THE IOWA STATE-WIDE RURAL WELL-WATER SURVEY: June 1991, Repeat Sampling of the 10% Subset

Technical Information Series 26

Iowa Department of Natural Resources
Larry J. Wilson, Director
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

The Iowa Department of Natural Resources, in conjunction with the University of Iowa, Center for Health Effects of Environmental Contamination, conducted the State-Wide Rural Well-Water Survey (SWRL) between April 1988 and June 1989. The SWRL survey systematically selected and sampled 686 sites and provided a statistically valid assessment of the proportion of private rural wells and rural Iowa residents affected by various environmental contaminants. The SWRL design framework also systematically selected a subset of 10% (68) of all sites for repeat sampling, to assess temporal changes in water quality during the original survey. The 10% repeat sites yielded a very consistent representation of the state-wide data, including proportionately representative detections of pesticides down to about a 1% occurrence interval. These sites provided a representative subset of SWRL for monitoring water quality over time as an indicator of temporal change. The first two samplings of this 10% subset of wells are termed SWRL 10-1 and 10-2, respectively (abbreviated as 10-1 and 10-2). The SWRL 10-1 was part of the full SWRL sampling, and therefore is used as the basis for comparison with subsequent samples.

The SWRL survey was conducted during the driest consecutive two-year period in Iowa's recorded history. The objective of the resampling studies was to resample the subset during more "normal" climatic conditions, and to assess changes in water-quality that may have occurred. The 10% subset was resampled in October 1990 (10-3) and June 1991 (10-4), after weather patterns in Iowa had changed from the drought conditions of 1988-1989, to more normal and wetter-than-normal conditions. Long-term monitoring has shown that a mid-fall period, such as October, often represents conditions near the annual average for many parameters, though typically fewer pesticide detections occur than in late-spring or summer, such as the 10-4 (June 1991) resampling. For cost and technical reasons fewer analytes were included in SWRL 10-3 and 10-4 than the full SWRL survey.

In June 1991, during 10-4, about 19% of the sites showed NO_3-N >10 mg/L; 57% were positive for total coliform bacteria and 24% positive for fecal coliform bacteria; 20% of wells had a detection of some herbicide compound, about 6% contained detectable atrazine (parent compound only), and about 11% showed detections of atrazine or one of two common metabolites. The pattern of greater nitrate concentrations and bacteria occurrences in samples from wells <100 feet deep and lower contaminant levels in wells $\geq$100 feet deep, continued to be statistically significant in the 10-3 and 10-4 sampling.

Using tritium (^3H) analysis as a groundwater dating tool, wells $\geq$100 feet deep were more likely

to produce groundwater with <6+/-4 Tritium Units, which averages >20 years old, than wells <100 feet deep. Groundwater containing detectable tritium showed much higher rates of nitrate, and total- and fecal-coliform contamination, as would be expected. The data indicate a relationship among shallow wells, relatively recently recharged groundwaters, and higher rates of contaminant occurrence. All of the wells $\geq$100 feet deep that exhibited >10 T.U. (i.e., modern recharge water) are from east-central or northeastern Iowa, where the hydrogeologic conditions promote much greater depth of groundwater circulation, and, hence, the depth to which contaminants occur is much greater than elsewhere in the state. This tool provides further insights on the mechanisms of groundwater contamination and may be useful for evaluating pollution potential of well waters.

Relative to prior sampling, the proportion of sites positive for total coliform bacteria and those with any detection of total atrazine or other pesticide increased slightly. The percentage of wells with NO_3-N >10 mg/L did not change, but the mean and median nitrate concentration did increase somewhat. The only water-quality changes and trends from the full SWRL and the 10-1 (1988-1989), the 10-3 (October 1990), and 10-4 (June 1991) samplings that were statistically significant as estimates for *all rural well waters, statewide* were: 1) the decline in the detection of dissolved organic-nitrogen in 10-3 and its increase again in 10-4; 2) the increase in fecal coliform positives in 10-3 and again in 10-4; 3) the decrease in NH_4-N in 10-4; and 4) the increase in atrazine detections in 10-3, which subsequently declined in 10-4.

The change from drought to wetter than normal conditions did not affect the 10-3 and 10-4 sample results as noticeably or consistently as it did in long-term monitoring projects in the state. Atrazine (parent) detections increased significantly in 10-3, but declined again in 10-4. Detections of other herbicides and total atrazine (metabolites included) increased somewhat in the June 10-4 sampling, as might be expected from the seasonal patterns discerned in other Iowa studies. While mean nitrate concentrations increased slightly, the proportion of wells with NO_3-N >10mg/L, and total coliform detections were largely unchanged. Fecal coliform detections increased, but this increase was unrelated to trends in other contaminants. As a sample of wells state-wide, this less pronounced response might be expected because the 10% subset integrates a variety of well-depths, well types and hydrogeologic settings. Also, the SWRL 10% sample may react more slowly to climatic change; one indication of this is the low tritium content and therefore, relatively old (>20 years) average age of almost half the well-water sampled during SWRL 10-3 and 10-4. The change to wetter conditions may explain the increases in total coliform and fecal coliform bacteria positives. Other studies have noted that bacteria, similar to chemicals, may be rapidly transmitted to the water table by preferential flow through the soil. Also, as water tables rise during wet periods, they are closer to the land surface and into contact with soil horizons where coliform bacteria are more abundant and more likely to survive.

One sample was collected from a site using a rural water-supply (RWS) system for its home and farm water. The RWS system uses surface water. Four herbicides were detected: alachlor (0.7 μg/L), atrazine (1.7 μg/L), cyanazine (1.5 μg/L), and metolachlor (1.2 μg/L).

Immunoassay (IMA) methods for triazine scans provided promising results. With further refinements, these methods may provide a tool for inexpensive screening of water supplies for triazine occurrence.

INTRODUCTION

As part of the implementation of the Iowa Groundwater Protection Act of 1987, the Iowa Department of Natural Resources (DNR), in conjunction with the University of Iowa, Center for Health Effects of Environmental Contamination (CHEEC), conducted a survey of the quality of private drinking-water supplies used by rural Iowans. Overall responsibilities for project management were shared by principal investigators from the DNR and The University of Iowa, Department of Preventive Medicine and Environmental Health (PM&EH). The State-Wide Rural Well-Water Survey (SWRL) was conducted between April 1988 and June 1989. The SWRL survey was designed to provide a statistically valid assessment of the proportion of private rural wells and rural Iowa residents affected by various environmental contaminants. The survey was a systematic sample, stratified by rural population density. SWRL demographic data indicate the sample is clearly representative of rural Iowans. In total, 686 sites were sampled and inventoried in the survey. Previous reports have presented the SWRL survey design and implementation (Hallberg et al., 1990), and reviewed details of the hydrologic conditions during the survey, the water-quality results, statistical and hydrological relationships among water-quality parameters, and analysis of relationships among site characteristics and water-quality findings (Kross et al., 1990, 1992; Hallberg et al., 1992).

The SWRL design framework also systematically selected a subset of 10% (68) of all sites for repeat sampling to assess temporal changes in water quality during the original survey. The results from the 10% repeat sites produced a consistent representation of the state-wide data, including proportionately representative detections of pesticides down to about a 1% occurrence interval (Kross et al., 1990). These sites provide a representative subset of SWRL for monitoring water quality over time. The design of the 10% subset dictates that the results be summarized only at the state level. The first two samplings of these wells are termed SWRL 10-1 and SWRL 10-2, respectively (also abbreviated herein as 10-1 and 10-2). The 10-1 was part of the full SWRL sampling, and therefore is used as the basis for comparison with subsequent samples.

The SWRL survey was conducted during the driest consecutive two years in Iowa's recorded history; state-wide, average precipitation was more than 18 inches below normal during 1988-1989. A third sample of the 10% sites, referred to as SWRL 10-3 (also abbreviated as 10-3), was conducted in October of 1990 following wetter than normal climatic conditions (Rex et al., 1993). This report presents the results of the fourth sampling of the 10% sites, termed SWRL 10-4 (also abbreviated as 10-4), which was done in June 1991.

PROCEDURES

Standardized procedures for participant contact and field activities were employed during SWRL 10-4. All 10% participants were contacted by mail, and subsequently by telephone, to confirm their interest in continued involvement and to determine if any relevant changes had been made to their well or water supply systems (i.e., a new well, the addition of treatment systems, etc.). A date for well-water collection was established if the well continued to meet the SWRL criteria for sampling. Detailed on-site evaluations and interviews were conducted during the initial SWRL survey. No new on-site interviews were conducted in association with this sampling; no significant changes in the well or surrounding characteristics were observed. All sampling was done between June 6, and June 27, 1991. There was some expected attrition of participants, for various reasons (e.g., no longer interested in participating, well no longer met criteria, participant deceased, farm house abandoned, etc.), and replacement sites were selected to return the sample count to 10% of the original survey.

Field procedures followed the standards and quality-assurance protocols of the original SWRL survey. Wells were pumped and the water-system purged until temperature and specific conductance stabilized (Hallberg et al., 1990). Dissolved oxygen concentrations were also measured in the field. Data for all three parameters and any additional notes or comments concerning each site were recorded in a SWRL field log book. Samples for laboratory analyses were collected in standard, pretreated containers supplied by the project laboratories: the University Hygienic Laboratory (UHL) and the Analytical Toxicology Laboratory (ATL) in the Department of Preventive Medicine and Environmental Health (PM&EH) at The University of Iowa. Field blanks and spikes, and blind duplicates were collected throughout the study at a rate of 10% of samples collected or one on each field trip. Duplicates and blanks for pesticides showed no "false" positives or negatives and quantitated detections matched within 0.2 μg/L. All well-water samples were analyzed for the following: total coliform and fecal coliform bacteria; nitrate (+nitrite)-nitrogen, ammonium-nitrogen, and organic-nitrogen; tritium and radon; 9 common herbicides; 9 common insecticides; 3 environmental metabolites of herbicides; and a pilot assessment of immunoassay scans for atrazine/triazines. Table 1 summarizes the chemical parameters analyzed in 10-4, the analytical laboratories, and abbreviated methods employed. Hallberg et al. (1990) and Kross et al. (1990) provide details on methods and quality-control/quality-assurance procedures. A subset of samples was analyzed for tritium at the Environmental Isotope Laboratory at the University of Waterloo (EIL).

There were differences in the analytes sampled for 10-4, relative to the earlier sampling periods. This was a result of both technical and economic factors. For example, major ion analyses were not included in 10-4 because a one-time geochemical characterization provided during SWRL (see Kross et al., 1990) was viewed as sufficient. In the original SWRL survey (10-1 and 10-2), samples were analyzed for 27 pesticide compounds and 5 pesticide metabolites, including: 17 herbicides and 3 herbicide metabolites; and 10 insecticides and 2 metabolites. For 10-4, the acid-based herbicides and the insecticide carbofuran (and metabolites), which require special separate processing, were eliminated. The 21 pesticides that were included for 10-4 (Table 1) comprised over 96% of the detections in the original SWRL survey. A pilot project for tritium analyses was also added during 10-3 and was continued in 10-4. This groundwater age-dating tool (e.g., Hendry, 1988) provides perspectives on the hydrologic systems supplying the wells.

Triazine Immunoassay Screening

During 10-4, samples were also analyzed using immunoassay (IMA) screening methods, to evaluate their potential for inexpensive monitoring. These methods, perhaps more appropriately termed ELISA — enzyme-linked immunosorbent assay procedures — have been shown to provide a rapid, reliable screening of water samples for triazine herbicide compounds, particularly atrazine, down to 0.1-0.05 μg/L concentrations. Goolsby et al. (1991) and Thurman et al. (1990) describe the methods in detail and illustrate rank correlation coefficients of 0.9 or greater with gas chromatography/ mass spectrometry (GC/MS) methods (also see Bushway et al., 1988). The methods involve several high sensitivity immunological reactions. First, selective antibodies are used that are specially designed to react and bind with compounds of a particular chemical structure. This is followed by a catalyzed enzyme reaction which changes the color of the sample and allows for the determination of chemical concentration through spectrophotometry. Two of the more widely tested commercial methods were evaluated for 10-4: UHL utilized the *Millipore* method (Millipore Corporation, Bedford, Massachusetts), using a microtiter plate procedure; and PM&EH/ATL utilized the *Ohmicron* method (Ohmicron Corporation), using a coated-tube procedure.

The IMA tests are *not* exclusively reactive to atrazine. In addition to atrazine, the *Millipore* method is reactive to ametryn, cyprazine, prometon, prometryn, propazine, simazine, and simetryn. Additionally, the method is less reactive to de-ethylatrazine, de-isopropylatrazine, hydroxyatrazine, and cyanazine; and shows no significant cross-reactivity to didealkylatrazine, alachlor, glyphosate, metolachlor, metribuzin, or 2,4-D (Bushway et al., 1988; Thurman et al., 1990; and Millipore Corporation materials). The *Ohmicron* method is stated as being cross-reactive with ametryn, prometon, prometryn, propazine, simazine, terbutryn, and terbutylazine while con-

Table 1. Summary of chemical parameters analyzed in SWRL 10-4, June 1991, samples, laboratory, methods, and holding time requirements. See Hallberg et al., 1990, Kross et al., 1990, and Hall and Moyer, 1990, for details of methods.

No.	Analyte Name	Other Name	Lab	Method	MDL / method detection limit	Sample holding time	Extract holding time
	Bacteria:						
1.	total coliform		UHL	MTF - Multiple	<2.2("0") to >16	48 hours	N/A
2.	fecal coliform		UHL	Tube Fermentation	MPN - Most Probable Number statistical function	48 hours	N/A
	Nitrogen Series:						
3.	nitrate (+ nitrite)-N		UHL	Cu-Cd reduction	0.10 mg/L	28 days	N/A
4.	ammonium-N		UHL	color-phenate	0.10 mg/L	28 days	N/A
5.	organic-N		UHL	TKN, block digestion	0.10 mg/L	28 days	N/A
	Field Measurements:						
6.	Specific conductance			conductivity meter	umho/cm @ 25 degrees C		
7.	Temperature			lab-grade thermometer	degrees C		
8.	Dissolved oxygen			D.O. probe	mg/L; variable calibration		
	Other chemical parameters:						
9.	Tritium		ATL	direct scintillation	6 +/- 4 T.U.	N/A	N/A
9.	Tritium		Univ. of Waterloo	direct scintillation	0.8 +/-0.4 T.U.	N/A	N/A
	Herbicides:						
10.	alachlor	Lasso	ATL	GC-ECD/NPD	0.05 μg/L	7 days	40 days
11.	atrazine	Atrazine	ATL	GC-ECD/NPD	0.13 μg/L	7 days	40 days
12.	butylate	Sutan	ATL	GC-ECD/NPD	0.10 μg/L	7 days	40 days
13.	cyanazine	Bladex	ATL	GC-ECD/NPD	0.12 μg/L	7 days	40 days
14.	dacthal	DCPA	ATL	GC-ECD/NPD	0.01 μg/L	7 days	40 days
15.	metolachlor	Dual	ATL	GC-ECD/NPD	0.04 μg/L	7 days	40 days
16.	metribuzin	Sencor	ATL	GC-ECD/NPD	0.01 μg/L	7 days	40 days
17.	propachlor	Ramrod	ATL	GC-ECD/NPD	0.02 μg/L	7 days	40 days
18.	trifluralin	Treflan	ATL	GC-ECD/NPD	0.02 μg/L	7 days	40 days
	metabolites:						
19.	de ethyl atrazine		ATL	GC-ECD/NPD	0.10 μg/L	7 days	40 days
20.	de isopropyl atrazine		ATL	GC-ECD/NPD	0.10 μg/L	7 days	40 days
21.	hydroxy alachlor		ATL	GC-ECD/NPD	0.10 μg/L	7 days	40 days
	Immunoassay scans:						
22.	atrazine/triazine		ATL	Ohmicron	0.10 μg/L	7 days	N/A
22.	atrazine/triazine		UHL	Millipore	0.10 μg/L	7 days	N/A
	Insecticides:						
23.	chlorpyrifos	Lorsban	UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
24.	diazinon		UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
25.	dimethoate	Cygon	UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
26.	ethoprop	Mocap	UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
27.	fonofos	Dyfonate	UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
28.	malathion		UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
29.	parathion		UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
30.	phorate	Thimet	UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days
31.	terbufos	Counter	UHL	GC-FP/NPD	0.10 μg/L	7 days	40 days

siderably less reactive to cyanazine. This method exhibits no significant (<0.01%) cross-reactivity to alachlor, benomyl, butachlor, butylate, metolachlor, metribuzin, picloram, propachlor, or 2,4-D, among other compounds (Ohmicron Corporation). Most of the other more reactive compounds are either rarely used compounds or not used at all in Iowa. Hence, these tests should primarily provide a screening for atrazine, but some positives *must be expected* related to other herbicides and metabolites.

Site Additions

Only 64 of the original 68 sites selected for inclusion in the 10% subset were sampled twice during SWRL (i.e., 10-1 and 10-2). However, various site problems were encountered (e.g., changes to treated water, or rural water supply hookups) so that only 62 sites were used in summary statistical analyses. For the SWRL 10-3 study, samples were collected and analyzed at 60 of the 62 sites. Two residents chose not to continue their involvement. For the 10-4 sample collection, 10 sites were added to bring the target population back to 68. Selection of a replacement site was made by taking the next closest original SWRL site in that county that met all criteria, following the spatial selection pattern of the original design (Hallberg et al., 1990). In total, from the original 10-1 sites, 6 were eliminated because they no longer met the criteria, and 4 by request of the participants. During 10-4, 66 of the 68 sites were actually sampled; one site could not be sampled for scheduling reasons, and at one site the house was destroyed before sampling. In the summary data presented, only 65 sites (96%) are used; one site was connected to a rural-water supply system prior to sampling. Figure 1 shows the general location of these sites.

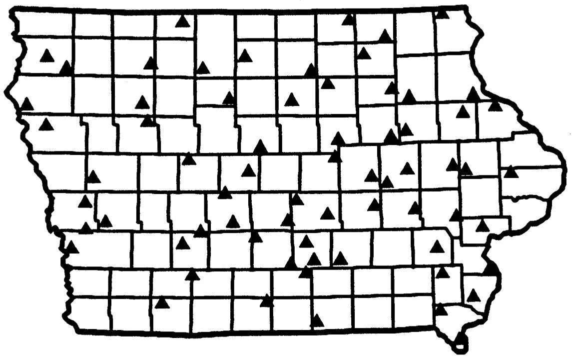

Figure 1. Location of SWRL 10-4 sample sites.

CLIMATIC AND HYDROLOGIC CONDITIONS

The SWRL survey was conducted during the two driest consecutive years in Iowa's recorded history. The average state-wide precipitation was more than 14 inches below normal during the April 1988 through June 1989 period of sample collection (Kross et al., 1990). Figure 2 shows the monthly state-wide precipitation and the departure from normal ("normal" is based on the period 1951-1980) for 1988 through 1991, inclusive of the original SWRL sample period. During the original survey, only two months showed above normal precipitation, and only one month—November 1988—was more than one inch above normal. Twelve months showed below normal precipitation, with nine of those months showing precipitation deficits of over one inch. For the calendar years 1988 and 1989, state-wide precipitation was 10.4 and 7.6 inches below normal, respectively.

As the drought progressed, recharge to groundwater was greatly restricted. The reduced volume of water moving through the soil likely affected the mass of substances that were leached or transported by this water. In turn, this decreased input influence quality of groundwater in hydrologic systems that were directly affected by recharge. Relatively long-term monitoring of such hydrologic systems in Iowa (e.g., Big Spring Basin, Floyd and Mitchell counties, and Bluegrass Watershed projects) suggested that the frequency of pesticide detections and the concentration of nitrates were lower during the drought period than in prior years or subsequent years (Kross et al., 1990; Rex et al., 1993). Therefore, the drought conditions may have influenced the results of the SWRL survey, presenting a "best-case" situation.

By October 1990, the month SWRL 10-3 samples were collected, the drought had ended. For 1990,

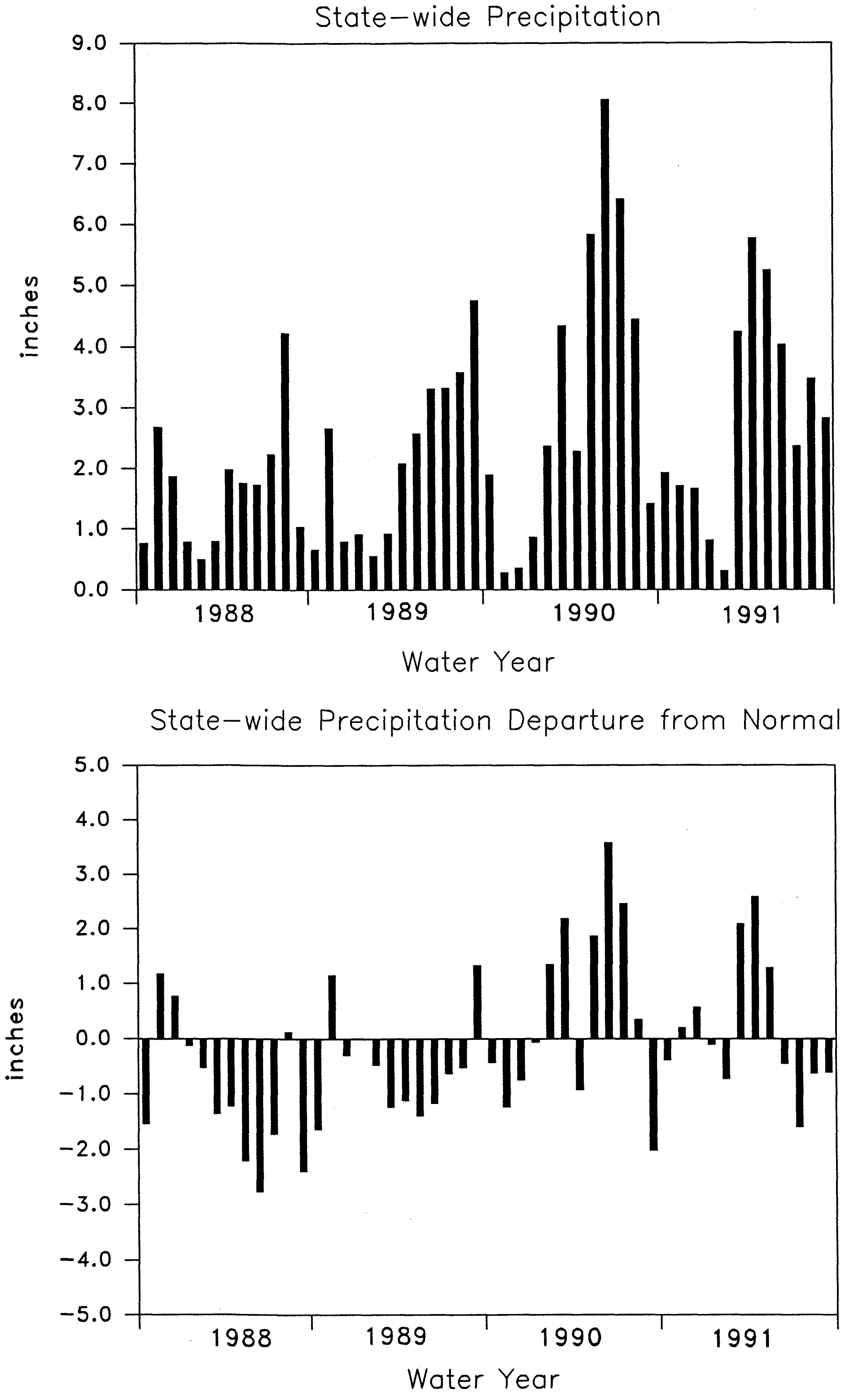

Figure 2. State-wide monthly precipitation and the departure from normal for water-years 1988-1991. SWRL survey from April 1988, through June, 1989; 10-3 in October 1990; and 10-4 in June 1991. (A water year is the period from October through September of the named year; i.e., Water Year 1990 is from October 1989, through September 1990.)

spring and early summer precipitation was above normal, with March, May, June and July each being more than one and half inches above normal. Only one month (September) showed a precipitation deficit of over one inch (Fig. 2). For calendar year 1990 the state-wide average precipitation was 7.4 inches above normal (see Rex et al., 1993). The relatively wet conditions continued into 1991. During the three months preceding 10-4, precipitation was more than 5 inches above normal, though June was slightly below normal.

Figure 3 illustrates the effects of these climatic variations on groundwater recharge at a set of nested monitoring wells located in Floyd County. The three graphs show water levels, precipitation, and departure from normal precipitation from January 1985 through June 1991. At FM1 research site, which has 4 nested wells, water levels had dropped 30 feet or more from the 1986-1987 period to the 1988-1989 drought period. During this interval, the percentage of wells with pesticide detections sampled in this area decreased from 70% to 40%, and finally dropped to as low as 12% in October, 1989, after two years of prolonged drought conditions (Kross et al., 1990; Rex et al., 1993). By the spring of 1990, precipitation patterns had changed and were above normal. By August 1990 water levels at FM-1 had recovered to pre-drought levels (Fig. 3). By October 1990 contaminant levels had increased in the wells, similar to pre-drought patterns; 60% of the wells showed pesticide detections and 24% had >10 mg/L NO_3-N. Water levels dropped over the winter months, and rose sharply again in spring and early summer of 1991. Contaminant concentrations were again well above those occurring during the drought.

In the Big Spring Basin and in the Bluegrass Watershed, similar patterns have been recorded. Declining detections of pesticides and nitrate concentrations occurred during the drought period. As the drought subsided, and normal, or greater than normal precipitation occurred, greater water flux and contaminant occurrence was detected in 1990 and 1991(Rex et al., 1993).

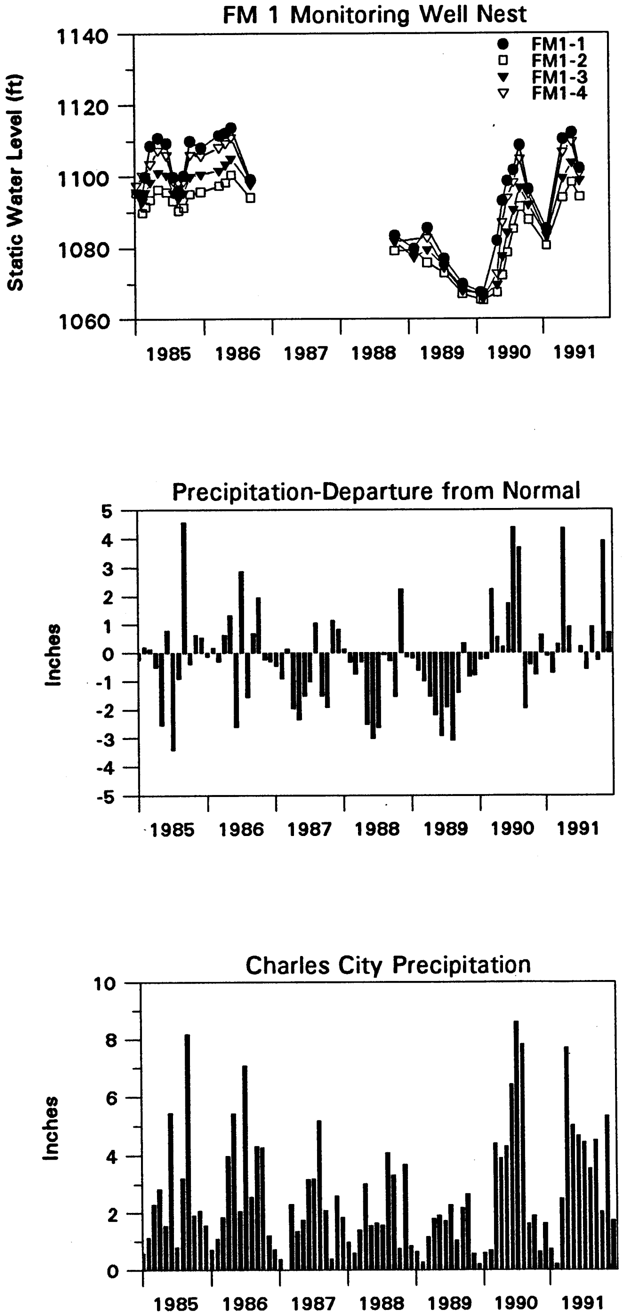

Figure 3. Water levels from nest of four research-monitoring wells in the Devonian aquifers in Floyd County, and departures from normal precipitation at Charles City, Floyd County. (The depth of the wells is : FM1-1=60 ft; FM1-2=140 ft; FM1-3=235 ft; and FM1-4=350 ft.)

Table 2. Summary of SWRL 10-4 (June 1991) water-quality results.

	All Wells	Wells <50ft	Wells >=50ft
Nitrate-N:			
%well >10 mg/L	19.2%	33.0%	9.5%
mean conc., mg/L	6.8	10.5	4.5
max conc., mg/L	110	34	110
HAL, mg/L	10	10	10
Total Coliform Bacteria:			
% positive	57.3%	88.1%	35.9%
Fecal Coliform Bacteria:			
% positive	24.2%	48.3%	8.4%
Pesticides:			
% wells with any pesticide detection	19.8%	22.5%	14.1%
Atrazine (parent):			
% wells with detections	6.0%	0.0%	7.5%
mean conc., μg/L	0.6	0	0.8
max conc., μg/l	0.9	0	0.9
HAL μg/L	3	3	3

WATER-QUALITY RESULTS

The basic water-quality results from the SWRL 10-4 sampling are presented in the following sections. The water-quality data are summarized by the concentration or occurrence of particular analytes and the proportion of the wells affected (Tables 2 and 3). Unless stated otherwise, population stratum weights based on the rural population density of the counties in Iowa were used to derive the given proportions. The equations for estimation of proportions, means, variances, and 95% confidence intervals are reported in Kross et al. (1990; see also Hallberg et al., 1990). Where needed, zero values were substituted for observations that were below method detection limits (for explanation see Rex et al., 1993). Later sections of the report compare results among SWRL 10-1, 10-2, 10-3, and 10-4, and apparent temporal trends.

Well depth is one of the most important variables affecting the potential for contaminants from the land surface to affect well water; therefore the 10-4 results are summarized by well-depth classes. As discussed by Kross et al., (1990), a well depth in the range of 50 to 100 feet serves as a definable approximation between shallow and deep wells that exhibit statistically significant differences in water quality among surficially derived contaminants, such as nitrate and pesticides. In addition, many of the wells that are less than 50 feet deep are large diameter bored wells which are usually open to the water table, and showed a relatively high degree of contamination in the SWRL survey (Kross et al., 1990; Hallberg et al., 1992). Therefore, <50 feet and $\geq$50 feet deep classes are used to summarize the data. Several summary tables also use <50 feet, 50-99 feet, and $\geq$100 feet classes for comparison with other studies. Well depths are known for 86% of the 10-4 wells, similar to the entire SWRL population. Summary data for "all" wells and "all" sites include the wells of unknown depth. State-wide, the SWRL 10% subset has an estimated mean well depth of

Table 3. Summary of SWRL 10-4 water-quality results for all sites and by well depth categories <50 ft., 50-99 ft., and >=100 ft.

Water-Quality Parameter		All Sites	Wells <50 ft deep	Wells 50-99 ft deep	Wells >= 100 ft deep
Wells:					
	% wells of known depth		35%	20%	45%
	median well depth, (feet)	86	30	74	178
Nitrate-N:					
	% sites > 10 mg/L (HAL)	19.2%	33.0%	30.6%	0.0%
	% sites > 3 mg/L	38.1%	71.5%	47.2%	16.7%
	% sites > 0.1 mg/L	56.6%	94.1%	55.6%	21.5%
	mean conc., mg/L	6.8	10.5	19	0.7
	median conc., mg/L	2.2	5.5	2.6	<0.1
	max conc., mg/L	110	34	110	5.6
Total Coliform Bacteria:					
	% sites positive:	57.3%	88.1%	52.7%	29.8%
Fecal Coliform Bacteria:					
	% sites positive:	24.2%	48.3%	16.7%	2.8%
Atrazine-parent:					
	% sites with detections	6.0%	0.0%	0.0%	7.5%
	% sites > 3.0 μg/L (HAL)	0%	0%	0%	0%
	mean conc. of detections, μg/L	0.6	*	*	*
	median conc., μg/L	0.6	*	*	*
	max conc., μg/L	0.9	*	*	0.9
Total Atrazine (with metabolites):					
	% sites with detections	10.5%	5.0%	0.0%	10.3%
	mean conc. of detections, μg/L	0.7	0.8	*	0.9
	median conc., μg/L	0.6	*	*	0.9
	max conc., μg/L	2	0.8	*	2
Any Pesticide Detection:					
	% sites with detections	19.8%	22.5%	13.8%	18.7%
Dissolved Oxygen:					
	mean conc., mg/L	2.6	3.9	2.4	1
	median conc., mg/L	1.3	3.4	1.9	0.5

Cumulative Proportion of Sites: With- Nitrate-N > 10 mg/L, and/or any pesticide detected, and/or total coliform bacteria -- 65.1%; and/or fecal coliform bacteria--45.5%

* indicates too few samples or no samples for this calculation

110 feet, a median of 86 feet, with a maximum depth of 322 feet. The well depth data have a standard deviation of 88 feet. For the entire SWRL population the mean was 135 feet, the median 100 feet, with a maximum of 880 feet. While these values differ slightly for the 10% subset, the proportion of wells in the well depth categories vary little and are not significantly different.

Nitrate

Nitrate concentrations are reported in milligrams per liter of nitrate-nitrogen (mg/L NO_3-N). Hallberg (1989) and Libra et al. (1984) report that natural background nitrate concentration in groundwater aquifers in Iowa is less than 2 mg/L NO_3-N, often less than 1 mg/L. Concentrations over 3 mg/L NO_3-N are generally considered indicative of anthropogenic sources of pollution (Madison and Burnett, 1985; Hallberg, 1989).

Approximately 19% of SWRL 10-4 sites had nitrate at concentrations exceeding the recommended Health Advisory Limit (HAL) of 10 mg/L of NO_3-N (Table 2). For wells <50 feet deep, about 33% were >10 mg/L; for wells $\geq$50 feet deep, about 9.5% were >10 mg/L. The mean NO_3-N concentration for all wells was 6.8 mg/L, with a maximum concentration of 110 mg/L. For wells <50 feet deep, the mean concentration was 10.5 mg/l; for wells than $\geq$50 feet deep, 4.5 mg/L. The differences in NO_3-N concentrations between the <50 feet deep and $\geq$50 feet deep wells is statistically significant ($p=0.001$), according to the Kruskal-Wallis nonparametric statistical test of significance.

Further separation of the well depth classes shows that about 31% of wells between 50-99 feet deep had NO_3-N >10 mg/L, while sites with wells $\geq$100 feet deep had *no* occurrences of NO_3-N >10 mg/L (Table 3). Thirty-eight percent of all sampled wells contained >3 mg/L NO_3-N. The proportion of wells exceeding 3 mg/L also decreases with depth, from 72% of the wells <50 feet deep, to 47% of the wells in the 50-99 foot depth class, and finally to 17% of the wells $\geq$100 feet deep. Median NO_3-N concentrations for wells $\geq$100 feet deep were <0.1 mg/L.

Coliform Bacteria

Results of the bacteria analyses are reported as standard MPN values ("most probable number") per 100 milliliters of water. The MPN is a statistically estimated number of coliform bacteria rather than a direct count (see Kross et al., 1990, for discussion). Using the 5 by 10 ml Multiple Tube Fermenter (MTF) procedure there are 6 MPN categories reported: <2.2, 2.2, 5.1, 9.2, 16, and >16. When coliforms are absent, the test results are reported as <2.2 (safe for total coliform bacteria). When coliforms are present the results are reported as 2.2, 5.1, 9.2, 16, or >16, depending on the number of positive tubes; these results are classified as "unsafe for human consumption".

The 10-4 results show a bimodal distribution; most samples were either absent for total coliform bacteria (<2.2 MPN) or the degree of contamination is great (>16 MPN). This bimodal distribution is typical for private well-water samples (e.g., Hallberg and Hoyer, 1982; Kross et al., 1990; Rex et al., 1993). The <2.2 MPN group is generally the largest, except for total coliforms for samples from systems with wells < 50 feet deep. Because of the bimodal nature of these data and because the standard procedure is to report any values $\geq$2.2 as unsafe, the data are simply summarized as negative (MPN = < 2.2) or positive (MPN $\geq$2.2).

About 57% of the SWRL 10-4 samples were positive for total coliform bacteria (Tables 2 and 3). About 88% of the samples from water-systems with wells <50 feet deep were reported as positive for total coliforms; while 36% of the samples from wells $\geq$50 feet deep were reported as positive for total coliforms (Table 2). In the 50-99 foot depth class, 53% of samples were positive for total coliforms, while about 30% of the samples from wells $\geq$100 feet deep were positive (Table 3). *Total* coliform bacteria are generally not disease causing organisms; their presence in a drinking water supply indicates that a pathway exists for relatively shallow groundwater or water from the surface to reach the water-supply system or the well. Therefore, the presence of total coliforms suggests that other surficially-derived contaminants or pathogens may be able to enter the water supply. Kross

Table 4. Proportions of private rural water systems with total and fecal coliform bacteria from SWRL 10-4, June 1991.

	% negative MPN < 2.2 (coliforms absent)	% positive MPN >= 2.2 (coliforms present)
SWRL 10-4, all sites % *Total coliform:*	42.7%	57.3%
SWRL 10-4; of samples with Total coliform positives, the % with Fecal coliform:	57.8%	42.2%
SWRL 10-4, all sites % *Fecal coliform:*	75.8%	24.2%
SWRL 10-4; of samples with Fecal positives, the % with Total coliform:	0%	100.%

et al. (1990) present a further, in-depth discussion of total coliform tests.

Approximately 24% of the sites tested were positive for fecal coliforms in 10-4. Samples from systems with wells less than 50 feet deep were 48% positive; wells greater than 50 feet, about 8.4%. Sites with wells in the 50-99 foot depth class showed 17% positives for fecal coliforms; sites with wells ≥100 feet deep showed only 3% positives. Table 4 shows the weighted proportions of private rural water systems with fecal coliform bacteria and/or total coliform bacteria. About 42% of the sites with total coliform bacteria positives also had fecal coliform positive detections, hence, 58% of total coliform positives were negative for fecal coliforms.

Pesticides

No insecticides were detected in any 10-4 samples. In the original SWRL survey the only insecticidal compounds detected were metabolites of carbofuran. In 10-4, the herbicide active ingredients butylate and dacthal were not detected. Cyanazine was only detected in one sample from a site using a rural water-supply system that uses surface water. This site is not included in the well-water summary data.

Herbicides

During SWRL 10-4, herbicide compounds were detected in about 20% of the wells sampled (Table 5). Approximately 23% of wells <50 feet deep had pesticide detections, compared to 14% for wells ≥50 feet deep. Total atrazine (atrazine and its metabolites, when combined, is referred to herein as total atrazine) was the most commonly detected herbicide in SWRL 10-4, occurring in 10.5% of the samples from all wells; in about 5% of the wells <50 feet deep, and in about 7.6% of the wells ≥50 feet deep (i.e., it was also detected from wells with unknown depths). The mean total atrazine concentration for all wells was 0.7 μg/L. Six percent of all wells contained parent atrazine; no detections occurred in wells <50 feet deep in the 10-4 sampling. Other herbicides detected in SWRL 10-4 included alachlor (1.8%), metolachlor (8.1%), metribuzin (3.0%), propachlor (1.8%), and trifluralin (3.5%). Hydroxy-alachlor was detected in approximately

Table 5. Summary of SWRL 10-4, June 1991, water-quality results for pesticides.

	All Wells	Wells <50ft	Wells >=50ft
Pesticides:			
% sites with any pesticide detection	19.8%	22.5%	14.1%
Atrazine (parent)			
% sites with detections	6.0%	0.0%	7.5%
mean conc., µg/L	0.6	0.0	0.8
max conc., µg/l	0.9	0.0	0.9
HAL µg/L	3.0	3.0	3.0
De ethyl atrazine			
% sites with detections	4.8%	5.0%	2.3%
mean conc., µg/L	0.6	0.8	0.6
De isopropyl atrazine			
% sites with detections	4.0%	0.0%	4.6%
mean conc., µg/L	0.4	0.0	0.3
Total Atrazine			
% sites with detections	10.5%	5.0%	7.6%
mean conc., µg/L	0.7	0.8	0.9
max conc., µg/l	2.0	0.8	2.0
Alachlor (Lasso)			
% sites with detections	1.8%	5.0%	0.0%
mean conc., µg/L	0.2	0.2	0.0
max conc., µg/l	0.2	0.2	0.0
HAL µg/L	0.4	0.4	0.4
hydroxy alachlor			
% sites with detections	2.7%	5.9%	0.0%
mean conc., µg/L	2.4	1.7	0.0
Metolachlor (Dual)			
% sites with detections	8.1%	5.0%	6.5%
mean conc., µg/L	20.4	151.0	1.9
max conc., µg/l	151.0	151.0	2.7
HAL µg/L	100.0	100.0	100.0
Metribuzin (Sencor)			
% sites with detections	3.0%	5.6%	2.3%
mean conc., µg/L	0.03	0.04	0.03
max conc., µg/l	0.04	0.04	0.03
HAL µg/L	200.0	200.0	200.0
Trifluralin (Treflan)			
% sites with detections	3.5%	5.6%	0.0%
mean conc., µg/L	0.02	0.02	0.0
max conc., µg/l	0.03	0.03	0.0
HAL µg/L	2.0	2.0	2.0

3% of wells, but method limitations hamper recovery of this compound (see Kross et al., 1990). For most herbicides, detections were more frequent in shallow wells. Water from one well exceeded the 100.0 μg/L USEPA Health Advisory Level (HAL) for metolachlor; this site exhibited 151 μg/L metolachlor. Investigations to date do not indicate any major spill or accident (e.g., back-siphoning) at the well head, or on the adjacent property. The well is shallow, and is finished in a shallow, local, alluvial aquifer where rapid lateral flow and little dispersion or dilution is likely.

Tritium

Tritium (^{3}H) is a radioactive isotope of hydrogen. Tritium is formed naturally by the interaction of incoming cosmic rays with the upper atmosphere, and has a half-life of about 12.4 years. Tritium concentrations are reported in Tritium Units (T.U.), and are determined from scintillation counts. Natural production of tritium in the atmosphere, prior to 1953, resulted in precipitation containing about 10 T.U. in the Midwest. During the 1950's and 1960's atmospheric testing of nuclear weapons resulted in individual rainfalls containing up to 5,000 T.U. (Bradbury, 1991). After this period, general atmospheric testing was stopped by most countries and tritium concentrations have declined to values generally in the range of 15-40 T.U. The relatively low rate of natural tritium production, the large inputs caused by nuclear testing, and tritium's relatively short half-life allow the concentration of tritium in groundwater to be utilized as a *general* age-dating tool. Several factors limit the usefulness of tritium for more absolute age-dating. Concentrations in precipitation vary geographically and from rainfall-to-rainfall. Groundwater that recharged following any individual precipitation event may mix with groundwater that recharged after different events, and that may contain a different tritium content. A detailed historical record of tritium in precipitation (available in very few locales, world-wide) is needed to overcome these obstacles. In the absence of such a record, Hendry (1988) offered general guidelines for interpreting groundwater tritium concentrations. Guidelines pertinent to this report are: 1) groundwater with a tritium content of 2 to 10 T.U. is considered, on average, to be greater than twenty years old (on *average*; these groundwaters may contain a minor amount of younger water); 2) groundwater with greater than 10 T.U. is on average less than twenty years old and may represent quite recent recharge; and 3) groundwater with a tritium content of <2 T.U. is considered to be pre-1953 in age, containing at most an insignificant amount of post-1953 recharge. In past work, for discussion and summary, we have used a simple categorization of samples, related to the essential presence or absence of tritium (>5 T.U., vs. ≤5 T.U.), into "old," (pre-1953) water, or "modern," (post-1953) water (Hallberg, 1989). The obvious significance is that 1953 predates the development and use of most of the modern pesticides and the significant increase in nitrogen loading of the 1970's and 1980's. The lack of contaminants in some groundwaters may not imply that contamination is not occurring in an area, it may simply be that the well/aquifer being sampled is producing groundwater too old to reflect any such influence.

For the 10-4 resample, tritium concentrations were determined by PM&EH/ATL. The detection limit for tritium was 6 T.U., with a 95% confidence interval of +/- 4 T.U. Therefore, the lowest possible reported values were <6+/-4 T.U. Samples with concentrations near the minimum detection limit (MDL), therefore, are difficult to interpret: they could be "old" or partly "modern". However, using Hendry's (1988) guidelines, groundwater with a tritium content of <6+/-4 T.U. has an *average* age of at least 20 years.

Table 6 summarizes the results of the tritium analyses, by well depth and in relation to the presence and concentration of contaminants. For all wells, the median tritium concentration was 7+/-4 T.U. About 55% of the wells produced water with >6+/-4 T.U., while the remainder were below the 6 T.U. MDL. Seventy-eight percent of the samples from wells <50 feet deep contained detectable tritium, compared to 34% of the wells ≥50 feet deep and 22% of wells ≥100 feet deep. For wells ≤26 feet deep, over 85% exhibit >10 T.U. The median concentration was 18+/-4 T.U. for wells

Table 6. **Summary of tritium concentration data, related to water-quality parameters and well depth.**

Tritium concentration group	Any Pesticide detection	*Percent of sites with:* *Parent* Atrazine detections	Nitrate-N <3 mg/L	Nitrate-N >10 mg/L	Total coliform positives	Fecal coliform positives
<6 +/-4 TU	19%	4%	85%	8%	35%	14%
>6 +/-4 TU	23%	8%	42%	29%	75%	32%

Well Depth Range	% Wells with <6 +/-4 TU	% Wells with >6 +/-4 TU	median Tritium Content TU
All wells	46%	55%	7
<50 ft	23%	78%	18
>=50-99 ft	25%	75%	10
>=50 ft	66%	34%	<6
>=100 ft	79%	22%	<6

<50 feet deep, and <6+/-4 T.U. for wells ≥50 feet deep. This data emphasize the general trend of deeper wells producing older groundwater, with two-thirds of the wells ≥50 feet deep yielding water that averages >20 years in age. Figure 4 shows the relationship between well depth and tritium concentrations for the 10-4 samples. This figure clearly illustrates why there is such a significant difference in water quality between wells <100 feet and those >100 feet deep. Also, all of the wells ≥100 feet deep that exhibit >10 T.U. (i.e., modern recharge water) are from east-central or northeastern Iowa, where the hydrogeologic conditions promote much greater depth of groundwater circulation, and, hence, the depth to which contaminants occur is much greater than elsewhere in the state (Kross et al., 1990).

Well-water samples that contained <6+/-4 T.U. showed considerably less contamination than samples with higher tritium concentrations (Table 6). Pesticides were detected in about 19% of the "older" water samples, compared to 23% of the more recently recharged waters. Only 15% of the older groundwaters contained >3 mg/L NO_3-N; of the 15%,over half contained >10 mg/L NO_3-N. In contrast, about 58% of the samples with >6+/-4 T.U. had >3 mg/L NO_3-N, with 29% exceeding 10 mg/L. Atrazine detections, and fecal-and total coliform positives, are at least twice as likely to occur in younger, relative to apparently older, groundwater.

Samples from 47 sites were also sent to the Environmental Isotope Laboratory, Department of Earth Sciences at the University of Waterloo (EIL) for tritium analysis. Forty-three of these samples were analyzed following an enrichment technique that allows for an MDL of 0.8+/-0.4 T.U. This allows for a more refined interpretation of groundwater ages. Results of these analyses are reported in Table 7. These data are given as unweighted percentages, because samples from the entire 10-4 well population were not analyzed. For the 47 sites, 57% produced samples with <10+/-1 T.U., and 40% were <2+/-0.6 T.U. Using Hendry's (1988) guidelines, wells exhibiting <2+/-0.6 T.U. produce groundwater that contains insignificant post-1953 recharge. Well depths were reported for 39 of the wells analyzed for tritium by EIL. Fourteen (36%) were less than 50 feet deep, and of these wells, three (21%) contained <10+/-1 T.U. and only 1 (7%) contained <2+/-0.6 T.U. Twenty-five (64%) of the

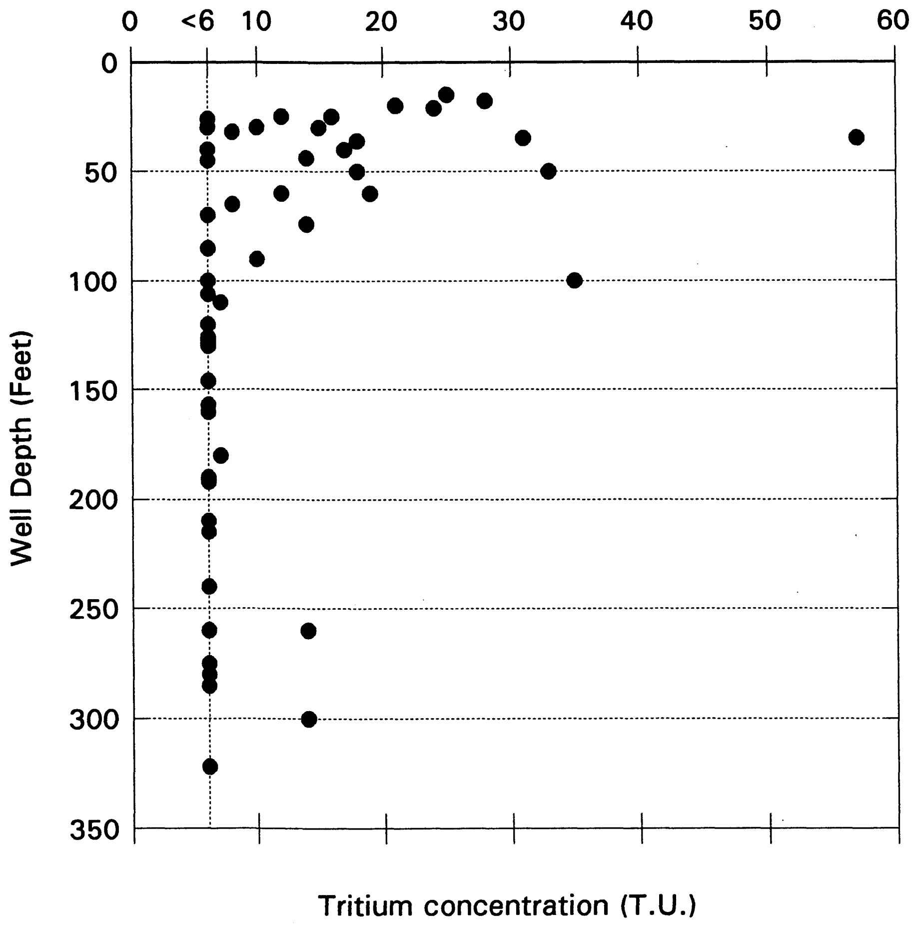

Figure 4. Well depth versus tritium content for SWRL 10-4.

wells were ≥50 feet deep; of these 18 (72%) produced samples with <10+/-1 T.U., and 16 (64%) samples were <2+/-0.6 T.U. The proportions of the wells in the well-depth classes are the same as for the entire 10-4 population.

The data from EIL allow for inter-lab comparison with results from PM&EH. The EIL analysis also allows the results to be used as a check on the interpretations made from the PM&EH results. Results from PM&EH indicate 49% of the samples analyzed by both labs contained <6+/-4 T.U. Results from EIL for these same samples indicate 96% contained <10+/-1 T.U., 91% contained <6+/-0.8 T.U., and 87% actually contained <2+/-0.6 T.U. Fifteen of the samples analyzed at PM&EH were reported to contain >14+/-4 T.U. and therefore carry 95% confidence they are >10 T.U. Results for EIL's analysis for these samples indicate 93% contained >10+/-1 T.U. The results from the two laboratories are very comparable, and therefore give confidence to the interpretations of data from PM&EH, even with the greater MDL and confidence interval.

Rural Water-Supply System Sample

As noted, one sample was collected from a site using a rural water-supply (RWS) system for its home and farm water. The RWS system uses surface water. The following four herbicides were detected in this sample: alachlor (0.7 μg/L), atr-

Table 7. Summary of enriched tritium analyses from EIL.

(Presented as unweighted percentages.)

	<2+/-0.6 T.U.	<10+/-1.0 T.U.	>10+/-1.0 T.U.
All Wells	40%	57%	43%
<50 feet	7%	21%	79%
>=50 feet	64%	72%	28%

azine (1.7 μg/L), cyanazine (1.5 μg/L), and metolachlor (1.2 μg/L). No bacteria were detected and the NO_3-N concentration was 6.1 mg/L.

Immunoassay Results

The results of the immunoassay (IMA) triazine screening tests are summarized in Table 8. Use of both the *Millipore* and *Ohmicron* methods produced very comparable results; for all but one sample both methods confirmed positive detections and produced similar concentration values. The rank ordering shown in Table 8 shows that the general order of concentration estimates are very similar. The mean difference between the methods was 0.09 μg/L. The greatest IMA concentrations were also related to samples with the greater atrazine concentrations determined by GC/MS. The majority of IMA positives did exhibit pesticide detections by GC, but not always for atrazine or its metabolites. Five samples showed positive IMA results that did not exhibit quantitated detections by GC. It is of interest that all five samples did show possible pesticide detections on one or more GC columns, but the detections were either below minimum quantitation limits or were not confirmed on multiple channels and hence not quantitated or reported. Table 8 also summarizes the range of tritium concentrations from samples collected for these sites. All the sites, except one, are producing "modern" water and, hence, are *capable* of being positive for triazines, or related modern contaminants. As noted above, the IMA methods are responsive to triazines not included in the GC scans used in this study. Without knowing the full range of compounds that the IMA tests may be responsive to, and without complete understanding of the full range of pesticide degradates, these results are quite promising. Only one site was not confirmed between the two IMA methods; this site exhibited no traces of pesticide residues by GC (not even unconfirmed traces), and produced "old" water in all tritium samples (10-3 and 10-4).

Subsequent to 10-4, the PM&EH and UHL labs have continued further refinement and testing of the IMA methods. These preliminary results suggest that IMA methods may prove useful for monitoring water quality in Iowa. With further refinement, these methods may provide a tool for inexpensive screening of water supplies for triazine occurrence, as suggested by Goolsby et al.(1991) and Thurman et al. (1990).

RELATIONSHIPS AMONG CONTAMINANTS

Table 9 provides an overview of the proportion of wells affected by combinations of contaminants. State-wide, the percentage of sites with NO_3-N >10 mg/L, occurring alone, was only 3%. Only about 2% of the sites had both NO_3-N >10 mg/L and pesticide detections, while about 11% of the sites had both NO_3-N >10 mg/L and total coliform bacteria positives. These values are very similar to the SWRL 10-3 sampling. Only 3% of sites were found to have all three contaminants occurring simultaneously. In the cumulative (or additive) sense, over 65% of wells had *either* a NO_3-N concentration >10 mg/L, and/or an atrazine detection, and/or was positive for total coliform bacteria.

Table 8. Comparison of IMA triazine analyses and herbicide concentrations from GC analysis from 10-4 samples, and the range of tritium concentrations.

Ohmicron "triazines"	Millipore "triazines"	atrazine	de ethyl atrazine	de isopr. atrazine	cyanazine	other herbicides	tritium range T.U.
- - ug/L - IMA - -		- - - - - - - - - ug/L - GC - - - - - - - - -					
2.10	2.14	1.74			1.52	1.86	12 - 19
1.56	1.30		0.75			151.40	6 - 11
1.39	1.34	0.89	0.61	0.48		0.13	26 - 35
0.60	0.37	0.42				3.16	8 - 22
0.38	0.24	0.23	0.37				12 - 16
0.32	0.28					**	24 - 25
0.26	0.14					**	10 - 17
0.26	< 0.10						< 6
0.23	0.18					**	5 - 10
0.20	0.14					**	6 - 21
0.19	--					**	11 - 14
0.18	0.14			0.58			11 - 16
0.18	0.18					0.66	7 - 27
0.10	0.12					0.33	12 - 21

** Possible pesticide residue present, but not confirmed on multiple channels, or below quantitation limits.

If fecal coliform positives are used the cumulative proportion of wells with any contaminant was approximately 45%.

Tables 10 and 11 present further relationships among contaminants. As discussed by Kross et al. (1990), total coliform bacteria are *not* reliable indicators of other kinds of contaminants, such as high nitrate concentrations or the likely presence of pesticides. In fact, if prediction were based on the presence of total coliform, the probability is much better that high nitrates or pesticides would *not* occur in the water supply. For those systems positive for total coliform only 25% exhibited NO$_3$-N >10 mg/L; i.e., 75% did not. The relationship with *any* pesticide detection is similar, only 3% of all total coliform positives were associated with atrazine detections. The relationships for fecal coliforms are similar; only 27% of fecal coliform positives are associated with NO$_3$-N >10 mg/L. As discussed, the presence of coliforms indicates that a pathway exists that may allow contaminants into the water supply; not contaminant presence. Coliforms, unlike chemical contaminants, are free living organisms and ubiquitous in the environment (i.e., topsoil). Thus, their occurrence in shallow water supplies should be much greater.

Conversely, wells with nitrate concentrations are more likely to be coliform positive (Tables 10 and 11). While there is an association between the presence of nitrate and the presence of coliforms, the results from SWRL 10-4, as well as the past samplings, show that there is no significant trend between nitrate concentrations and coliform positive rates above the detection limit for nitrate (Table 11). About 30% of the sites with <0.1 mg/L NO$_3$-N were positive for coliforms, while about 75% of those with detectable nitrate were positive (in all nitrate concentration categories). With fecal coliforms there is a more significant association with samples with detectable nitrate. Nitrate concentrations and fecal coliform positive rates tend to increase together, but even here there is not a consistent, statistically significant pattern.

These data underscore the importance of correctly interpreting the presence of total coliforms. Total coliforms indicate a pathway into the water supply, not necessarily the presence of chemical contaminants, i.e., high nitrates or pesticides. That

Table 9. Proportion of wells affected by combinations of nitrate-N >10 mg/L, any pesticide dectections, and/ or coliform bacteria positives, in SWRL 10-4. The right columns show the cumulative totals in each category (e.g., nitrate-N >10 mg/L); the bottom section shows the cumulative, or additive total for all categories (i.e., the left column).

		----- Cumulative -----		
Water-quality parameters	SWRL 10-4 %	Nitrate-N >10mg/L %	Pesticide detection %	Bacteria positive %
Nitrate-N >10 mg/L, ALONE;	3.1%	3.1%		
Pesticide(s) detection, ALONE;	3.0%		3.0%	
Total coliform bacteria, ALONE;	30.9%			30.9%
Nitrate-N >10 AND any pesticide; (but no total coliforms)	1.7%	4.8%	4.7%	
Nitrate-N >10 AND total coliform; (but no pesticide detections)	11.3%	16.1%		42.2%
Pesticide det. AND total coliform; (but no nitrate >10mg/L)	12.0%		16.7%	54.2%
Nitrate-N >10 AND any pesticide AND total coliform;	3.1%	19.2%	19.8%	57.3%
Cumulative Total:	*65.1%*	% wells with; nitrate-N >10mg/L, AND/OR any pesticide detected, AND/OR total coliform positive.		
Cumulative total: as above,	*45.5%*	BUT with fecal coliform positives instead of total coliform bacteria.		

pathway may simply be that the well is tapping shallow groundwater, or it may be related to features of the water-supply system (use of cisterns or other outside storage structures), or it may be related to defects in the well or water-distribution system that allow coliforms to enter. Presence of a cistern or storage tank in the distribution system may act as a source for coliforms. For example, it has been observed that coliforms will appear in systems with a cistern or storage tank even though coliforms are not present at the wellhead. Also, past studies have suggested that the pathway into the water supply may be different for various contaminants (Hallberg et al., 1983a; Kross et al., 1990). Clearly the presence of fecal coliforms *and* high nitrates can be indicative of contamination related to sewage effluents or manure, but even this relationship is not clearly defined. In depth statistical analysis of the SWRL survey data and inventories showed, for example, that wells located *in* feedlots had significantly higher concentrations of nitrate, but *not* bacteria problems and that wells located closer to septic systems actually showed less coliform positives than wells further away (Hallberg et al., 1992; Kross et al., 1990).

Analysis of the full SWRL survey data showed that while several site/well system factors are associated with water quality, most are subordinate to, or interrelated with the overriding factors of well (and casing) depth and well construction type (Hallberg et al., 1992). Shallow (<50 feet deep) wells of any construction type show the greatest proportions of all contaminants; coliforms, nitrate, and pesticides. Large-diameter seepage wells, which

Table 10. Summary of coliform data in relation to nitrate concentrations and atrazine and pesticide detections.

% of total coliform positive samples that had nitrate-N >10 mg/L;	25%	
% of fecal coliform positive samples that had nitrate-N >10 mg/L;	27%	
% of samples with stated water quality attribute, that were also positive for fecal and/or total coliform:	**Total Coliform positive**	**Fecal Coliform positive**
% of samples with:		
nitrate-N >10 mg/L	75%	38%
parent atrazine detection	28%	28%
total atrazine detection	56%	21%
any pesticide detection	72%	31%

are typically open to the water table, account for over half of the wells <50 feet deep, state-wide. Thus, they exhibit greater proportions of contamination, particularly for coliform positives. Water distribution and storage systems were not significantly associated with water-quality results, with the exception of the very high proportion of coliform positives associated with the use of cisterns or any other outside water-storage structures (even concrete tanks). Typically 70% or more of total or fecal coliform positive samples are *not* associated with high nitrate or pesticide occurrences. Samples with high nitrate or pesticide detections tend to be total coliform positive and to a far lesser extent, fecal positive. This one-directional relationship is a function of their co-occurrence related to well-depth, well-type, and water-system features.

COMPARISON OF SAMPLE PERIODS

Tables 12 and 13 present a comparison of principal water-quality variables and well depth among the full SWRL survey, the 10-1 and 10-2 10% subset samples, and the 10-3 and 10-4 repeat samplings. While there have been minor changes in the 10% subset, the general make-up of this subpopulation of the SWRL survey remains very similar and very comparable to the SWRL population, as illustrated by the comparative well depth groups (Table 13). In general, average values and proportions of sites affected by the various water-quality contaminants (Table 12) are quite similar across these repeat sampling periods, with a few notable significant differences. The statistical significance is evaluated using various nonparametric measures (see Kross et al., 1990; Rex et al., 1993). In perspective, statistically significant differences are evaluated in a different context than normal for the SWRL 10% results, however. The SWRL 10% sites are evaluated as a subset of the state-wide population of all private, rural wells, as originally defined by the full SWRL well sample (686 sites). The 95% confidence intervals (CIs, Table 12) are calculated in relation to their power to estimate actual proportions in all rural, private wells state-wide. Hence, the 95% CIs for the 10% subset is considerably greater than for the entire SWRL sample population. The full SWRL sample provided estimates of occurrence +/- 3%, at a 95% CI,

Table 11. Summary of coliform bacteria data in relation to nitrate concentration ranges.

Nitrate-N concentration range, in mg/L	% samples in nitrate-N range positive for Total coliform bacteria	Fecal coliform bacteria
<0.1	30%	7%
0.1 to 2.9	78%	26%
3.0 to 10.0	72%	43%
>10.0	75%	38%

whereas the much smaller 10% subset sample has a 95% CI of approximately +/- 10% (partly dependent on the variable in question). (In the media, with public opinion surveys, the 95% CI is often referred to as the "margin of error.") Hence, to be considered statistically significant, in relation to *all wells state-wide*, the change must be quite substantive. Taken as a simple monitoring network, the water quality changes reflected are real, because over 85% of the wells sampled in the 4 periods have remained the same. While some of the changes are significant in relation to the 10% sample, they are not substantive enough to imply *significant* differences, or changes in the entire rural well population. The changes in water quality over time within the 10% subset ("longitudinal" changes) will be further evaluated in subsequent analysis.

Water-quality changes (Table 12) that have been significant in relation to the estimate for all rural wells are: 1) the mean and percent of sites >0.1 mg/L for organic-nitrogen decreased significantly in the 10-3 sample period, and increased back to more typical values in 10-4; 2) the mean and percent of sites >0.05 mg/L for NH_4-N dropped significantly in 10-4, with proportions of wells affected declining from 45-55% to 18%; 3) fecal coliform positives increased from about 7% in the SWRL and 10-1 period to nearly 19% in 10-3 and further increased to 24% in 10-4; and 4) the percent of (parent) atrazine detections increased to 13.5% in 10-3, after being less than 5% in SWRL and 10-1, and 0% in 10-2, but dropped to 6% in 10-4.

Other variations in water quality have not been significant in relation to the estimates for *all rural wells*. The proportion of sites with >10 mg/L NO_3-N has remained relatively stable, ranging from about 18-20%. The mean and median nitrate concentrations did increase from 10-3; the mean NO_3-N during 10-4 was the second highest of any of the sampling periods, and the median the highest yet recorded. The increase in the mean NO_3-N was most noticeable in wells 50-99 feet deep, increasing from 6.1 mg/L in 10-3 to 19.0 mg/L in 10-4 (Table 13). The median, however, decreased slightly. The proportion of sites positive for total coliforms did increase from 45% in SWRL and 10-1 to 49% in 10-3 and to 57% in 10-4. As noted, the relative increase in fecal coliform positives has been much greater and the proportion of total coliform positives that were also positive for fecal bacteria increased from 36% in 10-3 to 42% in 10-4. The majority of the increase in fecal positives came from systems with wells <50 feet deep, increasing from 8% positives in the SWRL survey to 47-48% positives in 10-3 and 10-4.

The percentage of wells with detections of any pesticide has increased slightly from SWRL and 10-1 to 10-4. Atrazine was the only pesticide detected in 10-3, resulting in an *apparent* decrease in the proportion of wells with any pesticide present. However, for cost and technical considerations, 10-3 only included 7 herbicide analytes (alachlor, atrazine, butylate, cyanazine, metribuzin, metolachlor, and trifluralin). When the proportion

Table 12. Comparison of selected water-quality parameters among SWRL 10% repeat samplings.

Analyte	units	State-wide SWRL 1988-1989	10% repeat 10-1 1988-1989	10% repeat 10-2 1988-1989	10% repeat 10-3 10/1990	10% repeat 10-4 6/1991
nitrate-N						
mean	mg/L	6.2	5.4	7.0	5.0	6.8
median	mg/L	0.6	0.0	0.0	1.0	2.2
maximum	mg/L	100.0	31.0	140.0	40.0	110.0
>10mg/L	%	18.3%	20.0%	20.2%	20.3%	19.2%
95% C.I.	%	15.5-21.3%	9.7-30.4%	9.8-30.8%	10.0-30.7%	9.2-29.2%
ammonium-N						
mean	mg/L	0.8	0.9	1.0	1.1	0.4
median	mg/L	0.1	0.3	0.3	0.3	<0.1
maximum	mg/L	11.0	6.7	13.0	13.0	4.9
>0.05mg/L	%	45.2%	51.7%	54.7%	50.1%	17.7%
95% C.I.	%	41.5-49.0%	38.8-64.6%	41.8-67.7%	37.2-63.1%	4.1-30.2%
organic-N						
mean	mg/L	0.3	0.2	0.8	0.1	0.4
median	mg/L	0.1	0.1	0.1	0.0	0.2
>0.1mg/L	%	43.1%	43.3%	43.3%	21.9%	32.4%
95% C.I.	%	39.3-46.8%	30.9-55.6%	30.9-55.6%	11.2-32.6%	15.8-49.0%
total coliform						
MPN>=2.2	%	44.6%	45.4%	42.0%	48.7%	57.3%
95% C.I.	%	40.9-48.3%	33.0-57.8%	29.4-54.6%	35.9-61.5%	44.9-69.7%
fecal coliform						
MPN>=2.2	%	6.7%	- - -	- - -	18.6%	24.2%
95% C.I.	%	1.6-11.6%	- - -	- - -	8.7-28.5%	13.5-34.9%
Any pesticide detection	%	13.6%	14.5%	19.3%	13.5%	19.8%
95% C.I.	%	11.1-16.2%	5.8-23.2%	9.2-29.3%	4.9-22.2%	9.8-29.7%
For Comparative Analytes		*(7 herbicides)*				
detection	%	10.6%	9.8%	14.6%	13.5%	15.8%
95% C.I.	%	8.1-13.1%	1.2-18.4%	4.6-24.4%	4.9-22.2%	6.5-25.0%
atrazine, Total (atrazine plus metabolites)						
detection	%	8.0%	8.2%	3.2%	- - -	10.5%
95% C.I.	%	6.0-10.0%	1.3-15.1%	0.1-7.5%	- - -	2.9-18.1%
atrazine, parent compound only						
detection	%	4.4%	4.9%	0.0%	13.5%	6.0%
95% C.I.	%	2.8-5.9%	0.1-10.3%	0.- 0	4.9-22.2%	0.2-11.8%
mean	µg/L	0.9	0.5	0.0	0.2	0.6
median	µg/L	0.4	0.2	0.0	0.1	0.6
maximum	µg/L	6.6	0.7	0.0	0.9	0.9

Table 13. Summary comparison of water-quality data by well-depth ranges of the full SWRL sample and the 10% subset samplings (10-1, 10-3, and 10-4).

		All Sites	Wells < 50 ft deep	Wells 50-99 ft deep	Wells > 100 ft deep
			relative % of wells of known depth:		
wells in depth range:	SWRL		28%	21%	51%
	10-1		31%	19%	50%
	10-3		33%	19%	48%
	10-4		35%	20%	45%
			% of wells in the well-depth range:		
nitrate-N >10 mg/L;	SWRL	18%	35%	32%	4%
	10-1	20%	36%	20%	0%
	10-3	20%	36%	22%	8%
	10-4	19%	33%	31%	0%
concentrations, mg/L; mean nitrate-N;	SWRL	6.2	11.2	11.0	1.6
	10-1	5.4	9.1	8.0	0.3
	10-3	5.0	9.0	6.1	1.1
	10-4	6.8	10.5	19.0	0.7
median nitrate-N;	SWRL	0.6	6.0	4.3	<0.1
	10-1	<0.1	7.1	4.2	<0.1
	10-3	1.0	4.8	3.2	<0.1
	10-4	2.2	5.5	2.6	<0.1
total coliform positives;	SWRL	45%	72%	52%	27%
	10-1	45%	65%	59%	30%
	10-3	49%	77%	27%	25%
	10-4	57%	88%	53%	30%
fecal coliform positives;	SWRL	7%	8%	12%	2%
	10-1	- - -	- - -	- - -	- - -
	10-3	19%	47%	20%	0%
	10-4	24%	48%	17%	3%
atrazine-parent detections;	SWRL	4%	5%	6%	3%
	10-1	5%	6%	10%	4%
	10-3	14%	21%	15%	6%
	10-4	6%	0%	0%	8%
total atrazine detections; *(atrazine plus metabolites)*	SWRL	8%	10%	12%	6%
	10-1	8%	10%	15%	10%
	10-3	*na*	*na*	*na*	*na*
	10-4	11%	5%	0%	10%

of sites are compared that had detections for only these 7 herbicide analytes common to all the sample periods, 10-3 and 10-4 indicate slight increases over SWRL and 10-1, but not 10-2. In the sense that the other 6 analytes were not detected in 10-3, a significant decrease in their occurrence was noteworthy. (Of the 6 analytes, butylate was not detected in any prior samples and trifluralin has only been detected in a very small portion of sites.)

The increases in fecal coliform positives may be indicative of more local contaminant source influence in the 10-3 and 10-4 sampling which, as discussed below, may be related to the much wetter climatic conditions. However, this increase does not help to explain other changes; the majority of fecal coliform positives are not associated with other contaminant increases. For example, there was a significantly lower correspondence between the occurrence of atrazine and fecal positives in 10-3 or 10-4 than during SWRL and 10-1. During 10-3 no sites with atrazine detections were positive for fecal coliform. Similarly, there was a lower correspondence between total coliform and atrazine in 10-3 and 10-4. For sites with NO_3-N >10 mg/L, the co-occurrence with either coliform was also lower in 10-3 and 10-4.

The change from drought conditions during SWRL and 10-1, to more normal and wetter than normal conditions during 10-3 and 10-4, was not accompanied by as consistent an increase in NO_3-N concentrations, as noted in the long-term water-quality monitoring studies. The mean and median NO_3-N concentrations did increase somewhat, but the proportion of wells >10 mg/L has stayed relatively constant. Pesticide detections increased slightly in 10-3 and 10-4, but the change was more subtle than in the long-term studies. As an integrated sample of wells state-wide, this might be expected, because the sample integrates a variety of well-depths and well types and hydrogeologic settings. Also, the SWRL 10% sample may react more slowly to changing climatic conditions than the relatively responsive Big Spring, Bluegrass, and Floyd-Mitchell project monitoring sites discussed earlier. One indication of this is the low tritium content and therefore relatively old (>20 years) average age of almost half the well-waters sampled during SWRL 10-3 and 10-4. Sampling frequency likely plays another role. The increase in pesticide detections is clearly discernible in the longer-term monitoring programs because they are sampled on a frequent basis, ranging from weekly to quarterly, which makes these effects more apparent.

The change to wetter conditions may explain the increases in total coliform and fecal coliform bacteria. Other studies have noted that bacteria may be rapidly transmitted to the water table by preferential flow through the soil, similar to chemicals. Also, water tables rise during wet periods, and hence, the top of the groundwater system comes closer to the land surface and into contact with soil horizons where coliform bacteria are more abundant and more likely to survive. Hence, with the wetter conditions and increased recharge, there may have been greater movement of bacteria through the soil and through the shallow flow system affecting these water supplies. During the full SWRL, the proportion of coliform positives was highest in the relatively wetter months, even though these were winter months and normally would be periods of low water tables and typically lower coliform positives (see Kross et al., 1990).

State-wide sample data from the UHL show a similar, marked increase in fecal positives. Figure 5 shows the typical, expected seasonal trend of lower coliform positives during the winter, with increasing positives during the warmer and wetter seasons. With the advent of wet conditions in the late winter and spring of 1990 (Fig. 2), the percentage of total and fecal positive samples began to increase. UHL's state-wide data from private water supplies exhibit a slight increase in total coliform positives from 34%, in fiscal year (FY) 1990 (July 1989 through June 1990), to 36% in FY 1991. Fecal positives, however, increased from 6% to 20%, similar to the trends of the SWRL sampling. Monthly summary of these results (Fig. 5) also parallels the 10-4 findings. For June 1991, the UHL results showed 34% of samples positive for fecal coliform, the second highest positive total during the FY 1990 and 1991 period.

The season of sampling in 10-3 and 10-4 also likely influenced other water-quality results. The 10-3 resampling was conducted in October and 10-

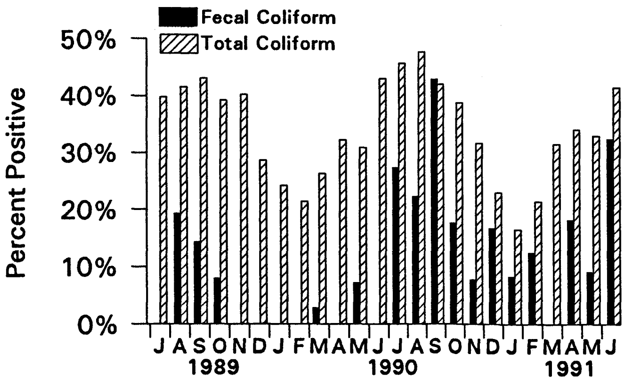

Figure 5. Percentage of samples positive for total or fecal coliform, by month, from the University Hygienic Laboratory's analysis of voluntarily submitted private water samples.

4 in June. While an October sample period usually presents an "average" condition for water-quality parameters such as nitrate, pesticides tend to show a seasonal distribution, with the maximum number of compounds detected in late spring and early summer. By fall only the most persistent and common compounds are usually present, and it is not uncommon for only atrazine to be detected, as was the case in 10-3. For 10-4 there was an increase in detections of other herbicides, as might be expected from the seasonal patterns discerned in other Iowa studies. These trends are not clear cut in the 10% resampling, however. While atrazine detections significantly increased in October 1990 (SWRL 10-3) they declined again in the June 1991 (SWRL 10-4), even though detections of "any" pesticides, including atrazine metabolites, increased. Total atrazine (atrazine and its metabolites) detections did increase slightly from SWRL and 10-1 to 10-4. There is no ready explanation for the decline of parent atrazine, particularly in the wells <50 feet deep.

SUMMARY DISCUSSION

The SWRL 10% subset was resampled in October 1990 and June 1991, after weather patterns in Iowa had changed from the drought conditions of 1988-1989 to more normal and wetter-than-normal conditions. About 19% of the SWRL 10-4 sites showed NO_3-N >10 mg/L; 57% were positive for total coliform bacteria and 24% positive for fecal coliform bacteria. Herbicide compounds were detected in approximately 20% of wells, of which about 6% contained detectable atrazine (the parent compound, no metabolites included). About 11% showed detections of atrazine or one of two common metabolites.

The pattern of greater nitrate concentrations and coliform bacteria occurrences in samples from wells <100 feet deep and lower contaminant levels in wells $\geq$100 feet deep, continued to be statistically significant in the 10-3 and 10-4 sampling. Using tritium (^3H) analysis as a groundwater dating tool, wells $\geq$100 feet deep were several times as likely to produce groundwater with <6+/-4 T.U., which averages >20 years old, than wells <100 feet deep. Groundwaters containing detectable tritium showed much higher rates of nitrate, and total- and fecal-coliform contamination, as would be expected. The data indicate a relationship between shallow wells, relatively recently recharged groundwaters, and higher rates of contaminant occurrence. All of the wells $\geq$100 feet deep that exhibit >10 T.U. (i.e., modern recharge water) are from east-central or northeastern Iowa, where the hydrogeologic conditions promote much greater depth of groundwater circulation. The depth to which contaminants occur is much greater in these areas than elsewhere in the state. This tool provides further insights on the mechanisms of groundwater contamination and may be useful for evaluating the pollution potential of well waters.

Relative to prior sampling of the SWRL 10% subset, the proportion of sites positive for total coliform bacteria and those with any pesticide detection and total atrazine increased slightly. The percentage of wells with NO_3-N >10 mg/L did not change, but the mean and median nitrate concentrations did increase somewhat. The only water-quality changes and trends from the full SWRL and the 10-1 sampling in 1988-1989 to the 10-3 sampling in October 1990, and 10-4 in June 1991, that were significant as estimates for *all* rural well waters, state-wide were: 1) the decline in the detection of dissolved organic-nitrogen in 10-3 and its increase in 10-4; 2) the increase in fecal coliform positives in 10-3 and in 10-4; 3) the decrease in NH_4-N in 10-4; and 4) the increase in atrazine detections in 10-3, which subsequently declined in 10-4.

The change from drought to wetter than normal conditions did not affect the 10-3 and 10-4 sample results as noticeably or consistently as it did other long-term monitoring projects in the state. Atrazine (parent) detections did increase significantly in 10-3, but declined again in 10-4. Other herbicide detections and total atrazine increased somewhat in the June 10-4 sampling, as might be expected from the seasonal patterns discerned in other Iowa studies. However, while nitrate mean concentrations increased slightly, the proportion of wells with NO_3-N >10 mg/L were largely unchanged and total coliform detections increased slightly. Fecal coliform detections significantly increased, but this increase was unrelated to trends in other contaminants. As a sample of wells state-wide, this might be expected, because the 10% subset integrates a variety of well-depths, well types and hydrogeologic settings. During 10-3 and 10-4 the most pronounced changes in nitrate, atrazine, and fecal coliforms occurred in wells <100 feet deep. Also, the SWRL 10% sample may react more slowly to climatic change, relative to the wells used in the longer-term monitoring projects. One indication of this is the low tritium content and therefore relatively old (>20 years) average age of almost half the well-waters sampled during SWRL 10-3 and 10-4. Also, pesticides in water resources tend to show a seasonal distribution and it is not uncommon for fall or winter samples to only show detections of atrazine, typically one of the most persistent pesticide contaminants in the environment in Iowa.

The change to wetter conditions may explain the increases in total coliform and particularly fecal coliform bacteria noted in SWRL 10-3 and 10-4 and state-wide UHL data. Other studies have noted that bacteria, similar to chemicals, may be rapidly transmitted to the water table by preferential flow through the soil. Also, during wet periods, as water tables rise and come closer to the land surface, the groundwater may come into contact with soil horizons where coliform bacteria are more abundant and more likely to survive. Both processes may be contributing to greater transmission of coliforms in the shallow groundwater system and their greater occurrence in shallow water supplies.

One sample was collected from a site which relies on a rural water-supply (RWS) system for household and farm-related uses. The RWS system uses surface water. Four herbicides were detected in this sample: alachlor (0.7 μg/L), atrazine (1.7 μg/L), cyanazine (1.5 μg/L), and metolachlor (1.2 μg/L).

Immunoassay (IMA) methods for triazine scans provided promising results. With the further refinements, these methods may provide a tool for inexpensive screening of water supplies for triazine occurrence.

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