LAND USE IMPACTS ON WATER QUALITY IN SMALL KARST AGRICULTURAL WATERSHEDS

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Introduction

Identification of the impacts of agriculturally related activities on surface and ground water quality in limestone and karst terranes is important for the management of this natural resource. Kentucky has highly vulnerable water resources in aquifers located in limestone that underlie approximately 50 percent of the state. Karst conditions occur in about 25 percent of the state, and much of the state's most productive agricultural soils are found in these same regions.

Eight years ago, there was very little information about agricultural effects on water resources in Kentucky. The extent and level of contamination of water resources by pesticides and nitrate-N had not been documented in areas of important agricultural production. The Kentucky Agricultural Chemical Use Impacts Assessment Program (SB-271 Project) studied the water quality in several representative and agriculturally significant areas. This program was conducted from October, 1990 to September, 1993. An analysis of the types of agricultural land uses (row crop and hay/pasture) and their areal percentages was conducted to determine the correlation to the quality of water discharging from eight small agricultural watersheds using the data base developed during the study. These eight watersheds were located in limestone geological settings. This report presents a comparison of these eight Kentucky watersheds to other water quality studies of karst/limestone watersheds that were found in the literature.

Background

Following the passage of the Federal Water Pollution Control Act Amendments of 1972, several studies were published that began to identify the significance of different land use impact on the watershed water quality. Several of these studies (2,3,4,5) found significant positive correlations between nitrogen concentrations in the discharge water and the area of a watershed in agriculture or row crop. Several papers established the influence of the dominant geology (sedimentary, igneous, metamorphic) on the nitrogen concentration in the water exported from basins (4,5,6). Limestone geology was identified as a significant sedimentary geology (5,6). Of all the geologies identified in the 1976 US National Eutrophication Survey of 930 watersheds, limestone hydrogeologic settings were found to have the highest inorganic nitrogen concentrations for agriculturally dominated basins (5). A 1974 reconnaissance study of seven Kentucky agricultural watersheds also supported the latter determination (6). Soil texture was also a significant influencing factor on the nitrogen concentration (4). These early studies did not present data concerning agricultural pesticides.

Since the mid-80's, studies have extended the understanding of the influence of land use on the inorganic nitrogen and pesticide concentrations in limestone hydrogeologic settings. Positive correlations between the percentage of agricultural land and nitrate-N concentrations in springs, draining basins in karst limestone terranes, were found in Pennsylvania (7), West Virginia (8), and Kentucky (9). In addition, concentrations of the triazine herbicide group have been reported in the literature. A positive association of the triazine concentration of basin drainage water with the intensity of agricultural land-use have been presented in the National Water Quality Assessment Program which started in 1991 (10) and in limestone hydrogeologic settings in Kentucky (9).

The literature was searched for additional water quality data sets in karst/limestone hydrogeologic settings to be included with the nitrate-N and triazines concentration data sets of eight Kentucky watersheds. The objective was to determine whether agricultural practices for crop production in these Kentucky watersheds impacted water quality in a different manner when compared to other watersheds in a karst/limestone setting.

Methodology

Kentucky Agricultural Chemical Use Impacts Assessment Program

The details of this study can be found in a series of reports published by Departments of Agronomy and Biosystems and Agricultural Engineering in the College of Agriculture (1,11) and the Kentucky Geological Survey (12, 13, 14). Eleven areas were selected for the assessment. Eight of these sites were located in limestone hydrogeologic settings and these data are being used for this report. The limestone watersheds are referred to by the county in which they are located: Bourbon, Fleming, Jessamine, Logan, Russell, Shelby, Todd and Woodford. These eight sites represent the five out of the seven agriculturally important physiographic regions of Kentucky: Inner Bluegrass, Outer Bluegrass, Eastern Pennyroyal, Western Pennyroyal, and Western Coalfields. The study watersheds were selected to reflect major agricultural production systems in important soil and hydrogeologic settings of Kentucky. These sites are predominantly agriculture with some residential areas in the large watersheds. One or two individuals owned land at six of eight assessment watersheds, which allowed for ease in determining agricultural production and chemical use. Land use information for the other two watersheds was determined through aerial photography with confirmation by ground truthing and/or from the USDA Farm Services Administration. The sites can also be characterized as being large watershed studies or farm-sized watershed studies. The Logan and Jessamine county sites are large watershed studies (approximately 4,082 and 1,903 ha.., respectively) that have many land owners. The other six are smaller farm-sized watersheds (32 to 972 ha..). All the watersheds are dominated by well to moderately well drained silt loam soils. Watershed sampling points included springs and streams (see Table 1) and were sampled at least monthly, if water flow was present. Additional water testing during the planting season was performed, but these were not included in the analyzed data sets.

On an annual basis, the predominant source of water that discharges from the assessment watersheds is ground water. Stream discharge points represent an accumulation of water from ground water sources (springs and seeps) throughout a watershed. Water quality at these watershed discharges is an integration of all the land-use impacts in the watershed. Tables 2 and 3 summarize the average annual land-use and water quality parameters over a three-year period for the Kentucky assessment sites. Row crops would include tobacco, corn, soybeans and double cropped wheat. The predominant row crop production system in these watersheds was a two-year rotation of corn-wheat-soybeans with some wheat-soybeans double cropped. This rotation is nearly continuous in high row crop percentage watersheds. In low row crop percentage watersheds, forages and tobacco are introduced into a crop rotation. At least one pasture or confinement animal production system for beef, dairy or swine is found in each watersheds with manure nutrients applied to the land.

Published Water Quality Studies of Watersheds in Carbonate Terranes

A search of the literature found fourteen water quality study areas which reported nitrate-N and/or triazine concentrations of water discharging from agricultural watersheds in carbonate terrains. These studies were in Arkansas (2 studies), Illinois, Indiana, Iowa, Kentucky, Pennsylvania (3 studies), Tennessee, Virginia, and West Virginia (2 studies). Not all these sites were included in this report. Some reports covered a few synoptic water quality samplings or quarterly water quality samplings and were not used to compare to the Kentucky assessment watersheds. Studies included in the comparison are those with monthly data that spanned at least one year with reported data in 10 or more months each year. Further, the reports needed to include the percentages of the watershed in row crop, pasture/hay, and/or agriculture. The dominant soils of these watersheds were silt loam. The chosen studies were Big Spring in Iowa (15), three springs at Mammoth Cave in Kentucky (16,17), two springs in Cumberland Valley (18) and four springs in Nittany Valley (19) in Pennsylvania, and four springs in the Greenbrier Hydrologic Unit in West Virginia (20,21). Two investigations did not include the land use: Monroe County Illinois (2 springs) (22) and Lost River in Indiana (23,24). For these basins, sampling points were able to be identified on soil and topographic maps. USGS Topographic quadrangles (7.5 minute) were used to estimate the areas of the watersheds, assuming the surface watershed matches the groundwater basin, and aerial photography from soil surveys were used to estimate land uses.

Results

Tables 2 and 3 present the available information for medians, arithmetic means for nitrate-N and triazine concentrations and also the geometric means for triazine concentration, sample size, and average percent of the watershed in row crop and pasture/hay for the Kentucky watersheds and the other watersheds noted above. In addition, the information available for the frequency distribution of the concentrations is presented. Standard deviations were not found or able to be calculated for all the published watersheds. The distribution of concentration of nitrate-N and triazines from the eight Kentucky SB-271 limestone geology watersheds were statistically assessed for departures from a normal distribution using the Moment Ratio Analysis (25). Nitrate-N observations were normally distributed. Triazine concentration distribution was found to be a log-normal distribution.

Nitrate-N. Figures 1 and 2 present the mean nitrate-N concentrations of the water from 21 watersheds in limestone geologies versus the percent of the watershed in row crop agriculture and percent agriculture (row crop + pasture/hay), respectively. The nitrate-N concentration of Big Spring in Iowa stands well above the rest of the watersheds and was not used in the following statistical analysis. A significant linear regression for nitrate-N versus row crop was found for the watersheds (α = .001). There was no significant difference (α = .025) between Kentucky 271 watersheds and the published watersheds when watersheds, with more than 80 percent of the land in forest, were removed from the analysis. The linear regression line (r^2 = 0.66) for these watersheds, as well as the lines representing +/- one standard error of the regression, are shown in Figure 1. The four forested watersheds lie below the lower standard error line as indicated in Figure 1. When the land use is designated as percent in agriculture, the 24 watersheds (excluding Big Spring IA) yield a significant linear trend (α = .001) with the nitrate-N concentration. Significant linear relationships between watershed mean nitrate-N and percent of the watershed in agriculture were also found in West Virginia (8) and Pennsylvania (7). The eight Kentucky watersheds are clustered above 80 percent agriculture. A t-test was ran on the nitrate-N means of published watersheds above 79 percent in agriculture and the Kentucky SB-271 watersheds. The nitrate-N mean of the Kentucky 271 watersheds was significantly lower (α = .05).

Triazines. Figures 3 and 4 present the geometric mean triazine concentrations of the water from 13 watersheds in limestone geologies versus the percent of the watershed in row crop agriculture and percent agriculture, respectively. A significant linear regression for triazine geometric mean versus row crop percentage was found for these watersheds (α = .001). The intercept was zero since triazines would not be used on non-agricultural land. There was no significant difference (α = .05) between Kentucky 271 watersheds and the published watersheds. The linear regression line (r^2 = 0.61) for these watersheds, as well as the lines representing +/- one standard error of the regression, are shown in Figure 3. When the land use is designated as percent in agriculture, the 13 watersheds do not yield a significant linear trend (α = .05) with the triazine concentration. A t-test was ran on the triazine geometric means of published watersheds and the Kentucky 271 watersheds and no significant difference was found (α = .05).

Discussion

The mean nitrate-N and geometric mean triazine concentrations in water discharging from watersheds in limestone geologies in Kentucky 271 Assessment Program are not significantly different than other agricultural limestone watersheds when land use is identified as percent of the watershed in row crop agriculture. This positive relationship occurred even when water quality data was taken in different years, different geographic locations, and possibly different weather conditions; primarily intensity, yearly total and timing of precipitation relative to crop production. The one difference was Big Spring IA where the nitrate-N concentration is 4 ppm higher than the regression line. This watershed was identified as not crediting legume and organic N fertilizers when determining the recommended commercial N fertilizer level (26). Nitrogen fertilizer usage in the Kentucky 271 Assessment watersheds were at recommended levels, e.g. ~170-200 kg/ha. for corn (11). When the watershed land use is identified as percent agriculture, the relationship does not exist and, for similar agriculture land percentages, Kentucky 271 Assessment watersheds were significantly lower. It is apparent that studies agricultural chemical concentrations in water discharging from watersheds should identify row crop land uses within the study area. A stronger relationship between triazine concentrations and the percent of a watershed in corn production would also lead to a stronger relationship than was found with row crop percent. Triazines are used predominantly on corn production fields for weed control.

Variability of the nitrate-N concentration can be attributed to denitrification as a result of perched water, saturated soils at seeps and riparian zones, and within the stream. These factors are nor easily determined or documented for watersheds. The appearance of iron-manganese concretions in the predominant silt loam soils of the Woodford County KY watershed was found during an intensive soil survey (27) and in a reconnaissance of the Bourbon County KY site at some of the monitored springs (28). Iron-manganese concretions form in perched water zones where there is alternating reducing and oxidizing environments. Perched water zones are found at both sites occurring above restrictive clayey soil horizons or above argillacious layers in the limestone bedrock or at the soil-rock interface (13). Seeps and low flowing springs are potential sites of denitrification in the Bourbon County KY (28). Denitrification in in-stream water (29) and the riparian zone (30) are significant factors that affect the mean nitrate-N concentrations of water discharging from a watershed and are not identified in the studies cited in this paper.

The variability of the concentration of triazines in the water discharging from a watershed is strongly affected by the timing of rainfall events after the herbicide application to corn fields, the soil moisture content and soil temperature after the time of herbicide application, and the amount active ingredient applied per hectare (31). These factors are also difficult to identify and also were not identified in studies cited in this paper.

Acknowledgments

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FIGURE 1. PERCENT OF WATERSHED IN ROW CROP PRODUCTION VERSUS MEAN NITRATE-N CONCENTRATION IN DISCHARGE WATER

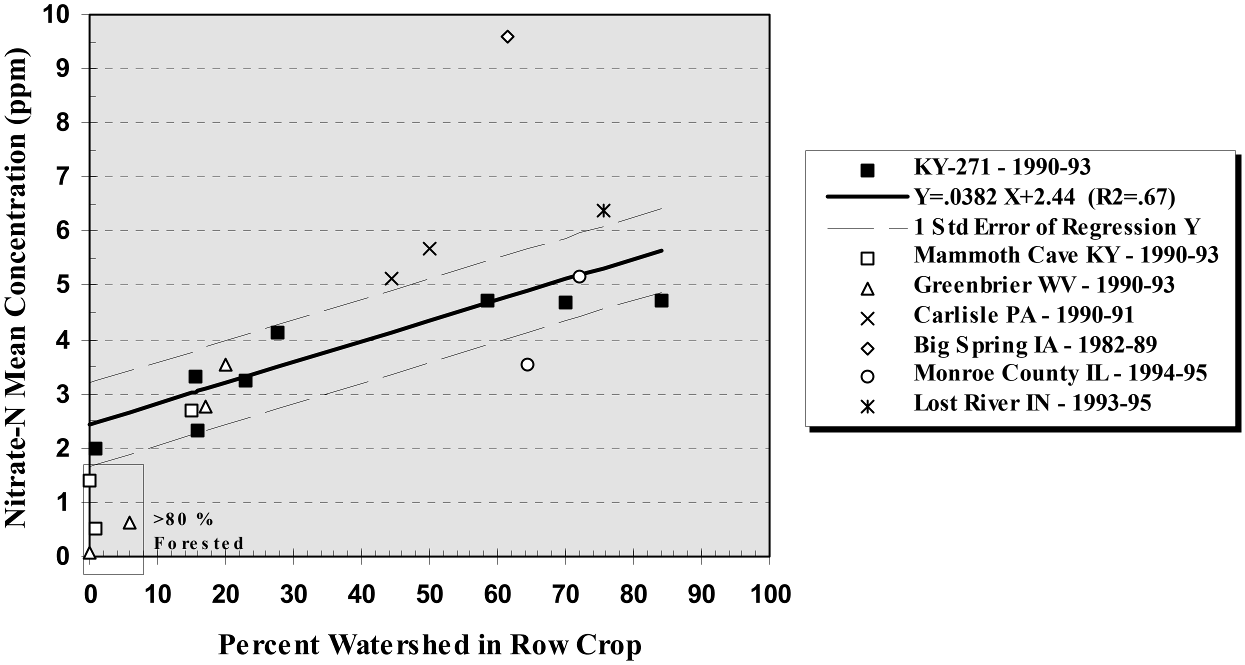

FIGURE 2. PERCENT OF WATERSHED IN AGRICULTURAL PRODUCTION (ROW CROP + HAY/PASTURE) VERSUS MEAN NITRATE-N CONCENTRATION IN DISCHARGE WATER

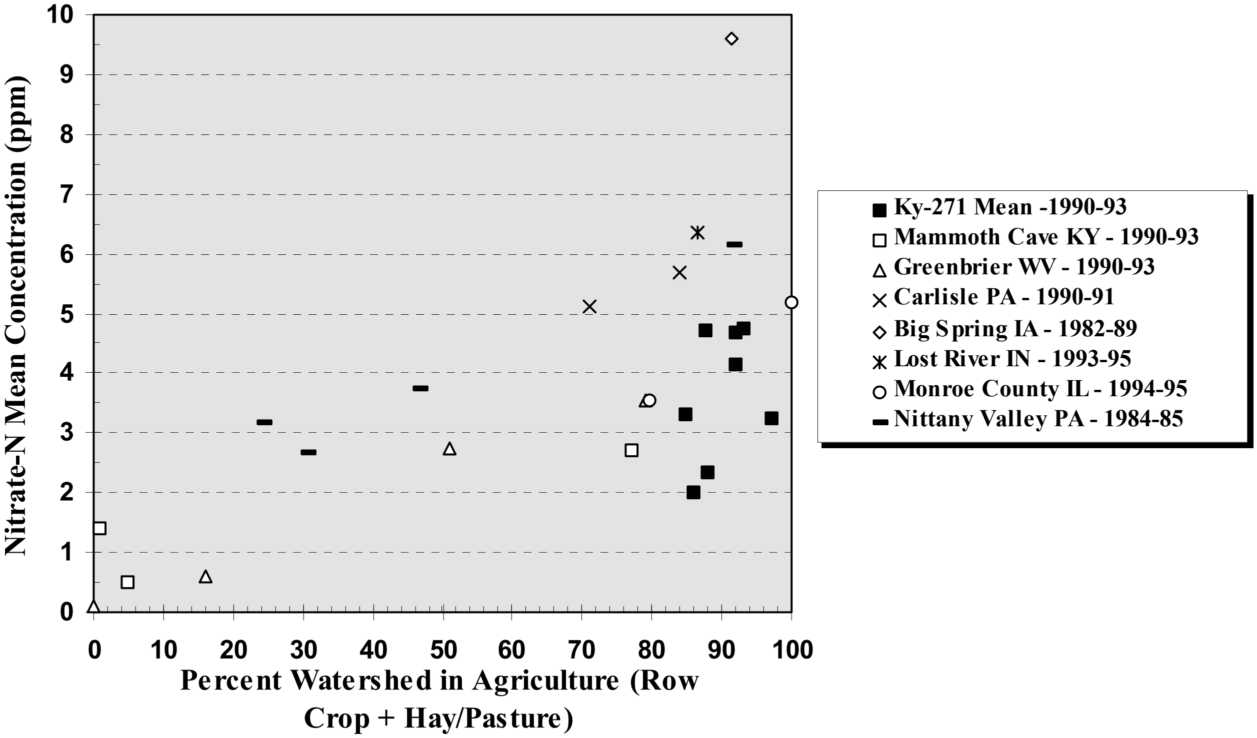

FIGURE 3. PERCENT OF WATERSHED IN ROW CROP PRODUCTION VERSUS GEOMENTRIC MEAN TRIAZINE CONCENTRATION IN DISCHARGE WATER.

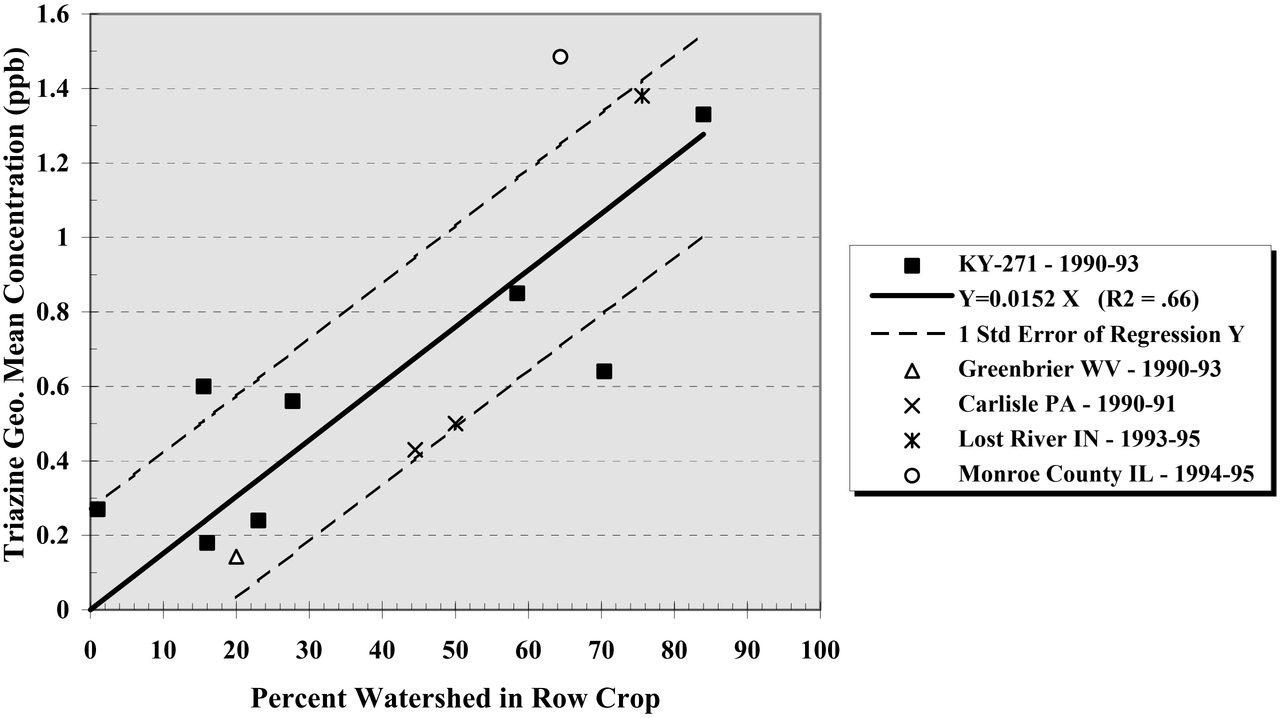

FIGURE 4. PERCENT OF WATERSHED IN AGRICULTURAL PRODUCTION (ROW CROP + HAY/PASTURE) VERSUS GEOMETRIC MEAN TRIAZINE CONCENTRATION IN DISCHARGE WATER

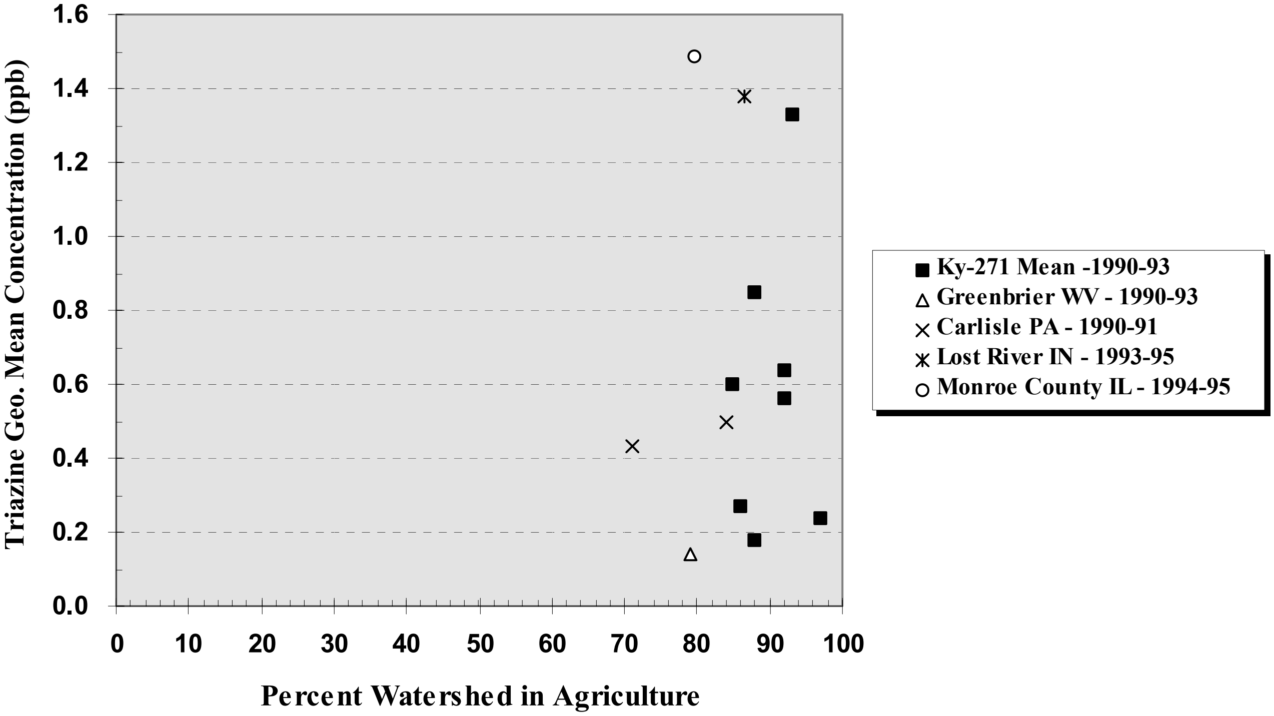

Table 1. Area and Water Source of Kentucky Karst Watersheds and Other Karst Studies

COUNTY/SITE	WATERSHED AREA (ha.)	WATER SOURCE
Bourbon	101	Stream
Fleming	51	Stream
Jessamine	1,903	Spring
Logan	4,082	Spring
Russell	32	Stream
Shelby	166	Stream
Todd	467	Spring
Woodford	972	Stream
Other Studies:		
Illinois:		
Sensel Spring	15	Spring
Kelly Spring	1,370	Spring
Indiana:		
Lost River	9,225	Stream
Iowa:		
Big Spring	26,410	Spring
Pennsylvania:		
Cumberland Valley --		
Alexanders Spring	~730	Spring
Mount Rock Spring	~730	Spring
Nittany Valley --		
Pleasant Gap Spring	1,815	Spring
Elk Creek Rise	7,770	Spring
Spring Bank	2,230	Spring
Axemann Spring	775	Spring
West Virginia:		
The Portal	?	Spring
Davis Hallow	1,140	Spring
Davis Spring	19,150	Spring
The Hole	1,450	Spring
Mammoth Cave-Kentucky:		
Buffalo Creek	3,240	Spring
Echo River	2,270	Spring
Turn Hole Bend	24,410	Spring

Table 2. Nitrate-N in Water from Karst Watersheds in Kentucky and Other Karst Studies

County/Site	**%[1]R**	**%[2] Agr.**	**N[3]**	**Nitrate-N (ppm)**		**Frequency %**		
				Mean	**Median**	**< 3ppm**	**5 - <10 ppm**	**>10ppm**
Bourbon	27.7	92	29	4.1	4.39	24.1	37.9	0
Fleming	1.0	86	35	2.00	2.04	85.7	0	0
Jessamine	16	88	35	2.34	2.36	94.3	0	0
Logan	70	92	25	4.69	4.59	0	28.0	0
Russell	15.5	84.3	31	3.32	3.52	41.9	25.8	0
Shelby	58.8	88.1	30	4.73	4.50	26.7	40.0	0
Todd	84.0	93	36	4.74	4.92	8.3	47.2	0
Woodford	23.0	97	13	3.25	2.83	53.8	15.4	0
Other Studies								
Illinois:								
Sensel Spring	72.2	100	26	5.18				
Kelly Spring	64.4	79.6	14	4.34	3.67	35.7	21.4	0
Indiana:								
Lost River	75.6	86.5	27	6.37	6.6	7.4	85.2	0
Iowa:								
Big Spring	61.4	91.4		9.6				
Pennsylvania:								
Cumberland Valley -								
Alexanders Spring	44.5	71	13	5.13	5.0	0	81.5	0
Mount Rock Spr.	50	84	12	5.68	5.6	0	84.6	0
Nittany Valley --								
Pleasant Gap		24.3		3.19				
Elk Creek Rise		30.8		2.69				
Spring Bank		46.7		3.75				
Axemann Spring		91.6		6.15				
West Virginia:								
The Portal	0	0		.09	.09			
Davis Hallow	6	22		0.61	0.63			
Davis Spring	17	68		2.75	2.75			
The Hole	20	99		3.55	3.31			
Mammoth Cave-Kentucky:								
Buffalo Creek	1	5		0.5				
Echo River	0	1		1.4				
Turn Hole Bend	15	77		2.7				

[1] - area of watershed in corn, tobacco and double cropped small grain

[2] - area of watershed in agriculture (row crop + hay/pasture)

[3] - number of samples

Table 3. Triazines in Water from Karst Watersheds in Kentucky and Other Karst Studies

County/Site	N[1]	Triazine(ppb)			Frequency %		
		Arith.[2] Mean	Geo.[3] Mean	Median	<0.3 ppb	>.5 ppb-<3ppb	>3ppb
Bourbon	24	1.02	0.56	0.33	37.9	3.4	6.9
Fleming	35	0.31	0.27	0.21	65.7	2.4	0
Jessamine	9	0.19	0.18	0.08	77.8	0	0
Logan	23	0.68	0.64	0.58	15.9	0	0
Russell	31	0.94	0.60	0.31	45.2	0	9.6
Shelby	30	1.47	0.85	0.58	16.7	13.3	6.7
Todd	36	1.6	1.33	0.99	0	22.2	5.6
Woodford	14	0.31	.24	0.09	71.4	0	0
Other Studies:							
Illinois:							
Kelly Spring	14	3.7	1.48	0.92	35.7	0	28.6
Indiana:							
Lost River	27	2.85	1.38	0.60	7.1	7.1	14.3
Pennsylvania:							
Cumberland Valley --							
Alexanders Spring	10	0.44	0.43	0.4	10	0	0
Mount Rock Spr.	10	0.5	0.5	0.5	0	0	0
West Virginia:							
The Hole	21	0.16	0.14	0.09	90.5	0	0

[1]- Number of Samples
[2]- Arithmetic Mean
[3]- Geometric Mean