THE IOWA STATE-WIDE RURAL WELL-WATER SURVEY:

October 1990

Repeat Sampling of the 10% Subset

Technical Information Series 25

Iowa Department of Natural Resources
Larry J. Wilson, Director
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THE IOWA STATE-WIDE RURAL WELL-WATER SURVEY: OCTOBER 1990, REPEAT SAMPLING OF THE 10% SUBSET

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ABSTRACT

The Iowa Department of Natural Resources, in conjunction with the University of Iowa, Center for Health Effects of Environmental Contaminants, 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 a one-time 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 provide 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 SWRL 10-2, respectively (abbreviated herein 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 this study, the third sampling of the SWRL 10% subset (referred to here as SWRL 10-3 or 10-3), was to resample the subset during more "normal" climatic conditions, and to assess changes in water-quality that may have occurred. The 10-3 sampling was done in October 1990, after weather patterns in Iowa had changed from the drought conditions of 1988-1989, to more normal, to wetter-than-normal conditions. Long-term monitoring has shown that this mid-fall period is typically "calm," hydrologically, and often represents conditions near the annual average for such parameters as discharge (general water-flux) and nitrate concentrations, though typically fewer pesticide detections occur than in late-spring or summer. For cost and technical reasons there were some differences in the analytes included in SWRL 10-3.

In October, 1990, during SWRL 10-3, about 20% of the sites showed nitrate-N >10 mg/L, almost 50% were positive for total coliform bacteria, 19% positive for fecal coliform bacteria, and 13.5% contained detectable atrazine (the parent active ingredient, no metabolites included). Only 6 other common herbicides were included in the analytes for 10-3; compared to the 17 herbicide active ingredients and 2 metabolites that were included in the full SWRL. None of these other compounds were detected in 10-3, but with the significant increase in atrazine there was no real change in the proportion of wells where *any* pesticide was detected. The pattern of statistically significant differences in nitrate concentrations, bacteria occur-

rences, and atrazine detections between wells <100 and ≥100 feet deep continue to be apparent in the 10-3 sampling.

The only statistically significant changes between the full SWRL (and 10-1) in 1988-1989 and the 10-3 sampling in October 1990, were: 1. the decline in the detection of dissolved organic-nitrogen; 2. the increase in fecal coliform positives; and 3. the increase in atrazine detections. Results for nitrate and total coliform bacteria from SWRL 10-3 are statistically similar to prior samples.

Based on the SWRL 10-3 sampling, and a relatively small subset sample of comparative well and kitchen tap samples (60 wells and 31 kitchen taps), no problems with lead in Iowa's rural drinking water-supplies were discerned. Lead concentrations in rural well-and tap-water are generally below 1 μg/L. No samples analyzed contained lead at a concentration greater than the 15 μg/L USEPA drinking water standard. Also, the 10-3 resampling supported the full SWRL survey's findings on fluoride in well-water supplies. A small portion of wells (2-3%), primarily deep wells, may exceed the recommended concentrations of fluoride, related to dental and skeletal fluorosis (2 and 4 mg/L). Rural well-water supplies should be tested for naturally occurring fluoride before supplements are prescribed for protection of dental cavities in young children.

Within SWRL 10-3, a pilot study was conducted to assess the use of tritium in water-quality assessment studies. Tritium is a naturally occurring isotope that can be used as a groundwater age-dating tool. From a limited number of tritium analyses, wells ≥50 feet deep were several times as likely to produce groundwater with <6+/-4 T.U., which averages >20 years old, than wells <50 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. This tool needs further application and testing.

The change from drought to wetter than normal conditions did not appear to affect the SWRL 10-3 water-quality results to the same degree noted in other long-term monitoring projects in state. While atrazine detections did significantly increase in sample 10-3, the detection of other herbicides fell. Nitrate concentrations, the proportion of wells with nitrate-N >10 mg/L, and total coliform detections were largely unchanged. Fecal coliform detections did increase, but this increase was unrelated to trends in other contaminants. The state-wide nature of the SWRL 10% subset wells may be less responsive to climatic change, relative to the wells used in the longer-term monitoring projects. The long-term monitoring studies also have more frequent sampling which allows more defined trend analysis. 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 of pesticide contaminants in the environment in Iowa.

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 Contaminants (CHEEC), conducted a survey of the quality of private drinking-water supplies used by rural Iowans. Overall responsibility for project management was 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, water-quality results, statistical and hydrological relationships among water-quality parameters, and the 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 a one-time 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 (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 (abbreviated herein 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; state-wide, average precipitation was more than 18 inches below normal. The objective of this study, the third sampling of the SWRL 10% subset of wells (referred to here SWRL 10-3 or 10-3), was to resample the 10% subset during more "normal" climatic conditions, and to assess changes in water-quality that may have occurred. The 10-3 sampling was done in October 1990. It was done at this time for both practical reasons, the schedules of required field staff, and technical reasons; long-term monitoring has shown that the mid-fall period is typically "calm," hydrologically, and often represents conditions near the annual average for such parameters as discharge (general water-flux) and nitrate concentrations, though typically fewer pesticide detections occur than in late-spring or summer.

METHODS

Standardized procedures for participant contact and field activities were employed during SWRL 10-3. 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). A date for well-water collection was established, if the well continued to meet the SWRL criteria for sampling. Sample collection for 10-3 took place between October 2 and October 25, 1990. On-site evaluations and interviews were conducted during the 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.

Field procedures followed those of the 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

Table 1. Summary of chemical parameters analyzed in SWRL samples, laboratory, methods, and data quality requirements. See Hallberg et al. (1990), Kross et al. (1990), and Hall and Moyer (1990) for detailed methods reference.

No.	Analyte name		Lab	Method	MDL /method detection limit	Sample holding time	Extract holding time
	Bacteria:						
1.	total coliform		UHL	MPN	0 to 16+ statistical function	48 hours	N/A
2.	fecal coliform		UHL	MPN	--- as above	---	
	Nitrogen-Series:						
3.	nitrate (+nitrite)-N		UHL	Cu-Cd reduction	0.05 mg/L	28 days	N/A
4.	ammonuim-nitrogen		UHL	color/phenate	0.05 mg/L	28 days	N/A
5.	organic-nitrogen		UHL	TKN, block digestion	0.10 mg/L	28 days	N/A
	Common Ions:						
6.	fluoride		DD	ion specific probe	0.10 mg/L	28 days	N/A
	Field Measurements:						
7.	Specific conductance			conductivity meter	µmho/cm sq. @ 25 degrees C		
8.	Temperature			mercury thermometer	degrees C		
9.	Dissolved oxygen			D.O. probe	mg/L		
	Other chemical tests:						
10.	tritium		ATL	direct scintillation	6 +/- 4 T.U.		
11.	lead		UHL	atomic absorption	0.1 µg/L		
	Herbicides:		Lab	Method	MDL /minimum quantitation limit	Sample holding time	Extract holding time
	common chemical name	common trade name					
12.	alachlor	Lasso	UHL	GC-NPD/ECD	0.1 µg/L	7 days	40 days
13.	atrazine	Atrazine	UHL	GC-NPD/ECD	0.1 µg/L	7 days	40 days
14.	butylate	Sutan	UHL	GC-NPD/ECD	0.1 µg/L	7 days	40 days
15.	cyanazine	Bladex	UHL	GC-NPD/ECD	0.1 µg/L	7 days	40 days
16.	metolachlor	Dual	UHL	GC-NPD/ECD	0.1 µg/L	7 days	40 days
17.	metribuzin	Sencor	UHL	GC-NPD/ECD	0.1 µg/L	7 days	40 days
18.	trifluralin	Treflan	UHL	GC-NPD/ECD	0.1 µg/L	7 days	40 days

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 following project laboratories: University Hygienic Laboratory (UHL), the Analytical Toxicology Laboratory (ATL), in the Department of Preventive Medicine and Environmental Health (PM&EH), and the Department of Dentistry (DD), at The University of Iowa. All well-water samples were analyzed for total coliform and fecal coliform bacteria; nitrate (+nitrite)-, ammonium-, and organic-nitrogen; fluoride; lead; and 7 common herbicides: atrazine (Atrazine), alachlor (Lasso), butylate (Sutan), cyanazine (Bladex), metolachlor (Dual), metribuzin (Sencor), and trifluralin (Treflan). All water analyses were performed by the UHL, except for a subset of samples, which were analyzed for radon and tritium by PM&EH, and for fluoride, by the Department of Dentistry. Table 1 presents a summary of chemical parameters analyzed in SWRL 10-3, and the laboratory and abbreviated methods employed. Hallberg et al.(1990) and Kross et al. (1990) provide details on methods and quality-control/quality-assurance procedures.

There were differences in the analytes determined for 10-3, relative to the earlier sampling periods (10-1 and 10-2) collection. This was a result of both technical and economic factors. For example, major ion analyses were dropped, as a one-time geochemical characterization provided during SWRL (see Kross et al., 1990) was viewed as sufficient. Only 7 of the most commonly used herbicide active ingredients were included in the 10-3 water analyses. In the original SWRL survey (and therefore 10-1 and 10-2) 27 pesticide compounds and 5 pesticide metabolites were analyzed for, and included: 17 herbicides and 3 herbicide metabolites; 10 insecticides and 2 metabolites. The seven pesticide compounds included for the 10-3 sampling (Table 1) comprised about 80% of the detections in the primary SWRL survey. Lead and radon in drinking water have emerged as health concerns, and these analytes were added to SWRL 10-3. A pilot project for tritium analyses was also added. This groundwater age-dating tool (e.g., Hendry, 1988) was tested to see if it would provide perspectives on the hydrologic systems supplying the SWRL 10-3 wells.

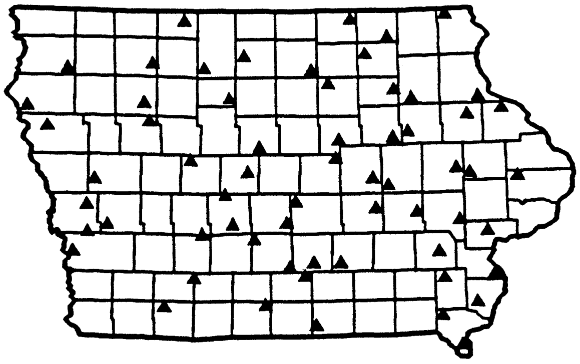

Figure 1. Location of SWRL 10-3 sample sites.

Sixty-four of the 68 10% sites were sampled twice during SWRL (i.e., 10-1 and 10-2). However, various site problems were encountered (e.g., changing to treated water, or rural water supply) 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. Figure 1 shows the general location of these 60 sites.

CLIMATIC AND HYDROLOGIC CONDITIONS

The SWRL survey was conducted during the two driest consecutive years in Iowa's recorded history. During the April 1988 through June 1989 period of sample collection, the average state-wide precipitation was more than 14 inches below normal (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) during SWRL and through 1991. Only two months had 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 having precipitation deficits of over one inch. For the calendar years 1988 and 1989, state-wide precipitation was 10.44 and 7.59 inches below normal, respectively.

As the drought progressed, recharge to groundwater was greatly restricted. Therefore, the potential for pesticides and nitrogen fertilizer to leach through the soil profile and into groundwater supplies was drastically reduced. In turn, this decreased input influenced the quality of groundwater in hydrologic systems which are directly affected by recharge. Relatively long-term monitoring of such hydrologic systems in Iowa (e.g., Big Spring Basin Study, Floyd and Mitchell Counties, and Upper Bluegrass Watershed) suggest that the frequency of pesticide detections and the concentration of nitrates were lower during this dry period than in prior years (Kross et al., 1990). Therefore the drought conditions may have influenced the results of the SWRL survey, presenting a "best-case" situation.

By October 1990, the month in which SWRL 10-3 data were collected, the drought had ended. For 1990, spring and early summer precipitation was above normal, with March, May, June and July 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 7.39 inches above normal (4.68 inches above normal for WY 1990). An evaluation of other longer term groundwater-quality monitoring data, reviewed below, give an indication of changes that occurred between 1988-89 and 1990-91 in the occurrence and/or concentration of contaminants.

Big Spring Basin Study

Beginning in October 1981, precipitation, groundwater discharge, and the concentrations and loads of various chemicals in surface and groundwater have been monitored within and around the Big Spring Basin, Clayton County, Iowa. Groundwater from this 100 mi^2 basin discharges to the surface largely through one spring. Results for Water years (WYs) 1988-1990 are given in Libra et al., (1991; 1992) and summarized below. During WYs 1988-1989, precipitation was 10.3 and 8.65 inches below normal, respectively. In WY 1990, precipitation was 4.9 inches above normal. The drought conditions during WYs 1988-1989 resulted in extremely limited groundwater recharge and runoff (Libra et al., 1991). In response, groundwater discharge and nitrate concentrations exhibited a slow general decline across the two water-years. Average discharge from the spring declined from 36 cubic feet/second (cfs) in WY 1988 to 18 cfs in WY 1989, and climbed to 24 cfs in WY 1990. During WY 1988, the Big Spring groundwater system discharged about 672,000 pounds of nitrate-N, at a flow-weighted mean concentration of 9.6 mg/L. The continuing drought resulted in WY 1989 having the lowest mean annual nitrate concentration (5.7 mg/L) and nitrate-N load (195,000 pounds) for the period of record at Big Spring. The return to normal and wetter-than normal conditions in WY 1990 was accompanied by an increase in the flow weighted mean nitrate-N concentration to 8.2 mg/L, with a total nitrate-N load of 391,000 pounds.

Herbicide concentrations and detections did not directly follow the trends shown by discharge rates and nitrate concentrations. Rather, atrazine, the most commonly detected herbicide in Big Spring groundwater, showed the lowest flow-weighted mean concentration (0.13 μg/L) and frequency of detection (75%) in WY 1988. The groundwater system discharged about 9 pounds of atrazine. In WY 1989, when discharge rates and nitrate concentrations reached their minima, the mean atrazine concentration increased to about 0.6 μg/L, and the herbicide was present in 88% of the groundwater samples from the spring. The total atrazine load was over 21 pounds. For WY 1990, the mean concentration was 1.1 μg/L, atrazine was present in all samples, and almost 50 pounds of the chemical were discharged from Big Spring. The rate of detection and concentrations of other herbicides followed that of atrazine during this period. While nitrate, atrazine, and other herbicides concentrations at Big Spring showed different timing in responses to changing recharge conditions, overall they declined during the drought and then increased after the drought in 1990.

Floyd and Mitchell Counties

A population-based groundwater-quality sur-

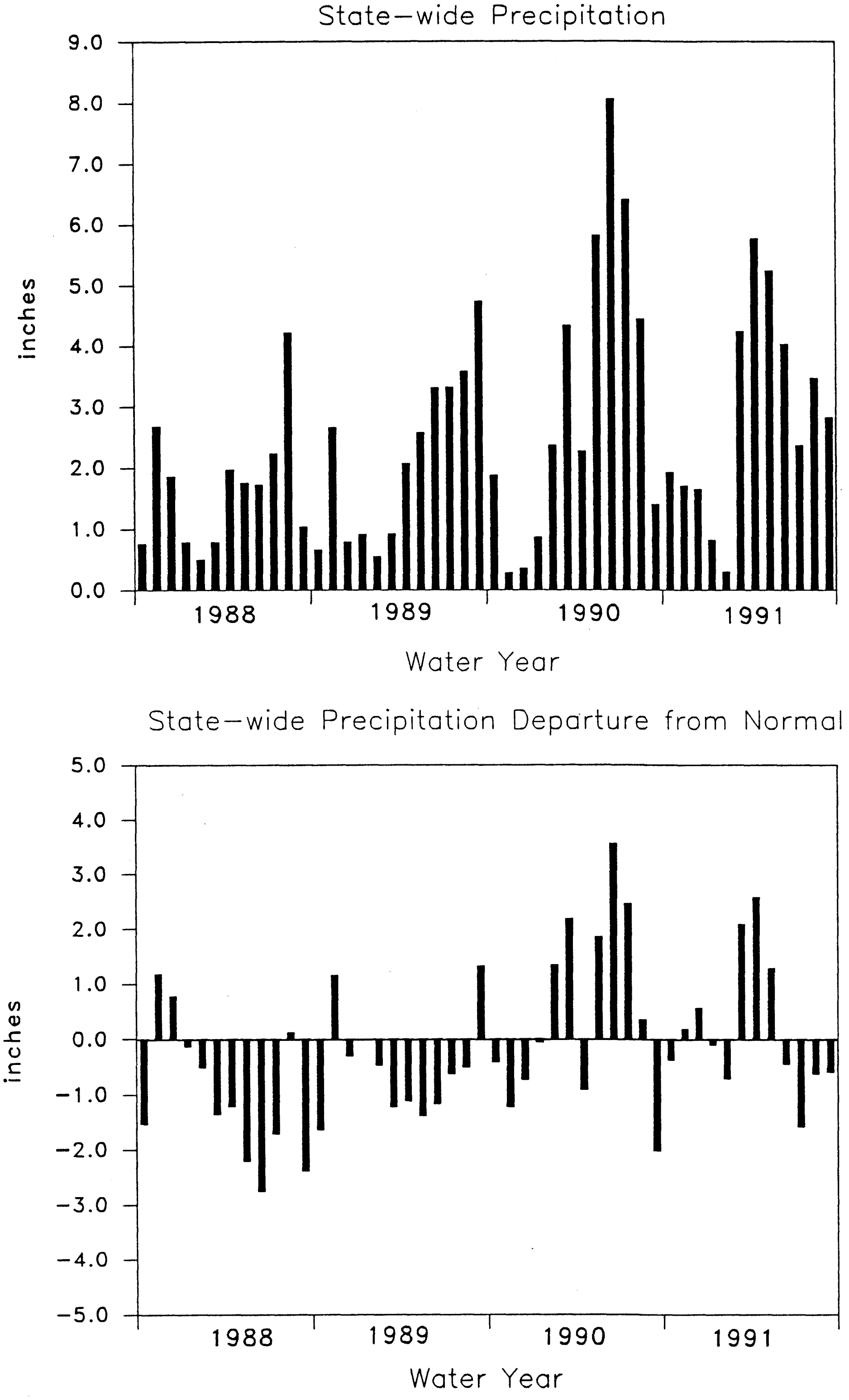

Figure 2. State-wide monthly precipitation and the departure from normal for water-years 1988-1991. SWRL Survey from April 1988 through June 1989; 10-3 in October 1990. (Water years run from October through September of the named year; i.e., Water Year 1990 runs from October 1989 through September 1990.)

vey was conducted in Floyd and Mitchell counties during 1986. (Hallberg and Libra, 1989). As a manageable monitoring network, 17 of the original 184 private wells and three nested research-well sites (Libra and Hallberg, 1985) have been sampled quarterly since October, 1988. Research wells and most private wells in these counties are completed in Devonian-age carbonate aquifers. Figure 3 shows water levels at research well site #1, precipitation, and departure from normal precipitation from January 1985 through June 1991. Water levels 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 decreased from 70% to 40%, and then dropped to 12% in October, 1989. Similarly, the percentage of wells exceeding the recommended health advisory level (HAL) for nitrate (10 mg/L, NO_3-N) declined from a high of 47% in the 1986-1987 period to 12% by October 1989. As the drought persisted, three of the 17 participants had to make changes in their water supply, either drilling new deeper wells or switching to an already existing deep well. By the spring of 1990, precipitation was above normal and by August 1990 water levels at the research well site 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.

Upper Bluegrass Watershed

The Upper Bluegrass Watershed project, a component of the Integrated Farm Management Demonstration Project, has sampled private wells, tile lines, surface waters, and monitoring wells since 1987. Private wells and monitoring wells in the watershed are shallow and open to the water table. From 1987 through 1990, during the drought period, nitrate concentrations declined in all site categories. With the return of more substantial precipitation in 1990, tile lines and surface water samples showed increases in average nitrate-N concentrations, exceeding the recommended drinking water standard (10 mg/L NO_3-N). Interestingly, private wells — both active and inactive -

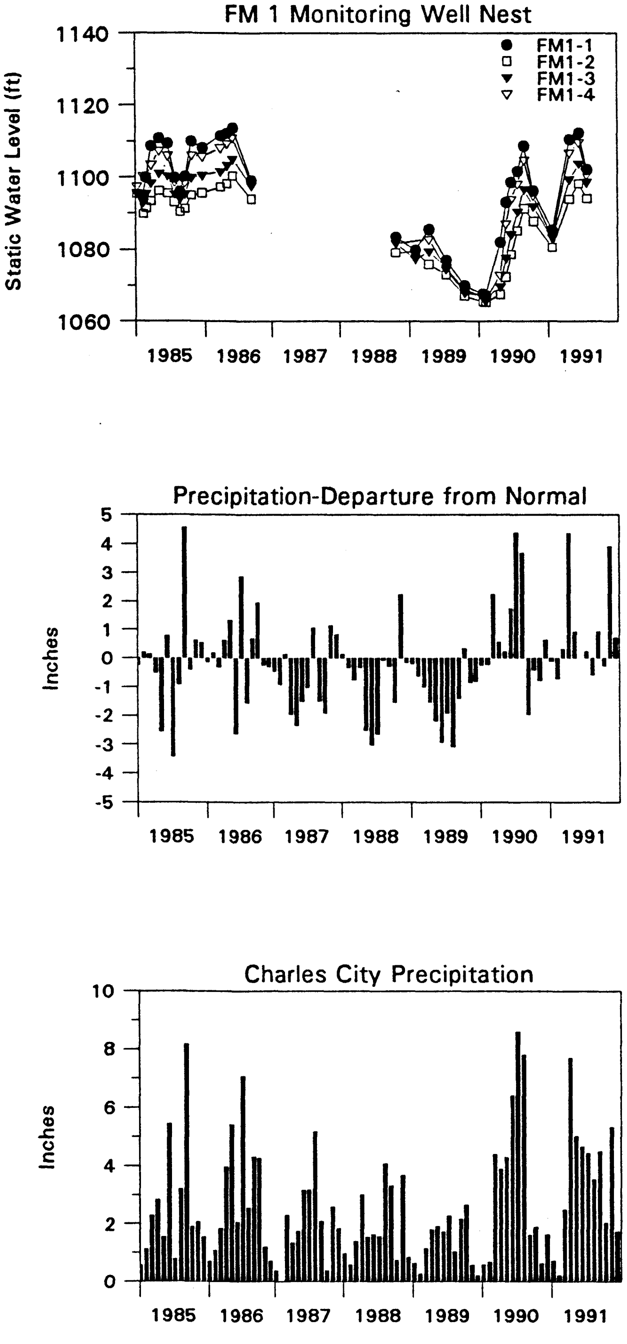

Figure 3. Water levels from a nest of four research-monitoring wells in the Devonian aquifers in Floyd County. Precipitation levels and departure from normal precipitation at Charles City, Floyd County. (The depth of the wells is: 1-1=60 ft; 1-2=140 ft; 1-3=235 ft; and 1-4=350 ft.)

continued to show a decline in annual median nitrate concentration. Seigley and Hallberg (1991) suggest that changes in landuse in the area surrounding these wells has affected the continued decline in nitrate concentrations.

STATISTICAL ANALYSIS

For various statistical analyses and for estimating state-wide proportions of affected wells for SWRL 10-3, population stratum weights were used, based on the rural population density of the counties in Iowa. 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).

Several additional comments are necessary regarding data measurement and statistical analysis. Many environmental data sets, such as SWRL 10-3, contain observations below the detection limit (DL) of some water-quality parameters. This is usually a function of method constraints, and/or cost and time considerations. The statistical techniques used by many environmental researchers, to handle such "left-censored" data, rely on simple procedures of substitution or deletion for estimating the mean and standard deviation. In terms of statistics, substitution or deletion of values present several problems. For example, the substitution of the DL value or the deletion (omission) of <DL values produces larger estimated means and smaller estimated standard deviations, whereas substitution of a zero value or half the DL results in smaller estimated means and larger estimated standard deviations (see Newman and Dixon, 1990). Until other statistical techniques that more adequately handle left-censored data are more widely available, substitution or deletion of <DL values, plus the use of nonparametric descriptors of central tendency (median) and dispersion, provide the best estimators for describing water-quality parameters. As in previous reports, we substitute a zero value for the less than detection values that were reported, unless otherwise noted.

WATER-QUALITY RESULTS

The basic water-quality results from the SWRL 10% sampling periods are presented in the following sections. The water-quality data will be summarized by the concentration or occurrence of particular analytes and the proportion of the wells affected (Tables 2 and 3). Unless otherwise stated, all data are reported as population-weighted values. Later sections of the report will compare results among SWRL 10-1, 10-2, and 10-3, and apparent temporal trends for selected water quality parameters. Results of the radon analysis are not presented here; only initial descriptive statistics are presented for fluoride analysis.

As reported in the previous SWRL study, well depth is one of the most important variables affecting the potential for contaminants from the land surface to affect well water. Therefore, the results will be presented in depth classes. As discussed by Kross et al., (1990), a depth in the range of 50 to 100 feet serves as a definable approximation between shallow and deep wells that exhibit significant differences in water quality among surficially derived contaminants, such as nitrates 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. In the SWRL survey, these wells showed a relatively high degree of contamination (Kross et al., 1990). To allow comparison with past research, data are summarized in classes of <50 feet and ≥50 feet depth and as <50 feet, 50-99 feet, and >100 feet classes. State-wide, the SWRL 10% subset has estimated mean well depth of 110 feet, median of 85 feet, and 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, and maximum of 880 feet. While these values differ slightly for the 10% subset, the proportions of wells in the well depth categories vary little.

Field Measurements

Several field measurements were taken at SWRL 10-3 sites as precursors to sample collec-

Table 2. Summary of selected SWRL 10-3 water-quality results; 10/1990.

	All Wells	Wells <50ft	Wells > =50ft
Nitrate-N:			
% wells >10 mg/L	20.3%	36.2%	13.5%
mean conc., mg/L	5.0	9.0	3.1
max conc., mg/L	40.0	25.0	40.0
HAL, mg/L	10.0	10.0	10.0
Total Coliform Bacteria:			
% sites with TCB	48.7%	77.2%	28.9%
FECAL Coliform Bacteria:			
% sites with FCB	18.6%	47.0%	7.7%
Pesticides:			
% sites with any pesticide detection	13.5%	20.8%	12.9%
Atrazine			
% sites with detections	13.5%	20.8%	12.9%
mean conc., ug/L	0.2	0.1	0.3
max conc., ug/l	0.9	0.2	0.9
HAL ug/L	3.0	3.0	3.0

tion. Temperature and specific conductance were tracked until stable prior to sample collection. Groundwater temperatures typically varied from about 10°C (10th percentile) to 18°C (90th percentile); mean and median temperatures recorded were approximately 12°C with a standard deviation of about 3°C. At some sites, temperatures could have been affected by water-storage systems. SWRL 10-3 samples showed a mean specific conductance of 685 microsiemens/cm @ 25°C, a median of 600, and a range of 310 to 1850. Dissolved oxygen concentrations were also measured in the field. Dissolved oxygen had a mean concentration of 2.3 mg/L, a median of 0.9 mg/L, and a standard deviation of 1.8 mg/L.

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 nitrate-N, often less than 1 mg/L. Concentrations over 3 mg/L nitrate-N are generally considered indicative of anthropogenic sources of pollution (Madison and Burnett, 1985; Hallberg, 1989).

Approximately 20% of SWRL 10-3 sites had nitrate concentrations exceeding the recommended HAL of 10 mg/L of NO_3-N (Table 2). For wells <50 feet deep, about 36% were >10 mg/L; for wells ≥50 feet deep, about 13.5% are >10 mg/L. The mean nitrate-N concentration for all wells was 5.0 mg/L, with a maximum concentration of 40 mg/L. For wells <50 feet deep, the mean concentration was 9.0 mg/l, whereas the mean concentration for wells ≥50 feet deep was 3.1 mg/L. The differences in nitrate-N concentrations between the <50 feet deep and ≥50 feet deep wells is statistically significant (p=0.001), according to Kruskal-Wallis non-

Table 3. Summary of SWRL 10-3 water-quality results; 10/1990.

Water-Quality Parameter	All Sites	Wells <50 ft deep	Wells 50-99 ft deep	Wells >= 100 ft deep
Wells:				
% wells of known depth	100%	33%	19%	48%
median well depth, (feet)	85	30	61	180
Nitrate-N:				
% sites > 10 mg/L (HAL)	20.3%	36.2%	21.7%	8.4%
% sites > 3 mg/L	35.5%	69.8%	60.0%	17.4%
% sites > 0.1 mg/L	45.4%	76.4%	74.4%	17.4%
mean conc., mg/L	5.0	9.0	6.1	1.1
median conc., mg/L	1.0	4.8	3.2	<0.1
max conc., mg/L	40.0	25.0	40.0	11.0
Total Coliform Bacteria:				
% sites positive:	48.7%	77.2%	26.7%	25.3%
Fecal Coliform Bacteria:				
% sites positive:	18.6%	47.0%	20.0%	0.0%
Atrazine:				
% sites with detections	13.5%	20.8%	15.1%	6.4%
% sites > 3.0 µg/L (HAL)	*	*	*	*
mean conc. of detections, µg/L	0.2	0.1	0.1	0.5
median conc., µg/L	0.1	0.1	<0.1	0.5
max conc., µg/L	0.9	0.2	0.1	0.9
Fluoride:				
% sites > 2 mg/L	1.7%	*	*	2.8%
% sites > 4 mg/L (MCL)	*	*	*	*
mean conc., mg/L	0.4	0.4	0.3	0.4
median conc., mg/L	0.3	0.3	0.2	0.3
Dissolved Oxygen:				
mean conc., mg/L	2.3	3.7	1.5	1.4
median conc., mg/L	0.9	3.6	0.8	0.7

Cumulative Proportion of Sites: With- Nitrate-N > 10 mg/L, and/or any pesticide detected, and/or total coliform bacteria -- 62%; and/or fecal coliform bacteria -- 47%

* indicates too few samples / or no samples for this calculation

parametric statistical tests.

Further separation of the well depth classes shows that about 22% of wells between 50-99 feet deep had NO_3-N >10 mg/L while sites with wells $\geq$100 feet deep only showed about 8% >10 mg/L (Table 3). Thirty-six percent of all sampled wells contained >3 mg/L nitrate-N. The proportion of wells exceeding 3 mg/L also decreases with depth, from 70% of the wells <50 feet deep to 17% of the wells $\geq$100 feet deep.

Coliform Bacteria

Results of the bacteria analyses are reported by the UHL as standard MPN values ("most probable number") per 100 milliliters of water. For this analysis, the number of coliform bacteria is calculated statistically rather than from a direct count (see Kross et al., 1990, for discussion). There are 6 MPN numbers reported: <2.2, 2.2, 5.1, 9.2, 16, and 16+. The "<2.2" (a 0 value, but statistically only < 2.2) is reported as safe, while all other positive detections of total coliform or fecal coliform bacteria are reported as "unsafe for human consumption".

Figure 4 shows the distribution of total coliform results for SWRL 10-3 by MPN classes. The results show a bimodal distribution; most samples were either free of total coliform bacteria (0 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). Note that a MPN of <2.2 is always the largest group, regardless of well-depth group or stratification. Because of the bimodal nature of these data and because the standard procedure is to report any values $\geq$2.2 as unsafe, the data are simply summarized as negative (MPN=0, < 2.2) or positive (MPN$\geq$2.2).

About 49% of the SWRL 10-3 samples were positive for total coliform bacteria (Tables 2 and 3). About 77% of the samples from water-systems with wells <50 feet deep were reported as positive for total coliforms; less than 29% of the samples from wells $\geq$50 feet deep were reported as positive for coliforms. Proportions are relatively similar between the 50-99 foot and $\geq$100 foot depth classes.

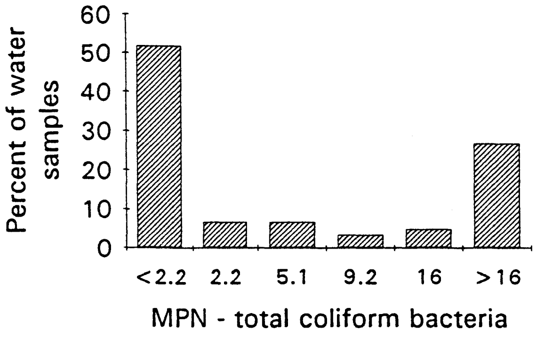

Figure 4. Frequency distribution of total coliform bacteria MPN results.

The presence of total coliform bacteria in a drinking water supply is not in itself a threat to human health. It is an indicator that relatively shallow groundwater or water from the surface is reaching the water-supply system or the well. More detailed site studies show: 1) essentially any well open to the water table will be positive for total coliforms, which are also naturally occurring in the soil biota; and 2) many total coliform positives result from the occurrence of total coliform in the water storage and/or distribution system and not the well. This confounds and limits the inferences that can be made from total coliform data. However, the presence of total coliforms suggests that other contaminants or pathogens may be able to enter the water supply. Kross et al. (1990) present a further, in-depth discussion of the use and limitations of total coliform tests.

Table 2 also gives the occurrence of *fecal* coliform bacteria in the well systems (see Hall and Moyer, 1990 for methods discussion). About 19% of the sites tested positive for fecal coliforms. Systems using wells <50 feet deep exhibited 47% fecal positives; wells $\geq$50 feet only about 8%. While the proportion of total coliform positive sites was similar for the 50-99 and $\geq$100 foot depth classes (Table 3), this was not the case for fecal bacteria; *no* systems with wells $\geq$100 feet deep were positive for fecal coliform. Table 4 shows the weighted proportions of private rural water systems with fecal coliform bacteria and/or total coliform bacteria. Considering sites that were positive for

Table 4. Proportions of private rural water systems with total and fecal coliform bacteria from SWRL 10-3.

	% "safe" MPN =0 (no coliforms)	% "unsafe" MPN >0
SWRL 10-3, all sites *% Total coliform:*	51.3%	48.7%
SWRL 10-3; samples with TC positives, % with Fecal coliform:	64.1%	35.9%
SWRL 10-3, all sites *% Fecal coliform:*	81.4%	18.6%
SWRL 10-3 samples with fecal positive % with Total coliform:	0.0%	100%

total coliform bacteria, only 36% were positive for fecal coliform. In other words, about 64% of the samples with total coliform bacteria positives were considered safe (negative) for fecal coliform. (Because fecal coliform are a specific subset of the more generic total coliforms, 100% of the samples positive for fecal coliform were positive for total coliform.)

Herbicides

Atrazine was the only herbicide detected in the SWRL 10-3 sampling. Atrazine was detected in 13.5% of the samples from all wells, a marked increase from SWRL, 10-1, and 10-2. During October of 1990, in 10-3, atrazine was detected in about 21% of water from wells <50 feet deep and in about 13% of the wells ≥50 feet deep (Table 2). Further subdividing the well depth classes shows 15% detections from samples from wells 50-99 feet deep but only 6% from the wells ≥100 feet deep (Table3). The mean concentration for all wells was 0.2 μg/L with a maximum of 0.9; no sites exceeded the 3.0 μg/L USEPA atrazine MCL. Nonparametric statistical tests (Kruskal-Wallis) indicate that there was no significant differences in atrazine between the <50 and ≥50 feet well depth classes. As in past surveys the significant break comes between those wells ≤99 feet and ≥100 feet.

Lead

As the understanding of the health risks from lead have been refined, exposure to lead through drinking water has gained increased attention. Lead is relatively immobile under the geochemical conditions existing in most potable groundwaters, and therefore concentrations are typically very low in raw water. However, lead contamination of drinking water may also occur at some point in the water-delivery system. Lead contamination commonly results from corrosion of older lead connections or pipes, or lead solder used to join copper pipes in the home. The USEPA recently lowered the recommended standard for lead in drinking water from 50 μg/L to 15 μg/L. Samples for lead analysis were collected during SWRL 10-3; when possible, samples were collected both at the hydrant nearest the well head and at a kitchen tap. The former samples were intended to evaluate lead concentrations in the groundwater, well water, and the latter to evaluate any effects of the distribution system and plumbing. As indicated in Table 1, the MDL for lead was 1 μg/L.

Samples were collected from kitchen taps at 50% of the sites. No samples, from either near the well head or kitchen taps, showed lead concentrations above the USEPA standard. Lead was detected in only 4 samples collected near the well head, and in one kitchen tap sample. The maximum concentration found at sampling points near the well head was 9 μg/L, and the one detection at a kitchen tap was 4 μg/L.

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 short half-life of about 12.4 years. Tritium concentrations are reported in Tritium Units (T.U.) derived from direct 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). 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 (which is only available in a 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. The following guidelines were incorporated during this analysis: 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 clearly to be pre-1953 in age. Groundwater in category 3 can contain only 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).

This part of the 10-3 analytical program was a pilot study to utilize ^{3}H for SWRL sites, with analyses performed by the PM&EH. The detection limit for tritium during SWRL 10-3 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 at the MDL, therefore, are difficult to interpret: they could be "old" or "modern" (albeit on the old end of the modern spectrum). Using Hendry's (1988) guidelines, groundwater with a tritium content of <6+/-4 T.U. has an average age of at least 20 years. (Procedures that lower the detection limit of tritium to 0.2+/-1 T.U. are also available, but only at select laboratories around the U.S. and Canada. These methods eliminate much of the ambiguity present in interpreting the results; these were used for the 10-4 resampling in 1991.)

Samples from 40 of the SWRL 10-3 wells were analyzed for tritium (Table 5). Because only about two-thirds of the wells were sampled for tritium, the results are reported as raw, not weighted, percentages. Nineteen of the wells, or 48%, contained <6+/-4 T.U., indicating the age of the groundwater produced by these wells averages over 20 years. Depths were known for 80% of these wells, and Figure 5 is a plot of tritium concentration versus well depth. Of the wells ≥50 feet deep, 65% produced relatively "old" groundwater, without

Table 5. Summary of Tritium concentration data, related to water-quality parameters and well depth.

Tritium concentration group	*Percent of sites with:* Atrazine detections	Nitrate-N <3 mg/L	Nitrate-N >10 mg/L	Total Coliform Positives	Fecal Coliform Positives
<6 +/-4 TU	16%	89%	0%	26%	0%
>6 +/-4 TU	10%	43%	14%	71%	38%

Well Depth Range	% Wells with <6 +/-4 TU	mean Tritium Content TU	median Tritium Content TU
<50 ft	25%	16	13
>50 ft	65%	6	<6
>100 ft	73%	5	<6

detectable tritium; 73% of the wells ≥100 feet deep produced water samples without detectable tritium. Mean and median tritium concentrations in these depth ranges are essentially at the detection limit. In contrast, only 25% of the wells <50 feet deep produced "old" groundwater, and these samples had mean and median concentrations of 16 T.U. and 13 T.U. This analysis supports the generality that deeper wells produce older water than shallower wells, and hence may not yet be subject to the presence of contaminants simply because the water they tap is currently too old. But the data also suggest that this is only a generalization: 27% of the wells ≥100 feet deep produce relatively younger ("modern") water, while 25% of the wells <50 feet deep produced old water with no tritium above the project MDL.

RELATIONSHIPS AMONG CONTAMINANTS

Table 6 provides an overview of the proportion of wells affected by combinations of contaminants. State-wide, the percentage of sites with nitrate-N >10 mg/L, occurring alone, was 4.8%, 2.0% of the sites had both nitrate-N >10 mg/L *and* atrazine detections, while 13.5% of the sites had both nitrate-N >10 mg/L and total coliform bacteria positives. Approximately 8.3% of the sites had atrazine detections alone (i.e., but neither NO_3-N >10 mg/L nor total coliforms); these sites accounted for over 60% of the total number of sites where atrazine was detected. About 32% of sites were positive for total coliform alone, which was nearly 66% of the total coliform positive sites. No site was found to have all three contaminants occurring simultaneously. In the cumulative sense, over 63% of wells had *either* a nitrate-N concentration >10 mg/L, and/or an atrazine detection, and/or was positive for total coliform bacteria. If fecal coliform positives are used the cumulative proportion of wells with these contaminants was approximately 45%.

Tables 7 and 8 present further relationships among contaminants. As discussed by Kross et al. (1990), total coliform bacteria are *not* good indicators of other kinds of contaminants, such as high nitrate concentrations or the likely presence of pesticides. While the occurrence of high nitrate concentrations is a good predictor of total coliforms, the reverse is not true. In fact, if predictions were based on the presence of total coliform, the probability is much better that high nitrate or pesticides would *not* occur in the water supply. As

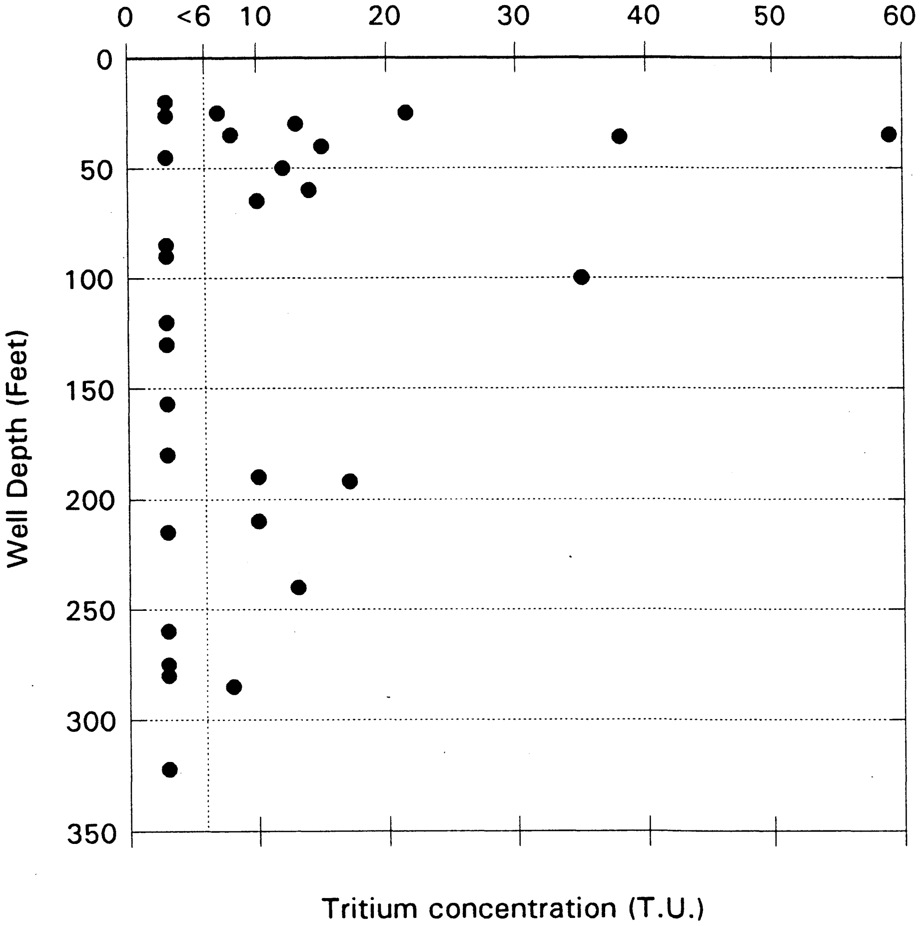

Figure 5. Tritium (^3H) concentration in Tritium Units (T.U.) by well depth.

noted above (Table 6) nearly 32% of total coliform positives occurred alone. As was shown from the primary SWRL survey, and as evident from Table 7 and 8, wells with higher nitrate concentrations are more likely to be coliform positive: 32% of wells with <0.1 mg/L nitrate-N were positive for coliforms, while 67% of those with nitrate >10 mg/L were positive. However, of those systems positive for total coliform only 27% had NO_3-N >10 mg/L, i.e., nearly 3/4 did not. There is an even lower coincidence between atrazine detections and total coliforms. Only about 1/4 of the sites that had atrazine detections also had total coliform present. None of the fecal-positive wells contained detectable levels of atrazine. These relationships reinforce the problems of using total coliform as a meaningful screening tool for chemical contamination. Any apparent relationship among total coliforms, NO_3-N, and pesticide occurrence is a function of their co-occurrence related to well-depth, well-type, and water-system features.

Table 6. Proportion of wells affected by combinations of NO_3-N>10 mg/L, any pesticide detections, and/or total coliform bacteria positives.

	State-wide	-----	Cumulative	-----
Water-quality parameters	SWRL 10-3 %	Nitrate-N >10mg/L %	Atrazine detection %	Bacteria positive %
Nitrate-N >10 mg/L, ALONE;	4.8%	4.8%		
Pesticide(s) detection, ALONE;	8.3%		8.3%	
Total coliform bacteria, ALONE;	32.0%			32.0%
Nitrate-N >10 AND any pesticide; (but no total coliforms)	2.0%	6.8%	10.3%	
Nitrate-N >10 AND tot coliform; (but no pesticide detections)	13.5%	20.3%		45.5%
Pesticide det. AND total coliform; (but no nitrate >10mg/L)	3.2%		13.5%	48.7%
Nitrate-N >10 & any pesticide & total coliform;	0.0%	20.3%	13.5%	48.7%
Cumulative Total, % wells with: nitrate-N >10mg/L, &/or any pesticide detected, &/or total coliform positive;			63.8%	
Cumulative total, as above, BUT with fecal coliform instead of total coliform bacteria;			44.5%	

Tritium-Contaminant Relationships

Table 5 also related contaminant occurrences from SWRL 10-3 wells to their tritium contents. Wells that produced groundwater with <6+/-4 T.U. had no occurrences of NO_3-N >10 mg/L or fecal coliform positives, and had considerably less total coliform positives than did wells with tritium. Forty-three percent of the wells with detectable tritium showed NO_3-N <3 mg/L, as opposed to 89% of those without detectable tritium. Atrazine detections were relatively similar between the two groups. Only 40 wells were sampled for tritium contents, and the results presented here are not definitive, partly because of the limitations imposed by the detection limits in this pilot study. However, the data show the inter-relationship among shallow wells, relatively recently recharged groundwater, and higher rates of contaminant occurrence. Further work with tritium holds considerable promise for helping to assess relationships among contaminants and the potential for contamination to occur.

Table 7. Summary of coliform bacteria data in relation to nitrate concentrations and atrazine detections.

Coliform bacteria class	% samples *with* *total coliform bacteria* that had NO_3-N >10 mg/L	*fecal coliform bacteria* that had NO_3-N >10 mg/L	% of samples *with NO_3-N > 10 mg/L*		%samples *with atrazine detection*	
			in total coliform bacteria class	in fecal coliform bacteria class	in total coliform bacteria class	in fecal coliform bacteria class
no bacteria			33%	71%	76%	100%
positive	27%	32%	67%	29%	24%	0%

Table 8. 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	% samples in nitrate-N range positive for fecal coliform bacteria
<0.1 mg/L	32%	5%
0.1 to 2.9	51%	13%
3.0 to 10.0	75%	47%
>10.0	67%	29%

COMPARISON OF SAMPLE PERIODS

Tables 9 and 10 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 repeat sampling. While there have been minor changes in the 10% subset, the general make-up of this sub-population of the SWRL survey remains very similar and very comparable to the SWRL population, as illustrated by the comparative well depth groups (Table 10). In general, average values and proportions of sites affected by the various water-quality contaminants (Table 9) remained virtually the same across these repeat sampling periods, with a the following notable significant differences: 1) the mean and percent greater than minimum detection level for organic-N decreased significantly in the 10-3 sample period; 2) the percent of atrazine detections increased to 13.5% in 10-3, after being less than 5% in SWRL and 10-1, and 0% in 10-2; and 3) fecal coliform positives increased from about 7% in the SWRL and 10-1 period to nearly 19% in 10-3 (table 2). The differences in the proportion of sites positive for total coliforms and sites with >10 mg/L NO_3-N are not significant.

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 did not include the entire suite of pesticide analytes in-

Table 9. 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**
Nitrate-N					
mean	mg/L	6.2	5.4	7.0	5.0
median	mg/L	0.6	0.0	0.0	1.0
maximum	mg/L	100.0	31.0	140.0	40.0
>10mg/L	%	18.3%	20.0%	20.2%	20.3%
95% C.I.	%	15.5-21.3%	9.7-30.4%	9.8-30.8%	10.0-30.7%
ammonium-N					
mean	mg/L	0.8	0.9	1.0	1.1
median	mg/L	0.1	0.3	0.3	0.3
maximum	mg/L	11.0	6.7	13.0	13.0
>0.05mg/L	%	45.2%	51.7%	54.7%	50.1%
95% C.I.	%	41.5-49.0%	38.8-64.6%	41.8-67.7%	37.2-63.1%
organic-N					
mean	mg/L	0.3	0.2	0.8	0.1
median	mg/L	0.1	0.1	0.1	0.0
>0.1mg/L	%	43.1%	43.3%	43.3%	21.9%
95% C.I.	%	39.3-46.8%	30.9-55.6%	30.9-55.6%	11.2-32.6%
Total coliform					
MPN>0	%	44.6%	45.4%	42.0%	48.7%
95% C.I.	%	40.9-48.3%	33.0-57.8%	29.4-54.6%	35.9-61.5%
Any pesticide					
detection	%	13.6%	14.5%	19.3%	13.5%
95% C.I.	%	11.1-16.2%	5.8-23.2%	9.2-29.3%	4.9-22.2%
For Comparative Analytes		*(7 herbicides)*			
detection	%	10.6%	9.8%	14.6%	13.5%
95% C.I.	%	8.1-13.1%	1.2-18.4%	4.6-24.4%	4.9-22.2%
atrazine, Total (atrazine plus metabolites)					
detection	%	8.0%	8.2%	3.2%	*NA/NS*
95% C.I.	%	6.0-10.0%	1.3-15.1%	0.1-7.5%	
atrazine, parent compound only					
detection	%	4.4%	4.9%	0	13.5%
95% C.I.	%	2.8-5.9%	0.1-10.3%	0.- 0	4.9-22.2%
mean	µg/L	0.9	0.5	0.0	0.2
median	µg/L	0.4	0.2	0.0	0.1
maximum	µg/L	6.6	0.7	0.0	0.9

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

		All Sites	Wells < 50 ft deep	Wells 50-99 ft deep	Wells > 100 ft deep
			% of wells in the well depth range:		
wells in depth range:	SWRL		28%	21%	51%
	10-1		31%	19%	50%
	10-3		33%	19%	48%
atrazine-parent detections;	SWRL	4%	5%	6%	3%
	10-1	5%	6%	10%	4%
	10-3	14%	21%	15%	6%
nitrate-N >10 mg/L;	SWRL	18%	35%	32%	4%
	10-1	20%	36%	20%	0%
	10-3	20%	36%	22%	8%
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
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

cluded in the full SWRL sample (or 10-1 and 10-2). When the proportion of sites are compared that had detections for only the 7 herbicide analytes common to all the sample periods, 10-3 indicates a minor increase over SWRL and 10-1, but not 10-2. In the sense that the other 6 analytes were not detected (alachlor, butylate, cyanazine, metribuzin, metolachlor, and trifluralin) in 10-3, a significant decrease in their occurrence is noteworthy. Of the 6 analytes, butylate was not detected in any prior samples and trifluralin was only detected in a very small portion of sites in the full SWRL population, but not in the 10-1 subset. There were minor differences in the MDLs used in 10-3 , but this would only account for a small portion of the differences. The greatest portion of the differences in the total occurrences of pesticides detected among the different periods is comprised by the analysis for atrazine metabolites in SWRL and 10-1, but not in 10-3.

The increases in fecal coliform positives is indicative of more local contaminant source influence in the 10-3 sampling. However, this increase (and its implications) does not help to explain the increase in atrazine detections. For example, there was a significantly lower correspondence between the occurrence of atrazine and fecal positives in 10-3 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. For sites with NO_3-N >10 mg/L, the co-occurrence of atrazine with total coliform was lower in 10-3, but the co-occurrence with fecal positives was slightly greater.

The change from drought conditions during SWRL, 10-1 and 10-2, to normal or wetter-than-normal conditions during 10-3, was not accompanied by any discernible increase in nitrate concentrations. Likewise, no discernible increase in detections of herbicides, other than atrazine, was found, as was noted in other, more long-term water-quality monitoring. The state-wide nature of 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. Two other factors may play a 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 may make these effects more apparent. Also, 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. Further monitoring, through different seasons, should help to address these effects in this state-wide network.

SUMMARY DISCUSSION

The SWRL 10% subset was resampled in October, 1990, after weather patterns in Iowa had changed from the drought conditions of 1988-1989, to more normal, or wetter-than-normal conditions. About 20% of the SWRL 10-3 sites showed nitrate-N >10 mg/L, almost 50% were positive for total coliform bacteria, 19% positive for fecal coliform bacteria, and 13.5% contained detectable atrazine (the parent active ingredient only, no metabolites). Only 6 other common herbicides (Table 1) were included in the analytes for 10-3, compared to the 17 herbicide active ingredients and 2 metabolites that were included in the full SWRL. None of the compounds other than atrazine were detected in 10-3. However, with the significant increase in atrazine there was no real change in the proportion of wells where *any* pesticide was detected.

The pattern of statistically significant differences in nitrate concentrations, bacteria occurrences, and atrazine detections between wells <100 and ≥100 feet deep continue to be apparent in the 10-3 sampling. The only changes between the full SWRL and the 10-1 sampling in 1988-1989 and the 10-3 sampling in October, 1990 that were significant were: 1) the decline in the detection of dissolved organic-nitrogen; 2) the increase in fecal coliform positives; and 3) the increase in atrazine detections. Results for nitrate and total coliform bacteria from SWRL 10-3 are statistically similar to prior samples.

Based on the SWRL 10-3 sampling, and a relatively small subset of comparative well and kitchen tap samples (60 wells and 31 kitchen taps), no problems with lead in Iowa's rural drinking water-supplies were discerned. Lead concentrations in rural well-and tap-water are generally below 1 μg/L. None of the samples analyzed contained lead at a concentration greater than the 15 μg/L USEPA drinking water standard. Also, the 10-3 resampling, supported the full SWRL survey findings on fluoride in well-water supplies. A small portion of wells (2-3%), primarily deep wells, may exceed the recommended concentrations of fluoride, related to dental and skeletal fluorosis (2 and 4 mg/L). Rural well-water supplies should be tested for naturally occurring fluoride before supplements are prescribed for protection of dental cavities in young children.

Based on a pilot study and a limited number of tritium analyses, wells ≥50 feet deep were several times as likely to produce groundwater with <6+/-4 T.U., which averages >20 years old, than wells <50 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. This tool needs further application and testing.

The change from drought to wetter than normal conditions did not affect the SWRL 10-3 sample in the manner noted at other long-term monitoring projects in state. While atrazine detections did increase in 10-3, the detection of other herbicides fell; however, nitrate concentrations or the proportion of wells with nitrate-N >10 mg/L, and total coliform detections were largely unchanged. Fecal coliform detections did increase, but this increase was unrelated to trends in other contaminants. The state-wide nature of the SWRL 10% subset wells may be less responsive to climatic change, relative to the wells used in the longer-term monitoring projects. 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.

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