Concentrations of Triazine Herbicides in the Unsaturated Zone in Western Harvey County, Kansas, Spring and Fall 1992–93

By KYLE E. JURACEK

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

For additional information write to:

District Chief
U.S. Geological Survey
4821 Quail Crest Place
Lawrence, Kansas 66049-3839

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CONVERSION FACTORS

Multiply	By	To obtain
inch	2.54	centimeter
foot	0.3048	meter
square mile	2.590	square kilometer
acre	4,047	square meter
ounce	28.35	gram
pound per acre	1.121	kilogram per hectare
foot per day	0.3048	meter per day

Concentrations of Triazine Herbicides in the Unsaturated Zone in Western Harvey County, Kansas, Spring and Fall 1992–93

By Kyle E. Juracek

Abstract

To assess the potential transport of triazine herbicides into the Equus Beds aquifer, soil samples were collected from the unsaturated zone at 27 dryland and 30 irrigated sites in western Harvey County, Kansas. All sites were sampled at a depth of 4 to 6 feet (that is, immediately below the root zone) during March and October–November 1992 and March and October–November 1993. During the October–November 1992 and March 1993 sampling periods, five sites also were sampled at depths of 0 to 4 and 6 to 10 feet. All samples were analyzed for total triazine concentrations using a 20-gram extraction, immunoassay technique with a 0.02-microgram per kilogram detection level. Additionally, 20 samples from each sampling period were analyzed specifically for atrazine and two atrazine metabolites (deethylatrazine and deisopropylatrazine) using a 20-gram extraction, gas chromatography/mass spectrometry procedure with a 0.5-microgram per kilogram detection level.

Total triazine concentrations at the 4- to 6-foot depth, with one exception, were less than 1.0 microgram per kilogram, with the majority of the concentrations less than 0.10 microgram per kilogram. Triazine concentrations at the 0- to 4-foot depth ranged from 0.51 to 12.20 micrograms per kilogram. Triazine concentrations at the 6- to 10-foot depth ranged from less than 0.02 to 0.33 microgram per kilogram. The atrazine metabolite deethylatrazine was detected in three samples with concentrations of 0.63, 1.44, and 1.48 micrograms per kilogram. The atrazine metabolite deisopropylatrazine was not detected in any of the soil samples analyzed. Because the 1992 and 1993 growing seasons included periods of above-normal rainfall, the concentrations of triazine herbicides and metabolites measured during this study may not be indicative of average conditions.

INTRODUCTION

The Equus Beds aquifer in south-central Kansas (fig. 1) provides the majority of the public-water supplies to the City of Wichita and nearby communities. Concern about the possible transport of triazine herbicides into the aquifer is due to the shallow depth to the ground water (typically, 12 to 30 feet), the frequently permeable soils overlying the ground water, and the predominance of agricultural land use that involves annual applications of triazine herbicides. In Harvey County, Kansas, the major triazine herbicide used is atrazine (Kirk Miles, District Conservationist, Soil Conservation Service, Harvey County, oral commun., 1991). The Harvey County Conservation District, in cooperation with the U.S. Geological Survey, investigated the potential for triazine herbicide transport into the aquifer in western Harvey County, Kansas.

Purpose and Scope

The purpose of this report is to present the results of a study to assess the potential transport of triazine herbicides into the Equus Beds aquifer throughout western Harvey County, Kansas. Risk was assessed by measuring the concentration of triazine herbicides and the atrazine metabolites deethylatrazine and deisopro-

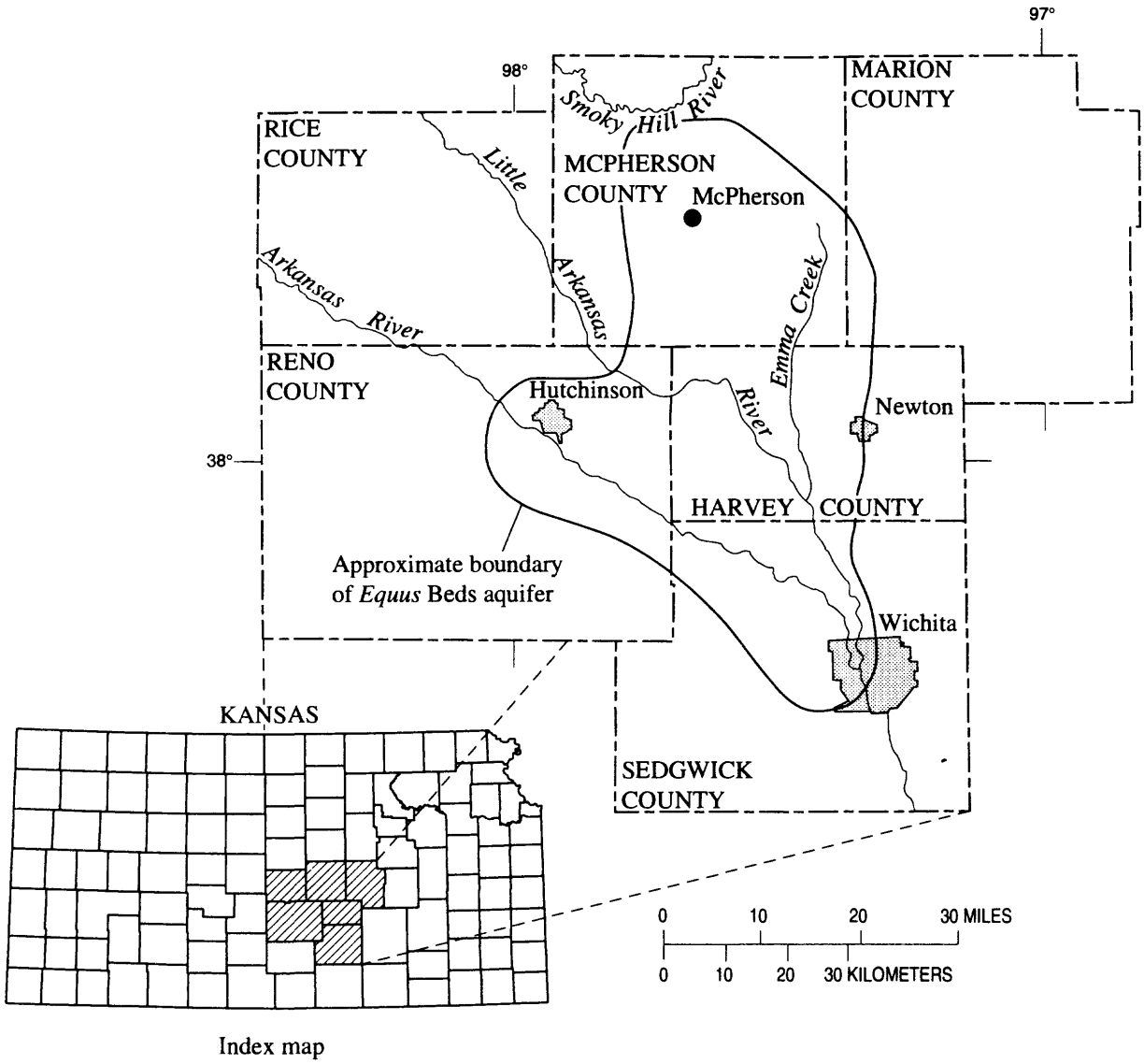

Figure 1. Approximate extent of Equus Beds aquifer in Kansas (modified from Perry, 1990).

pylatrazine in the unsaturated zone. The unsaturated zone is of particular interest because chemicals must be transported through it to reach the ground water (fig. 2). The specific study objectives were to:

- establish approximately 30 dryland and 30 irrigated sites for the collection of soil-core samples from the unsaturated zone;
- collect soil-core samples for multiple dates;
- analyze the soil-core samples for triazine herbicides and two atrazine metabolites (deethylatrazine and deisopropylatrazine); and
- summarize the results.

Acknowledgments

The author gratefully acknowledges the assistance provided by the Harvey County Conservation District, the Kansas Department of Health and Environment, the Kansas Geological Survey, the U.S. Department of Agriculture's Soil Conservation Service, and the many farmers in Harvey County without whom the study would not have been possible.

Description of Study Area

The study area, shown in figure 3, covers an area of approximately 200 square miles in western Harvey

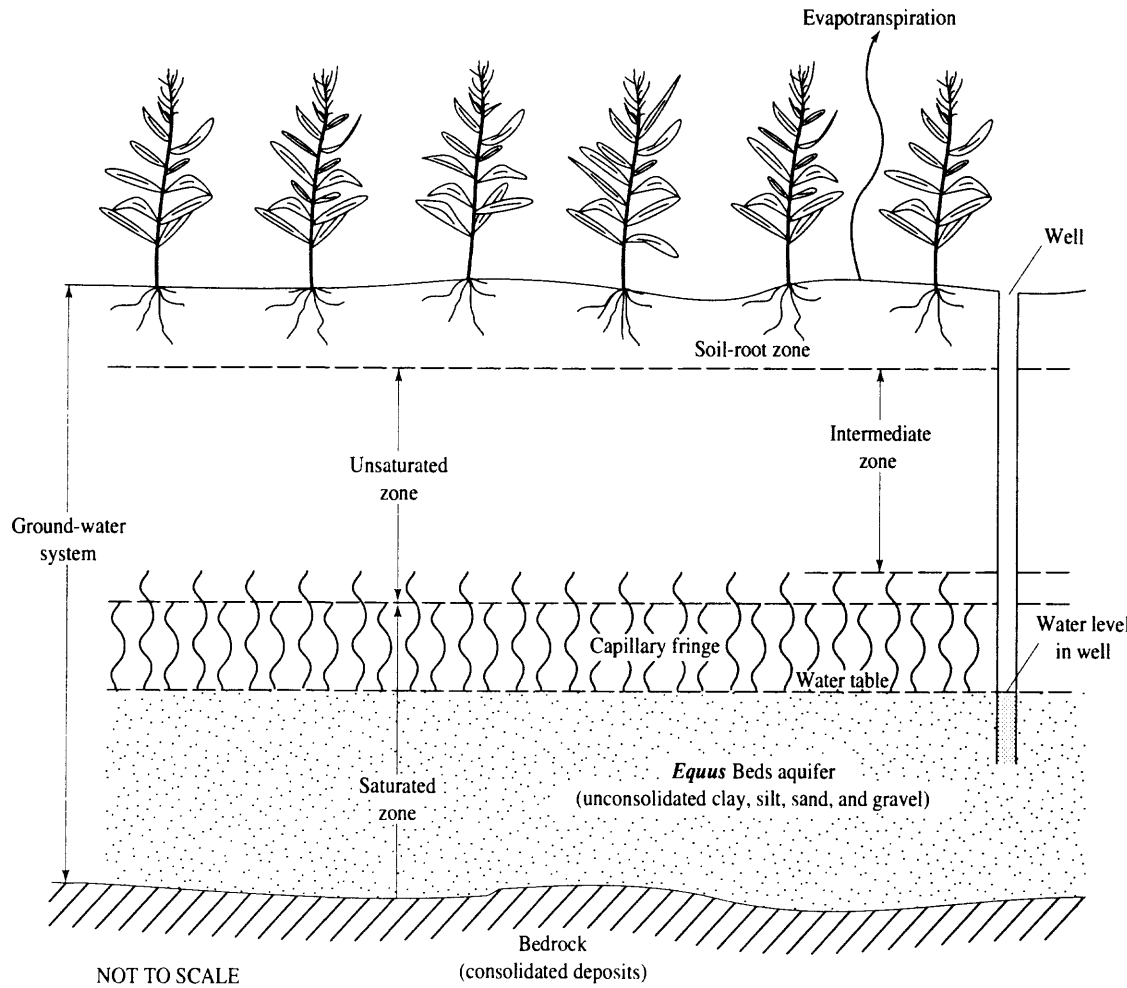

Figure 2. Ground-water system in western Harvey County, Kansas (modified from Heath, 1987).

County, Kansas. Located primarily within the Arkansas River Lowlands, the surface topography is essentially that of a plain modified by the presence of low sand dunes, shallow depressions, and the southeasterly trending Little Arkansas River. Surface drainage in the study area is provided mainly by the Little Arkansas River and its tributary streams. The soils vary throughout the study area and include sandy loams, silty loams, and silty clay loams. Subsurface drainage ranges from somewhat poorly drained to well drained (U.S. Department of Agriculture, Soil Conservation Service, 1974).

Within the study area, the Equus Beds aquifer and Little Arkansas River alluvium consist mainly of unconsolidated deposits of Pleistocene age (Kansas Geological Survey, 1964). The deposits are mostly sand and gravel but also contain clay lenses interbedded with silt, sand, and gravel (Spinazola and others, 1985). The saturated thickness of the aquifer varies across the study area and is generally in the range of 100 to 200 feet. Likewise, the depth to ground water is variable, ranging from less than 10 to about 40 feet. Ground-water flow is generally to the southeast (Equus Beds Groundwater Management District No. 2, 1990), with a lateral velocity of less than 1 foot per day (Stullken and others, 1987). The entire aquifer is believed to be hydrologically connected as an unconfined system (Spinazola and others, 1985), with the discontinuous clay layers acting as local confining units.

The study area has a continental climate characterized by large diurnal and annual temperature ranges, low to moderate humidity, moderate and irregular precipitation, and a high percentage of days with sunshine. Annual precipitation averages 30.5 inches, 80 percent of which is accounted for by showers and thunderstorms during the growing season (April through October) (U.S. Department of Agriculture, Soil Conservation Service, 1974).

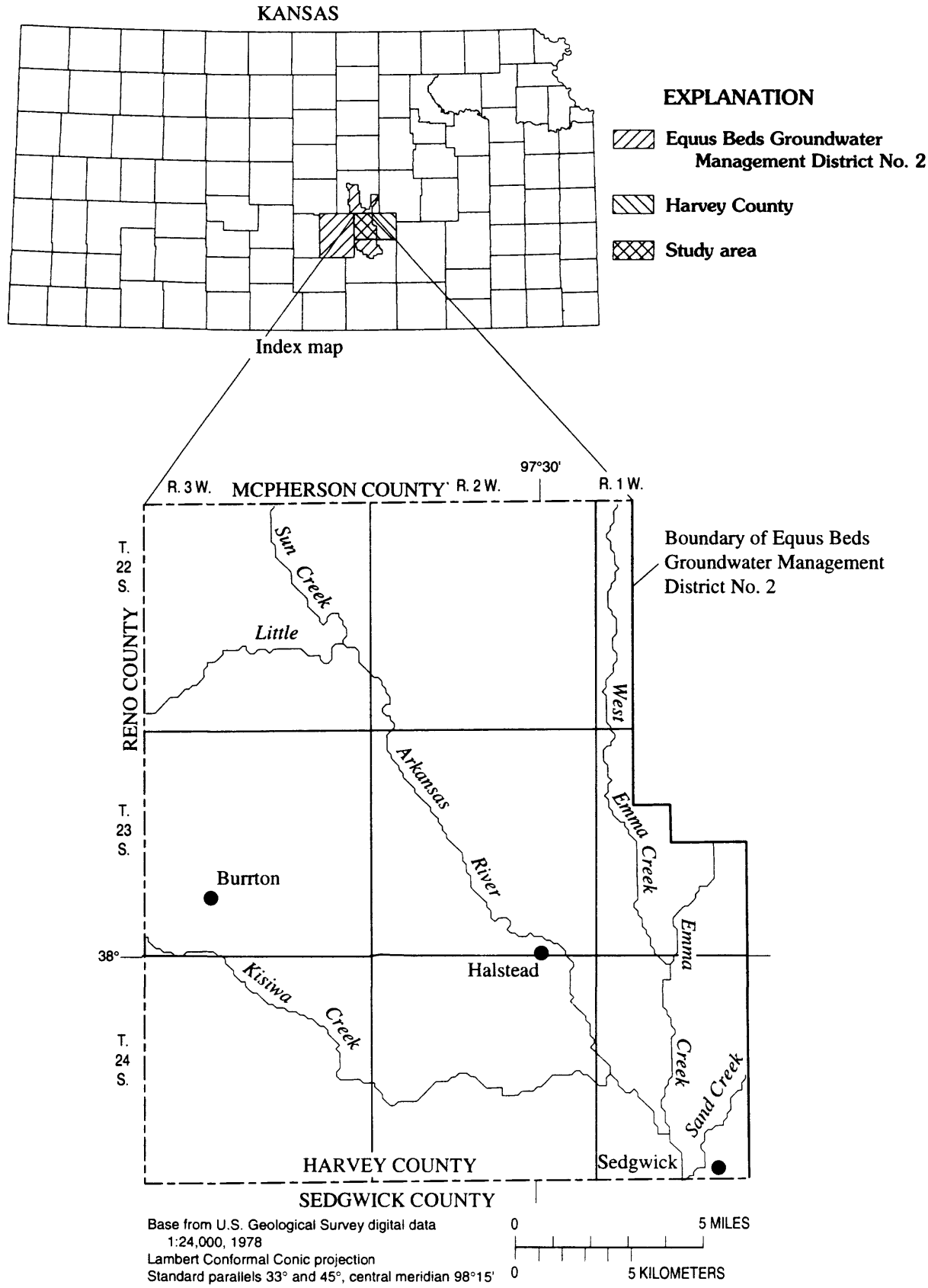

Figure 3. Location of study area in western Harvey County, Kansas.

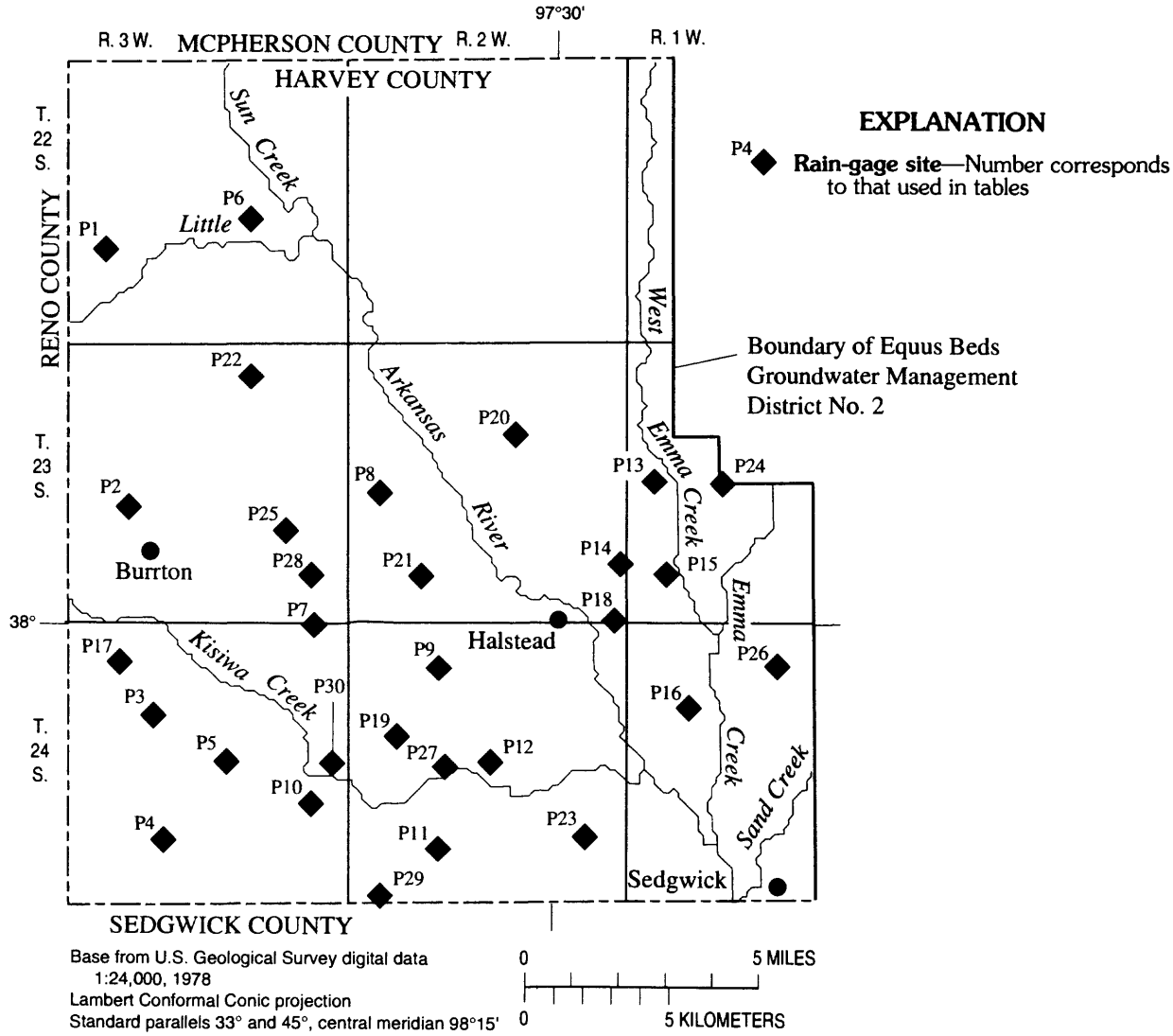

Figure 4. Location of rain-gage sites in study area.

Precipitation during the 1992 and 1993 growing seasons was characterized by 1 or more months of rainfall that was much above normal. Rainfall data collected by the U.S. Geological Survey (see table 19 at end of this report) at 30 sites within the study area (fig. 4) and compared to the 30-year monthly normal precipitation for Newton, Kansas, revealed that the study area received abnormally high rainfall in June 1992, May 1993, and July 1993. The June 1992 average rainfall across the study area was 9.18 inches, which is 97 percent above the 1961–90 average of 4.67 inches (National Oceanic and Atmospheric Administration, 1993a). Average rainfall for May 1993 was 10.92 inches or 147 percent above the 1961–90 average of 4.43 inches (National Oceanic and Atmospheric Administration, 1993b). Finally, average rainfall for July 1993 was 11.65 inches or 276 percent above the 1961–90 average of 3.1 inches (National Oceanic and Atmospheric Administration, 1993c).

The predominate land use in Harvey County is agriculture. The majority of Harvey County's 345,600 acres are devoted to the production of four principal crops: wheat (132,000 acres planted in 1992), sorghum (73,000 acres), soybeans (17,800 acres), and corn (15,500 acres) (Kansas State Board of Agriculture, 1993).

Previous Studies

Several studies have examined the presence and movement of herbicides in the subsurface environ-

ment in Kansas. Helgesen and Rutledge (1989) conducted a study of the High Plains aquifer in south-central Kansas to determine whether or not a relation existed between land use and ground-water quality. Ground-water samples were collected at 30 irrigated cropland sites and 22 nonirrigated rangeland sites. Atrazine (with concentrations ranging from less than 0.1 to 3.8 micrograms per liter) was detected in eight samples, seven of which were from irrigated cropland sites. However, the results did not indicate a statistically significant difference associated with land use (for a more detailed discussion of the study see Helgesen and others, 1994).

Sophocleous and others (1990) conducted flooding experiments on central Kansas croplands to examine the potential of atrazine leaching to the water table under favorable conditions. The vertical distribution of atrazine in the soil profile was found to decrease exponentially with depth. No atrazine was detected at depth in the unsaturated zone or in the underlying aquifer. Further, no evidence was found of atrazine accumulation on top of clay layers.

Ground-water flow and chemical transport in the unsaturated and saturated zones beneath flood- and sprinkler-irrigated fields were the subjects of a study in south-central Kansas by Rutledge and Helgesen (1990). Atrazine concentrations in water samples collected from the unsaturated and saturated zones were found to be generally larger from the flood-irrigated field than from the sprinkler-irrigated field. The fraction of atrazine applied at the land surface that reaches the top of the saturated zone was determined to be about 0.004 for the flood-irrigated field and less than 0.0002 for the sprinkler-irrigated field.

Perry (1991), using experimental leaching sites, examined the distribution of several herbicides in silty loam, sandy loam, and clay soil profiles at a site near Topeka, Kansas. Soil-core and soil-water analyses revealed that: (1) no significant difference in atrazine occurrence existed between irrigated and nonirrigated sites, and (2) a doubling of the amount of atrazine applied to the land surface more than doubled the concentrations found in the soil cores. Perry (1991) also simulated herbicide concentrations using the Pesticide Root Zone Model (Carsel and others, 1984) and demonstrated that: (1) doubling precipitation increased the peak concentration of herbicide (monitored at the 6-foot depth) by one order of magnitude and decreased herbicide traveltime by 30 percent, (2) doubling the atrazine application rate doubled the peak concentration, (3) irrigation or chemigation had the same effect on the peak concentration as a similar increase in precipitation, and (4) doubling the amount of water applied (either by irrigation or precipitation) was much more critical to leaching than doubling the rate of herbicide application.

A laboratory experiment to determine the transport and degradation of alachlor and atrazine in columns of soil under saturated and unsaturated flow conditions was conducted by Schwab and others (1992). Results of the study indicated that: (1) herbicides leached faster in coarse-textured soils low in organic matter than in fine-textured soils, (2) organic matter and clay provided adsorption sites for alachlor and atrazine and thus retarded their movement in soils, and (3) herbicides did not leach to great depths and into the ground water in large quantities. However, Schwab and others (1992) did acknowledge that continuous use of atrazine could result in a buildup in the ground water where the herbicide degrades very slowly. Moreover, the authors, citing White (1985) and Jarvis and others (1991), noted that preferential flow through macropores (cracks, worm channels, and so forth) had the potential to significantly increase the amount and depth of herbicide leaching within the unsaturated zone.

Schwab and Sonon (1991) investigated the persistence and mobility of atrazine under field conditions in four Kansas soils with unique textural and chemical properties. In all of the soils, the largest concentrations of residual atrazine were detected in the upper 8 inches of the soil profile throughout the study year.

METHODOLOGY

The study of triazine herbicides in the unsaturated zone described in this report involved the collection and analysis of soil-core samples for triazine herbicides and two atrazine metabolites. Within the study area, soil-core sampling sites were established with the objective being to select sites that had the greatest potential for ground-water contamination on the basis of several criteria. One criterion was the DRASTIC index (Aller and others, 1985), which is a system for evaluating the ground-water contamination potential of hydrogeologic settings. The settings are defined by the major hydrogeologic factors that affect and control ground-water movement, including depth to water table, net recharge, aquifer media, soil media,

topography, impact of the unsaturated zone, and hydraulic conductivity of the aquifer. The factors are weighted and combined to provide an index that indicates the ground-water contamination potential for a given area. The index ranges from 1 (least contamination potential) to 10 (greatest contamination potential). In this study, candidate sites were required to have a DRASTIC index of at least 5 and preferably to be in the 6-to-10 range.

A second criterion was soil texture. Given that coarse-textured soils have a greater leaching potential than fine-textured soils, potential sites were required to have soil types that were predominantly coarse textured. Within the study area, targeted soils included the Dillwyn series (loamy fine sand), the Farnum series (fine sandy loam), the Naron series (fine sandy loam), and the Pratt series (loamy fine sand) (U.S. Department of Agriculture, Soil Conservation Service, 1974).

A third criterion was crop type. Whereas triazine herbicides (principally atrazine) are used primarily in corn and sorghum production, candidate sites were required to be in corn or sorghum production for the 1992 and 1993 growing seasons. Ideally, the candidate sites had a long history (that is, 3 or more years) of continuous corn/sorghum production. However, sites with corn/sorghum production for the past 2 years and sites in rotation (corn/sorghum and soybeans with corn/sorghum planted for the years sampled) also were used.

The final criterion was herbicide usage. To be considered, each candidate site was required to have triazine-herbicide usage in 1992 and 1993 (and, preferably, 2 or more years of continuous triazine-herbicide usage). The site-selection process was concluded in the field where such considerations as site accessibility could be evaluated.

In all, 33 dryland and 35 irrigated sites were initially selected. During the course of the study, 6 dryland and 5 irrigated sites were not sampled for various reasons. The location of the sites actually sampled is depicted in figure 5. Descriptions of the dryland and irrigated sampling sites are provided in tables 1 and 2, respectively. The tables provide, for each sampling site, information on the location (that is, legal description), number of years of consecutive atrazine use through 1992, amount of atrazine applied during the 1992 growing season, and the crop planted in 1992. Atrazine-usage and crop-type information was obtained from cooperating farmers in the study area.

Soil cores were collected during the following sampling periods: March 1992 (pre-plant), October–November 1992 (post-harvest), March 1993 (pre-plant), and October–November 1993 (post-harvest). Using a 2-foot split-spoon sampler, the cores were collected to a depth of 10 feet, or the water table, whichever occurred first. From each core, the segment located at a depth of 4 to 6 feet (that is, immediately below the root zone) was extracted, homogenized, and sampled. Also, for the October–November 1992 and March 1993 sampling periods, five sites were sampled at the 0- to 4- and 6- to 10-foot depths. All samples were analyzed for total triazine concentrations using a 20-gram extraction, immunoassay technique (approximate detection level: 0.02 microgram per kilogram) (Mills and Thurman, 1992; Aga and Thurman, 1993, in press). In addition, 20 samples from each sampling period were analyzed for atrazine and two atrazine metabolites (deethylatrazine and deisopropylatrazine) using a 20-gram extraction, gas chromatography/mass spectrometry (GC/MS) procedure (approximate detection level: 0.5 microgram per kilogram) (Thurman and others, 1990; Mills and Thurman, 1992). All samples were analyzed at the U.S. Geological Survey's organic research laboratory in Lawrence, Kansas.

Total sample variance, which is equal to the sum of temporal variance, spatial variance, and analytical variance, was evaluated by replicate sampling of some of the sites and duplicate analyses. Specifically, temporal variance was evaluated by the use of multiple sampling periods—March 1992, October–November 1992, March 1993, and October–November 1993. Spatial variance was addressed by the collection of duplicate cores (within 3 feet of the original cores) at 10 randomly selected sites (first sampling period only). Finally, analytical variance was addressed by performing a duplicate analysis of samples collected from 10 randomly selected cores (first sampling period only).

RESULTS

The results of the analyses of the soil-core samples for total triazines and two atrazine metabolites are grouped by sampling period, site type (dryland, irrigated), and method of analysis.

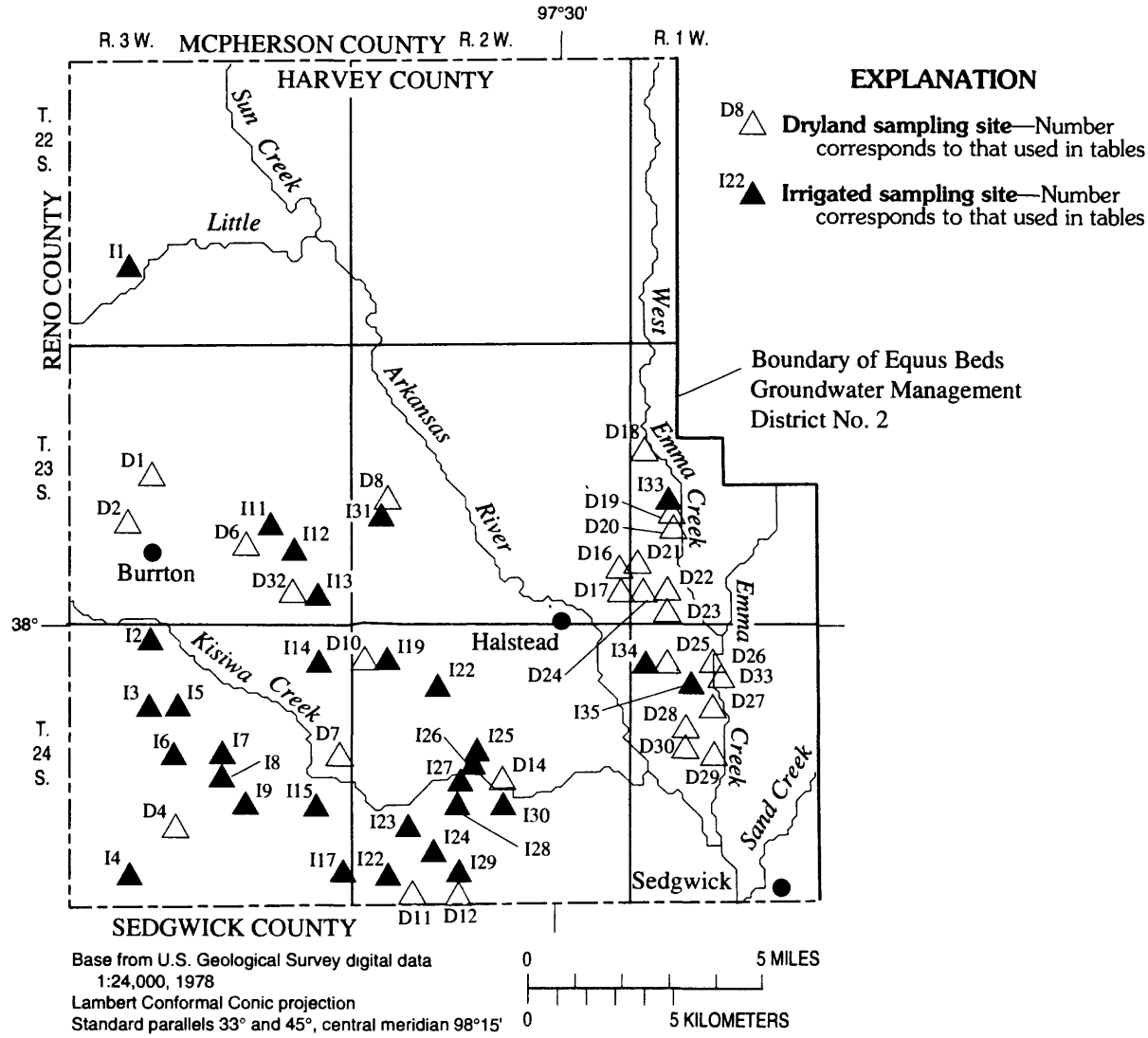

Figure 5. Location of sampling sites in study area.

March 1992 Samples

Dryland Sites

Total triazine concentrations measured using the immunoassay method for the March 1992 dryland samples are presented in table 3. Of the 26 "A" samples (4- to 6-foot depth) analyzed, 17 (65.4 percent) had detectable concentrations of triazine herbicides (that is, a measured concentration equal to or greater than the detection level of 0.02 microgram per kilogram), and 9 (34.6 percent) did not have detectable concentrations (that is, a measured concentration less than the detection level of 0.02 microgram per kilogram). The median concentration of the "A" samples was 0.02 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 0.53 microgram per kilogram.

Concentrations of atrazine and two atrazine metabolites (deethylatrazine and deisopropylatrazine) measured using the GC/MS method for nine of the March 1992 dryland samples are presented in table 4. The atrazine concentrations paralleled those determined using the immunoassay method. None of the samples analyzed using GC/MS had detectable concentrations of deethylatrazine or deisopropylatrazine.

Irrigated Sites

Total triazine concentrations measured using the immunoassay method for the March 1992 irrigated

Table 1. Description of dryland sampling sites in western Harvey County, Kansas
[--, site discontinued]

Sampling-site no. (fig. 5)	Location (township, range, section, qualifier)	Years of consecutive atrazine use through 1992	Atrazine applied in 1992 (pounds of active ingredient per acre)	Crop planted in 1992
D1	23S 03W 17 SE	2	0.35	Sorghum
D2	23S 03W 20 SW	2	.35	Sorghum
D3	--	--	--	--
D4	24S 03W 28 NW	1	1.00	Sorghum
D5	--	--	--	--
D6	23S 03W 27 NE	7	.35	Sorghum
D7	24S 03W 13 SE	2	.75	Sorghum
D8	23S 02W 19 NE	1	1.00	Sorghum
D9	--	--	--	--
D10	24S 02W 6 SW	5	1.60	Sorghum
D11	24S 02W 32 SW	5	1.20	Sorghum
D12	24S 02W 33 SW	1	1.00	Sorghum
D13	--	--	--	--
D14	24S 02W 22 NW	4	1.00	Sorghum
D15	--	--	--	--
D16	23S 02W 25 SE	7	1.00	Sorghum
D17	23S 02W 36 NE	4	1.00	Sorghum
D18	23S 01W 18 NW	0	0	Sorghum
D19	23S 01W 19 SE	5	1.10	Sorghum
D20	23S 01W 19 SE	5	1.10	Sorghum
D21	23S 01W 30 SW	3	.50	Sorghum
D22	23S 01W 31 NE	7	1.00	Sorghum
D23	23S 01W 31 SE	0	0	Sorghum
D24	23S 01W 31 NW	3	1.00	Sorghum
D25	24S 01W 6 SE	7	1.00	Sorghum
D26	24S 01W 5 SE	0	0	Sorghum
D27	24S 01W 8 SE	0	0	Sorghum
D28	24S 01W 17 NW	1	.75	Sorghum
D29	24S 01W 17 SE	6	1.00	Sorghum
D30	24S 01W 17 SW	4	1.25	Sorghum
D31	--	--	--	--
D32	23S 03W 35 NE	7	1.60	Sorghum
D33	24S 01W 8 NE	7	1.00	Sorghum

Table 2. Description of irrigated sampling sites in western Harvey County, Kansas
[--, site discontinued]

Sampling-site no. (fig. 5)	Location (township, range, section, qualifier)	Years of consecutive atrazine use through 1992)	Atrazine applied in 1992 (pounds of active ingredient per acre)	Crop planted in 1992
I1	22S 03W 29 NW	1	1.30	Corn
I2	24S 03W 5 NE	1	1.20	Corn
I3	24S 03W 8 SE	0	0	Sorghum
I4	24S 03W 32 NW	3	1.10	Corn
I5	24S 03W 9 SW	1	1.00	Sorghum
I6	24S 03W 16 SW	1	1.30	Corn
I7	24S 03W 15 SW	1	1.20	Corn
I8	24S 03W 22 NW	1	1.20	Corn
I9	24S 03W 22 SE	1	1.20	Corn
I10	--	--	--	--
I11	23S 03W 23 SW	0	0	Corn
I12	23S 03W 26 NE	3	1.10	Corn
I13	23S 03W 36 NW	2	1.70	Corn
I14	24S 03W 1 SW	2	1.60	Corn
I15	24S 03W 24 SW	5	1.20	Corn
I16	--	--	--	--
I17	24S 03W 36 NE	1	1.10	Corn
I18	--	--	--	--
I19	24S 02W 6 SE	3	1.10	Corn
I20	24S 02W 31 NE	1	1.20	Corn
I21	--	--	--	--
I22	24S 02W 8 NE	2	.17	Corn
I23	24S 02W 29 NW	2	.94	Corn
I24	24S 02W 29 SE	1	1.66	Corn
I25	24S 02W 16 SE	3	1.60	Corn
I26	24S 02W 16 SE	1	1.60	Corn
I27	24S 02W 21 NW	4	1.00	Corn
I28	24S 02W 21 SW	1	.94	Corn
I29	24S 02W 33 NW	2	2.00	Corn
I30	24S 02W 22 SW	1	1.83	Corn
I31	23S 02W 19 SE	3	1.10	Corn
I32	--	--	--	--
I33	23S 01W 19 NE	2	.09	Sorghum
I34	24S 01W 6 SW	3	1.50	Sorghum
I35	24S 01W 8 NW	2	.50	Sorghum

Table 3. Results of immunoassay analysis of dryland soil samples for total triazine herbicides, March 1992
[--, not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)			
	Sample A[1]	Sample B[1]	Sample C[1]	Sample D[1]
D1	0.35	--	--	--
D2	.02	--	--	--
D3	--	--	--	--
D4	<.02	--	--	--
D5	--	--	--	--
D6	.03	--	0.08	--
D7	.53	0.68	--	--
D8	.03	.11	<.02	--
D9	--	--	--	--
D10	.02	--	<.02	0.02
D11	.02	--	--	--
D12	.10	--	--	--
D13	--	--	--	--
D14	.12	.11	--	--
D15	--	--	--	--
D16	<.02	--	--	--
D17	.06	--	--	--
D18	<.02	--	--	--
D19	.05	.07	.28	.39
D20	--	--	--	--
D21	.53	--	--	--
D22	.02	--	--	--
D23	<.02	--	--	--
D24	.08	.12	.03	.05
D25	.11	--	--	--
D26	.11	--	--	--
D27	<.02	--	--	--
D28	<.02	--	<.02	--
D29	<.02	--	--	--
D30	.02	--	--	--
D31	--	--	--	--
D32	<.02	--	--	--
D33	<.02	--	<.02	--

[1]Sample: A, 4- to 6-foot depth.
B, Duplicate sample for 4- to 6-foot depth.
C, Duplicate core for 4- to 6-foot depth.
D, Duplicate sample for duplicate core for 4- to 6-foot depth.

Table 4. Results of gas chromatography/mass spectrometry analysis of dryland soil samples from 4- to 6-foot depth for atrazine and two atrazine metabolites, March 1992
[<, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)		
		Atrazine metabolites	
	Atrazine	Deethyl-atrazine	Deisopropyl-atrazine
D1	<0.50	<0.50	<0.50
D6	<.50	<.50	<.50
D7	.65	<.50	<.50
D11	<.50	<.50	<.50
D19	<.50	<.50	<.50
D21	.78	<.50	<.50
D22	<.50	<.50	<.50
D23	<.50	<.50	<.50
D26	<.50	<.50	<.50

samples are presented in table 5. Of the 30 "A" samples analyzed, 28 (93.3 percent) had detectable concentrations of triazine herbicides, and 2 (6.7 percent) had no detectable concentrations. The median concentration of the "A" samples was 0.05 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 0.67 microgram per kilogram.

Concentrations of atrazine and two atrazine metabolites measured using the GC/MS method for 10 of the March 1992 irrigated samples are presented in table 6. The atrazine concentrations paralleled those determined using the immunoassay method. One sample had a measurable concentration of deethylatrazine of 1.44 micrograms per kilogram. None of the samples analyzed using GC/MS had detectable concentrations of deisopropylatrazine.

October–November 1992 Samples

Dryland Sites

Total triazine concentrations measured using the immunoassay method for the October–November 1992 dryland samples are presented in table 7. Due to inclement weather conditions, only 15 dryland samples were collected during the fall of 1992. Of the 15 "A" samples analyzed, 3 (20 percent) had detect-

Table 5. Results of immunoassay analysis of irrigated soil samples for total triazine herbicides, March 1992
[--, not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)			
	Sample A[1]	Sample B[1]	Sample C[1]	Sample D[1]
I1	0.18	--	--	--
I2	.03	--	--	--
I3	.02	--	0.03	--
I4	.14	--	--	--
I5	.03	--	--	--
I6	.58	--	--	--
I7	.23	0.31	--	--
I8	.02	<.02	--	--
I9	.10	--	--	--
I10	--	--	--	--
I11	.09	--	--	--
I12	.03	--	--	--
I13	.06	--	--	--
I14	<.02	<.02	--	--
I15	.06	--	--	--
I16	--	--	--	--
I17	.04	--	.04	--
I18	--	--	--	--
I19	.08	--	--	--
I20	.05	--	--	--
I21	--	--	--	--
I22	.11	--	--	--
I23	.06	--	--	--
I24	.05	--	.04	--
I25	.34	.34	--	--
I26	.03	--	--	--
I27	.02	--	--	--
I28	.67	.55	--	--
I29	.02	--	--	--
I30	.03	--	--	--
I31	.04	--	--	--
I32	--	--	--	--
I33	.37	--	--	--
I34	.02	--	--	--
I35	<.02	--	--	--

[1]Sample: A, 4- to 6-foot depth.
B, Duplicate sample for 4- to 6-foot depth.
C, Duplicate core for 4- to 6-foot depth.
D, Duplicate sample for duplicate core for 4- to 6-foot depth.

Table 6. Results of gas chromatography/mass spectrometry analysis of irrigated soil samples from 4- to 6-foot depth for atrazine and two atrazine metabolites, March 1992
[<, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)		
		Atrazine metabolites	
	Atrazine	Deethyl-atrazine	Deisopropyl-atrazine
I3	<0.50	<0.50	<0.50
I6	.66	1.44	<.50
I11	<.50	<.50	<.50
I12	<.50	<.50	<.50
I19	<.50	<.50	<.50
I22	<.50	<.50	<.50
I24	<.50	<.50	<.50
I28	.58	<.50	<.50
I31	<.50	<.50	<.50
I33	<.50	<.50	<.50

able concentrations of triazine herbicides, and 12 (80 percent) had no detectable concentrations. The median concentration of the "A" samples was less than 0.02 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 1.22 micrograms per kilogram.

During the October–November 1992 sampling period, two dryland sites (D8 and D30) were sampled at the 0- to 4- ("E" samples) and 6- to 10- ("G" samples) foot depths. The immunoassay results for the "E" samples (table 7) showed total triazine concentrations of 2.75 and 11.27 micrograms per kilogram for sites D8 and D30, respectively. The "G" sample results (table 7) showed a total triazine concentration of less than 0.02 microgram per kilogram for site D8 and a total triazine concentration of 0.14 microgram per kilogram for site D30.

Concentrations of atrazine and two atrazine metabolites measured using the GC/MS method for 10 of the October–November 1992 dryland samples are presented in table 8. The atrazine concentrations paralleled those determined using the immunoassay method. None of the samples analyzed using GC/MS had detectable concentrations of deethylatrazine or deisopropylatrazine.

Table 7. Results of immunoassay analysis of dryland soil samples for total triazine herbicides, October–November 1992

[Note: Due to inclement weather, several of the dryland sites were not sampled during October–November 1992. --, not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)		
	Sample A[1]	Sample E[1]	Sample G[1]
D1	--	--	--
D2	--	--	--
D3	--	--	--
D4	--	--	--
D5	--	--	--
D6	--	--	--
D7	--	--	--
D8	1.22	2.75	<0.02
D9	--	--	--
D10	<.02	--	--
D11	<.02	--	--
D12	--	--	--
D13	--	--	--
D14	<.02	--	--
D15	--	--	--
D16	<.02	--	--
D17	<.02	--	--
D18	--	--	--
D19	<.02	--	--
D20	--	--	--
D21	--	--	--
D22	--	--	--
D23	<.02	--	--
D24	<.02	--	--
D25	.05	--	--
D26	<.02	--	--
D27	<.02	--	--
D28	<.02	--	--
D29	--	--	--
D30	.04	11.27	.14
D31	--	--	--
D32	--	--	--
D33	<.02	--	--

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
G, 6- to 10-foot depth.

Table 8. Results of gas chromatography/mass spectrometry analysis of dryland soil samples for atrazine and two atrazine metabolites, October–November 1992

[<, less than]

Sampling-site no. (fig. 5)	Sampling depth[1]	Concentrations (micrograms per kilogram)		
			Atrazine metabolites	
		Atrazine	Deethyl-atrazine	Deisopropyl-atrazine
D8	A	0.55	<0.50	<0.50
	E	2.00	<.50	<.50
	G	<.50	<.50	<.50
D14	A	<.50	<.50	<.50
D17	A	<.50	<.50	<.50
D25	A	<.50	<.50	<.50
D28	A	<.50	<.50	<.50
D30	A	<.50	<.50	<.50
	E	12.00	<.50	<.50
	G	<.50	<.50	<.50

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
G, 6- to 10-foot depth.

Irrigated Sites

Total triazine concentrations measured using the immunoassay method for the October–November 1992 irrigated samples are presented in table 9. Due to inclement weather conditions, only 21 irrigated samples were collected. Of the 21 "A" samples analyzed, 19 (90.5 percent) had detectable concentrations of triazine herbicides, and 2 (9.5 percent) had no detectable concentrations. The median concentration of the "A" samples was 0.06 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 0.99 microgram per kilogram.

During the October–November 1992 sampling period, three irrigated sites (I1, I11, and I12) also were sampled at the 0- to 4- ("E" samples) and 6- to 10- ("G" samples) foot depths. The immunoassay results for the "E" samples (table 9) showed total triazine concentrations of 4.17, 0.51, and 12.2 micrograms per kilogram for sites I1, I11, and I12, respectively. The "G" sample results (table 9) were 0.33 microgram per kilogram for site I1, 0.07 micro-

Table 9. Results of immunoassay analysis of irrigated soil samples for total triazine herbicides, October–November 1992

[Note: Due to inclement weather, several of the irrigated sites were not sampled during October–November 1992. --, not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)		
	Sample A[1]	Sample E[1]	Sample G[1]
I1	0.18	4.17	0.33
I2	.28	--	--
I3	--	--	--
I4	.18	--	--
I5	--	--	--
I6	--	--	--
I7	.19	--	--
I8	.99	--	--
I9	.02	--	--
I10	--	--	--
I11	.04	.51	.07
I12	.21	12.2	<.02
I13	<.02	--	--
I14	.06	--	--
I15	--	--	--
I16	--	--	--
I17	--	--	--
I18	--	--	--
I19	.03	--	--
I20	--	--	--
I21	--	--	--
I22	.03	--	--
I23	.06	--	--
I24	--	--	--
I25	.07	--	--
I26	.02	--	--
I27	--	--	--
I28	.10	--	--
I29	.02	--	--
I30	--	--	--
I31	.02	--	--
I32	--	--	--
I33	.03	--	--
I34	.19	--	--
I35	<.02	--	--

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
G, 6- to 10-foot depth.

gram per kilogram for site I11, and no detection for site I12.

Concentrations of atrazine and two atrazine metabolites measured using the GC/MS method for 11 of the October–November 1992 irrigated samples are presented in table 10. The atrazine concentrations paralleled those determined using the immunoassay method. One sample had a measurable amount of deethylatrazine, with a concentration of 1.48 micrograms per kilogram. None of the samples analyzed using GC/MS had detectable concentrations of deisopropylatrazine.

March 1993 Samples

Dryland Sites

Total triazine concentrations measured using the immunoassay method for the March 1993 dryland samples are presented in table 11. Of the 25 "A"

Table 10. Results of gas chromatography/mass spectrometry analysis of irrigated soil samples for atrazine and two atrazine metabolites, October–November 1992

[<, less than]

Sampling-site no. (fig. 5)	Sampling depth[1]	Concentrations (micrograms per kilogram)		
			Atrazine metabolites	
		Atrazine	Deethyl-atrazine	Deisopropyl-atrazine
I1	A	<0.50	<0.50	<0.50
	E	3.3	<.50	<.50
	G	<.50	<.50	<.50
I8	A	.68	<.50	<.50
I11	A	<.50	<.50	<.50
	E	<.50	<.50	<.50
I12	A	<.50	<.50	<.50
	E	12.2	1.48	<.50
	G	<.50	<.50	<.50
I29	A	<.50	<.50	<.50
I35	A	<.50	<.50	<.50

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
G, 6- to 10-foot depth.

Table 11. Results of immunoassay analysis of dryland soil samples for total triazine herbicides, March 1993

[--, not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)			
	Sample A[1]	Sample E[1]	Sample G[1]	Sample J[1]
D1	--	--	--	--
D2	<0.02	--	--	--
D3	--	--	--	--
D4	.06	--	--	--
D5	--	--	--	--
D6	.03	--	--	--
D7	.03	--	--	--
D8	.14	0.63	0.02	--
D9	--	--	--	--
D10	.03	--	--	0.63
D11	.04	--	--	--
D12	.22	--	--	--
D13	--	--	--	--
D14	.10	--	--	--
D15	--	--	--	--
D16	.06	--	--	--
D17	.13	--	--	--
D18	<.02	--	--	--
D19	.10	--	--	--
D20	.03	--	--	--
D21	--	--	--	--
D22	.06	--	--	--
D23	.13	--	--	--
D24	.07	--	--	--
D25	.08	--	--	--
D26	<.02	--	--	--
D27	.04	--	--	--
D28	.03	--	--	--
D29	<.02	--	--	--
D30	.10	1.97	.12	--
D31	--	--	--	--
D32	.05	--	--	--
D33	.03	--	--	--

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
G, 6- to 10-foot depth.
J, 4- to 6-foot depth (extra sample collected at alternate location to accommodate cropping plans and fall 1993 sampling).

samples analyzed, 21 (84 percent) had detectable concentrations of triazine herbicides, and 4 (16 percent) had no detectable concentrations. The median concentration of the "A" samples was 0.05 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 0.22 microgram per kilogram.

Again, during the March 1993 sampling period, dryland sites D8 and D30 were sampled at the 0- to 4- ("E" samples) and 6- to 10- ("G" samples) foot depths. The immunoassay results for the "E" samples (table 11) showed total triazine concentrations of 0.63 and 1.97 micrograms per kilogram for sites D8 and D30, respectively. The "G" sample results (table 11) for sites D8 and D30 were 0.02 and 0.12 microgram per kilogram, respectively. To accommodate 1993 cropping plans and the subsequent fall sampling, site D10 also was sampled at an alternate location. The alternate "J" sample for site D10 had a total triazine concentration of 0.63 microgram per kilogram.

Concentrations of atrazine and two atrazine metabolites measured using the GC/MS method for nine of the March 1993 dryland samples are presented in table 12. The atrazine concentrations paralleled

Table 12. Results of gas chromatography/mass spectrometry analysis of dryland soil samples for atrazine and two atrazine metabolites, March 1993

[<, less than]

Sampling-site no. (fig. 5)	Sampling depth[1]	Concentrations (micrograms per kilogram)		
			Atrazine metabolites	
		Atrazine	Deethyl-atrazine	Deisopropyl-atrazine
D8	E	<0.50	<0.50	<0.50
D10	J	1.35	<.50	<.50
D12	A	<.50	<.50	<.50
D17	A	<.50	<.50	<.50
D23	A	<.50	<.50	<.50
D26	A	<.50	<.50	<.50
D29	A	<.50	<.50	<.50
D30	E	1.91	<.50	<.50
D32	A	<.50	<.50	<.50

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
J, 4- to 6-foot depth (extra sample collected at alternate location to accommodate cropping plans and fall 1993 sampling).

those determined using the immunoassay method. None of the samples analyzed using GC/MS had detectable concentrations of deethylatrazine or deisopropylatrazine.

Irrigated Sites

Total triazine concentrations measured using the immunoassay method for the March 1993 irrigated samples are presented in table 13. Of the 29 "A" samples analyzed, 24 (82.8 percent) had detectable concentrations of triazine herbicides, and 5 (17.2 percent) had no detectable concentrations. The median concentration of the "A" samples was 0.05 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 0.74 microgram per kilogram.

Again, during the March 1993 sampling period, the irrigated sites I1, I11, and I12 were sampled at the 0- to 4- ("E" samples) and 6- to 10- ("G" samples) foot depths. The immunoassay results for the "E" samples (table 13) showed total triazine concentrations of 1.57, 1.24, and 2.09 micrograms per kilogram for sites I1, I11, and I12, respectively. The "G" sample results (table 13) were 0.24 microgram per kilogram for site I1, no detectable concentration for site I11, and 0.10 microgram per kilogram for site I12. To accommodate 1993 cropping plans (that is, crop rotation) and the subsequent fall sampling, the following irrigated sites also were sampled at alternate locations: I2, I7, I11, I12, I14, I17, I20, I24, I28, I30, and I35. The alternate "J" samples had total triazine concentrations that ranged from less than 0.02 to 0.23 microgram per kilogram, with a median concentration of 0.04 microgram per kilogram.

Concentrations of atrazine and two atrazine metabolites measured using the GC/MS method for 11 of the March 1993 irrigated samples are presented in table 14. The atrazine concentrations paralleled those determined by the immunoassay method. None of the samples analyzed using GC/MS had detectable concentrations of deethylatrazine or deisopropylatrazine.

October–November 1993 Samples

Dryland Sites

Total triazine concentrations measured using the immunoassay method for the October–November 1993 dryland samples are presented in table 15. Of the 21 "A" samples analyzed, 20 (95.2 percent) had

Table 13. Results of immunoassay analysis of irrigated soil samples for total triazine herbicides, March 1993

[--, not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)			
	Sample A[1]	Sample E[1]	Sample G[1]	Sample J[1]
I1	0.74	1.57	0.24	--
I2	.04	--	--	0.16
I3	.03	--	--	--
I4	<.02	--	--	--
I5	<.02	--	--	--
I6	.41	--	--	--
I7	<.02	--	--	.23
I8	.06	--	--	--
I9	.05	--	--	--
I10	--	--	--	--
I11	.05	1.24	<.02	<.02
I12	.27	2.09	.10	.04
I13	.02	--	--	--
I14	<.02	--	--	<.02
I15	.02	--	--	--
I16	--	--	--	--
I17	.03	--	--	.14
I18	--	--	--	--
I19	.31	--	--	--
I20	.04	--	--	<.02
I21	--	--	--	--
I22	--	--	--	--
I23	.06	--	--	--
I24	.14	--	--	.05
I25	.29	--	--	--
I26	.09	--	--	--
I27	.03	--	--	--
I28	<.02	--	--	.02
I29	.22	--	--	--
I30	.16	--	--	.04
I31	.10	--	--	--
I32	--	--	--	--
I33	.03	--	--	--
I34	.11	--	--	--
I35	.10	--	--	.03

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
G, 6- to 10-foot depth.
J, 4- to 6-foot depth (extra sample collected at alternate location to accommodate cropping plans and fall 1993 sampling).

Table 14. Results of gas chromatography/mass spectrometry analysis of irrigated soil samples for atrazine and two atrazine metabolites, March 1993
[<, less than]

Sampling-site no. (fig. 5)	Sampling depth[1]	Concentrations (micrograms per kilogram)		
			Atrazine metabolites	
		Atrazine	Deethyl-atrazine	Deisopropyl-atrazine
I1	A	2.00	<0.50	<0.50
	E	2.92	<.50	<.50
	G	<.50	<.50	<.50
I4	A	<.50	<.50	<.50
I5	A	<.50	<.50	<.50
I11	E	2.03	<.50	<.50
	J	<.50	<.50	<.50
I12	A	<.50	<.50	<.50
	E	1.99	<.50	<.50
I28	A	<.50	<.50	<.50
	J	<.50	<.50	<.50

[1]Sample: A, 4- to 6-foot depth.
E, 0- to 4-foot depth.
G, 6- to 10-foot depth.
J, 4- to 6-foot depth (extra sample collected at alternate location to accommodate cropping plans and fall 1993 sampling).

detectable concentrations of triazine herbicides, and 1 (4.8 percent) had no detectable concentration. The median concentration of the "A" samples was 0.04 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 0.75 microgram per kilogram. The "J" sample for site D10 had no detectable concentration.

Concentrations of atrazine and two atrazine metabolites measured using the GC/MS method for 10 of the October–November 1993 dryland samples are presented in table 16. The atrazine concentrations paralleled those determined using the immunoassay method. None of the samples analyzed using GC/MS had detectable concentrations of deethylatrazine or deisopropylatrazine.

Table 15. Results of immunoassay analysis of dryland soil samples for total triazine herbicides, October–November 1993
[--, not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)	
	Sample A[1]	Sample J[1]
D1	0.04	--
D2	.12	--
D3	--	--
D4	.04	--
D5	--	--
D6	--	--
D7	.03	--
D8	.03	--
D9	--	--
D10	--	<0.02
D11	<.02	--
D12	.04	--
D13	--	--
D14	.35	--
D15	--	--
D16	.05	--
D17	.04	--
D18	.22	--
D19	.02	--
D20	--	--
D21	--	--
D22	.03	--
D23	--	--
D24	.75	--
D25	--	--
D26	.03	--
D27	.04	--
D28	.37	--
D29	.03	--
D30	.02	--
D31	--	--
D32	.06	--
D33	.03	--

[1]Sample: A, 4- to 6-foot depth.
J, 4- to 6-foot depth (sample collected at alternate location to accommodate 1993 cropping plans).

Irrigated Sites

Total triazine concentrations measured using the immunoassay method for the October–November

Table 16. Results of gas chromatography/mass spectrometry analysis of dryland soil samples from 4- to 6-foot depth for atrazine and two atrazine metabolites, October–November 1993
[<, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)		
		Atrazine metabolites	
	Atrazine	Deethyl-atrazine	Deisopropyl-atrazine
D2	<0.50	<0.50	<0.50
D4	<.50	<.50	<.50
D12	<.50	<.50	<.50
D14	<.50	<.50	<.50
D18	<.50	<.50	<.50
D19	<.50	<.50	<.50
D24	.63	<.50	<.50
D26	<.50	<.50	<.50
D28	<.50	<.50	<.50
D30	<.50	<.50	<.50

1993 irrigated samples are presented in table 17. Of the seven "A" samples analyzed, five (71.4 percent) had detectable concentrations of triazine herbicides, and two (28.6 percent) had no detectable concentrations. The median concentration of the "A" samples was 0.08 microgram per kilogram. The range of concentrations from the "A" samples was less than 0.02 to 0.25 microgram per kilogram. Of the 11 "J" samples analyzed, 8 (72.7 percent) had detectable concentrations of triazine herbicides, and 3 (27.3 percent) had no detectable concentrations. The median concentration of the "J" samples was 0.03 microgram per kilogram. The range of concentrations from the "J" samples was less than 0.02 to 0.58 microgram per kilogram.

Concentrations of atrazine and two atrazine metabolites measured using the GC/MS method for 10 of the October–November 1993 irrigated samples are presented in table 18. The atrazine concentrations paralleled those determined by the immunoassay method. In this case, all 10 samples had atrazine concentrations less than the GC/MS detection level of 0.5 microgram per kilogram. None of the samples analyzed using GC/MS had detectable concentrations of deethylatrazine or deisopropylatrazine.

Table 17. Results of immunoassay analysis of irrigated soil samples for total triazine herbicides, October–November 1993
[--not determined; <, less than]

Sampling-site no. (fig. 5)	Concentrations (micrograms per kilogram)	
	Sample A[1]	Sample J[1]
I1	--	--
I2	--	0.12
I3	--	--
I4	--	--
I5	--	--
I6	0.04	--
I7	--	.19
I8	--	--
I9	.25	--
I10	--	--
I11	--	.05
I12	--	.02
I13	.21	--
I14	--	<.02
I15	--	--
I16	--	--
I17	--	.04
I18	--	--
I19	--	--
I20	--	.58
I21	--	--
I22	--	--
I23	--	--
I24	--	.03
I25	.23	--
I26	.08	--
I27	<.02	--
I28	--	<.02
I29	--	--
I30	--	<.02
I31	--	--
I32	--	--
I33	<.02	--
I34	--	--
I35	--	.02

[1]Sample: A, 4- to 6-foot depth.
J, 4- to 6-foot depth (sample collected at alternate location to accommodate 1993 cropping plans).

Table 18. Results of gas chromatography/mass spectrometry analysis of irrigated soil samples for atrazine and two atrazine metabolites, October–November 1993
[<, less than]

Sampling-site no. (fig. 5)	Sampling depth[1]	Concentrations (micrograms per kilogram)		
			Atrazine metabolites	
		Atrazine	Deethy-latrazine	Deisopropyl-atrazine
I2	J	<0.50	<0.50	<0.50
I7	J	<.50	<.50	<.50
I9	A	<.50	<.50	<.50
I13	A	<.50	<.50	<.50
I17	A	<.50	<.50	<.50
I20	J	<.50	<.50	<.50
I25	A	<.50	<.50	<.50
I27	A	<.50	<.50	<.50
I28	J	<.50	<.50	<.50
I35	A	<.50	<.50	<.50

[1]Sample: A, 4- to 6-foot depth.
J, 4- to 6-foot depth (sample collected at alternate location to accommodate 1993 cropping plans).

ASSESSMENT OF ANALYTICAL VARIANCE

Analytical variance was evaluated by performing a duplicate analysis of samples collected from 10 randomly selected sites during the March 1992 sampling period. Duplicate samples were collected at the 4- to 6-foot depth and analyzed for the dryland sites D7, D8, D14, D19, and D24, and the irrigated sites I7, I8, I14, I25, and I28. To enable statistical analysis, all samples with measured triazine herbicide concentrations less than the immunoassay detection level of 0.02 microgram per kilogram were given a concentration of 0.01 microgram per kilogram. A comparison of the original "A" samples with the duplicate "B" samples (refer to tables 3 and 5) revealed that the triazine concentrations of the duplicate samples deviated from the concentrations of the originals by an average of $\pm$0.05 microgram per kilogram (or $\pm$10 percent at the 0.5 microgram per kilogram level), which indicates that the analytical variation is acceptable for the trace analysis of herbicides in soil (Mills and Thurman, 1992). The standard deviation, estimated from the differences between the concentrations of the original and the duplicate samples (Taylor, 1987), was 0.05 microgram per kilogram.

SUMMARY

The potential transport of triazine herbicides into the Equus Beds aquifer was assessed by analyzing soil samples collected from the unsaturated zone at 27 dryland and 30 irrigated sites in western Harvey County, Kansas. All sites were sampled at a depth of 4 to 6 feet (that is, immediately below the root zone) during March 1992, October–November 1992, March 1993, and October–November 1993. Also, during the October–November 1992 and March 1993 sampling periods, five sites were sampled at depths of 0 to 4 and 6 to 10 feet. All samples were analyzed for total triazine concentrations using a 20-gram, immunoassay technique with a 0.02-microgram per kilogram detection level. Additionally, about 20 samples from each sampling period were analyzed for atrazine and two atrazine metabolites (deethylatrazine and deisopropylatrazine) using a 20-gram, gas chromatography/mass spectrometry procedure with a 0.50-microgram per kilogram detection level.

Triazine concentrations at the 4- to 6-foot depth, with one exception, were less than 1.0 microgram per kilogram, with the majority of the concentrations less than 0.10 microgram per kilogram. Triazine concentrations at the 0- to 4-foot depth ranged from 0.51 to 12.2 micrograms per kilogram. Triazine concentrations at the 6- to 10-foot depth ranged from less than 0.02 to 0.33 microgram per kilogram. The atrazine concentrations measured using the gas chromatography/mass spectrometry method paralleled the concentrations determined using the immunoassay method. The atrazine metabolite deethylatrazine was detected in three samples with concentrations of 0.63, 1.44, and 1.48 micrograms per kilogram. The atrazine metabolite deisopropylatrazine was not detected in any of the samples analyzed. Because the 1992 and 1993 growing seasons included periods of above-normal rainfall, the concentrations of triazine herbicides and metabolites measured during this study may not be indicative of average conditions.

REFERENCES

Aga, D.S., and Thurman, E.M., 1993, Coupling solid-phase extraction and enzyme-linked immunosorbent assay for ultratrace determination of herbicides in pristine water: Analytical Chemistry, v. 65, no. 20, p. 2894–2898.

_____in press, Application of solid-phase extraction (SPE) for ultratrace analysis of herbicides in water and soil by enzyme-linked immunosorbent assay (ELISA), *in* Agrochemical Immunoanalysis-93: Ann Arbor, Michigan, Lewis Publishers.

Aller, Linda, Bennett, Truman, Lehr, J.H., and Petty, R.J., 1985, DRASTIC—A standardized system for evaluating ground water pollution potential using hydrogeologic settings: U.S. Environmental Protection Agency, EPA/600/2-85/018, 163 p.

Carsel, R.F., Smith, C.N., Mulkey, L.A., Dean, J.D., and Jowise, P., 1984, Users manual for the Pesticide Root Zone Model (PRZM), release 1: Athens, Georgia, U.S. Environmental Protection Agency, Environmental Research Laboratory, EPA-600/3-84-109, 216 p.

Equus Beds Groundwater Management District No. 2, 1990, Management program, July 1, 1990: Halstead, Kansas, 91 p.

Heath, R.C., 1987, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Helgesen, J.O., and Rutledge, A.T., 1989, Relations between land use and water quality in the High Plains aquifer of south-central Kansas, *in* Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88–4220, p. 437–443.

Helgesen, J.O., Stullken, L.E., and Rutledge, A.T., 1994, Assessment of nonpoint-source contamination of the High Plains aquifer in south-central Kansas, 1987: U.S. Geological Survey Water-Supply Paper 2381–C, 51 p.

Jarvis, N.J., Bergstrom, L., and Dik, P.E., 1991, Modelling water and solute transport in macroporous soil—II. Chloride breakthrough under non-steady flow: Journal of Soil Science, v. 42, p. 71–81.

Kansas Geological Survey, 1964, Geological map of Kansas: Kansas Geological Survey Map M-1, 1 sheet, scale 1:500,000.

Kansas State Board of Agriculture, 1993, 1993 Kansas farm facts: Topeka, Kansas State Board of Agriculture, 116 p.

Mills, M.S., and Thurman, E.M., 1992, Mixed-mode isolation of triazine metabolites from soil and aquifer sediments using automated solid-phase extraction: Analytical Chemistry, v. 64, no. 17, p. 1985–1990.

National Oceanic and Atmospheric Administration, 1993a, Climatological data—Kansas, June 1993: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, v. 107, no. 6, unnumbered pages.

_____1993b, Climatological data—Kansas, May 1993: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, v. 107, no. 5, unnumbered pages.

_____1993c, Climatological data—Kansas, July 1993: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, v. 107, no. 7, unnumbered pages.

Perry, C.A., 1990, Source, extent, and degradation of herbicides in a shallow aquifer near Hesston, Kansas: U.S. Geological Survey Water-Resources Investigations Report 90–4019, 24 p.

_____1991, Observed and simulated distribution of selected herbicides in silty loam, sandy loam, and clay soil profiles near Topeka, Kansas, 1986–88: U.S. Geological Survey Water-Resources Investigations Report 91–4017, 61 p.

Rutledge, A.T., and Helgesen, J.O., 1990, Characterization of ground-water flow and chemical transport beneath two irrigated fields in south-central Kansas, 1988: U.S. Geological Survey Water-Resources Investigations Report 90–4065, 37 p.

Schwab, P.A., Sarong-Sonon, Leticia, and Kluitenberg, G.J., 1992, Leaching of atrazine, alachlor, and nitrate through soil and into groundwater: Manhattan, Kansas Water Resources Research Institute, Contribution 293, Report G2020-03, 65 p.

Schwab, P.A., and Sonon, L.S., 1991, Leaching of atrazine and nitrate through soil and into groundwater: Manhattan, Kansas Water Resources Research Institute, Contribution 286, Report G1563-03, 43 p.

Sophocleous, Marios, Townsend, M.A., Orountiotis, Costas, Evenson, R.A., Whittemore, D.O., Watts, C.E., and Marks, E.T., 1990, Movement and aquifer contamination potential of atrazine and inorganic chemicals in central Kansas croplands: Kansas Geological Survey Ground Water Series 12, 64 p.

Spinazola, J.M., Gillespie, J.B., and Hart, R.J., 1985, Ground-water flow and solute transport in the Equus Beds area, south-central Kansas, 1940–79: U.S. Geological Survey Water-Resources Investigations Report 85–4336, 68 p.

Stullken, L.E., Stamer, J.K., and Carr, J.E., 1987, Reconnaissance of water quality in the High Plains aquifer beneath agricultural lands, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 87–4003, 25 p.

Taylor, J.K., 1987, Quality assurance of chemical measurements: Chelsea, Michigan, Lewis Publishers, Inc., 328 p.

Thurman, E.M., Meyer, Michael, Pomes, Michael, Perry, C.A., and Schwab, A.P., 1990, Enzyme-linked immunosorbent assay compared with gas chromatography/mass spectrometry for the determination of triazine herbicides in water: Analytical Chemistry, v. 62, no. 18, p. 2043–2048.

U.S. Department of Agriculture, Soil Conservation Service, 1974, Soil survey of Harvey County, Kansas: Washington, D.C., Soil Conservation Service, 55 p.

White, R.E., 1985, The influence of macropores on the transport of dissolved and suspended matter through soil: Advances in Soil Science, v. 3, p. 95–119.

SUPPLEMENTAL INFORMATION

Table 19. Monthly rainfall totals for western Harvey County, Kansas, March 1992 through November 1993

[Rainfall data, in inches, from files of the U.S. Geological Survey, Lawrence, Kans., --, not determined]

Gage-site no.	Location (township, range, section, qualifier)	Year	Monthly rainfall totals											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P-1	22S 03W 30 NE	1992	--	--	2.42	0.63	3.25	7.40	4.40	3.30	0	2.50	3.40	0
		1993	0	2.05	2.30	1.45	11.40	4.05	8.50	7.80	2.20	.35	0	--
P-2	23S 03W 20 SW	1992	--	--	3.26	3.20	1.26	12.25	4.02	3.03	1.20	2.63	5.73	1.14
		1993	.39	1.42	2.59	1.38	9.70	4.39	11.05	6.28	--	--	--	--
P-3	24S 03W 17 NE	1992	--	--	3.31	.73	2.60	12.19	4.70	3.10	--	--	--	--
		1993	--	--	--	--	--	--	--	--	--	--	--	--
P-4	24S 03W 28 SW	1992	--	--	4.38	1.12	2.73	9.87	4.20	2.77	1.35	1.99	3.87	1.28
		1993	.43	2.31	2.97	1.51	10.79	3.55	13.64	3.30	--	--	--	--
P-5	24S 03W 22 NW	1992	--	--	3.90	1.20	2.40	9.40	4.10	3.10	1.30	2.10	3.40	1.90
		1993	.20	2.10	3.00	2.00	10.80	2.50	12.20	3.10	2.60	.70	1.10	--
P-6	22S 03W 22 NE	1992	--	--	3.29	.46	2.62	7.42	3.95	4.31	1.35	2.72	5.39	--
		1993	--	3.12	--	--	--	--	--	--	--	--	--	--
P-7	24S 03W 01 NW	1992	--	--	3.66	1.85	2.31	9.65	4.22	2.05	1.54	2.27	5.02	1.38
		1993	.66	2.18	3.02	.76	13.19	1.90	11.15	3.67	2.96	.55	1.18	--
P-8	23S 02W 19 NE	1992	--	--	3.30	1.69	2.50	10.05	4.65	3.15	1.55	2.60	4.65	1.30
		1993	1.10	2.48	--	--	--	--	--	--	--	--	--	--
P-9	24S 02W 08 NE	1992	--	--	4.45	1.21	2.56	10.04	3.82	2.72	1.48	1.91	4.31	2.32
		1993	.18	3.05	--	--	--	--	--	--	--	--	--	--
P-10	24S 03W 24 SW	1992	--	--	4.75	1.24	4.12	7.97	5.11	2.48	1.68	1.90	4.10	1.78
		1993	.92	1.91	1.80	2.92	8.45	2.77	11.68	2.89	2.15	1.21	1.08	--
P-11	24S 02W 29 SE	1992	--	--	3.97	1.06	3.39	9.94	3.06	2.23	1.90	.80	3.48	1.95
		1993	0	2.20	3.01	1.85	10.74	2.29	11.28	1.75	2.98	.55	.68	--
P-12	24S 02W 22 NW	1992	--	--	3.83	1.13	3.57	9.10	4.09	3.41	1.56	2.27	4.22	1.39
		1993	.20	1.87	2.72	2.09	10.08	2.78	10.06	2.23	1.95	1.24	1.07	--
P-13	23S 01W 19 NC	1992	--	--	4.24	2.11	3.81	7.93	5.04	0.92	1.86	2.14	4.68	0
		1993	0	3.65	2.10	1.75	15.70	3.80	13.58	3.02	2.52	1.00	1.00	--
P-14	23S 02W 25 SE	1992	--	--	4.43	1.78	3.12	8.02	4.78	2.14	1.63	2.68	4.54	1.45
		1993	.21	2.42	2.78	2.24	11.32	4.42	13.21	2.38	2.20	.84	1.09	--
P-15	23S 01W 31 NE	1992	--	--	4.27	1.83	3.26	8.76	4.72	2.37	1.52	2.69	4.33	1.35
		1993	.03	2.41	1.98	1.51	11.96	3.75	12.74	1.93	2.04	.87	1.11	--

Table 19. Monthly rainfall totals for western Harvey County, Kansas, March 1992 through November 1993—Continued

Gage-site no.	Location (township, range, section, qualifier)	Year	Monthly rainfall totals											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P-16	24S 01W 08 SW	1992	--	--	3.73	1.27	3.59	7.63	4.87	3.19	1.59	2.45	4.66	1.72
		1993	0.84	2.24	2.02	2.57	10.13	4.47	10.21	1.94	2.25	.63	1.09	--
P-17	24S 03W 05 SW	1992	--	--	2.75	1.24	2.44	10.88	4.41	4.01	1.35	2.01	4.18	1.50
		1993	.55	1.74	2.27	1.86	9.82	3.75	12.23	6.12	2.47	.85	1.31	--
P-18	24S 02W 01 NE	1992	--	--	4.61	1.92	3.02	9.28	4.40	2.57	1.40	2.36	4.52	1.91
		1993	.79	1.12	1.96	2.05	10.73	3.57	8.51	1.97	2.06	.76	.85	--
P-19	24S 02W 17 SW	1992	--	--	4.04	1.37	3.28	9.09	3.40	2.97	1.55	2.21	3.86	1.39
		1993	.80	2.09	--	--	--	--	--	--	--	--	--	--
P-20	23S 02W 15 NC	1992	--	--	3.36	2.24	1.87	10.40	5.52	3.29	1.67	3.26	4.34	1.61
		1993	.14	2.22	--	--	--	--	--	--	--	--	--	--
P-21	23S 02W 32 NW	1992	--	--	3.66	2.27	2.64	10.36	3.58	2.87	1.60	2.27	4.38	1.46
		1993	.48	2.31	--	--	--	--	--	--	--	--	--	--
P-22	23S 03W 03 SE	1992	--	--	4.43	1.25	2.90	10.74	5.33	3.39	1.21	2.73	5.66	.17
		1993	0	2.45	--	--	--	--	--	--	--	--	--	--
P-23	24S 02W 25 SW	1992	--	--	3.39	1.11	3.71	8.04	4.57	2.88	1.45	2.17	4.65	1.42
		1993	.15	1.87	--	--	--	--	--	--	--	--	--	--
P-24	23S 01W 21 NW	1992	--	--	3.96	2.21	3.57	8.10	4.43	3.00	1.60	2.87	5.11	1.73
		1993	.80	2.53	--	--	--	--	--	--	--	--	--	--
P-25	23S 03W 26 NE	1992	--	--	3.11	1.92	2.36	7.19	3.78	2.42	1.48	2.52	4.57	1.11
		1993	1.29	2.20	2.84	1.91	8.90	3.49	13.69	4.88	2.36	.54	1.11	--
P-26	24S 01W 10 NW	1992	--	--	3.33	1.19	3.39	9.17	4.94	3.29	1.60	2.89	4.21	2.00
		1993	.15	1.45	--	--	--	--	--	--	--	--	--	--
P-27	24S 02W 21 NW	1992	--	--	4.26	1.10	3.21	9.24	4.24	2.78	1.57	2.05	4.34	1.45
		1993	.12	2.41	2.93	2.31	10.13	2.81	11.93	2.25	1.60	1.08	.99	--
P-28	23S 03W 36 NW	1992	--	--	3.56	2.07	2.79	9.74	4.14	2.57	1.59	2.56	4.72	2.13
		1993	.50	1.60	3.23	2.14	12.89	3.30	14.15	4.15	3.28	.62	1.06	--
P-29	24S 02W 31 SE	1992	--	--	6.50	.80	3.54	7.35	3.20	1.15	1.35	1.45	3.40	--
		1993	.60	--	3.55	1.75	9.68	2.22	7.82	1.55	3.00	.85	1.40	--
P-30	24S 03W 24 NE	1992	--	--	4.45	1.39	3.14	8.31	4.39	3.21	1.63	2.58	3.27	1.40
		1993	.14	2.04	2.58	2.11	11.09	2.58	13.71	3.09	--	--	--	--