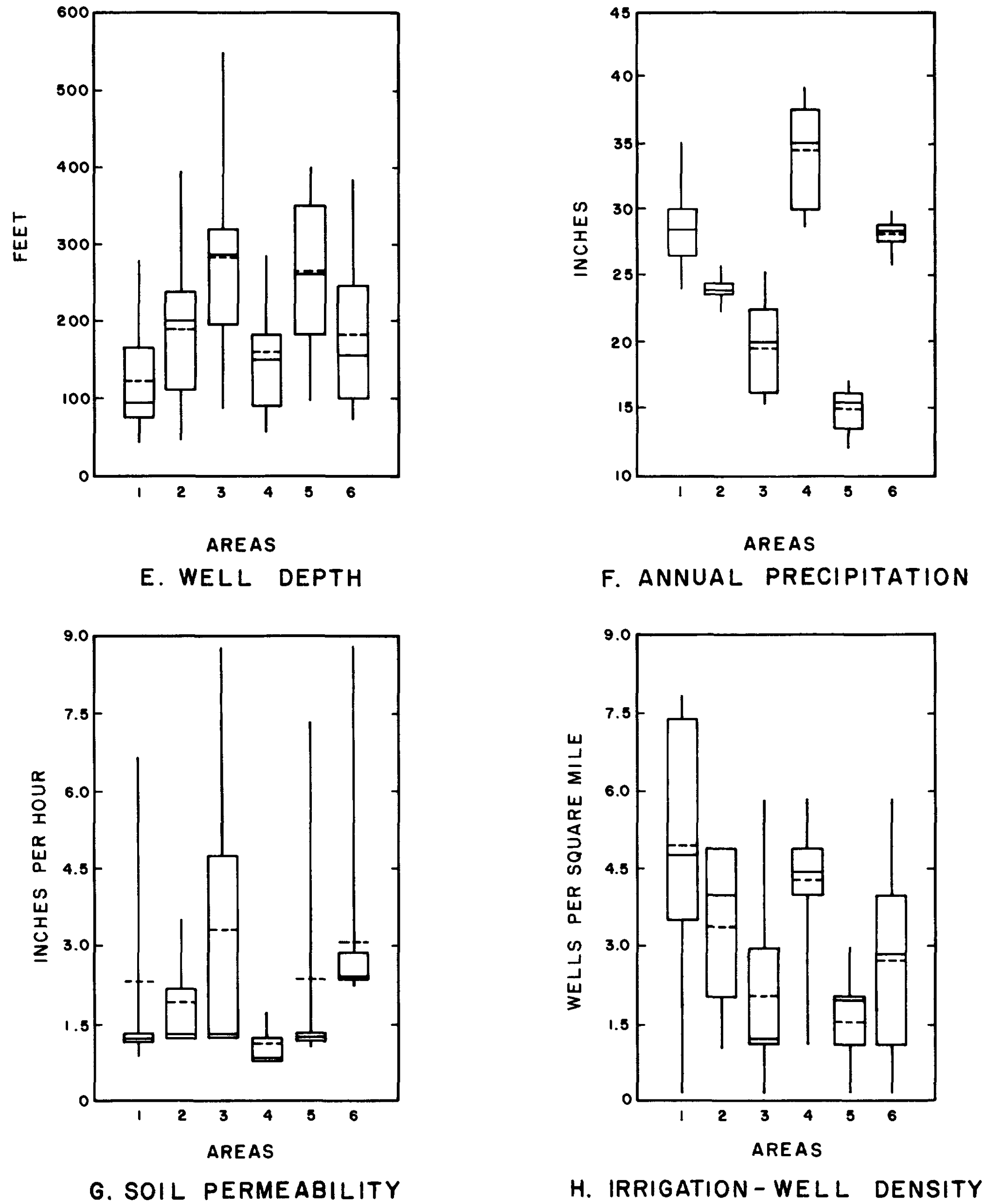


Figure 8.--Statistical comparisons of 8 independent



variables for 82 sites in the 6 study areas.

Hydraulic Conductivity

Hydraulic conductivity, the ability to transmit fluids, is a fundamental aquifer property related to the transport and dispersion of ground-water contaminants. Aquifer material with relatively large hydraulic-conductivity values, such as unconsolidated sand and gravel, will transmit dissolved contaminants much more quickly than will clay and silt.

The hydraulic-conductivity values for sampled sites in the six study areas ranged from 5 to 149 feet per day (table 7). Aquifer material in areas 3 and 5 had the smallest median hydraulic-conductivity values and area 4 had the largest median value (fig. 8B).

Specific Discharge

Specific-discharge values for saturated aquifer material at the 82 sample sites were determined by multiplying the hydraulic gradient by the hydraulic conductivity. This variable may affect ground-water quality through a combination of effects exerted by both the hydraulic gradient and hydraulic conductivity. The values for specific discharge ranged from 0.0128 to 0.2998 foot per day (table 7). Aquifer materials in area 4 had the greatest range of specific-discharge values (fig. 8C).

Depth to Water

The depth to water represents the approximate distance that contaminants must travel through the unsaturated zone to reach the water table. Generally, the greater the thickness of the unsaturated zone, the more time it takes for the contaminants to reach the water table, and the greater the probability that the contaminants will be chemically degraded, adsorbed, or otherwise dissipated before reaching the water table.

The depth-to-water values at each of the 82 well sites were determined by subtracting the potentiometric-surface elevation from the ground-surface elevation. Depths to water for wells sampled in all areas ranged from 3 to 239 feet (table 7). Depths to water were greatest in area 3 (median depth of 95 feet) and in area 2 (median depth of 92 feet) (fig. 8D). The area with the shallowest depth to water was area 6 (median depth of 35 feet).

Well Depth

Well depth is measured from the ground surface to the bottom of the well. It is significant, because contaminants enter the aquifer at the water table and usually are diluted and dispersed with depth, depending on the nature of the contaminant. Therefore, the probability of finding detectable concentrations for most agricultural chemicals is less at greater depth.

Well depths for the 82 sampled wells in the six study areas ranged from 40 feet in area 1 to 550 feet in area 3 (fig. 8E). The median depth of wells sampled in area 1 was 95 feet. The median depths of wells sampled in area 3 was 287 feet and in area 5, 260 feet.

Climatic Variable--Annual Precipitation

Climatic data, including annual precipitation and mean annual temperature, have been obtained from the National Oceanic and Atmospheric Administration (NOAA) for 33 meteorological stations located in or near each of the six study areas. In the reconnaissance phase of the study, only the annual precipitation data were examined in detail; seasonal precipitation data also have been obtained.

Local precipitation is important in estimating the susceptibility of an aquifer to ground-water contamination. Generally, the greater the precipitation, the deeper the contaminants may penetrate the unsaturated zone.

NOAA data from the six study areas indicate that mean annual precipitation ranges from 17 inches in area 5 to 27 inches in area 4. The temporal distribution of values for these two areas displays a uniform difference from 1930 through 1984 (fig. 9). During 1984, precipitation data for the six study areas indicated a maximum of 39.3 inches in area 4 and a minimum of 12.0 inches in area 5 (fig. 8F).

Soil Variable--Soil Permeability

Contaminants can be stored in, degraded, or transported through the soil; therefore, the hydrological, physical, and chemical characteristics of the soil may greatly affect ground-water quality. Dugan (1984) quantified soil permeability, available water capacity, slope, and other hydrological soil characteristics for Nebraska.

The less permeable a soil is, the longer a solute will remain near the surface of the soil profile, and the more likely the solute will be removed in runoff, adsorbed onto the soil, degraded, or consumed by plants. Sandy soils generally are more permeable, contain less available water, and have less ion-adsorption capability than silty and clayey soils; therefore, the mobility of contaminants is greater in sandy soils than in other soil types.

The permeability of a 60-inch soil profile for the 82 sample sites in the six study areas ranged from 0.76 inch per hour for clayey soils to 9.0 inches per hour for sandy soils (table 7). Both of these extremes occurred in area 3. Area 4 had the minimum overall soil permeability of the six study areas with a median of 0.8 inch per hour; area 6 had the maximum overall soil permeability with a median of 2.4 inches per hour (fig. 8G).

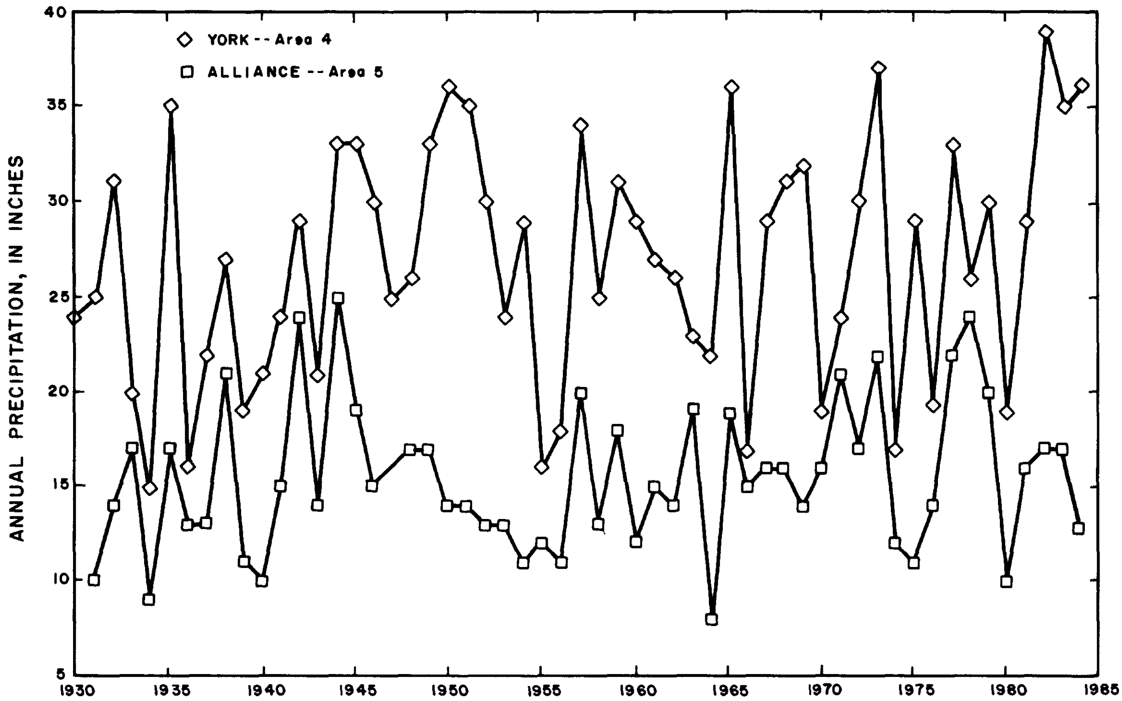


Figure 9.--Annual precipitation for two meteorological stations in areas 4 and 5, 1930-84.

Land Use Variables

Most forms of environmental contamination are the result of human activity. The kinds of human activities or the land use in a given area usually dictate the types of materials that may become ground-water contaminants.

Land-use categories in the six study areas include cropland, pasture and rangeland, rivers and adjacent flood plains, urban and industrial areas, lakes, forests, and barren areas. The principal land use in the six study areas is almost exclusively agricultural, with about 95 percent of all land used for crop or livestock production (figs. 10-12).

The cropland category can be divided into row crops (corn, sorghum, and soybeans) and small-grain crops (wheat, oats, and barley); these can be subdivided further into specific crop types. Tillage techniques used for row crops are different than those used for small-grain crops; these tillage techniques produce considerable land-surface disruption, which may facilitate the movement of chemicals through the soil profile. Row crops generally are treated with larger quantities of fertilizers and pesticides and require larger volumes of irrigation water than small-grain crops.

The acreage planted in major row and small-grain crops for each of the study areas is summarized in table 2. Areas 1, 2, and 6 have the largest number of acres planted in row crops; corn is the dominant crop. Areas 3 and 5 have the largest number of acres planted in wheat, the dominant small-grain crop in the six study areas.

Since the mid 1940's, many acres of pastureland and nonirrigated cropland have been converted to irrigated land in Nebraska. The number of irrigated acres in the six study areas has increased by about 18 percent per year since 1950 (fig. 13). The marked increase in irrigated acres since the mid 1970's represents increasing use of center-pivot irrigation systems. The increase in irrigated farmland has resulted in an increase in the application of fertilizers and pesticides. The combination of more chemically treated acres and the greater leaching potential of these chemicals, when moisture is applied, has increased the possibility of ground-water contamination.

Five independent variables are identified with land use: irrigation-well density, nitrogen-fertilizer use, percent of irrigated land, pesticide use, and human-caused rises and declines of the water level. Only irrigation-well density and nitrogen-fertilizer use are discussed in this report.

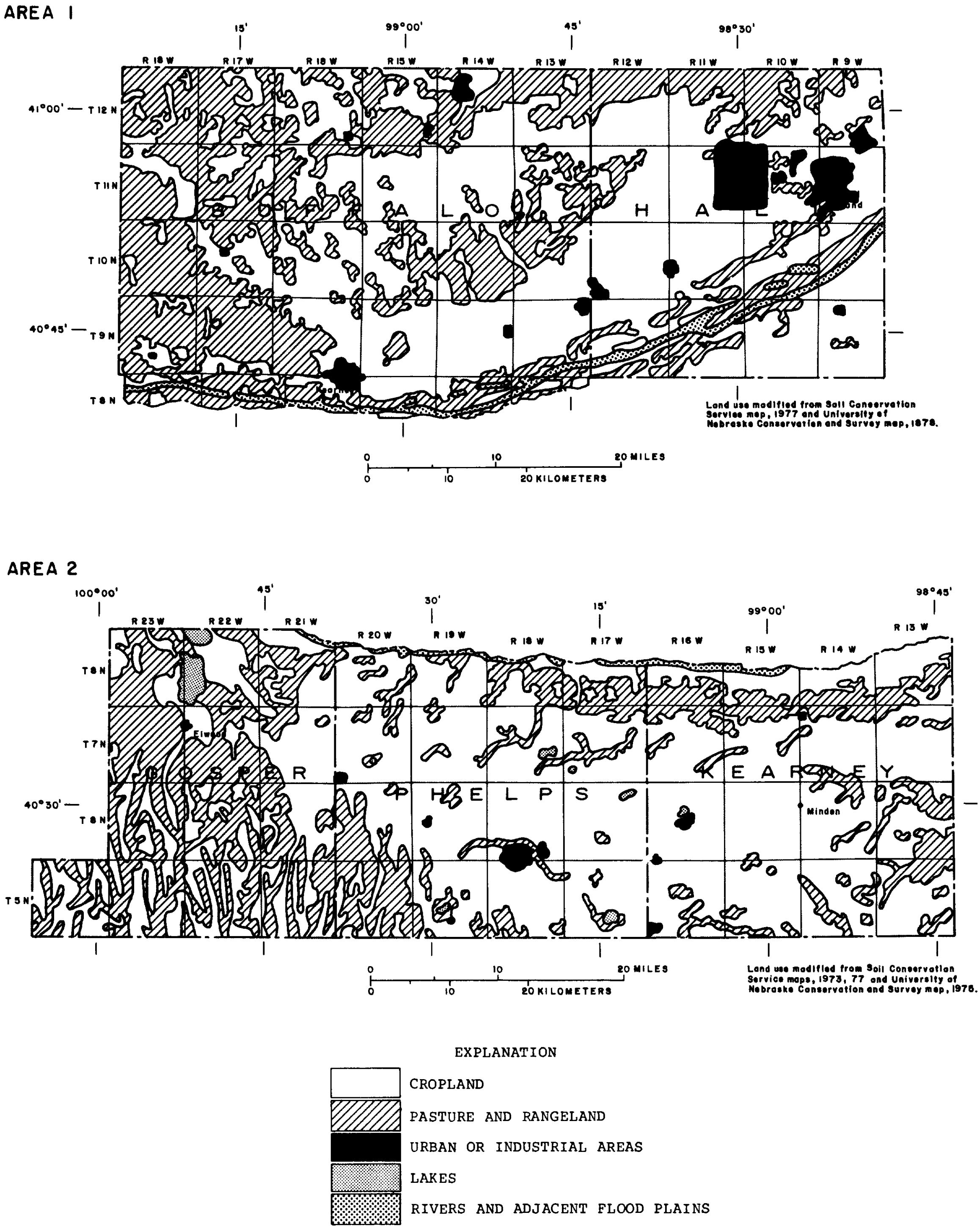


Figure 10.--General land uses of the High Plains aquifer in areas 1 and 2.

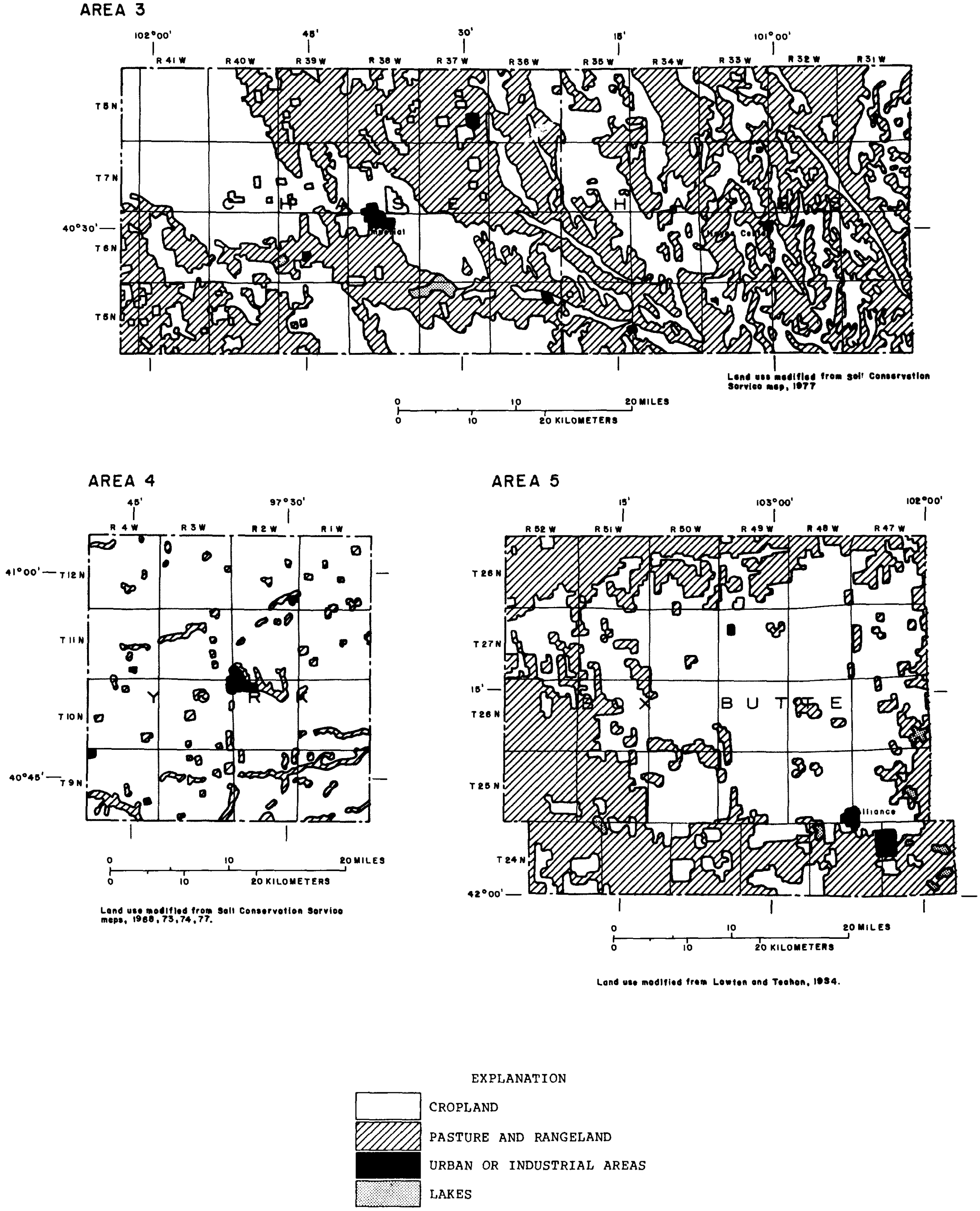


Figure 11.--General land uses of the High Plains aquifer in areas 3, 4, and 5.

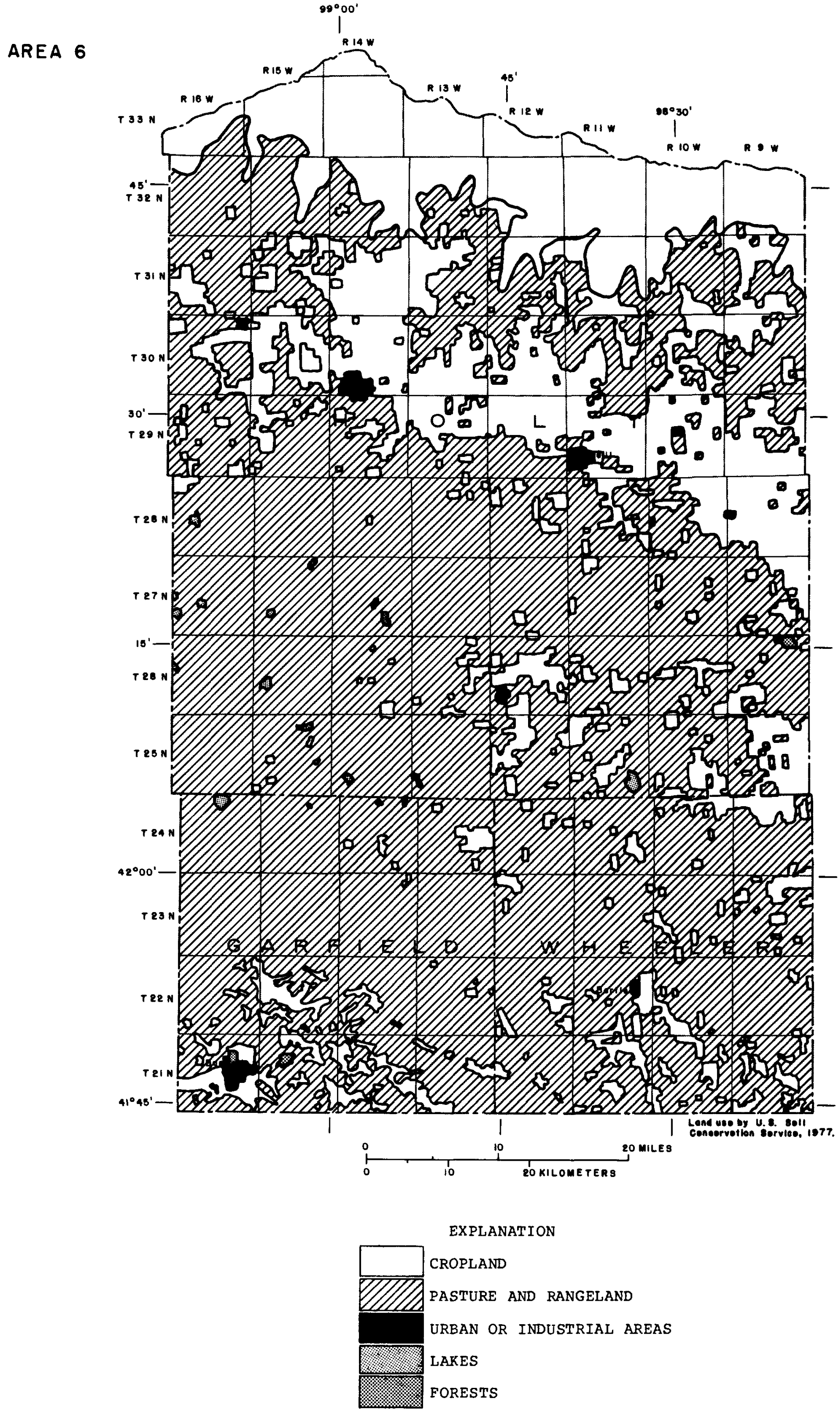


Figure 12.--General land uses of the High Plains aquifer in area 6.

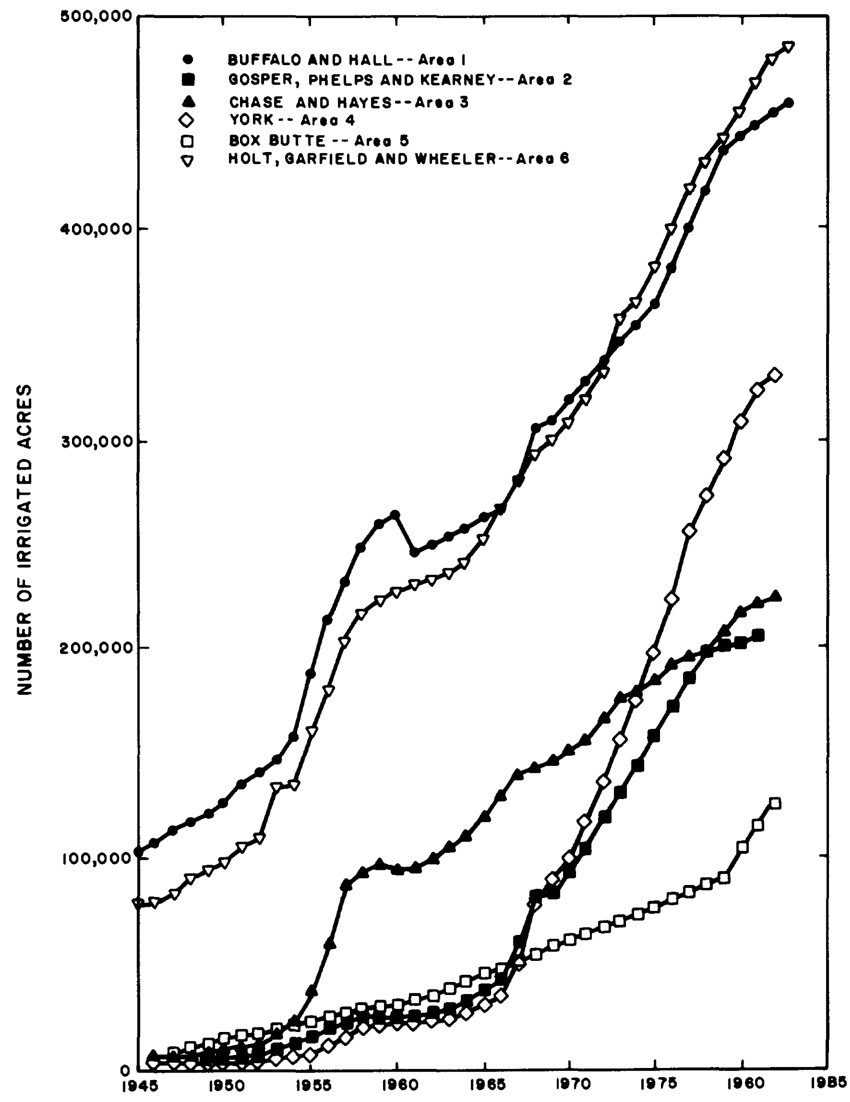


Figure 13.--Irrigated acres in each of the six study areas, 1945-82.

Irrigation-Well Density

Irrigation-well density is the number of active irrigation wells per square mile. The irrigation-well density at the 82 sites in the six study areas ranged from 0 to 8 wells per square mile (table 7 and fig. 8H). The western and northeastern areas (areas 3, 5, and 6) had a median density ranging from 1.0 to 3.0 wells per square mile (figs. 14-16). The remaining study areas (areas 1, 2, and 4) had a median density ranging from 4.0 to 5.0 wells per square mile; area 1 had the maximum density.

Intensive ground-water withdrawal can affect the distribution and transport of contaminants in an aquifer system. Withdrawal from large-capacity irrigation wells (600 to 1,000 gallons per minute) can lower the potentiometric surface near the wells (drawdown) and affect the local direction and velocity of ground-water flow. These localized depressions also may cause contaminants to move toward the well. In addition, return flow of irrigation water may increase leaching of agricultural chemicals into the aquifer.

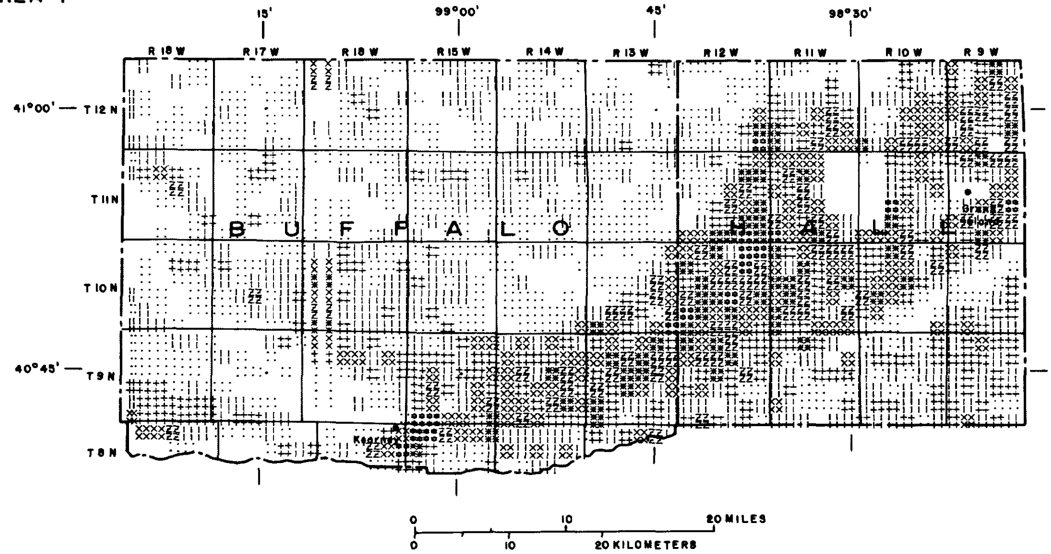
Ground-water use in Nebraska increased from about 3,100 million gallons per day during 1970 to about 7,350 million gallons per day during 1980 (Engberg, 1984). About 85 percent of the water used during 1970 and about 91 percent used during 1980 was for irrigation. Predictably, the number of irrigation wells and irrigated acres in the six study areas have increased considerably since the 1970's (fig. 13). Engberg (1984) suggested that the increase in ground-water irrigation during this period may have increased nitrate concentrations in ground water in areas with sandy soils and shallow depths to water.

Nitrogen-Fertilizer Use

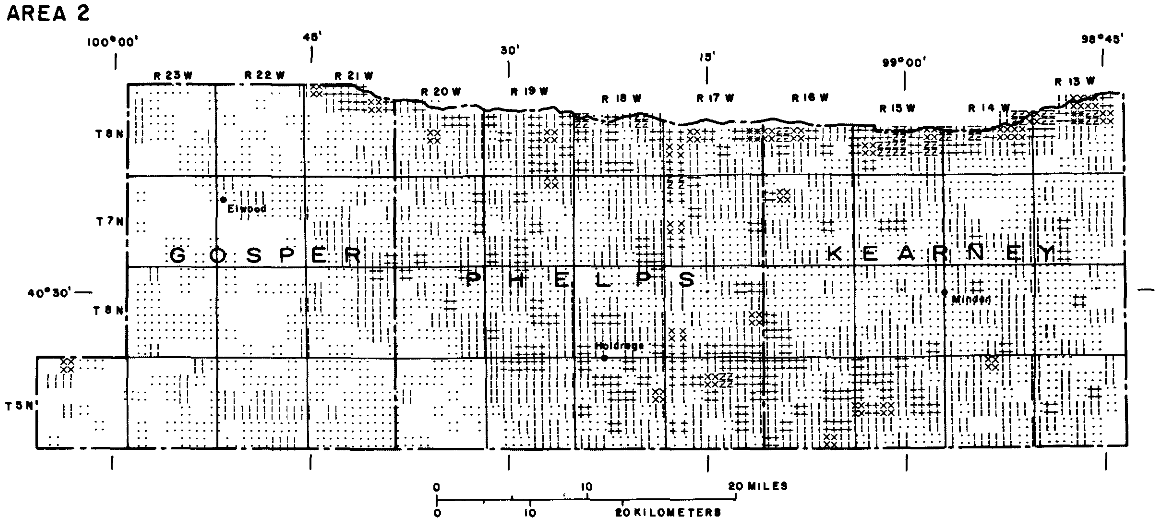
The use of nitrogen fertilizer has increased markedly in the High Plains as well as the six study areas in Nebraska during the last 23 years. A study in Nebraska conducted by Linderman and others (1976) determined that nitrate concentrations in ground water increased from 25 to 30 milligrams per liter in a furrow-irrigated cornfield with sandy soil when the fertilizer-application rate was increased from 167 to 198 pounds of total nitrogen per acre. The estimated nitrogen-fertilizer sales in 8 of 12 counties comprising the six study areas are shown in figure 17. The sales of nitrogen fertilizer in these eight counties increased about 413 percent from 1961 through 1978. Since 1978, nitrogen-fertilizer sales in the six study areas have decreased slightly; however, from 1961 through 1983, an estimated 2.0 million tons of nitrogen were applied in these eight counties and adjacent areas. This trend in nitrogen-fertilizer use appears to be related to the increase in irrigated acres (fig. 13).

The most commonly used form of nitrogen fertilizer in the six study areas is anhydrous ammonia, which is 82 percent nitrogen by weight. Anhydrous ammonia usually is applied by injection or "knifing" into the soil in March and April, although some is applied in the fall. The next most commonly applied form is "liquid nitrogen" (urea-ammonium nitrate solution), which is 28 to 32 percent nitrogen by weight. It is applied in the spring and early summer by spraying or by injection through center-pivot systems.

AREA 1



AREA 2



EXPLANATION

NUMBER OF WELLS PER SECTION

:: 1 - 2

|| 3 - 4

‡‡ 5 - 6

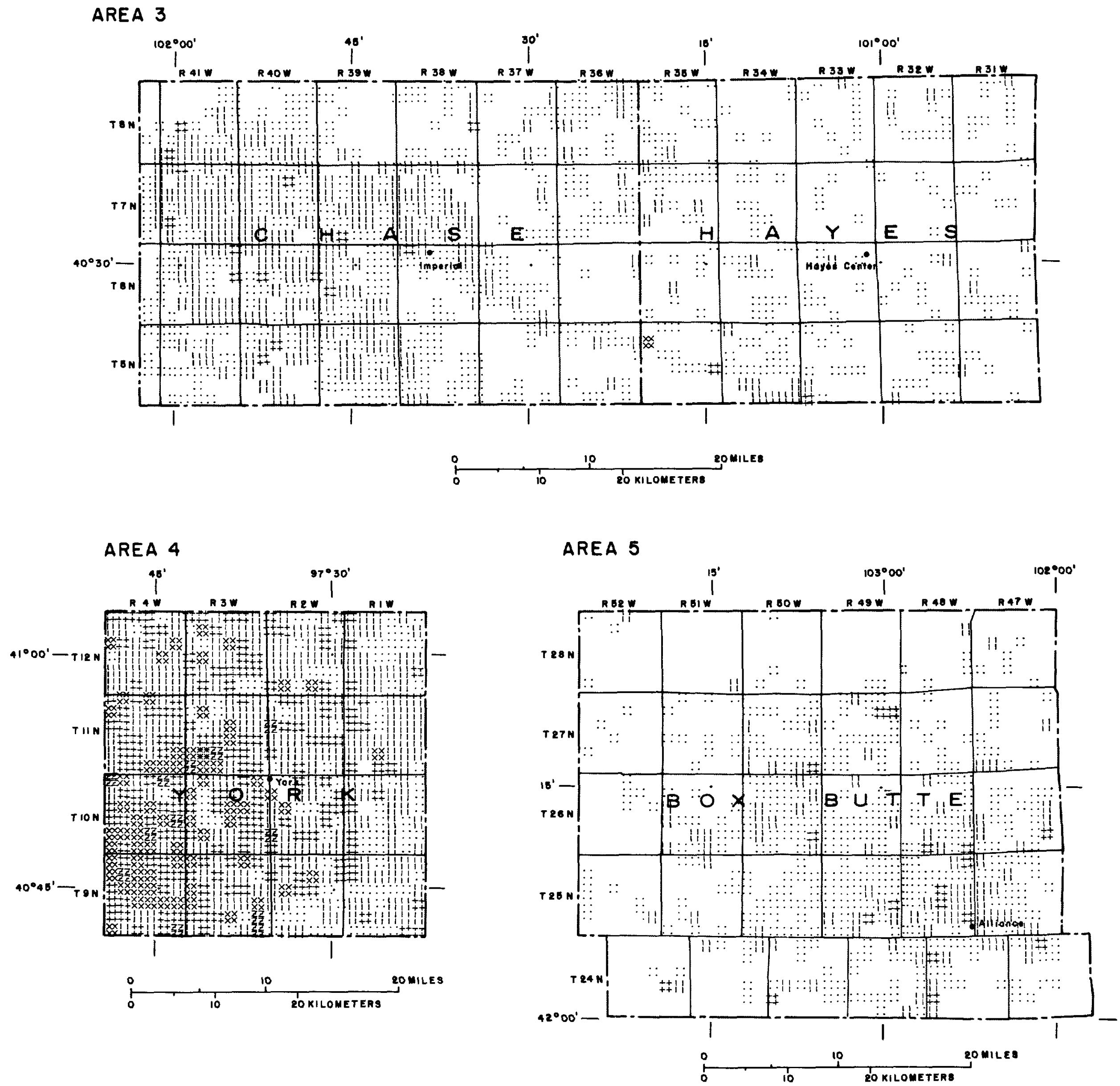
XX 7 - 8

ZZ 9 - 10

** 11 - 12

•• 13 OR MORE

Figure 14.--Number of irrigation wells per section of the High Plains aquifer in areas 1 and 2.



EXPLANATION

NUMBER OF WELLS PER SECTION

::	1 - 2
¦¦	3 - 4
‡‡	5 - 6
XX	7 - 8
ZZ	9 - 10
✱✱	11 - 12

Figure 15.--Number of irrigation wells per section of the High Plains aquifer in areas 3, 4, and 5.

AREA 6

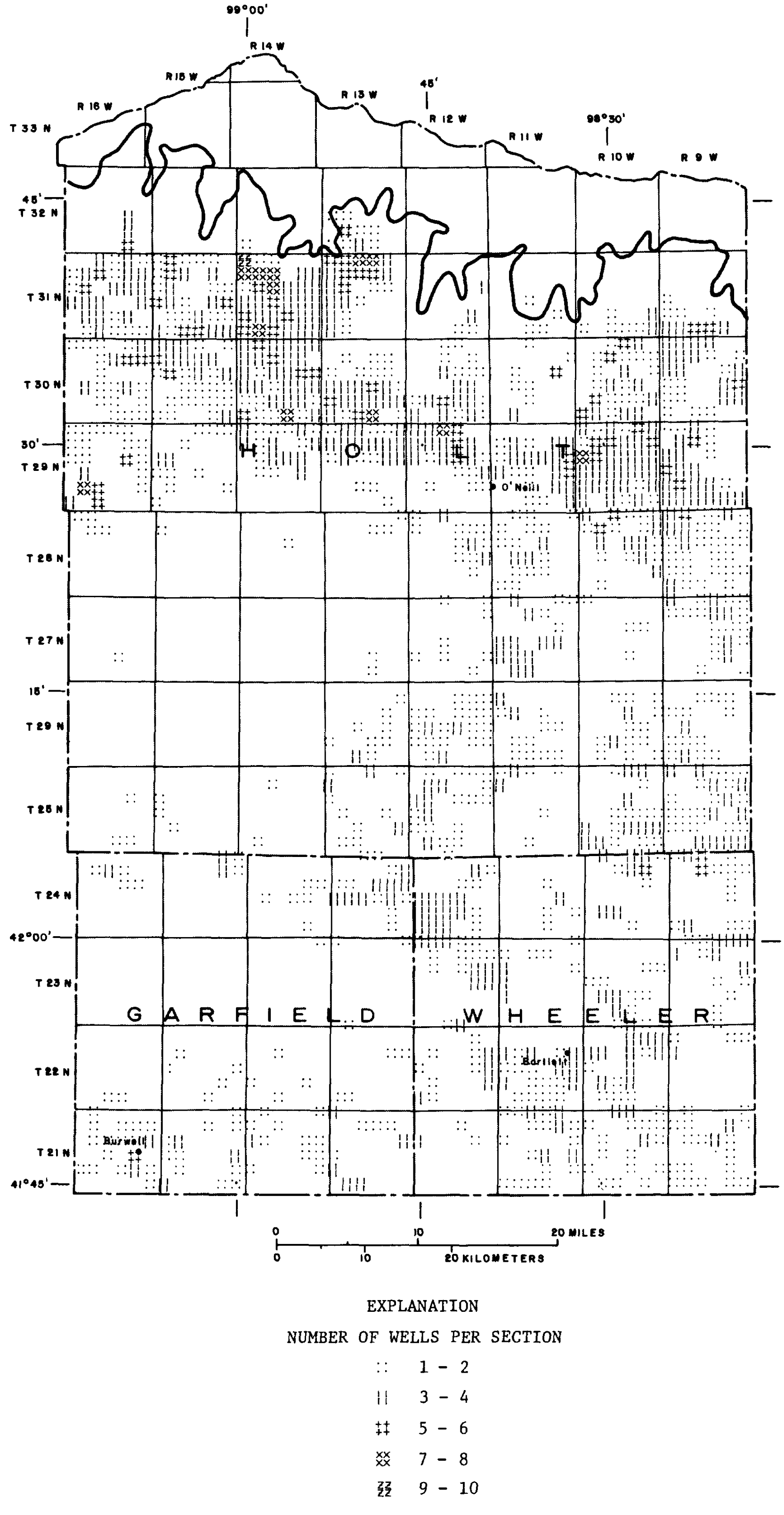


Figure 16.--Number of irrigation wells per section of the High Plains aquifer in area 6.

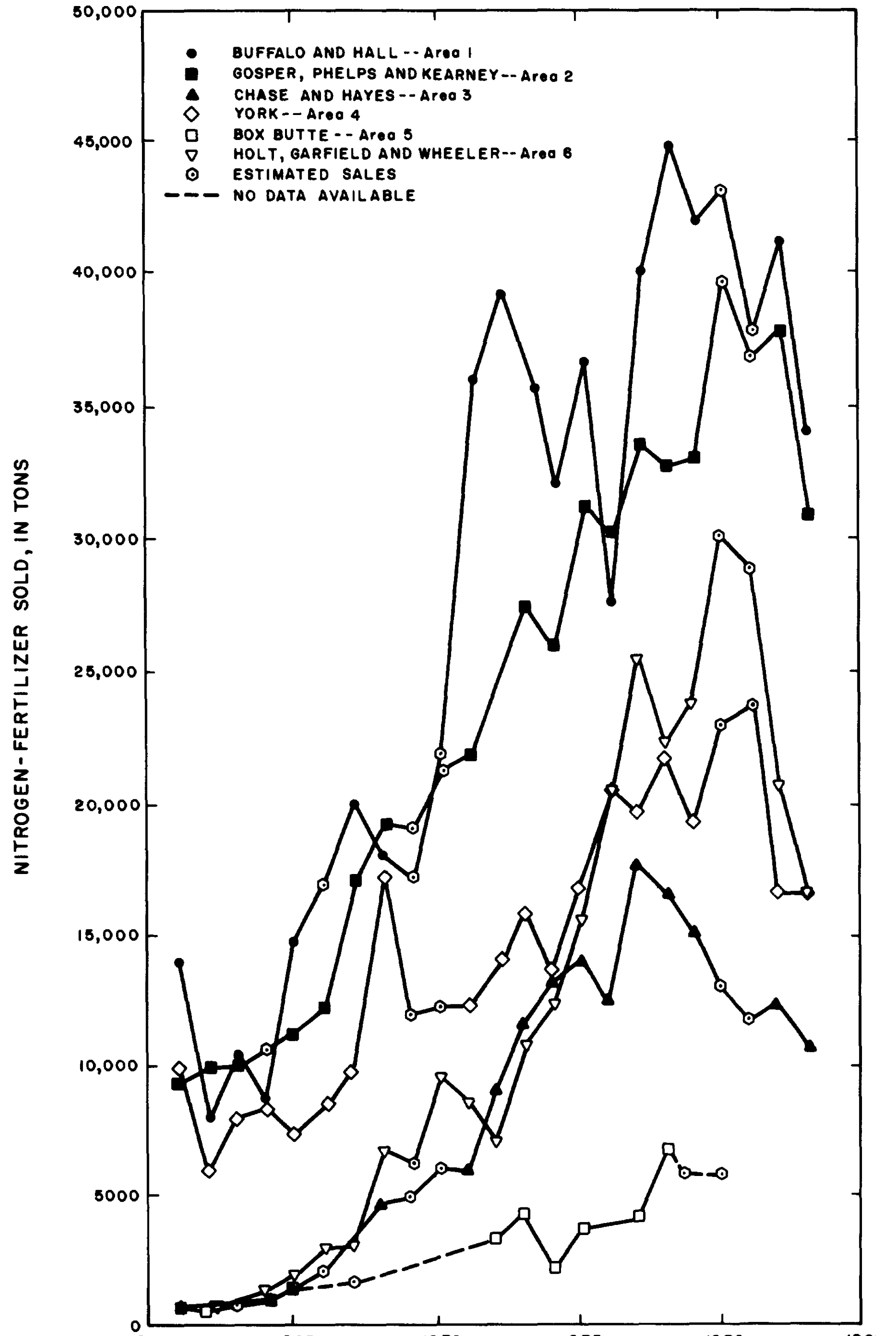


Figure 17.--Nitrogen-fertilizer sales in each of the six study areas, 1961-83.

An onsite survey of areas adjacent to the 82 well sites indicated that application rates varied from 0 to 260 pounds of nitrogen per acre (table 7). For cornfields, applied nitrogen fertilizer ranged from 80 to more than 200 pounds per acre. Areas 2 and 6 had the largest nitrogen-fertilizer application rates.

NONPOINT-SOURCE CONTAMINATION DERIVED FROM AGRICULTURAL CHEMICALS

Historical Data

Water-quality data related to agricultural chemicals have been collected in the six study areas during the last 35 years by the U.S. Geological Survey, the University of Nebraska Conservation and Survey Division, the Nebraska Department of Environmental Control, the Nebraska Department of Health, and Natural Resources Districts. Most of the available data consists of nitrate concentrations, although pesticide data have been collected in limited areas. Sample collection, analyses, and quality-assurance procedures for data collected by agencies other than the U.S. Geological Survey usually were not documented. Therefore, these data were used in this study only to delineate areas of existing ground-water contamination and to examine possible trends.

Nitrate

Nitrate analyses were available for 2,459 ground-water samples collected in the six study areas from 1936 through 1983. About 39 percent of these data were from the U.S. Geological Survey's WATSTORE program. Most of the remaining data were collected as part of the National Uranium Resource Evaluation Project (NURE) (1980a, 1980b, 1981a, 1981b, and 1981c) from 1977 through 1979 and from special studies (Exner and Spalding, 1974 and 1979; Spalding, 1975 and 1981; Spalding and others, 1978; Gormly and Spalding, 1979; and Spalding and Exner, 1980) by the University of Nebraska Conservation and Survey Division from 1971 through 1981. About 20 percent of the 2,459 nitrate analyses were made prior to 1970 as part of small projects. These data may have been concentrated in areas of suspected nitrate contamination. Many of the data collected from 1970 through 1983 were the result of large areal studies, such as the NURE project and other University of Nebraska Conservation and Survey Division studies that were designed to characterize the regional ground-water quality of various parts of the High Plains aquifer in Nebraska. Most samples were collected from privately owned domestic and irrigation wells, but a few have been collected from public-supply and observation wells.

For ease of comparison in this report, nitrate concentrations in all forms were converted to nitrate-nitrogen concentrations and will be referred to hereafter as nitrate concentrations. Average yearly nitrate concentrations were substituted for wells where more than one sample was collected during a year. Three percent of all water samples had nitrate concentrations of 25 milligrams per liter or more; these water samples are considered to be affected by point-source contaminants. Point-source contaminants originate at discrete points rather than in broad areas; thus, point-source contamination generally can be recognized because it appears areally as points of anomalously large nitrate concentration in the midst of an area with much smaller nitrate concentrations. Of the 2,459 nitrate analyses, 71 were considered to represent point-source contamination and were eliminated from the data set. These included analyses with a nitrate concentration equal to or exceeding 30 milligrams per liter in area 1, or 25 milligrams per liter in the other areas.

A statistical summary, by years, of the available nitrate data for each of the six study areas is shown in figure 18. Only years with 10 or more analyses are included in this summary. Although the number of analyses for some years is small and earlier sample collection may have emphasized areas of suspected nitrate contamination, these data provide a basis for a preliminary comparison of nitrate contamination in the six study areas.

A Kendall Test (Crawford, Slack, and Hirsch, 1983) was applied to the data for each study area to detect trends in nitrate concentration with time. Only years with 10 or more nitrate analyses were used to eliminate the disproportional affect of small groups of analyses. Area 1, with more than 1,000 analyses, was the only area for which a trend was determined at the 95-percent confidence level. This trend indicated an average increase of 0.12 milligram per liter per year. This trend is most apparent in the maximum concentrations in table 8 and in the box plot of nitrate concentrations (fig. 18). The lack of adequate historical data prevented the determination of a trend in the other five areas.

Twenty wells in three of the six study areas were sampled intermittently for 12- to 31-year periods. Although the nitrate concentrations were variable, analyses for five of the eight monitoring wells (wells 1 through 8) in area 1 indicated a trend of increasing nitrate concentrations as indicated by the Kendall Test at the 95-percent confidence level (fig. 19). The trend slopes indicate average yearly increases of 0.11 to 1.41 milligrams per liter nitrate in water from these wells. Similarly, analyses for four of the nine monitored wells in area 6 indicated increasing nitrate concentrations; analyses for one well indicated decreasing concentrations with time. The trend slopes varied from 0.43 to 0.64 milligram per liter per year. Analyses for three wells with long-term records in area 4 had no apparent nitrate trend.

The areal distribution of existing nitrate data from the middle to late 1970's indicated large areas where nitrate concentrations in ground water equaled or exceeded 10 milligrams per liter in areas 1, 2, 5, and 6 (figs. 20-22). These areas are indicative of nonpoint-source contamination and may represent areas susceptible to pesticide contamination.

Table 8.--Nitrate concentrations in the six study areas, 1936-82

Study area	Year	Number of analyses	Milligrams per liter: Maximum	Minimum	Mean	25th percentile	50th percentile	75th percentile
1	1936	4	6.3	0.1	3.0	0.3	2.7	5.9
	1947	5	4.5	.9	2.3	1.0	1.8	4.0
	1953	6	3.8	.1	1.4	.2	.7	3.1
	1958	6	9.3	.1	3.1	.2	.6	8.1
	1959	5	9.9	.5	5.3	1.0	5.3	9.4
	1960	10	9.9	.0	3.7	.2	1.4	8.0
	1961	11	9.0	.0	3.2	.2	.7	7.7
	1962	11	9.7	.1	3.3	.2	1.2	7.5
	1963	15	8.6	.0	2.5	.3	1.2	4.5
	1964	20	12.9	.0	2.5	.1	.8	3.6
	1965	14	14.7	.0	2.7	.1	.3	3.6
	1966	16	16.7	.0	3.2	.1	1.0	4.0
	1967	17	19.3	.1	3.1	.1	.7	4.7
	1968	13	18.7	.0	3.5	.1	1.0	4.6
	1969	15	28.0	.0	4.5	.0	.8	5.9
	1970	18	25.0	.0	4.2	.0	1.3	6.6
	1971	173	24.2	.1	3.8	.2	2.7	6.1
	1973	17	27.0	.0	4.1	.4	.8	3.9
	1974	280	28.2	.1	6.4	1.1	4.5	10.0
	1975	40	20.0	.0	6.1	.2	4.6	11.4
	1976	32	16.0	.1	3.4	.3	1.3	3.9
	1977	77	29.0	.1	13.6	9.9	14.5	18.6
	1978	130	28.0	.0	4.1	.8	1.3	4.2
	1980	39	29.9	.0	11.4	1.9	8.6	20.5
	1981	59	30.9	.1	8.1	1.6	5.3	13.7
	1983	16	23.0	.1	3.7	.2	2.4	4.8
2	1936	1	22.1	22.1	22.1	22.1	22.1	22.1
	1945	1	0	0	0	0	0	0
	1947	6	11.3	2.3	4.8	2.3	3.2	7.8
	1948	7	3.6	.0	1.5	.4	1.3	2.7
	1949	12	4.5	.1	1.7	.3	.8	3.5
	1952	1	1.4	1.4	1.4	1.4	1.4	1.4
	1967	2	.5	.2	.4	.2	.4	.5
	1969	38	11.0	.0	3.5	.8	2.8	5.8
	1970	21	11.0	.0	3.1	1.0	2.4	3.7
	1975	2	2.8	2.2	2.5	2.2	2.5	2.8
	1978	100	21.0	.0	4.0	1.4	2.6	5.2
	1979	25	22.0	.0	4.2	.1	.8	6.6
	1980	203	19.0	.0	4.5	2.0	3.4	6.0
	1981	13	12.0	.9	3.2	1.6	2.5	3.5
	1982	1	.4	.4	.4	.4	.4	.4

Table 8.--Nitrate concentrations in the six study areas, 1936-82--Continued

Study area	Year	Number of analyses	Milligrams per liter					
			Maximum	Minimum	Mean	25th percentile	50th percentile	75th percentile
3	1936	1	3.2	3.2	3.2	3.2	3.2	3.2
	1947	1	.5	.5	.5	.5	.5	.5
	1952	3	2.7	1.5	2.1	1.5	2.1	2.7
	1957	1	1.1	1.1	1.1	1.1	1.1	1.1
	1970	1	1.6	1.6	1.6	1.6	1.6	1.6
	1973	2	1.7	1.0	1.4	1.0	1.4	1.7
	1974	10	3.4	.0	1.9	1.7	2.0	2.1
	1976	1	22.0	22.0	22.0	22.0	22.0	22.0
	1977	2	2.0	1.7	1.8	1.7	1.8	2.0
	1978	3	11.0	1.8	5.9	1.8	5.0	11.0
	1979	20	3.7	1.8	2.5	2.2	2.4	3.0
4	1952	2	5.2	1.2	3.2	1.2	3.2	5.2
	1953	2	2.3	1.2	1.8	1.2	1.8	2.3
	1961	23	10.4	.0	2.5	.9	1.8	2.7
	1962	2	2.5	.0	1.2	.0	1.2	2.5
	1963	1	1.1	1.1	1.1	1.1	1.1	1.1
	1970	9	6.0	.0	2.6	2.0	2.0	3.6
	1971	3	4.4	3.8	4.2	3.8	4.4	4.4
	1972	3	5.4	3.2	4.0	3.2	3.3	5.4
	1973	5	5.0	.0	2.0	.6	1.3	3.8
	1974	3	5.6	3.6	4.7	3.6	4.9	5.6
	1975	3	5.0	4.4	4.7	4.4	4.8	5.0
	1976	5	4.9	1.1	2.9	1.8	2.7	4.1
	1977	4	3.7	.2	2.4	.8	2.8	3.5
	1978	49	24.0	.0	4.1	1.8	2.7	4.2
	1979	2	4.0	1.0	2.5	1.0	2.5	4.0
	1980	3	5.0	.4	3.2	.5	4.2	5.0
	1983	3	5.2	1.0	3.5	1.0	4.4	5.2
5	1936	2	4.5	0.8	2.6	0.8	2.6	4.5
	1938	14	5.0	1.5	2.6	1.8	2.4	3.2
	1947	11	2.7	.1	1.2	.3	1.4	1.8
	1970	2	1.9	.9	1.4	.9	1.4	1.9
	1977	1	.6	.6	.6	.6	.6	.6
	1978	82	16.0	.0	3.6	2.2	3.1	4.0
	1979	5	5.3	2.2	3.2	2.2	3.0	4.4

Table 8.--Nitrate concentrations in the six study areas, 1936-82--Continued

Study area	Year	Number of analyses	Milligrams per liter Maximum	Minimum	Mean	25th percentile	50th percentile	75th percentile
6	1936	2	0.1	0.0	0.1	0.0	0.1	0.1
	1943	1	14.7	14.7	14.7	14.7	14.7	14.7
	1952	6	2.9	.1	1.0	.1	.8	1.8
	1958	1	1.7	1.7	1.7	1.7	1.7	1.7
	1959	3	2.7	.1	1.0	.1	.1	2.7
	1961	5	16.2	4.3	10.0	5.8	10.2	14.2
	1963	45	24.8	.2	6.9	3.8	5.0	8.8
	1964	21	23.6	1.7	9.0	3.8	5.5	12.2
	1965	16	21.9	1.7	8.3	3.7	5.9	12.1
	1966	42	24.8	.0	7.7	1.1	5.4	11.7
	1967	12	16.2	1.6	7.9	3.9	6.8	11.7
	1968	7	2.7	.2	.7	.3	.4	.7
	1969	3	14.0	1.0	9.3	1.0	13.0	14.0
	1970	5	21.0	.3	6.7	1.1	3.8	13.9
	1971	14	24.0	2.0	10.2	4.6	7.3	20.0
	1972	15	19.0	.7	8.5	4.4	7.1	13.0
	1974	2	3.0	.2	1.6	.2	1.6	3.0
	1975	14	22.9	.4	8.5	5.7	6.7	10.0
	1976	284	23.9	.1	4.5	.5	2.0	6.6
	1978	77	18.0	.0	1.9	.6	1.1	1.9
	1979	13	24.0	1.7	10.7	7.2	10.0	15.5
	1980	11	17.0	.3	3.9	.8	2.2	6.1
	1982	12	7.1	.1	1.9	.1	1.0	2.6

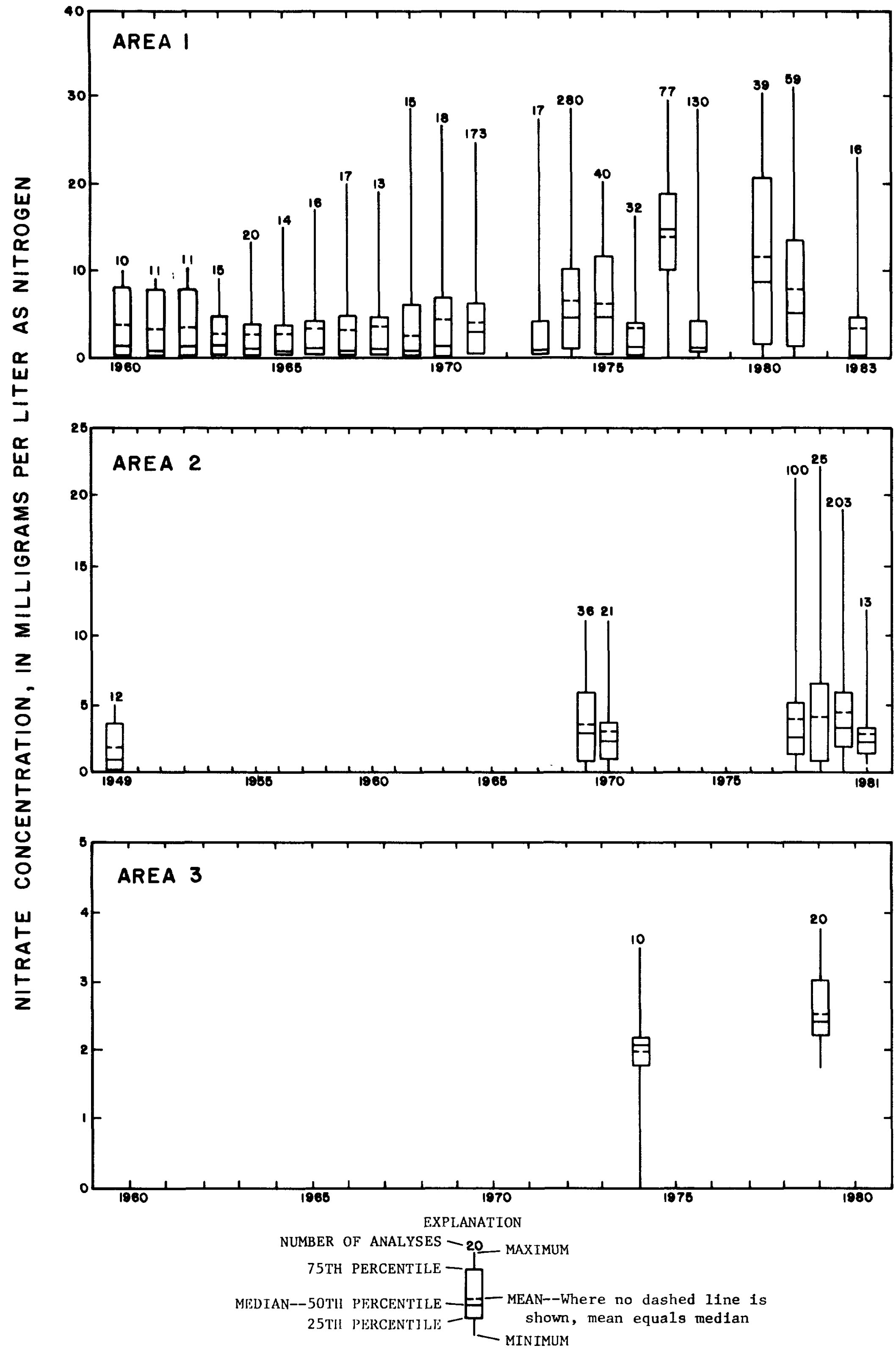
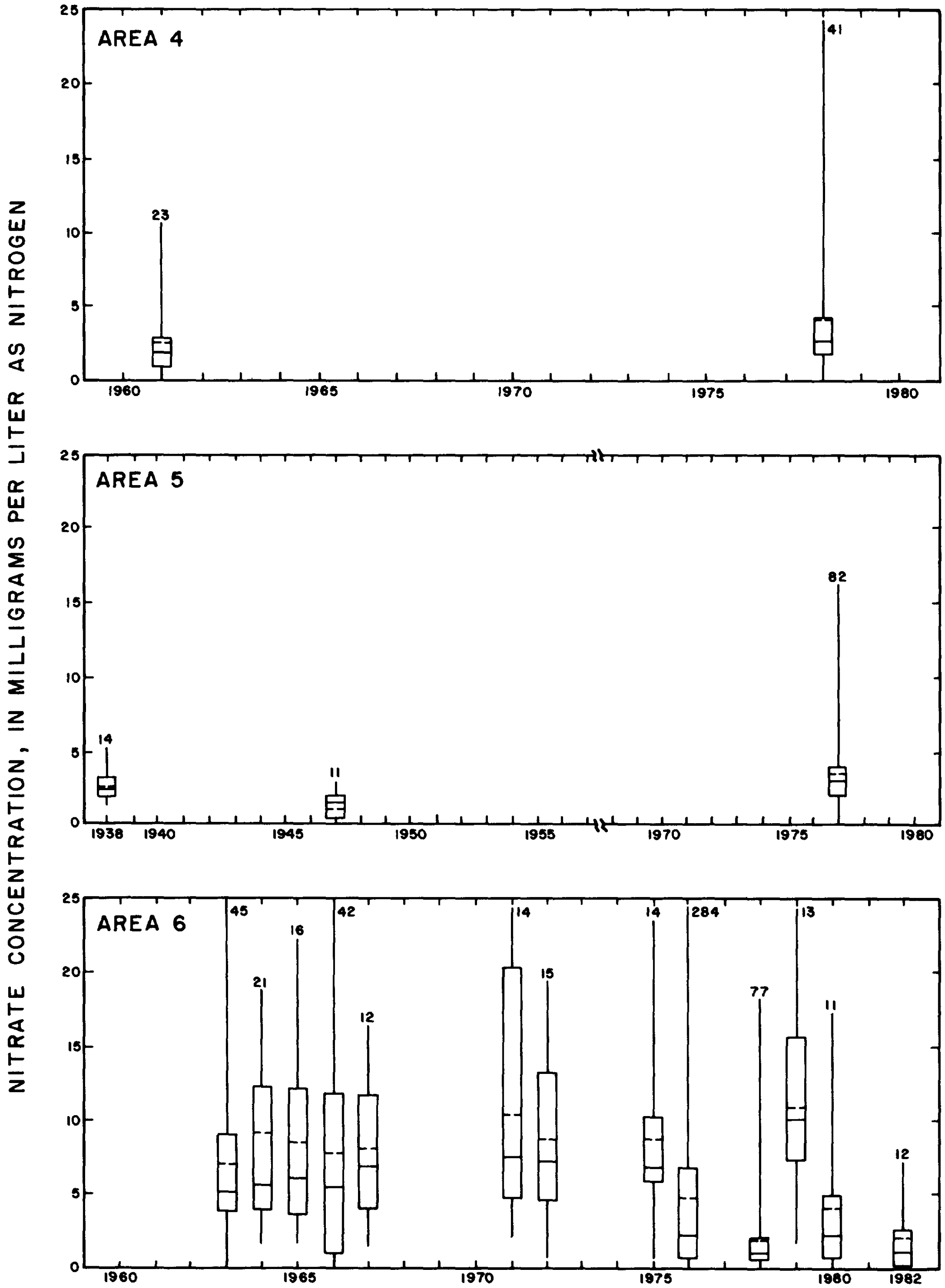


Figure 18.--Summary of nitrate concentrations in ground water in the



six study areas, based on years with 10 or more analyses available.

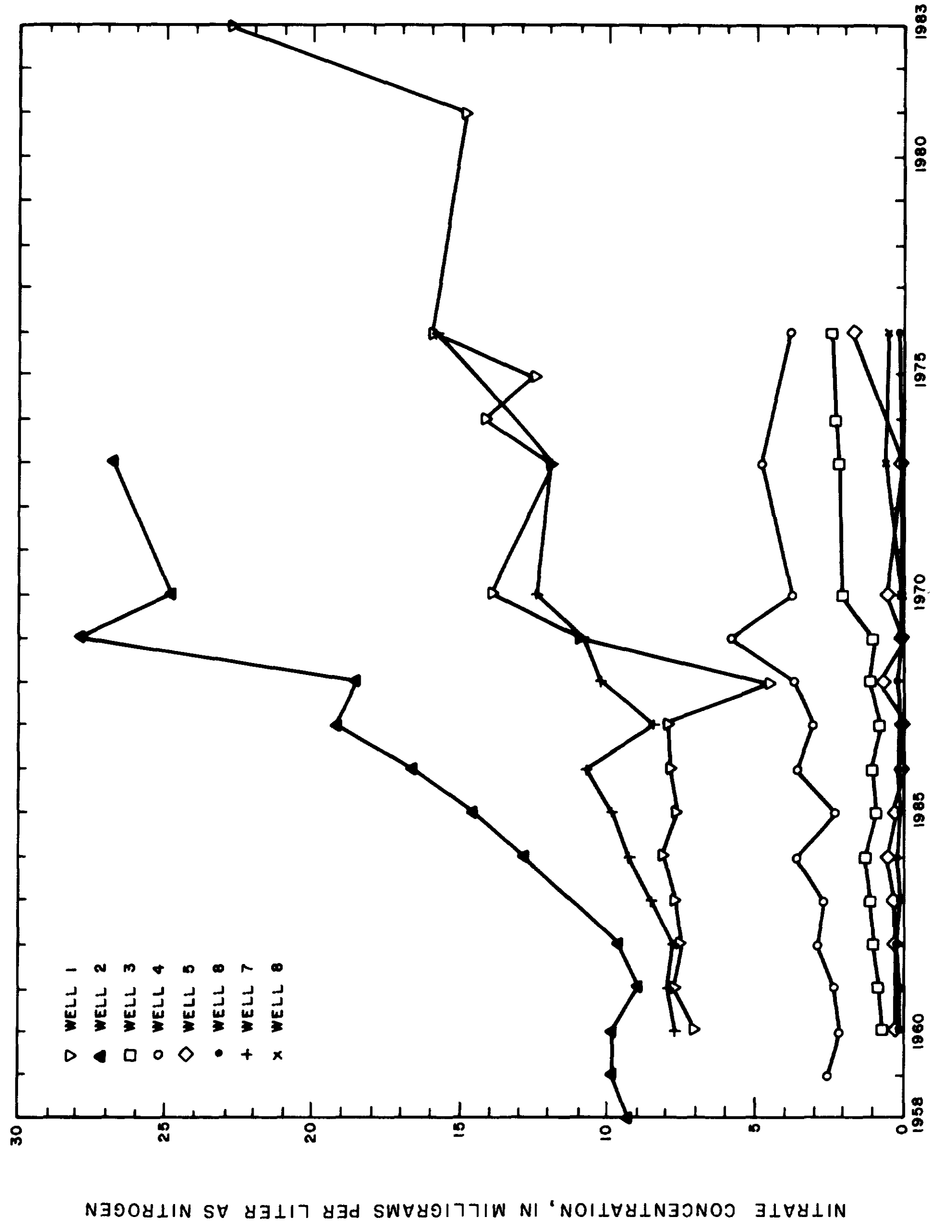
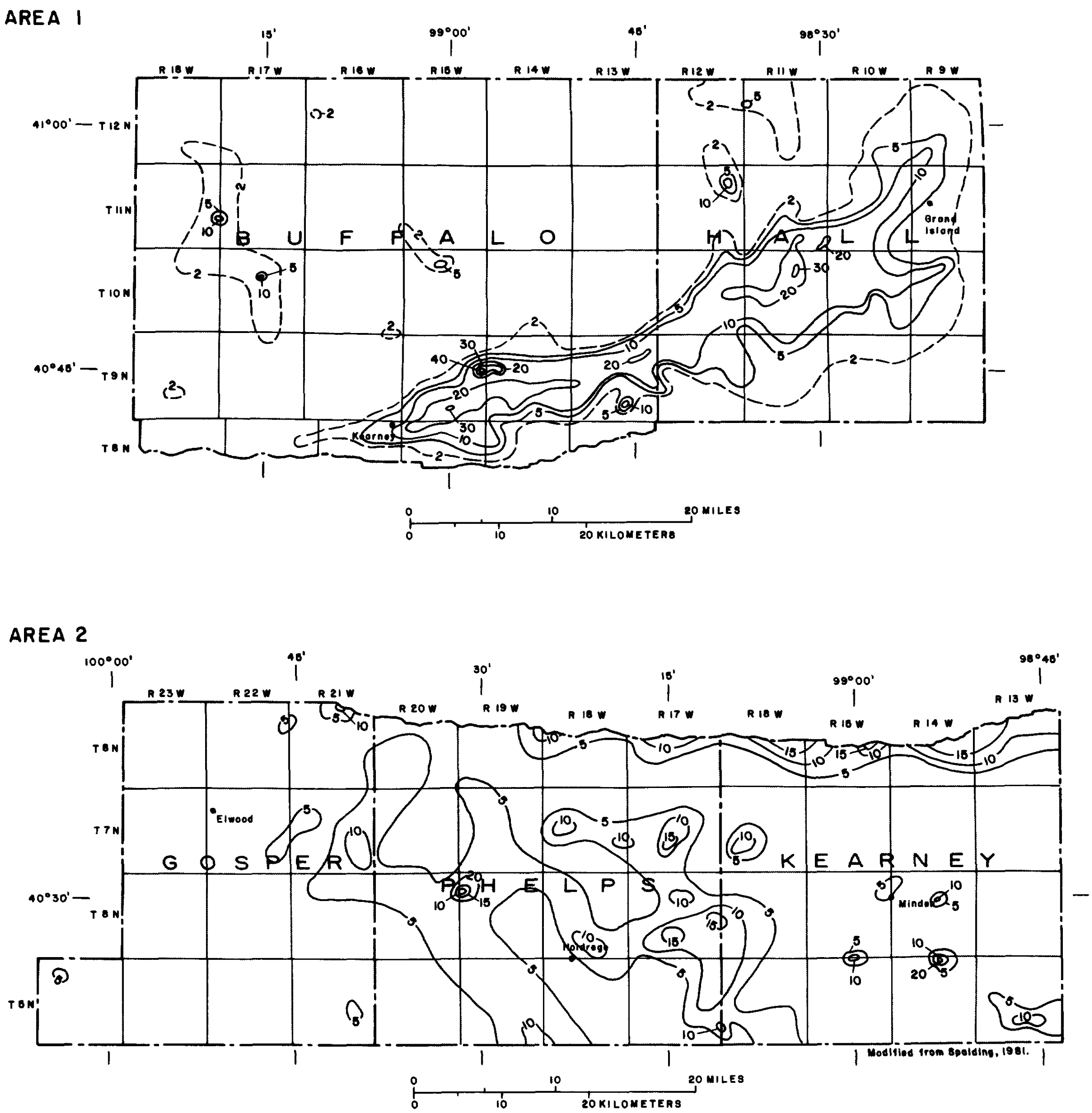


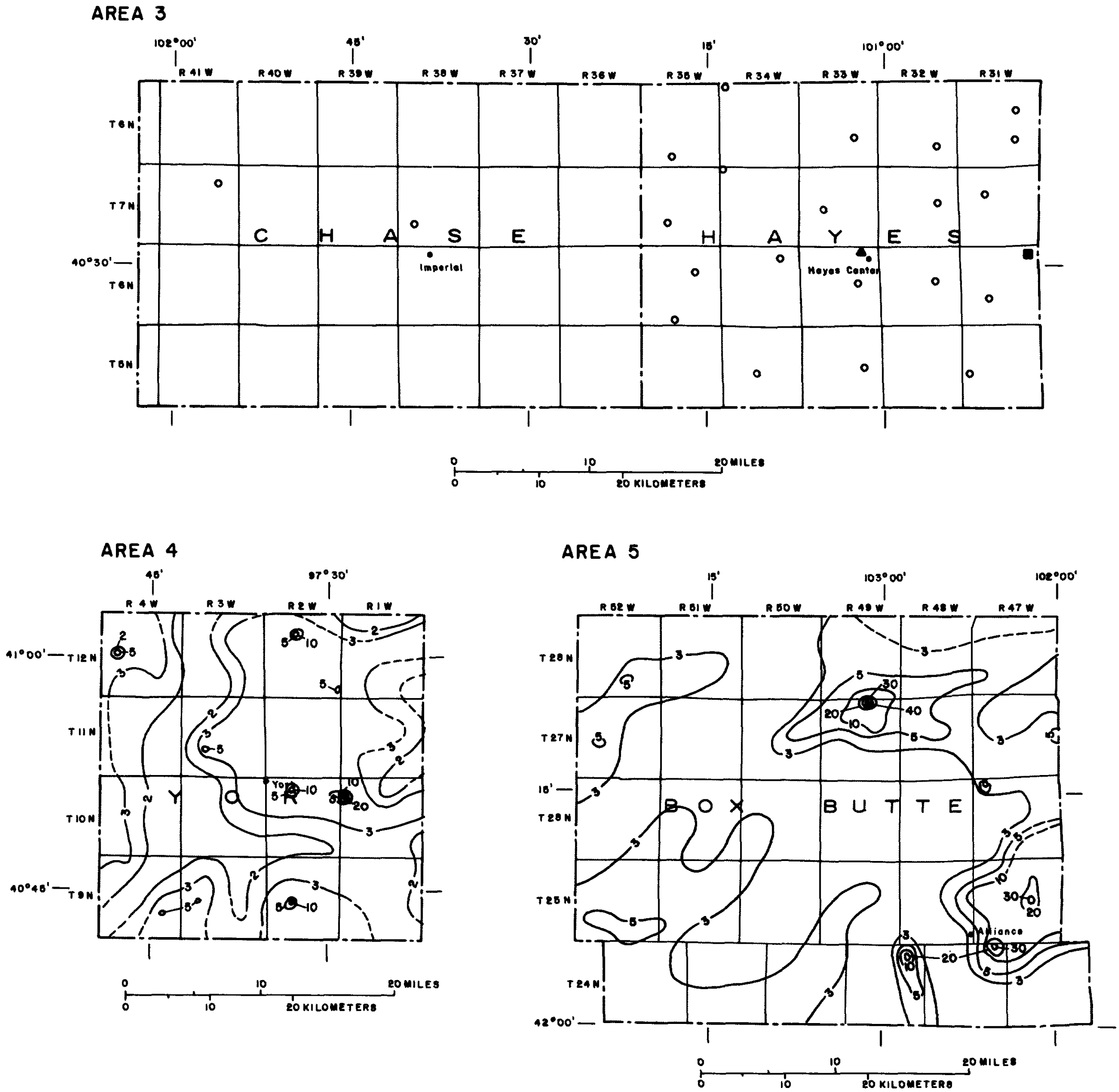
Figure 19.--Trend of nitrate concentrations in ground water from monitoring wells in area 1.



EXPLANATION

—— 10 - - - LINE OF EQUAL NITRATE CONCENTRATION IN GROUND WATER--Dashed where approximately located. Interval, in milligrams per liter as nitrogen, is variable

Figure 20.--Areal distribution of nitrate concentration in ground water in area 1, 1975-79, and area 2, 1978-81.



EXPLANATION

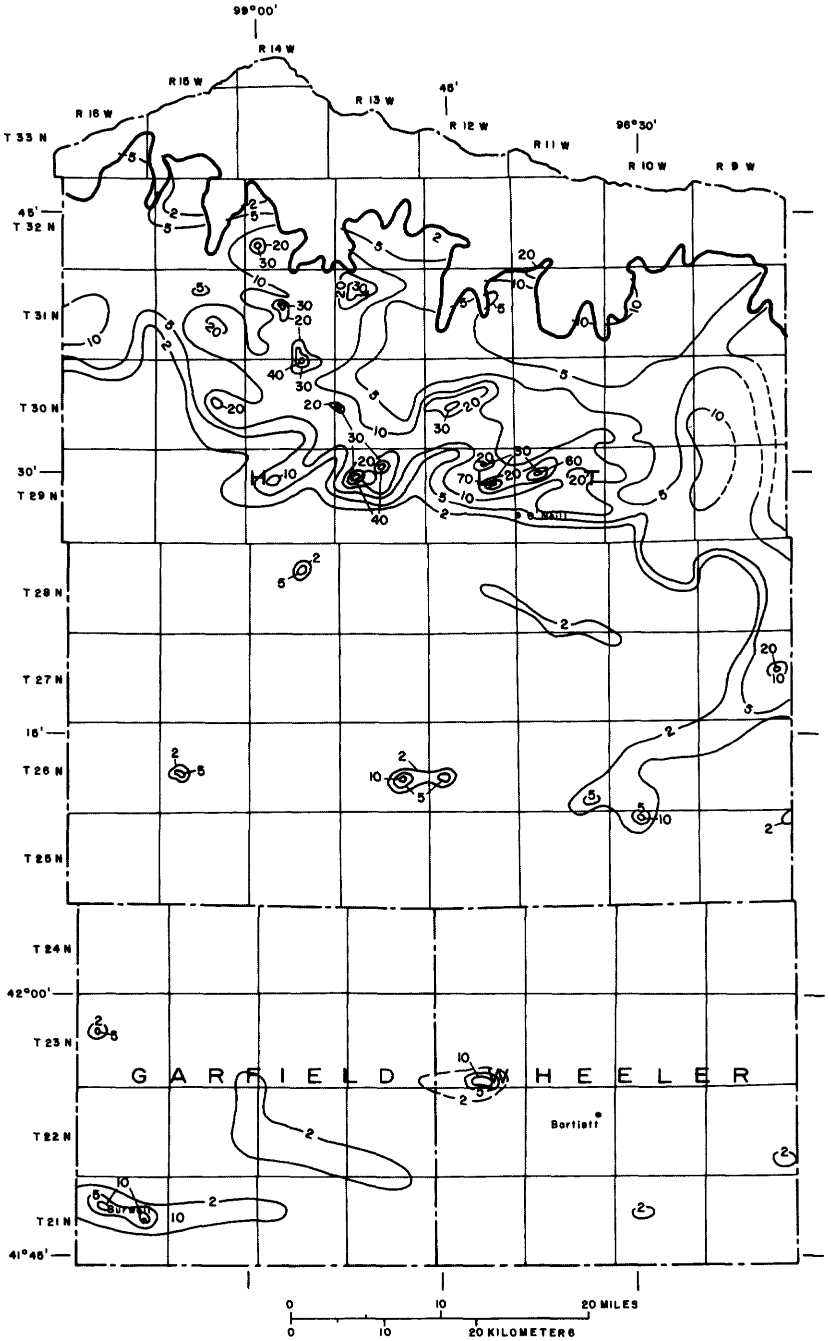
NITRATE CONCENTRATION IN GROUND WATER, IN MILLIGRAMS PER LITER AS NITROGEN

- o Less than 4.0
- ▲ 4.0 - 8.0
- ■ More than 8.0

——3——— LINE OF EQUAL NITRATE CONCENTRATION IN GROUND WATER--Dashed where approximately located. Interval, in milligrams per liter as nitrogen, is variable

Figure 21.--Areal distribution of nitrate concentration in ground water in areas 3, 4, and 5, 1975-79.

AREA 6



EXPLANATION

——10——— LINE OF EQUAL NITRATE CONCENTRATION IN GROUND WATER--Dashed where approvimately located. Interval, in milligrams per liter as nitrogen, is variable

——— NORTHERN BOUNDARY OF HIGH PLAINS AQUIFER

Figure 22.--Areal distribution of nitrate concentration in ground water in area 6, 1975-79.

Pesticides

No data for determining pesticides in ground water were collected in Nebraska prior to 1977. Several studies were conducted from 1977 through 1982 in Merrick County and in parts of areas 1 and 6 by the University of Nebraska Conservation and Survey Division (table 9).

In the most comprehensive study, water from 14 wells in area 1 were analyzed for 12 pesticides by Spalding, Junk, and Richard (1980). Atrazine (a triazine herbicide) and alachlor (an organochlorine herbicide) were the only pesticides detected. In a separate study in area 1 during which 17 wells were sampled, Junk, Spalding, and Richard (1980) detected atrazine in all the samples, alachlor in 2 samples, and dieldrin in 1 sample; the concentration of dieldrin was equal to the detection limit. Subsequent studies (table 9) have focused on atrazine; 64 wells were sampled in study areas 1 and 2. Atrazine was detected in 126 of the 211 samples taken from the wells; concentrations ranged from less than 0.01 to 14.72 micrograms per liter.

These previous studies in Nebraska have provided some insight into the distribution, transport, and dissipation of atrazine in ground water. Spalding and others (1979) notes that atrazine contamination commonly occurs in areas where ground water is characterized by large concentrations of nitrate. Water-management practices also may cause the contamination of ground water. For example, atrazine appears to be vertically transported by irrigation return flows (Junk, Spalding, and Richard, 1980). Wehtje and others (1983) determined atrazine to be nonconservative in ground water; they suggested atrazine concentrations are decreased by adsorption, chemical degradation, and dispersion. They further suggested that current (1981) ground-water levels of atrazine (in their area) represented a steady-state condition, which maintained a balance between the transport of recently applied herbicide into the ground water and the degradation of resident atrazine.

Nitrate and Pesticide Sampling Program, 1984

Review of the available nitrate and pesticide data indicated that pesticide data were restricted to only a few locations in the State that are characterized by intensive row-crop development. These areas represented a limited diversity in hydrogeologic, climatic, soil, and land-use conditions. Additional ground-water samples for pesticide analysis needed to be collected from areas of greater diversity to determine the areal extent of ground-water contamination by pesticides.

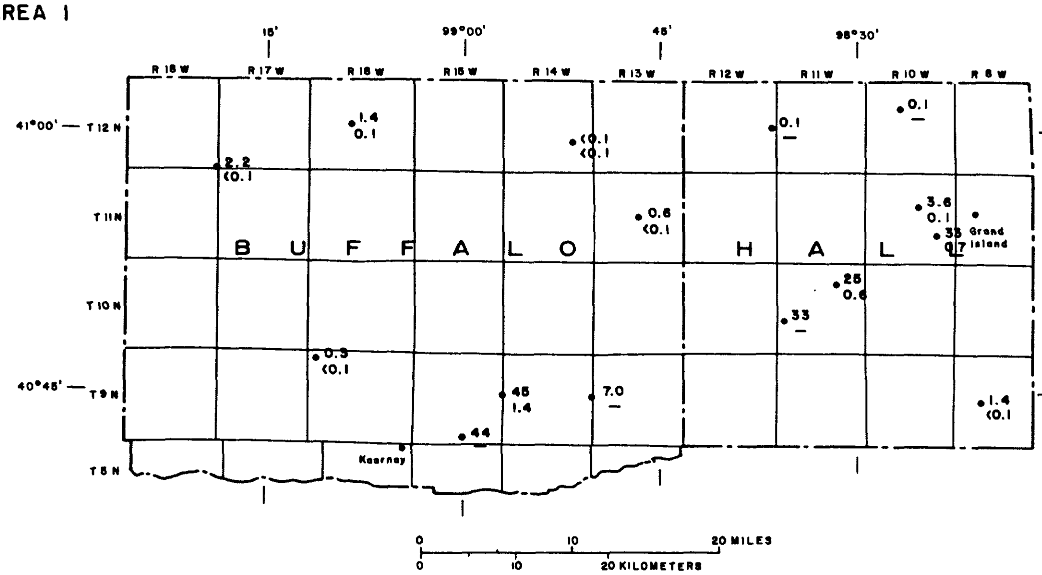
Eighty-two wells distributed among the six study areas were selected for sampling during the 1984 irrigation season (figs. 23-25). The wells were chosen to provide the maximum possible diversity for the independent variables discussed earlier. Primary considerations included estimated average hydraulic conductivity, depth to water, well depth, soil type, and local land use.

Table 9.--Summary of pesticides detected in ground water throughout Nebraska

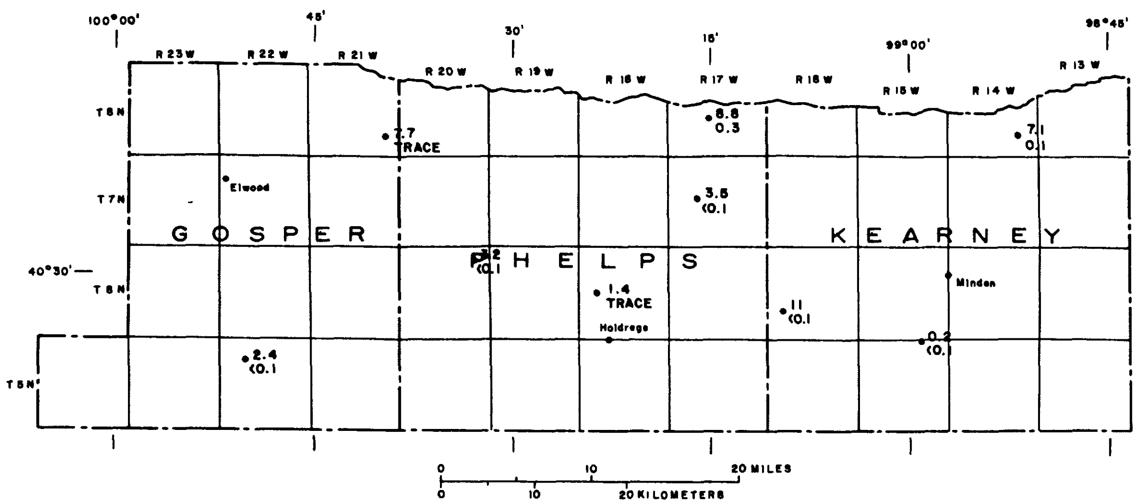
Reference	County	Year of study	Number of wells sampled	Number of samples analyzed	Pesticide analyzed	Number of samples in which pesticides were detected	Micrograms per liter: Detection limit	Mean2/	Range2/	25th percentile 2/	50th percentile 2/	75th percentile 2/
Spalding and others, 1979	Merrick	1977	18	18	Atrazine	16	0.01	1.15	0.30- 6.96	0.35	0.44	1.10
Spalding, Junk, and Richard, 1980	Buffalo and Hall (area 1)	1978	14	14	Atrazine	14	.01	.75	.38- 3.12	.52	.52	1.00
			14	14	Alachlor	2	.01	.04	.02 - .07	.02	.04	.07
			14	14	2, 4-D	0	.05	--	--	--	--	--
			14	14	EPTC	0	.01	--	--	--	--	--
			14	14	Silvex	0	.005	--	--	--	--	--
			14	14	Alpha-BHC	0	.001	--	--	--	--	--
			14	14	Dieldrin	0	.005	--	--	--	--	--
			14	14	Heptachlor	0	.002	--	--	--	--	--
			14	14	DDT	0	.01	--	--	--	--	--
			14	14	DDE	0	.01	--	--	--	--	--
			14	14	Endrin	0	.01	--	--	--	--	--
			14	14	Methoxychlor	0	.01	--	--	--	--	--
Junk, Spalding, and Richard, 1980	Buffalo and Hall (area 1)	1978	17	59	Atrazine	46	.01	1.02	.02-14.72	.02	.08	.36
			17	34	Alachlor	2	.01	.04	.01 - .07	.01	.04	.07
			17	34	Dieldrin	1	.01	--	.01	--	--	--
Wehtje and others, 1983	Buffalo and Hall (area 1)	1980-1981	21	116	Atrazine	116	.01	.39	.05- 2.02	.13	.30	.50
			21	40	Atrazine	40	.01	.25	.01 - .99	.04	.16	.40
Spalding (unpublished data)	Garfield and Wheeler (part of area 6)	1982	16	22	Atrazine	4	.01	.06	.02 - .10	.02	.06	.10

1/ Values from well clusters were averaged and treated as one well.
2/ Statistics were computed using averaged values for well clusters and averaged values for wells that were sampled more than once.

AREA 1



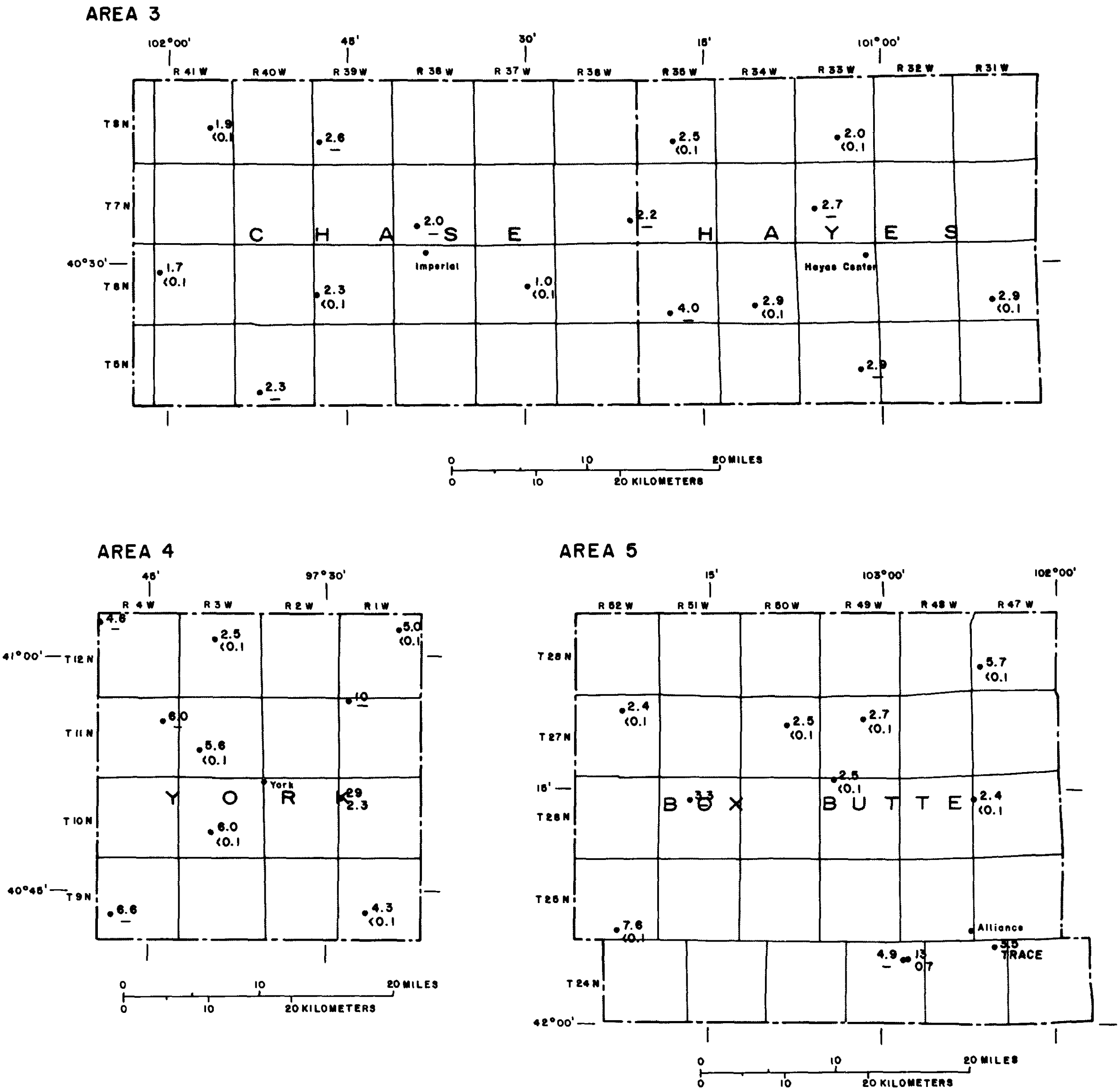
AREA 2



EXPLANATION

● 0.3 <0.1 WELL--Upper number is nitrate concentration, in milligrams per liter as nitrogen. Lower number is triazine-herbicide concentration, in micrograms per liter. Dash indicates no triazine-herbicide analysis. < indicates less than detection limit. Trace indicates triazine-herbicide present at concentrations too low to quantify

Figure 23.--Location of wells sampled in 1984 in areas 1 and 2.

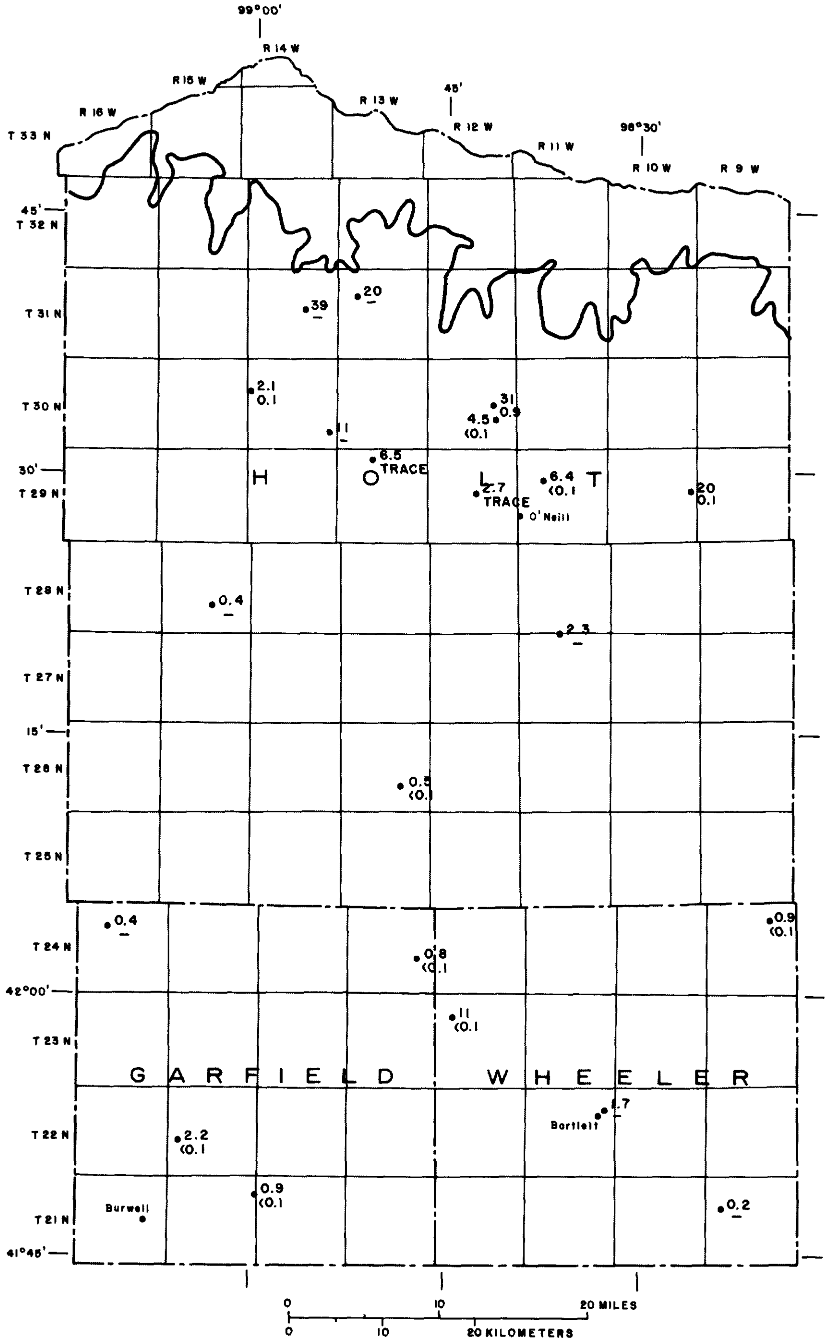


EXPLANATION

• 2.7 <0.1 WELL--Upper number is nitrate concentration, in milligrams per liter as nitrogen. Lower number is triazine-herbicide concentration, in micrograms per liter. Dash indicates no triazine-herbicide analysis. < indicates less than detection limit. Trace indicates triazine-herbicide present at concentrations too low to quantify

Figure 24.--Location of wells sampled in 1984 in areas 3, 4, and 5.

AREA 6



EXPLANATION

• 6.4 <0.1 WELL--Upper number is nitrate concentration, in milligrams per liter as nitrogen. Lower number is triazine-herbicide concentration, in micrograms per liter. Dash indicates no triazine-herbicide analysis. < indicates less than detection limit. Trace indicates triazine-herbicide present at concentrations too low to quantify

——— NORTHERN BOUNDARY OF HIGH PLAINS AQUIFER

Figure 25.--Location of wells sampled in 1984 in area 6.

Triazine herbicides were considered the most likely indicators of ground-water contamination by pesticides for several reasons: (1) The general absence of pesticides other than triazine herbicides in the ground water; (2) the moderate solubility and longevity of triazine herbicides in soil and ground water; and (3) the nearly universal application of triazine herbicides on row crops in Nebraska. Other less conservative and less used pesticides may be investigated in the second phase of this project.

Sampling Techniques and Analyses

Fifty-one of the 82 samples were collected from large-capacity (600 to 1,000 gallons per minute) irrigation wells and 4 samples were collected from public-supply wells that yield similar volumes of water. Twenty-seven samples were collected from 21 smaller capacity (10 to 100 gallons per minute) domestic wells and 6 stock wells. Most irrigation wells had been pumped for several hours to several days prior to sampling. Wells started for the purpose of sampling were pumped long enough to draw 4 to 5 casing volumes through the system prior to sampling. Irrigation-well samples were obtained from gates (on gravity systems) or faucets (on center-pivot systems) as close to the pump as possible. Operators of center-pivot systems were interviewed whenever possible prior to sample collection to determine which, if any, faucets were used for the injection of fertilizers or pesticides. Samples were not collected from those faucets to avoid sample water contamination from fertilizer or pesticide residuals. Samples also were not collected from center-pivot systems in which chemicals were being injected. Access to most domestic wells was by faucets or hydrants on pressure systems. Pressure tanks were flushed to obtain representative samples.

Water samples were analyzed by the U.S. Geological Survey laboratory in Denver, Colorado. Analysis for nitrite plus nitrate as nitrogen were performed on all samples using the cadmium-reduction method (Skougstad and others, 1979). Fifty-seven samples were analyzed for a variety of triazine herbicides including ametryn, atrazine, cyanazine, prometon, prometryne, propazine, simazine, and simetryn, using an acid extraction followed by gas chromatography (Wershaw and others, 1983). Triazine herbicides indicated by unidentifiable peaks of significant magnitude on the gas chromatograms were further analyzed using mass spectrometry.

Sampling Results

Nitrate concentrations for the 82 ground-water samples collected during the 1984 irrigation season ranged from less than 0.1 to 45 milligrams per liter as nitrogen, with a mean of 7.7 and a median of 3.2 milligrams per liter. The U.S. Environmental Protection Agency (1976) limit of 10 milligrams per liter as nitrogen in drinking water was exceeded in samples from 18 wells. The maximum concentrations detected exceeded the limit in all study areas except area 3 (fig. 26). Areas 1 and 6 had the greatest number of samples with concentrations exceeding the limit.

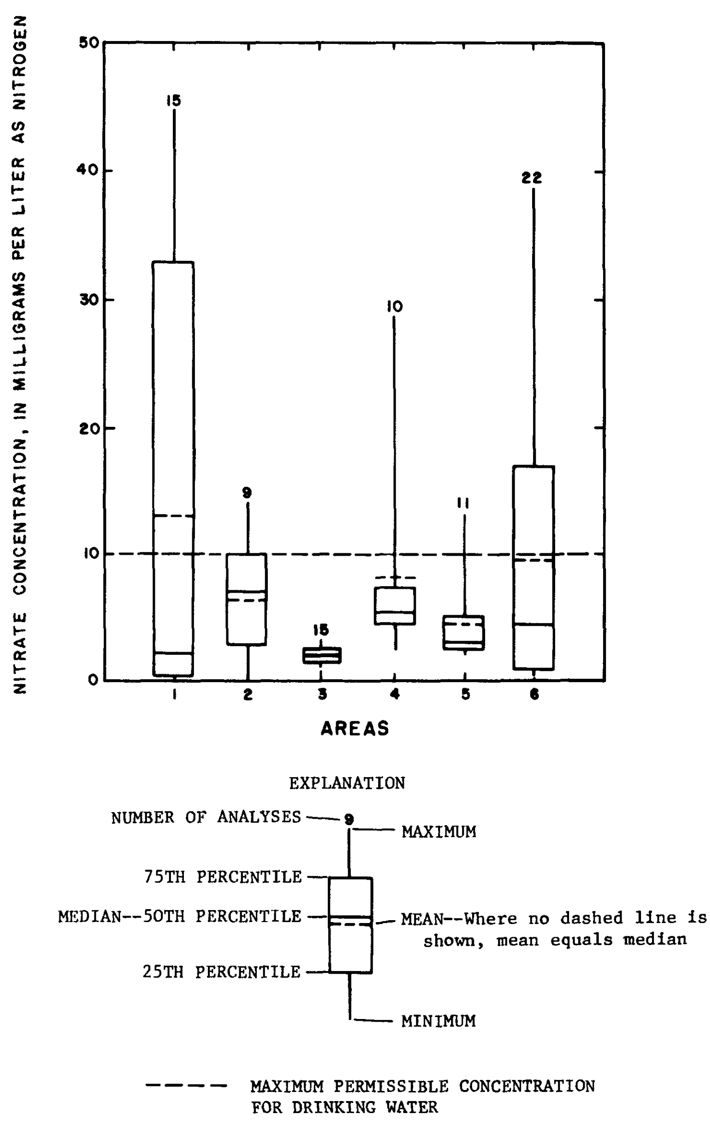


Figure 26.--Nitrate concentrations from 1984 samples for each of the six study areas.

The median test (Conover, 1980) indicated that nitrate concentrations in ground water varied significantly among the six study areas at the 95-percent confidence level. Although these results are based on a rather small sampling, they suggest that different independent variables or different combinations of independent variables are affecting the movement of nitrate into the ground-water system in some of the study areas.

Triazine herbicides were detected in water from 18 of the 57 wells sampled (32 percent) in concentrations that ranged from 0.1 to 2.30 micrograms per liter (table 10). All 18 samples contained atrazine; concentrations in 6 of the samples were at the detection limit of 0.1 microgram per liter. Two of the 18 samples also contained propazine at the detection limit of 0.1 microgram per liter. One of the 18 samples also contained simazine at detection limit of 0.1 microgram per liter.

Areas 1 and 2 had the greatest number of samples with detected triazine herbicides; triazine herbicides were present in water from 5 of 10 wells in area 1 and in water from 4 of 9 wells in area 2. No triazine herbicides were detected in water from the nine wells in area 3. However, the differences in the numbers of samples with detected herbicides among the six study areas using contingency-table analyses (Helsel and Ragone, 1984) were not determined to be significant at the 95-percent confidence level.

Table 10.--Statistical summary of triazine-herbicide concentrations in ground-water samples collected in 1984 for the six study areas

Study area	Number of samples	Number of samples in which triazine herbicides were detected[1]	Micrograms per liter		
			Estimated median[2]	Estimated mean[2]	Range
1	10	5	0.08	0.31	< 0.1 - 1.43
2	9	4	.01	.05	< .1 - .30
3	9	0	(3)	(3)	(3)
4	6	2	<.01	.39	< .1 - 2.30
5	10	2	<.01	.07	< .1 - .71
6	13	5	<.01	.10	< .1 - .90

1/ Detection limit was 0.1 microgram per liter.
2/ Methods by Helsel and Gilliom (1985) were used to estimate values less than the detection limit for use in the summary statistics.
3/ Not detected.

PRELIMINARY EVALUATION OF RELATIONS BETWEEN SELECTED INDEPENDENT VARIABLES AND NITRATE AND TRIAZINE-HERBICIDE CONCENTRATIONS IN GROUND WATER

This section of the report is a preliminary evaluation of the relations between land-use groups and nitrate and triazine-herbicide concentrations, and between the nine independent variables and those constituents. First, the relations between land-use groups and nitrate and triazine-herbicide concentrations are examined. Second, the relations between the nine independent variables and nitrate and triazine-herbicide concentrations (dependent variables) are examined.

Land-Use Group

The effect of land use on agriculturally derived ground-water contaminants was examined by grouping the 82 sampled wells into two land-use categories and then comparing the corresponding concentrations of nitrate and the number of detected triazine herbicides between categories. Sampled wells were grouped according to the irrigation-well density in the vicinity of the wells. Sampled wells were classified as being in an intensively irrigated area if two or more irrigation wells were located within the same legal section (1 square-mile) containing the sampled well. Alternatively, sampled wells were classified as being in a less intensively irrigated area if less than two irrigation wells were present within the same legal section.

Differences in nitrate concentrations between corresponding land-use groups were determined by a ranked T-test (Conover, 1980). Comparisons between the two groups indicated that nitrate concentrations were significantly larger beneath the intensively irrigated areas at the 95-percent confidence level (fig. 27A). Similarly, the number of wells with water containing detectable triazine herbicides was significantly greater in the intensively irrigated group than in the less intensively irrigated group at the 95-percent confidence level (fig. 27B). Therefore, ground water beneath intensively irrigated cropland appears to contain significantly greater concentrations of agriculturally derived chemicals. Relations between the nine independent variables and nitrate or triazine-herbicide concentrations are examined in the following section.

Nine Independent Variables

In this section, simple correlation and regression analyses are applied to determine preliminary relations between the nine independent variables previously discussed and nitrate or triazine-herbicide concentrations. The Statistical Analysis System[1] (SAS Institute, Inc., 1982) was used for data processing and statistical analyses. Water-quality data used in these analyses were limited to data collected in 1984. Nine independent variables (table 11) were used for the preliminary nitrate correlation analyses: Hydraulic gradient (X1), hydraulic conductivity (X2), Specific discharge (X3), depth to water (X4), well depth (X5), annual precipitation (X6), soil permeability (X7), irrigation-well density (X8), and nitrogen-fertilizer use (X9).

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

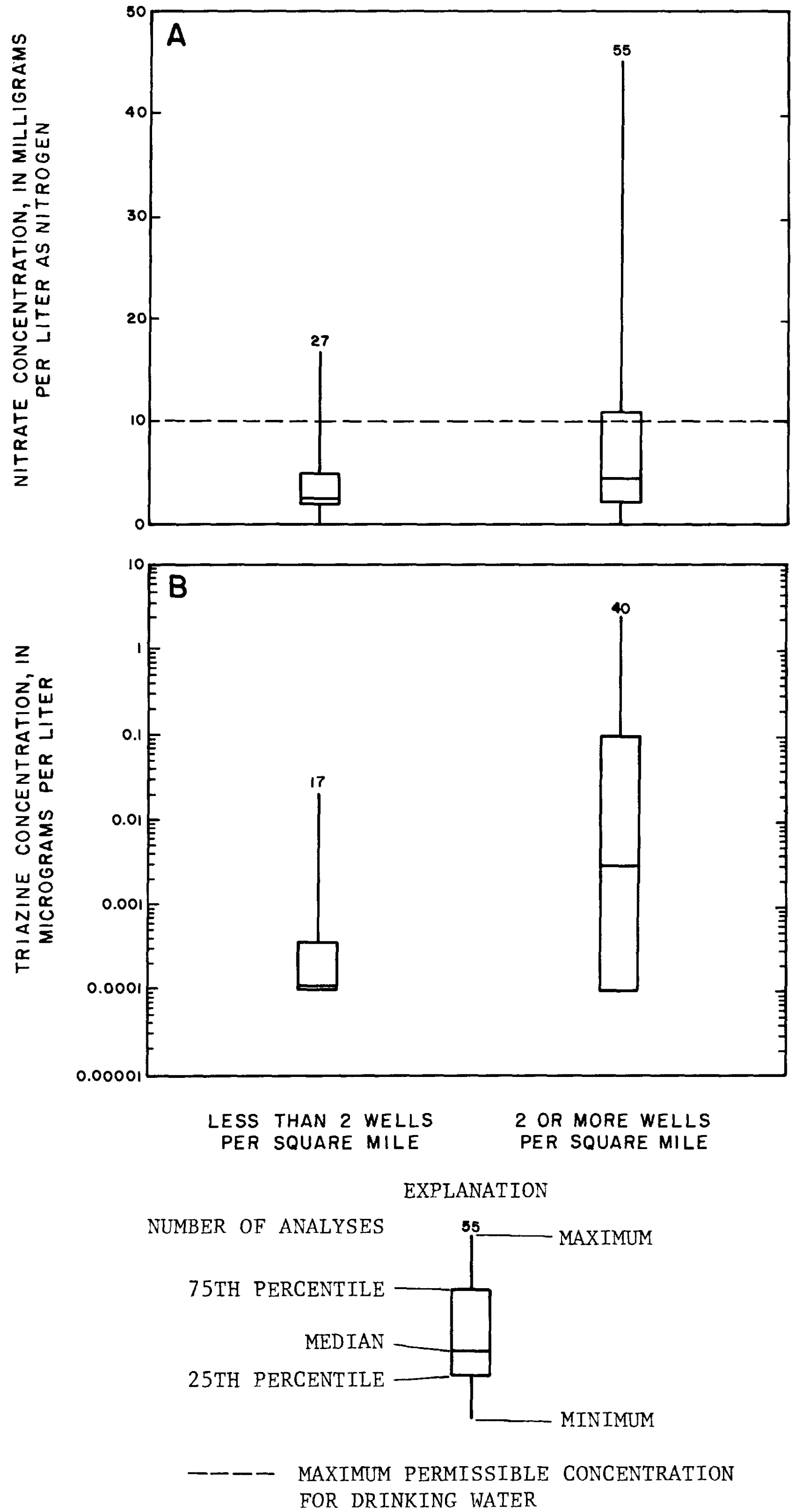


Figure 27.--Relation of contaminants in ground water to intensively irrigated land and less intensively irrigated land in six study areas of Nebraska. A, Nitrate concentrations; B, Estimated triazine-herbicide concentrations (Helsel and Gilliam, 1985). (Source: U.S. Geological Survey files.)

The original data for some of the nine independent variables indicated considerable departure from the normal distribution that is required for simple, linear regression models. The transformation of such data may be sufficient for their application in regression models (Draper and Smith, 1981). Data for three of the nine variables used in the correlation with nitrate concentrations were transformed to logarithmic (X1 and X5) and exponential (X8) forms; data from eight of the nine variables used in the correlation with triazine-herbicide concentrations were transformed to cube (X1 and X3), square (X2), square root (X4), reciprocal (X5), and exponential (X6, X7, and X8) forms.

The correlation coefficient, r, measures the degree of linear association between independent and dependent variables. It is a dimensionless value that may range from -1 through 1. A positive correlation coefficient indicates that the slope of the linear association between variables is positive; a negative correlation indicates a negative slope. The degree of association between variables is greatest as r increases toward -1 or 1 from 0.

The results of the correlation analyses of nitrate concentrations and of triazine-herbicide concentrations for each of the selected independent variables are summarized in table 11. Rankings based on coefficients of correlation indicate the relative nature of the relations.

Three of the nine independent variables (X2, X5, and X8) yielded correlation coefficients with nitrate concentration of more than 40 percent at the 95-percent confidence level. Five of the nine independent variables (X2, X3, X5, X6, and X8) and nitrate concentration (X10) yielded correlation coefficients with triazine-herbicide concentration of 40 percent, or more, at the 95-percent confidence level. Of these, the nitrate concentration had a positive correlation with variables X2 and X8, and a negative correlation with variable X5; whereas, the triazine-herbicide concentration had a positive correlation with all six variables. These preliminary correlations indicate the concentrations of nitrate and triazine herbicide in ground water are sensitive to local hydrogeologic, climatic, and land-use characteristics.

Multiple linear-regression analysis was used to estimate the relative importance of selected independent variables to nitrate and triazine-herbicide concentrations. A general multiple-regression equation with n independent variables is written as:

$$Y = a + b1\ X1 + b2\ X2 + \ldots + bn\ Xn$$

where Y = predicted value of dependent variable (nitrate or triazine-herbicide concentration),
a = regression constant, and
b1-bn = regression coefficients comprising the slope of the line.

The effectiveness of the equation in predicting the concentration of the dependent variable, Y, is determined by the equation's coefficient of determination, r^2, which is the ratio of the variation explained by the independent variables to the total variation in the dependent variable.

Table 11.--Correlations of the independent variables with nitrate and triazine-herbicide concentrations

Independent variables	Dependent variable: nitrate (n = 82)			Dependent variable: triazine herbicide (n = 57)		
	Transformation[2/]	r value	Rank	Transformation[2/]	r value	Rank
Hydraulic gradient (X1)	Logarithmic	[1/]-0.25	5	Cube	[1/]0.26	8
Hydraulic conductivity (X2)	--	[1/]0.45	3	Square	[1/]0.40	5
Specific discharge (X3)	--	[1/]0.22	7	Cube	[1/]0.68	2
Depth to water (X4)	--	[1/]-0.33	4	Square root	[1/]-0.30	7
Well depth (X5)	Logarithmic	[1/]-0.54	1	Reciprocal	[1/]0.56	3
Annual precipitation (X6)	--	0.23	6	Exponential	[1/]0.40	6
Soil permeability (X7)	--	0.05	9	Exponential	-0.08	9
Irrigation-well density (X8)	Exponential	[1/]0.51	2	Exponential	[1/]0.41	4
Nitrogen-fertilizer use (X9)	--	0.21	8	--		
Nitrate concentration (X10)	--			--	[1/]0.78	1

1/ Significant at the 95-percent confidence level.
2/ Dashes indicate no transformation was done.

A stepwise procedure was applied to the two regression models. The MAXR procedure (SAS Institute, Inc., 1982) prioritized the independent variables based on the proportion of variation each explained in the dependent variable. The MAXR procedure first selects the one-variable model that explains the most variation (the largest value of r^2) in the dependent variable, then the best two-variable model, and so on. Each model produced with a coefficient of determination for the nitrate and triazine-herbicide dependent variables greater than 2 percent is listed in table 12.

Equation 1 in table 12 indicates that 29 percent of the total variation in nitrate concentration can be explained by the well depth (X5). In equation 2, the irrigation-well density (X8) explains an additional 14 percent of the total variation in nitrate concentrations.

A combination of three variables (equation 3) explained a total variation of 51 percent in nitrate concentrations. The three independent variables are well depth (X5), irrigation-well density (X8), and nitrogen-fertilizer use (X9). The remaining independent variables each explained less than 1.5 percent of the total nitrate variation when added to the regression model.

Similarly, a combination of two variables (X3 and X5) explained 60 percent of the variation in triazine-herbicide concentrations (equation 5). With nitrate concentration (X10) as an additional independent variable, two variables (X10 and X3) explained 84 percent of the variation in triazine-herbicide concentrations (equation 7). The remaining independent variables each explained less than 1 percent of the total triazine-herbicide variation when added to the regression model.

Although the combinations of variables explained more than one-half of the variation in nitrate and triazine-herbicide concentrations, they failed to explain about 49 percent of the nitrate concentrations and 16 percent of the triazine-herbicide concentrations. Furthermore, several independent variables thought to be critical in affecting ground-water contamination explained only small proportions or none of the variation in nitrate or triazine-herbicide concentrations. This indicates that further improvements can be made in the quantification of site-specific data for the nine variables and in the techniques used to evaluate the variables.

Annual precipitation is an example of a variable, thought to be critical, that explained no significant variation in either regression equation. Hebb and Wheeler (1978) have reported that major rainstorms are instrumental in transporting some pesticides through the soil into aquifers. The data used in the correlations and regression equations in this report did not specify individual rainstorms capable of leaching agricultural chemicals through the soil profile. These data also did not address the seasonal occurrence of precipitation to chemical application. The use of seasonal or individual-storm precipitation data or both in the correlation and regression equations may explain part of the variation in concentrations of nitrate and triazine herbicides.

Table 12.--Equations and coefficients of determination (r^2) for selected independent variables and nitrate or triazine-herbicide concentrations
[X3 = specific discharge; X5 = well depth; X8 = irrigation-well density; X9 = nitrogen-fertilizer use; X10 = nitrate concentration]

Equation	r^2 (percent)	Increase in r^2 (percent)
Dependent variable (Y)--Nitrate concentration:		
1. $Y - 55.83 - 9.38X5$	29	29
2. $Y = 44.45 - 7.44X5 + 0.006X8$	43	14
3. $Y = 41.97 - 7.85X5 + 0.006X8 + 0.036X9$	51	8
Dependent variable (Y)--Triazine-herbicide concentration:		
Without nitrate concentration as an independent variable:		
4. $Y = 0.062 + 10.561X3$	46	46
5. $Y = -0.139 + 8.707X3 + 31.347X5$	60	14
With nitrate concentration as an independent variable:		
6. $Y = -0.096 + 0.033X10$	61	61
7. $Y = -0.11 + 0.027X10 + 7.693X3$	84	23

Nitrogen-fertilizer use and soil permeability also were thought to be among the more critical variables of the nine investigated. However, they were not determined to be significant in the preliminary correlation and only nitrogen-fertilizer use was found to be marginally significant in the regression equations. This may be the result of the limited ranges of data for these variables. Draper and Smith (1981) state that such limited variability generally may cause the corresponding regression coefficients to be found "nonsignificant," a conclusion that may be contradictory to onsite observation or empirical data. In the case of the data for nitrogen-fertilizer application, the data are nonspecific, that is, they usually consist of pounds of fertilizer applied per acre. For further study, these data need to be refined to include the total quantity applied for each part of each field determined to affect the sampled well.

Similarly, the soil-permeability data were interpreted from generalized soil maps (Dugan, 1984). It may be necessary to use weighted-average values of soil permeability, computed by using detailed soil maps of the area in the vicinity of sampled wells, in the correlation and regression equations.

The elimination of multicollinearity that may be associated with the regression equations also may improve the reliability of the equations. Multicollinearity is the existence of two or more "independent" variables in a multiple-regression equation that are significantly correlated with each other--a condition that is inappropriate for classical multiple-regression models. This condition makes it impossible to separate the effects of the two independent variables on the dependent variable. The second phase of this study will investigate whether multicollinearity exists among independent variables in the regression equations listed in table 12 and methods for eliminating this phenomenon from the equations.

In this preliminary multiple-regression analysis, nitrate concentration, which explained 61 percent of the variation in triazine-herbicide concentrations, appears to be more critical in predicting triazine-herbicide concentrations than are other variables (table 12). This finding indicates that nitrate concentrations may be an inexpensive test to identify areas of potential ground-water contamination with triazine herbicides in the High Plains aquifer in Nebraska.

SUMMARY AND CONCLUSIONS

The quality of water in the High Plains aquifer is being affected by hydrogeologic, climatic, soil, and land-use variables. The effects are greatest in intensely irrigated areas where the greatest quantities of agricultural chemicals are applied.

Since the early 1960's, the number of irrigated acres and the use of fertilizers and organic pesticides have increased. The effect of these increases in relation to hydrogeologic, climatic, soil, and land-use variables is indicated by the trend of increasing nitrate concentrations in water from the High Plains aquifer in area 1. Nitrate concentrations also may be increasing in the other five study areas; however, insufficient data prevents verification of such a trend.

Based on pre-1984 and 1984 data, concentrations of triazine herbicides greater than the detection limit probably are common in the ground water of many areas of the State. Triazine herbicides, with concentrations ranging from 0.1 to 2.3 micrograms per liter, were detected in five of the six study areas. These samples represented 32 percent of all samples analyzed for triazine herbicides. The absence of nitrate concentrations greater than 10 milligrams per liter and detectable concentrations of triazine herbicides in samples from area 4 probably is related to the relatively large depths to water in sampled wells in that area. Although the nitrate concentrations varied significantly among the six study areas at the 95-percent confidence level, triazine-herbicide concentrations did not differ significantly at the 95-percent confidence level among the six study areas. Pesticide-use data collected during the study and from published reports indicate that the potential may exist for ground-water contamination with other pesticides.

Twenty-one independent variabales that may affect ground-water quality have been identified. Nine of these variables were selected for preliminary analyses using correlations with nitrate and triazine-herbicide concentrations and simple multiple-regression analyses: hydraulic gradient, hydraulic conductivity, specific discharge, depth to water, well depth, annual precipitation, soil permeability, irrigation-well density, and nitrogen-fertilizer use. Three of these variabales, hydraulic gradient, well depth, and irrigation-well density yielded correlation coefficients greater than 40 percent with the 82 nitrate concentrations at the 95-percent conficence level. Five of the variables--hydraulic conductivity, specific discharge, well depth, annual precipitation, and irrigation-well density--plus a nitrate concentration yielded correlation coefficients equal to or greater than 40 percent with the 57 triazine-herbicide concentrations at the 95-percent confidence level.

Using the SAS Stepwise procedures, three variables--well depth, irrigation-well density, and nitrogen-fertilizer use--explained about 51 percent of the variation in nitrate concentration. Two variables--specific discharge and well depth--explained about 60 percent of the variation in triazine-herbicide concentration. Similarly, with the addition of nitrate concentration as an independent variable, two variables--nitrate concentration and specific discharge--explained 84 percent of the variation in triazine-herbicide concentration. This suggests that nitrate concentration may be an inexpensive means of identifying areas in which triazine-herbicide concentrations may be present in ground water.

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