Iowa Statewide Rural Well Water Survey Phase 2 (SWRL2)

Results and Analysis

Submitted to:

Watershed Monitoring and Assessment Section
Iowa Department of Natural Resources

Submitted by:

Center for Health Effects of Environmental Contamination
The University of Iowa

August 2009

Table of Contents

List of Tables

Table

Table Page

This report presents results and analysis of the Iowa Statewide Rural Well Water Survey Phase 2 (SWRL2) project, which was conducted from May 2006–December 2008. SWRL2 was supported in part by Contract # 09-04HA-08 from the Iowa Department of Natural Resources. The Contractor on the project was the University of Iowa (UI) Center for Health Effects of Environmental Contamination (CHEEC). Project collaborators and advisors included county Environmental Health and Public Health Departments, the Iowa Department of Natural Resources, the Iowa Department of Public Health, the Iowa Department of Agriculture and Land Stewardship, the University Hygienic Laboratory, the UI College of Public Health, Iowa State University, and the U.S. Geological Survey. Special thanks to private well owners across the state of Iowa for participating in the survey.

Background on private well water surveillance in Iowa Water quality in the U.S. and state of Iowa public water supplies is monitored and regulated under the Safe Drinking Water Act; private drinking water wells are not monitored under any regulatory framework. An estimated 450,000 Iowans currently use private wells for drinking water (Iowa Geological Survey, 2009). Statewide monitoring of private wells in Iowa has been sporadic over the past twenty years. The Iowa Statewide Rural Well Water Survey (SWRL: 1988–89), a one-time random systematic sampling of 686 private rural wells, was designed to estimate both the proportion of rural private wells that that were affected by various environmental contaminants and the proportion of rural Iowa residents using contaminated private well water supplies. SWRL documented widespread nitrate and bacteria contamination and, to a lesser extent, herbicide contamination of wells. Ten percent of SWRL wells were re-sampled in 1990–91. In 1994, 526 Iowa wells were tested in a CDC-funded study in nine states impacted by the 1993 floods. Bacteria and nitrate were frequently detected; atrazine and environmental degradates of atrazine were also detected, but less frequently. No systematic sampling of Iowa private drinking water wells has been done since 1994. In 2002, the Iowa Community Private Well Study (ICPWS) was conducted to develop a baseline of data on drinking water quality in Iowa incorporated communities without public water supplies. ICPWS included a random sampling of 103 wells in a total of 50 communities, mainly in eastern Iowa, and a more intensive focused sampling of 131 wells in 15 communities, also in eastern Iowa. ICPWS wells (community-based) and SWRL wells (rural) are similar in that within a given region they tap the same aquifers, may have similar construction characteristics (age-dependent), and have similar vulnerability issues (land use-dependent). Comparison of ICPWS and SWRL results indicated that private well water quality had not improved over time regarding nitrate, bacteria and atrazine. ICPWS data also showed that arsenic was prevalent in private wells, with ~28% of wells with detectable levels of arsenic (minimum detection limit (MDL) = 0.001 mg/L).

SWRL2 project rationale and objectives SWRL2 (2006–08) was designed as a follow-up to the original SWRL, with a goal of sampling up to 500 private rural drinking water wells. The rationale for conducting SWRL2 was the ongoing public health concern related to poor drinking water quality in private wells documented by SWRL, the 1994 CDC study, and ICPWS. Emerging water contaminants with potential health impacts (arsenic, perchlorate, herbicide degradates) were also included in SWRL2. Perchlorate (Iowa Dept. of Public Health, 2003) and arsenic had been detected in private wells in Iowa; arsenic has also been detected in public water supplies. Degradates of commonly used herbicides have been found in Midwest groundwater sources by USGS (Kolpin et al, 2004). SWRL2 objectives were to estimate the status of drinking

water quality from a sample of Iowa private rural wells, including still active SWRL wells and newer (post-1991 construction) wells; compare current well water quality (for still-active SWRL wells) to SWRL baseline data to estimate trends over the past 15 years, and collect baseline data for emerging contaminants in private well water.

SWRL2 sampling frame A total of 473 private drinking water wells located in 89 counties were each sampled once from May 2006–December 2008 (Table 1). One well was sampled twice for nitrate (in 2006 and 2007); both samples are included in these analyses. One hundred sixteen (116) of these wells (still active original SWRL wells) were sampled in 2006, 6 wells were randomly selected from 28 wells in an intensive well water sampling program in Carroll County (2008). The remaining 351 wells were randomly selected from the IDNR's Private Well Tracking System (PWTS). Ten counties had few (or no) wells in the PWTS. Well owners were contacted by mail and by telephone to solicit their participation. County environmental health specialists/sanitarians contacted well owners to arrange a time to collect well water samples. A sampling frame was developed that defined "wet" months as April–September and "dry" months as October–March, based on historical precipitation records (see Table 29). Two hundred ninety-eight (298) wells were sampled in wet months; 175 were sampled in dry months. The disparity in sampling (wet vs. dry) was due to sanitarian schedules being more flexible in the spring through summer months, and to colder weather in the dry period impacting the ability to sample wells.

Well construction and site surveys A well construction and site survey was mailed to participating well owners for review and updating. Information from the original SWRL survey was included for the 116 SWRL wells. Information from the PWTS was provided for the wells randomly selected from that database. Initial response on returning surveys was poor; intensive follow-up that included re-mailing of surveys and telephone calls was conducted by study staff. Final response rates on the surveys were 94% for wells sampled in 2006, 85% for wells sampled in 2007, and 82% for wells sampled in 2008. The overall 3-year response rate was 87%; 412 surveys were returned with verified or updated information. In an attempt to locate missing information on key variables (i.e., year well was constructed, well depth, casing depth), SWRL2 wells were linked to the IDNR GEOSAM database, and an additional review of the PWTS was conducted. After these linkages, 92% of the sampling sites had information on some or all of the key variables. Survey information was double-key entered into the project database to assure the data were entered correctly.

Water quality analytical results Water samples from the 473 wells were analyzed at the UI Hygienic Laboratory (UHL) in Iowa City and Ankeny. Contaminants of interest for SWRL2 are listed in Table 2. UHL analytical methods and QA/QC procedures are detailed in the Appendix. Not all contaminants have 473 samples, either due to problems encountered in shipping samples or during laboratory analyses.

Table 1. Frequency of well water samples (# wells) by County and Year, SWRL2

County	2006	2007	2008	Total		County	2006	2007	2008	Total
Adair	2	1	-	3		**Jefferson ***	1	-	-	1
Adams	-	-	-	-		**Johnson ***	1	2	5	8
Allamakee *	4	2	2	8		**Jones ***	4	1	3	8
Appanoose	-	-	-	-		**Keokuk ***	2	1	3	6
Audubon	-	3	-	3		**Kossuth ***	2	1	2	5
Benton *	1	1	-	2		**Lee**	2	2	-	4
Black Hawk *	2	2	3	7		**Linn**	-	3	4	7
Boone *	1	2	5	8		**Louisa ***	2	3	4	9
Bremer *	2	3	3	8		**Lucas ***	1	-	-	1
Buchanan *	1	2	2	5		**Lyon**	-	-	-	-
Buena Vista*	4	2	1	7		**Madison**	2	-	-	2
Butler *	3	6	4	13		**Mahaska**	1	-	-	1
Calhoun *	1	1	1	3		**Marion ***	2	1	-	3
Carroll *	1	1	6	8		**Marshall**	-	-	-	-
Cass *	2	2	-	4		**Mills**	2	6	4	12
Cedar *	1	4	1	6		**Mitchell ***	3	2	2	7
Cerro Gordo *	1	1	3	5		**Monona**	-	-	-	-
Cherokee *	1	3	2	6		**Monroe**	-	-	-	-
Chickasaw *	2	2	3	7		**Montgomery**	-	4	-	4
Clarke	1	3	-	4		**Muscatine**	-	3	-	3
Clay *	1	2	1	4		**O'Brien**	-	2	-	2
Clayton *	4	3	5	12		**Osceola**	-	-	-	-
Clinton *	2	-	4	6		**Page ***	1	2	-	3
Crawford	-	1	2	3		**Palo Alto**	2	1	-	3
Dallas	2	2	-	4		**Plymouth ***	1	2	2	5
Davis	-	-	-	-		**Pocahontas ***	2	2	2	6
Decatur	-	-	-	-		**Polk ***	1	5	2	8
Delaware *	4	3	3	10		**Pottawattamie ***	5	1	-	6
Des Moines *	3	2	-	5		**Poweshiek ***	2	-	1	3
Dickinson *	2	-	-	2		**Ringgold**	2	2	-	4
Dubuque *	1	1	3	5		**Sac ***	2	2	1	5
Emmet *	1	2	-	3		**Scott ***	1	1	3	5
Fayette *	3	1	3	7		**Shelby ***	1	2	3	6
Floyd *	2	2	2	6		**Sioux ***	1	-	-	1
Franklin *	1	5	2	8		**Story ***	1	1	2	4
Fremont *	2	1	-	3		**Tama**	-	2	3	5
Greene	1	3	-	4		**Taylor ***	1	-	-	1
Grundy *	1	-	-	1		**Union**	1	1	-	2
Guthrie *	1	2	-	3		**Van Buren ***	1	-	-	1
Hamilton *	1	1	2	4		**Wapello**	1	3	-	4
Hancock *	1	1	1	3		**Warren**	-	3	1	4
Hardin *	2	1	4	7		**Washington ***	3	2	2	7
Harrison	1	6	1	8		**Wayne**	-	-	-	-
Henry	1	3	2	6		**Webster ***	2	2	2	6
Howard *	1	4	1	6		**Winnebago ***	3	2	4	9
Humboldt *	3	2	3	8		**Winneshiek**	2	8	6	16
Ida *	1	5	2	8		**Woodbury ***	2	1	2	5
Iowa *	3	1	2	6		**Worth ***	1	5	1	7
Jackson *	2	2	4	8		**Wright ***	1	2	3	6
Jasper *	1	-	-	1						
						Total	143	181	149	473

* Counties with original SWRL wells re-sampled for SWRL2 in 2006

Table 2. SWRL2 Analytes

Common herbicides & OP insecticides: alachlor, acetochlor, atrazine, desethylatrazine, desisopropylatrazine, butylate, carbofuran, cyanazine, chlorpyrifos, ethoprop, fonofos, metolachlor, metribuzin, pendamethalin, phorate, terbufos, trifluralin
Acetanilide herbicide degradates: acetochlor ESA & OXA; metolachlor ESA & OXA; alachlor ESA & OXA
Total coliform bacteria, *E. coli*, enterococci
Nitrate-nitrogen
Nitrite
Ammonia
Chloride
Perchlorate
Orthophosphate as P
Metals: arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, antimony, selenium thallium
Somatic coliphage (virus indicator)

Bacteria: Forty-three percent (43%) of water samples had coliform bacteria detections, 19% had enterococci, and 11% had *E. coli*. Total coliform bacteria (no *E.coli* or enterococci) was detected in 24% of samples, total coliform with enterococci (no *E. coli*) in 8%, total coliform with *E. coli* (no enterococci) in 2%, and total coliform with *E. coli* and enterococci in 8%. Enterococci (no *E. coli* or enterococci) were detected in 3% of samples; *E. coli* was never detected alone.

Table 3. Frequency of bacteria detections

Bacteria	Total # Samples	# Samples < (MDL) (%)	# Samples ≥ MDL (%)	Quartile exposure levels for detections in MPN/100 ml				
				25%	median	75%	Max	Mean
Total Coliform	469	268 (1) (57%)	201(43%) 16 >2400 (3%)	5	30	310	2400	274
Enterococci	459	371 (1) (81%)	88 (19%)	1	4	37	2000	100
E. coli	469	419 (1) (89%)	50 (11%)	1	4	22	1200	53

Nutrients and chloride: Nutrient contamination of groundwater comes mostly from nonpoint sources. Nitrogen and phosphate use on corn from 1991-2005 is shown in Table 4. While nitrogen use has increased over time; phosphate use has remained fairly stable.

Table 4. Fertilizer usage on corn in Iowa from 1991 – 2005 (NASS, 2009)

	1991 (12.5 M acres)			1998 (12.5M acres)			2005 (12.8M acres)		
	% acres treated	Lbs / acre	M lbs applied	% acres treated	Lbs / acre	M lbs applied	% acres treated	Lbs / acre	M lbs applied
Nitrogen	98	120	1469	96	127	1529	92	141	1653
Phosphate	79	58	570	81	61	613	70	64	579

49% of water samples had detectable nitrate-N); 12% had levels ≥10 mg/L (EPA MCL). Forty-five percent (45%) of samples had detectable ammonia and 40% had detectable orthophosphate as P. Nitrate-N (no bacteria) was detected in 20% of samples, nitrate-N with total coliform (no *E. coli* or enterococci) in 12%, nitrate-N with enterococci (no total coliforms) in <1%, and nitrate-N with total coliform and/or *E. coli* in 15%. Chloride is pervasive in Iowa groundwater (94% detections).

Table 5. Frequency of nutrient and chloride detections

Nutrients	Total # Samples	# Samples < (MDL in mg/L)	# Samples ≥ MDL (%)	Quartile exposure levels for detections In mg/L				
				25%	Median	75%	Max	Mean
Nitrate-N (NO_3-N)	474	243 (0.10) (51%)	231 (49%) (56 ≥10mg/L)	1.355	3.97	9.6	63.00	6.766
Ammonia nitrogen as N	473	260 (0.05) (55%)	213 (45%)	0.32	0.69	1.50	13.00	1.21
Orthophosphate as P (Ortho-P)	473	282 (0.02) (60%)	191 (40%)	0.03	0.04	0.06	1.00	0.074
Chloride	473	26 (0.05) (5%)	447 (94%)	1.90	6.60	17.00	230.00	15.40

Pesticides: Atrazine use on corn remained fairly consistent from 1991-2005. Alachlor was replaced by acetochlor in the early 1990s; metolachlor use has dropped considerably since 1991.

Table 6. Herbicide usage on corn in Iowa (NASS, 2009)

	1991 (12.5 M acres)			1998 (12.5M acres)			2005 (12.8M acres)		
	% acres treated	Lbs / acre	M lbs applied	% acres treated	Lbs / acre	M lbs applied	% acres treated	Lbs / acre	M lbs applied
Acetochlor	–	–	–	40	1.9	9.48	32	1.66	6.70
Alachlor	24	2.29	6.75	–	–	–	–	–	–
Atrazine	62	0.95	7.35	67	0.93	7.83	61	1.05	8.27
Metolachlor	42	2.18	11.32	30	2.12	8.07	22	1.53	4.33

Results for triazine herbicides, acetanilide herbicides and organophosphate insecticides show that only atrazine was frequently detected (8% of samples). There were no detections of butylate, carbofuran, chlorpyrifos, cyanazine, ethoprop, fonofos, metribuzin, pendimethalin or terbufos. Atrazine was found without atrazine degradates in six samples, and in combination with degradates in thirty-four samples. Metolachlor was detected without metolachlor degradates in two samples, and in combination with degradates in seven samples.

Table 7. Frequency of pesticide detections

Pesticides	Total # Samples	# Samples < (MDL in µg/L)	# Samples ≥ MDL (%)	Quartile exposure levels for detections in µg/L				
Parent compound				25%	Median	75%	Max	Mean
Acetochlor	469	468 (0.05)	1 (<1%)	0.21	0.21	0.21	0.21	0.21
Alachlor	469	467 (0.05)	2 (<1%)	0.05	0.0525	0.055	0.055	0.0525
Atrazine	469	429 (0.05)	40 (8%)	0.065	0.087	0.115	0.50	0.104
Metolachlor	469	460 (0.05)	9 (2%)	0.110	0.130	0.780	3.70	0.771
Trifluralin	469	468 (0.05)	1 (<1%)	2.3	2.3	2.3	2.3	2.3

Herbicide degradates: Atrazine use since SWRL is reflected in the presence of desethylatrazine (DEA) in SWRL2. Alachlor use stopped in the 1990s; alachlor degradates were commonly detected in SWRL2. Metolachlor use has declined, metolachlor degradates were also common. The 2006 MDL for acetanilide herbicide degradates was 0.025 µg/L; in 2007–08 it was 0.05 µg/L. Acetochlor ethane sulfonic acid (ESA) was detected in 11% of samples, alachlor ESA in 27%, metolachor ESA and metolachlor oxanilic acid (OXA) in 33% and 8%, respectively. DEA (desethylatrazine) was detected in 11% of samples. 14% had one degradate detected, 27% had two or more degradates.

Table 8. Frequency of herbicide degradate detections

Herbicide Degradates	Total # Samples	# Samples < (MDL in µg/L)	# Samples ≥ MDL (%)	Quartile exposure levels for overall detections in µg/L				
				25%	Median	75%	Max	Mean
Acetochlor ESA	141 331	123 (0.025) 296 (0.050)	53 (11%)	0.075	0.110	0.240	1.20	0.201
Acetochlor OXA	141 331	138 (0.025) 328 (0.050)	6 (1%)	0.062	0.0785	0.150	0.150	0.096
Alachlor ESA	141 331	96 (0.025) 250 (0.050)	126 (27%)	0.100	0.230	0.570	7.100	0.5114
Alachlor OXA	141 331	133 (0.025) 325 (0.050)	14 (3%)	0.067	0.155	0.420	4.20	0.5395
Desethylatrazine (DEA)	469	419 (0.050)	50 (11%)	0.068	0.093	0.140	0.370	0.109
Deisopropylatrazine (DIA)	469	465 (0.050)	4 (<1%)	0.05	0.051	0.057	0.061	0.053
Metolachlor ESA	141 331	87 (0.025) 229 (0.050)	156 (33%)	0.110	0.250	0.610	6.30	0.655
Metolachlor OXA	141 331	122 (0.025) 311 (0.050)	39 (8%)	0.070	0.170	0.340	2.60	0.364

Degradates were detected with bacteria in 4% of samples, with nitrate in 13%, and with nitrate and bacteria in 19%. There was a statistically significant association between detections of degradates and total coliform bacteria (CMH=12.9141, p=0.0003).

Table 9. Co-presence of detections of herbicide degradate and total coliform bacteria

Total coliform bacteria	Herbicide degradates		
	Present	Absent	Total # Samples
Present	98	101	199
Absent	86	177	263
Total	184	278	462

Other compounds: Arsenic was detected in 48% of samples; 8% of samples had ≥0.010 mg/L (EPA MCL). 19% of the samples had arsenic (no bacteria or nitrate), 7% had arsenic and nitrate (no bacteria), 10% had arsenic with bacteria (no nitrate), and 11% had arsenic with nitrate and bacteria. Perchlorate was detected only once.

Table 10. Frequency of detections of other compounds of public health interest

Compound	Total # Samples	# Samples < (MDL)	# Samples ≥ MDL (%)	Quartile exposure levels for detections				
				25%	Median	75%	Max	Mean
Arsenic (total)	473	247 (0.001 mg/L)	226 (48%) (40 ≥0.01 mg/L)	0.002	0.004	0.008	0.160	0.0076
Perchlorate	471	436 (4 µg/L) 34 (8 µg/L)	1 (<1%)	20	20	20	20	20

Data analysis

Univariable analyses of possible relationships between well age (construction date), well depth, distance from septic system to well, sampling season, and sampling region of the state with contaminant presence and concentration were tested using the Cochran-Mantel-Haenszel statistic (CMH, α=0.05, DF=1). Dependent and independent factors were analyzed as categorical variables. Following linkage of surveys with missing data to GEOSAM and PWTS, well age was available for 454 surveys (96%), well depth for 458 surveys (97%), septic system distance from well for 251 surveys (53%), and well casing depth for 188 surveys (40%). A well casing depth analysis was not preformed, due to the limited sample size. Frequencies (detections/concentration) are reported as number of wells.

***Well depth*:** Previous studies have shown a positive correlation between shallow well depth and higher levels of contamination with nitrate and bacteria in private wells (Kross et al., 1993). This may be due to greater vulnerability of shallow aquifers to contamination, poor well construction, or to a combination of factors. Well depth is categorized as <50 feet, 50–100 feet, and >100 feet. Chloride concentration may be as important as well depth; there is more chloride near the surface than in deeper strata. There were 15 wells with unknown well depths; total number of wells varies by table depending on the number of contaminant detections.

Bacteria: There was an association between decreasing bacteria detections and increasing well depth (total coliform bacteria: CMH=40.7679, p<0.0001; enterococci: CMH=33.7603, p<0.0001; *E. coli*: CMH=43.5208, p<0.0001.)

Table 11. Bacteria detections by well depth

Well depth	Total coliform			Enterococci			*E. coli*		
	Present	Absent	Total	Present	Absent	Total	Present	Absent	Total
<50 feet	54	28	82	31	49	80	24	58	82
50–100 feet	58	46	104	26	77	103	15	89	104
>100 feet	80	186	266	28	231	259	10	256	266
Total	192	260	452	85	357	442	49	403	452

Nitrate: There was an association between decreasing nitrate-N concentration and increasing well depth (CMH=21.0960, p<0.0001).

Chloride: There was an association between decreasing chloride concentration and increasing well depth (CMH=61.2861, p<0.0001).

Table 12. Nitrate-N concentration by well depth

Well Depth	Nitrate-N (NO_3-N) in mg/L			Total
	< 0.1	0.1 - < 10	≥10	
<50 feet	19	45	21	85
50–100 feet	47	43	14	104
>100 feet	169	81	18	268
Total	235	169	53	457

Table 13. Chloride concentration by well depth

Well depth	Chloride concentrations (mg/L)				
	<1.90	1.9 - <6.60	6.60 - <17	≥17.0	Total
<50 feet	4	9	38	34	85
50–100 feet	17	25	23	39	104
>100 feet	108	76	45	39	268
Total	129	110	106	112	457

Herbicide degradates: There was an association between decreasing number of herbicide degradate detections and increasing well depth (CMH=41.1158, p<0.0001).

Table 14. Herbicide degradate detections by well depth

Well depth	Herbicide degradates		
	# wells with detections	# wells without detections	Total
<50 feet	56	29	85
50–100 feet	56	49	105
>100 feet	80	189	269
Total	192	267	459

Arsenic: There was no association between arsenic concentration and well depth (CMH=0.6146, p=0.4330).

Table 15. Arsenic concentration by well depth

Well Depth	Arsenic Concentration (mg/L)			Total
	< 0.001	0.001 - < 0.01	≥ 0.01	
<50 feet	44	37	4	85
50–100 feet	47	47	10	104
>100 feet	147	96	24	267
Total	238	180	38	456

Orthophosphate as P: There was an association between decreasing orthophosphate as P concentration and increasing well depth (CMH=10.1147, p=0.0015).

Table 16. Orthophosphate as P concentration by well depth

Well Depth	Ortho-P Concentration (mg/L)			Total
	< 0.001	0.001 - < 0.01	≥ 0.01	
<50 feet	34	42	9	85
50–100 feet	56	39	9	104
>100 feet	183	70	15	268
Total	273	151	33	457

Chloride: Water sample results demonstrated that chloride is pervasive in Iowa groundwater; we therefore conducted an analysis to investigate possible correlations between chloride concentration and presence or concentration of other contaminants.

Bacteria detections were associated with chloride concentration (total coliform bacteria: CMH=28.0837, p<0.0001; enterococci: CMH=24.4225, p<0.0001; *E. coli*: CMH=8.9125, p=0.0028).

Table 17. Bacteria detections by chloride concentrations

Chloride Concentration (mg/L)	Total coliform			Enterococci			*E. coli*		
	Present	Absent	Total	Present	Absent	Total	Present	Absent	Total
<1.90	34	97	131	7	124	131	1	130	131
1.90 - <6.60	40	70	110	16	94	110	9	101	110
6.60 - <17	57	49	106	31	75	106	25	81	106
≥17	66	45	111	34	77	111	15	96	111
Total	197	261	458	88	370	458	50	408	458

Increasing nitrate-N concentration was associated with increasing chloride concentration (CMH=35.4945, p<0.0001).

Table 18. Nitrate concentration by chloride concentration

Nitrate-N Concentration (mg/L)	Chloride concentrations (mg/L)				
	<1.90	**1.9 - <6.60**	**6.60 - <17**	**≥17.0**	**Total**
<0.1	119	76	27	16	238
0.1 - <10	12	30	55	70	167
≥10	–	4	24	25	53
Total	131	110	106	111	458

Degradate detections were associated with chloride concentration (CMH=121.6420, p<0.0001).

Table 19. Presence of herbicide degradates by chloride concentration

Herbicide degradates	Chloride concentrations (mg/L)				
	<1.90	**1.9 - <6.60**	**6.60 - <17**	**≥17.0**	**Total**
Present	1	36	77	83	197
Absent	132	78	33	32	275
Total	133	114	110	115	472

There was an inverse association between arsenic concentration and chloride concentration (CMH=35.4945, p<0.0001).

Table 20. Arsenic concentration by chloride concentration

Arsenic Concentration (mg/L)	Chloride concentrations (mg/L)				
	<1.90	**1.9 - <6.60**	**6.60 - <17**	**≥17.0**	**Total**
<0.001	56	51	62	69	238
0.001 – 0.01	55	50	39	37	181
≥0.01	20	9	5	5	39
Total	131	110	106	111	458

***Well age*:** The age of a well (year constructed) may be related to the presence/absence of contaminants (Iowa well contractor certification requirements were implemented in 1991). Approximately 76% of SWRL2 wells were constructed before 1991; a comparison of presence and concentration of contaminants by well age (older wells: pre-1991 vs. new wells: 1991 and since) was done. There were 19 wells with an unknown age; total number of wells varies by table depending on the number of contaminant detections

Bacteria: There was an association between presence of total coliform bacteria and well age (CMH=9.8225, p=0.0017), with older wells have more total coliform detections. There was no association between presence of enterococci and well age (CMH=0.8661, p=0.3534) or *E. coli* and well age (CMH=1.5139, p=0.2185).

Table 21. Bacteria detections by well age

Well age	Total coliform			Enterococci			*E. coli*		
	Present	Absent	Total	Present	Absent	Total	Present	Absent	Total
Old (<1991)	161	178	339	68	264	332	40	299	339
New (≥1991)	32	74	106	17	87	104	8	98	106
Total	193	252	445	85	351	436	48	397	445

Nitrate: There was no association between nitrate-N concentration and well age (CMH=0.5083, p=0.4759).

Table 22. Nitrate-N concentration by well age

Well age	Nitrate-N (NO_3-N) in mg/L			Total
	< 0.1	0.1 - < 10	≥10	
Old (<1991)	163	135	42	340
New (≥1991)	73	26	11	110
Total	236	161	53	450

Herbicide degradates: There was an association between the presence of herbicide degradates and well age (CMH=5.2167, p=0.0224), with older wells having more degradate detections.

Table 23. Herbicide degradate detections by well age

Well age	Herbicide degradates		
	# wells with detections	# wells without detections	Total
Old (<1991)	151	191	342
New (≥1991)	35	75	110
Total	186	266	452

Arsenic: There was no association between arsenic concentration and well age (CMH=2.0758, p=0.1496).

Table 24. Arsenic concentration by well age

Well Age	Arsenic Concentration (mg/L)			Total
	< 0.001	0.001 - < 0.01	≥ 0.01	
Old (<1991)	169	140	31	340
New (≥1991)	65	38	6	109
Total	234	178	37	449

***Distance from septic system to the well*:** Possible sources of nitrate and bacteria in well water are poorly maintained septic systems in close proximity to wells. In Iowa, county boards of health have responsibility for regulating sewer systems serving <15 persons; a general guideline for distance (separation) from a septic system to a drinking water well is 100 feet. This distance was used to identify possible relationships between the presence of contaminants in well water and proximity of the septic system to the well. Only 53% of the surveys had information on distance from the septic system to the well.

Bacteria: There was an association between a greater number of detections of bacteria and increasing distance of the septic system from the well (total coliform bacteria: CMH=5.4291, p=0.0198; enterococci: CMH= 4.4743, p=0.0344; *E. coli*: CMH=8.9605, p=0.0028).

Table 25. Bacteria detections by distance from septic system to well

Septic system distance to well	Total coliform			Enterococci			*E. coli*		
	Present	Absent	Total	Present	Absent	Total	Present	Absent	Total
≤100 feet	34	66	100	12	86	98	4	96	100
>100 feet	72	75	147	33	110	143	24	123	147
Total	106	141	247	45	196	241	28	219	247

Nitrate: There was no association between nitrate detections and distance from the septic system to the well (CMH=0.5510, p=0.4579); there was no association between nitrate concentration and distance from the septic system to the well (CMH=1.6033, p=0.2054).

Table 26. Nitrate-N detections/concentration by distance from septic system to well

Septic system distance to well	Nitrate-N Detections			Nitrate-N Concentration		
	Present	Absent	Total	<10 mg/L	≥10 mg/L	Total
≤100 feet	46	55	101	91	10	101
>100 feet	75	74	149	126	23	149
Total	121	129	250	217	33	250

Chloride: There was no association between chloride concentration and distance from the septic system to the well (CMH=0.0879, p=0.7668).

Table 27. Chloride concentration by distance from septic system to well

Chloride Concentration (mg/L)	Septic system distance to well		
	≤100 feet	>100 feet	Total
<1.9	36	38	74
1.9 - <6.60	22	37	59
6.60 - <17	18	40	58
≥17	25	33	58
Total	101	148	249

There was no association between orthophosphate as P concentration and distance from the septic system to the well (CMH=0.0451, p=0.8318).

Table 28. Orthophosphate as P concentration by distance from septic system to well

Orthophosphate as P Concentration (mg/L)	Septic system distance to well		
	≤100 feet	>100 feet	Total
<0.01	69	83	152
0.01 – 0.1	19	52	71
≥0.1	13	13	26
Total	101	148	249

***Sampling season*:** A sampling time frame was constructed to look at possible differences in frequency of contaminant detections during historically dry months in Iowa (October–March) compared to historically wet months (April–September). Table 29 presents monthly precipitation over the three year period, compared to normal (historical) monthly precipitation. Previous research had shown that movement of surface-related nonpoint source contaminants is limited during dry conditions (Kross, et al. 1990), so the expectation was there may be more contamination of wells during wetter periods. While 2006 was a normal year for precipitation, 2007 and 2008 were very wet years. Overall, the October–March periods were drier than the April–September periods.

Table 29. Iowa monthly precipitation (inches) by year, 2006–08 (IDALS, 2006–08)

	2006	2007	2008	Normal* precip
January	1.03	0.99	0.70	1.05
February	0.35	1.76	1.79	0.98
March	3.26	3.05	1.25	2.21
April	4.38	4.66	5.88	3.33
May	2.51	5.38	5.84	4.23
June	2.57	3.49	9.01	4.64
July	3.20	3.50	5.92	4.25
August	5.80	9.78	1.98	4.19
September	4.19	2.89	4.30	3.41
October	1.73	5.09	3.35	2.52
November	1.84	0.19	1.78	2.14
December	2.14	2.57	2.00	1.23
Total	33.0	43.35	43.80	34.18

* Iowa precipitation data: 1873–2008

Bacteria: There was no association between total coliform bacteria detections and sampling season (CMH=0.0031, p=0.9559). There was an association between enterococci detections and sampling in wet months (CMH=5.1271, p=0.0236), and a suggestive association between *E. coli* detections and sampling in wet months (CMH=3.7429, p=0.0530).

Table 30. Bacteria detections by sampling season

Sampling Season	Total coliform			Enterococci			*E. coli*		
	Present	Absent	Total	Present	Absent	Total	Present	Absent	Total
Dry (Oct – March)	73	98	171	23	145	168	12	159	171
Wet (April – Sept)	128	170	298	65	226	291	38	260	298
Total	201	268	469	88	371	459	50	419	469

Nitrate: There was no association between nitrate-N concentration and sampling season (CMH=0.2916, p=0.5892). There was a slight difference in percent detections by sampling months: 45% of wells sampled in dry months, 50% of wells sampled in wet months. This difference may be explained by the possibility that nitrate can build up in the unsaturated zone during dry periods and is flushed out into groundwater during wet periods.

Table 31. Nitrate-N concentration by sampling season

Sampling Season	Nitrate-N (NO_3-N) in mg/L			Total
	< 0.1	0.1 - < 10	≥10	
Dry (Oct – March)	97	60	19	176
Wet (April – Sept)	150	111	37	298
Total	247	171	56	474

Herbicide degradates: There was an association between herbicide degradate detections and sampling during the dry season (CMH=6.6097, p=0.0101)

Table 32. Herbicide degradate detections by sampling season

Degradates	Season		
	Dry (Oct–March)	Wet (April–Sept)	Total
Present	96	101	197
Absent	101	174	275
Total	197	277	472

Arsenic: There was no association between arsenic concentration and sampling season (CMH=0.0153, p=0.9015). There was no difference in percent detections by sampling season: 48% of wells sampled in dry months, 47% of wells sampled in wet months.

Table 33. Arsenic concentration by sampling season

Sampling Season	Arsenic Concentration (mg/L)			Total
	< 0.001	0.001 - < 0.01	≥ 0.01	
Dry (Oct – March)	91	70	14	175
Wet (April – Sept)	156	117	25	298
Total	247	187	39	473

Considering contaminant presence by sampling season in wells <100 feet deep (Table 34), only detections of enterococci and herbicide degradates had associations with sampling season. Enterococci was more prevalent during wet seasons (CMH=4.5976, p+0.0320), while herbicide degradate detections were more prevalent during dry seasons (CMH=6.7100, p=0.0096).

***Sampling region of state*:** Analysis of the original SWRL data included a breakdown by regions defined by soil, landscape and hydrogeologic characteristics, which can affect susceptibility of aquifers to contamination, well construction practices and water availability (Kross et al., 1990). Geology and hydrogeologic characteristics can promote and produce conditions impacting the presence and concentration of contaminants in aquifers Erickson and Barnes, 2005; Simpkins and Parkin, 1993). We therefore analyzed SWRL2 data using the SWRL hydrogeologic regions.

Table 34. Contaminant presence by sampling season in wells <100 ft deep

	Season		
Enterococci	**Dry (Oct–March)**	**Wet (April–Sept)**	**Total**
Present	14	38	42
Absent	44	54	98
Total	58	92	150
Degradates			
Present	50	50	100
Absent	16	40	56
Total	66	90	156

Bacteria: There were associations between detections of total coliform bacteria and sampling region (CMH=36.7113, p<.0001), enterococci and sampling region (CMH=20.3997, p<.0001) and *E. coli* and sampling region (CMH=43.8486, p<.0001): all three contaminants were more prevalent in the northwest, south-central and southwest, where wells are generally shallow. The 1988–89 SWRL had a similar regional distribution of coliform bacteria with the northwest (60.1%), southwest (66.6%), and south-central/southeast (62.3%) having the greatest prevalence of wells with coliform detections.

Table 35. Bacteria detections by sampling region

Sampling Region	**Total coliform**			**Enterococci**			***E. coli***		
	Present	**Absent**	**Total**	**Present**	**Absent**	**Total**	**Present**	**Absent**	**Total**
East-central	44	109	153	15	135	150	4	149	153
North-central	36	65	101	17	80	97	6	95	101
Northeast	31	49	80	12	67	79	4	76	80
Northwest	24	7	31	11	20	31	6	25	31
South-central	28	12	40	15	25	40	15	25	40
Southwest	38	26	64	18	44	62	15	49	64
Total	201	268	469	88	371	459	50	419	469

Nitrate: There was an association between nitrate-N concentration and sampling region (Table 36: CMH=5.8228, p=0.0158): higher nitrate-N concentrations (≥10 mg/L) were more prevalent in the northwest (29% of samples) and southwest (18%). East-central and north-central regions had fewer nitrate detections ≥10 mg/L NO_3-N (9% and 8%, respectively). SWRL had a similar distribution of high nitrate wells (northwest: 32.3%, southwest 32.3%). Simpkins and Parkin (1993) showed aquifers under the DM Lobe (north-central Iowa) produce low redox conditions and promote denitrification; the north-central region had the lowest % detections in SWRL2.

Chloride: There was an association between chloride concentration and sampling region (Table 37: CMH= 11.8833, p=0.0006): higher concentrations were prevalent in the south-central and northwest.

Herbicide degradates: There was no association between detections of acetanilide herbicide degradates and sampling region (Table 38: CMH=0.2743, p=0.6005). The original SWRL did not analyze water samples for the acetanilide herbicide degradates.

Table 36. Nitrate-N concentration by sampling region

Sampling Region	Nitrate-N (NO_3-N) in mg/L			Total
	< 0.1	0.1 - <10	≥ 10	
East-central	105	35	14	154
North-central	70	23	8	101
Northeast	34	39	9	82
Northwest	6	16	9	31
South-central	10	26	4	40
Southwest	22	32	12	66
Total	247	171	56	474

Table 37. Chloride concentration by sampling region

Sampling Region	Chloride concentrations (mg/L)				
	<1.90	1.9 - <6.60	6.60 - <17	≥17.0	Total
East-central	52	41	28	33	154
North-central	42	21	19	18	100
Northeast	24	19	19	20	82
Northwest	3	6	12	10	31
South-central	4	6	12	18	40
Southwest	9	21	20	16	66
Total	134	114	110	115	473

Table 38. Herbicide degradate detections by sampling region

Sampling Region	Acetanilide herbicide degradates		
	Present	Absent	Total
East-central	72	84	156
North-central	30	68	98
Northeast	38	44	82
Northwest	16	15	31
South-central	18	21	39
Southwest	23	43	66
Total	197	275	472

Arsenic: There was no association between arsenic concentration and sampling region (Table 39: CMH=0.1434, p=0.7049). Arsenic was most common in the southwest, north-central, and northwest. High arsenic (≥0.01 mg/L) was most prevalent in the north-central region. In the Midwest, high arsenic in public water has been related to the northwest provenance late Wisconsin-aged drift (Erickson and Barnes, 2005); Iowa's north-central region is in this formation. A map of SWRL2 arsenic detections is shown below.

Arsenic detections in SWRL2 (red/large dots ≥0.01 mg/L; blue/small dots 0.001–0.009 mg/L)

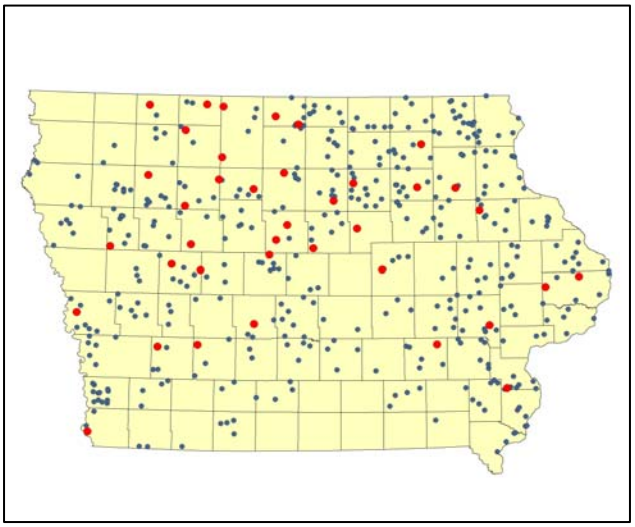

Table 39. Arsenic concentration by sampling region

Sampling Region	Arsenic Concentration (mg/L)			Total
	< 0.001	0.001 - < 0.01	≥ 0.01	
East-central	89	56	9	154
North-central	39	43	19	101
Northeast	58	20	3	81
Northwest	13	17	1	31
South-central	23	16	1	40
Southwest	25	35	6	66
Total	247	187	39	473

Orthophosphate as P: There was an association between orthophosphate as P concentration and sampling region (CMH=28.7705, p<0.0001): higher concentrations were most common in southwest and south-central regions.

Table 40. Orthophosphate as P concentration by sampling region

Sampling Region	Orthophosphate as P (mg/L)			Total
	< 0.01	0.01– <0.1	≥ 0.01	
East-central	102	42	10	154
North-central	70	28	2	100
Northeast	63	19	0	82
Northwest	9	20	2	31
South-central	18	16	6	40
Southwest	20	33	13	66
Total	282	158	33	473

Comparison of SWRL and SWRL2 analytical results

A comparison of results for atrazine (and metabolites DEA and DIA), nutrients (nitrate-N, ammonia) and total coliform bacteria from 116 SWRL wells (1988–89) that were re-sampled in SWRL2 (2006) is shown in Table 41. Percent detections of atrazine and DEA are greater in SWRL2; SWRL2 MDLs were lower than SWRL MDLs. Maximum concentrations of these compounds were higher in SWRL. There were only 2 atrazine detections in the SWRL2 sampling when using the SWRL MDL (0.13 µg/L); 6 SWRL wells had atrazine detections ≥0.13 µg/L. These numbers are insufficient to determine whether there was a statistical difference between SWRL and SWRL2 atrazine detections in these wells over time. Numbers are also insufficient to compare DEA detections in SWRL and SWRL2.

While nitrate continues to be prevalent in private drinking water wells, the McNemar test showed there was a significant decrease in the number of nitrate detections in the 116 wells ($p=0.0029$) in SWRL2 compared to SWRL when using the same detection limit. The Wilcoxon signed-rank test found a significant difference between SWRL and SWRL2 median nitrate concentrations in wells with detections; the SWRL2 median was 1.012 mg/L less than the SWRL median ($p<0.001$).

Ammonia and total coliform bacteria percent detections and median concentrations are similar between SWRL and SWRL2 samplings for these 116 wells.

Table 41. Comparison of results from 116 wells sampled in both SWRL and SWRL2

	SWRL (1988–89)			SWRL2 (2006)		
Contaminant	**wells (%) w/ detections**	**Median Conc.+**	**Max Conc.**	**wells (%) w/detections**	**Median Conc.+**	**Max Conc.**
Atrazine	4%*	0.44 µg/L	3.36 µg/L	9%*	.087 µg/L	0.14 µg/L
Desethylatrazine (DEA)	5%*	0.16 µg/L	1.3 µg/L	11%*	.093 µg/L	0.19 µg/L
Deisopropylatrazine (DIA)	4%*	0.34 µg/L	0.63 µg/L	0%*	<0.05 µg/L	<0.05 µg/L
Nitrate-N (NO3-N)	58%	4.9 mg/L	79 mg/L	47%	2.24 mg/L	47 mg/L
Ammonia-N	55%	0.9 mg/L	7.1 mg/L	50%	0.87 mg/L	7 mg/L
Total coliform bacteria	41%	>16 MPN	>16 MPN	44%	33 MPN	>2400 MPN

***** MDLs – SWRL: atrazine: 0.13 µg/L; DEA, DIA: 0.10 µg/L; SWRL2: atrazine, DEA, DIA: 0.05 µg/L

+ Median concentration for detections

SWRL was conducted during two of the driest years in Iowa on record (1988–89), with more than an 18 inch deficit in average annual rainfall across the state. Previous Iowa studies show that there is limited movement of surface-related nonpoint source contaminants to groundwater during drought conditions (Kross, et al. 1990). 2007 and 2008 were two of the wettest years on record (+ 19 inches in average annual rainfall). A comparison of SWRL (1988–89) and SWRL2 (2007–08) results is presented in Table 42. The number of wells sampled for SWRL2 during this time frame was less than half the number sampled during SWRL. The percent detections and median concentrations of atrazine and DEA were considerably higher in SWRL2, due to the lower SWRL2 MDLs. Maximum concentrations for atrazine, DEA and DIA were higher in SWRL than in SWRL2. Percent detections for nitrate, ammonia, and total coliform bacteria were lower in SWRL2 (2007–08) compared to SWRL.

Comparing overall SWRL results (686 wells) to overall SWRL2 results (473 wells), percent detections were lower in SWRL2 for nitrate-N, ammonia and total coliform bacteria. 18% of SWRL wells had high nitrate-N (≥10 mg/L) compared to 12% of SWRL2 wells.

Table 42. Comparison of results from SWRL (1988–89) and SWRL2 (2007–08)

	SWRL 686 wells				SWRL2 332 wells		
Contaminant	**wells (%) w/detections**	**Median Conc.+**	**Max Conc.**		**wells (%) w/detections**	**Median Conc.+**	**Max Conc.**
Atrazine	5%*	0.41 µg/L	6.61 µg/L		8%*	0.087 µg/L	0.50 µg/L
Desethylatrazine (DEA)	4%*	0.2 µg/L	2.86 µg/L		10%*	0.092 µg/L	0.37 µg/L
Deisopropylatrazine (DIA)	5%*	0.34 µg/L	3.54 µg/L		<1%*	0.052 µg/L	0.061 µg/L
Metolachlor	2%	0.15 µg/L	9.9 µg/L		2%	0.13 µg/L	3.7 µg/L
Nitrate-N (NO_3-N)	59%	5.5 mg/L	140 mg/L		47%	5.3 mg/L	63 mg/L
Ammonia-N	53%	0.9 mg/L	13 mg/L		45%	0.61 mg/L	13 mg/L
Total coliform bacteria	47%	>16 MPN	>16 MPN		39%	59 MPN	>2400 MPN

***** MDLs – SWRL: atrazine: 0.13 µg/L; DEA, DIA: 0.10 µg/L; SWRL2: atrazine, DEA, DIA: 0.05 µg/L

+ Median concentration for detections

Special Studies

Special studies conducted using SWRL2 water samples included a virus coliphage analysis and an arsenic speciation analysis. Brief descriptions of these projects are presented below.

Virus coliphage analysis Coliphages are viruses that infect *E. coli* bacteria; they are shed in human and animal feces. While not known to be hazardous to humans, the presence of coliphage in drinking water may indicate contamination from a relatively fresh fecal source, thus representing an acute health hazard, as disease-producing microorganisms from sewage may be present. As viruses are much smaller then bacteria; coliphage may be present in groundwater in the absence of traditional fecal bacteria indicators (fecal coliform, *E. coli*, enterococci). One hundred fifty-eight (158) SWRL2 water samples (2006–08) were analyzed for virus coliphage; about 1% of samples had male-specific coliphage (infect bacteria via the pili) present, while about 10% of samples had somatic coliphage (infect bacteria via the cell membrane) present.

Table 43. Frequency of virus coliphage detections

Virus coliphage	# Samples w/ coliphage present (%)	# Samples w/ no coliphage	Total samples
Male-specific	2 (1.2%)	156	158
Somatic	16 (10.1%)	142	158

There were no associations between male-specific coliphage and total coliform bacteria (CMH=1.4240, p=0.2327), *E.coli* (CMH=0.9912, p=0.3194), or enterococci (CMH=0.0019, p=0.9651). There were associations between somatic coliphage and total coliform bacteria (CMH=14.2852, p=0.0002), *E. coli* (CMH=35.9217, p<0.0001), and enterococci (CMH=21.1353, p<0.0001). These results provide support for use of somatic coliphage as another indicator of fecal contamination in well water. As reported in the literature, the male-specific coliphage occurrence is lower than somatic coliphage and (as shown in this study) does not indicate private well fecal contamination as well as *E. coli*, enterococci or somatic coliphage.

Table 44. Presence/absence of virus coliphage by presence/absence of bacteria

	Male coliphage			Somatic Coliphage		
	Present	**Absent**	**Total**	**Present**	**Absent**	**Total**
Total coliform						
Present	2	70	72	14	58	72
Absent	0	86	86	2	84	86
Total	2	156	158	16	142	158
E. coli						
Present	1	15	16	8	8	16
Absent	1	141	142	8	134	142
Total	2	156	158	16	142	158
Enterococci						
Present	1	40	41	11	30	41
Absent	1	112	113	3	110	113
Total	2	152	154	14	140	154

Arsenic speciation study In 2006, a CHEEC Seed Grant was awarded to the UHL for the purpose of developing an analytical method to speciate arsenic in groundwater and surface water samples. More than 50 SWRL2 water samples (collected in 2007) were analyzed using an HPLC–ICPMS method implemented and validated at UHL, which resulted in six arsenic species being identified: arsenite (As-III), arsenate (As-V), monomethylarsonic acid (MMA), dimethylarsinic acid (DMA), arsenobetaine (AsB), and 2-Nitrophenol-4-arsonic acid (Roxarson) (Chai et al, 2008). As-III and As-V are the most common forms of arsenic in environmental water, are highly toxic and are considered to be carcinogenic (Casarett and Doull, 1996). The SWRL2 arsenic speciation study found that As-III accounted for up to 75% of the total arsenic concentration in water samples. Arsenic in water is generally measured as total arsenic; speciating arsenic will allow water quality researchers to pinpoint the more problematic inorganic species that have public health implications.

Summary of Findings, and Recommendations

SWRL2 objectives were to 1) estimate the status of drinking water quality in a sample of Iowa private rural wells, including still active SWRL wells and newer (post-1991 construction) wells; 2) compare current well water quality (for still active SWRL wells) to SWRL baseline data to assess trends over the past 20 years; 3) collect baseline data for emerging contaminants in private well water. Pertinent study findings are presented below, and recommendations on addressing contaminant issues are discussed.

Iowa's rural private drinking water wells have several contaminant problems, some long-standing and some emerging. Prevalence of some contaminants is dependent on well depth (shallow alluvial wells are more susceptible to contamination) and region of state (hydrogeologic characteristics of regions impact redox conditions and other factors that can affect contaminant concentrations and movement in soils and groundwater).

- **Bacteria:** Forty-three percent (43%) of SWRL2 wells had total coliform bacteria detections, 19% had enterococci, and 11% had *E. coli*. There were statistically significant associations between decreasing number of bacteria detections and increasing well depth,

and between sampling region and detections of total coliform bacteria, enterococci, and *E. coli*.; all three contaminants were more prevalent in the northwest, south-central and southwest. The percent detections of total coliform bacteria were similar in SWRL and SWRL2, indicating an ongoing problem with contamination of Iowa's private rural wells.

Recommendation: Full use of Grants to Counties funds for annual testing of private wells for bacteria (and possible well remediation, e.g., removal of pits or buried slab upgrade for large diameter wells) is encouraged. Dissemination of information on sources of bacteria, factors impacting bacterial contamination of wells, possible health impacts of consuming contaminated water, and well treatment options is also encouraged. UHL recommends purchasing bottled water intended for drinking, obtaining water from a known safe source, or lastly, boiling water with any detectable bacteria before drinking. A finding of note was that enterococci was more prevalent (additional 8% detections) than *E. coli*, the routine fecal contamination indicator. This has also been demonstrated in other recent private well studies[+]. It is believed that enterococci survives longer in the environment than *E. coli*. More work is needed to evaluate whether enterococci should be added to routine private well water quality testing and/or the fecal indicator of choice for Iowa in the implementation of the Groundwater Rule.

- **Nitrate:** Forty-nine percent (49%) of SWRL2 wells had detectable nitrate-N; 12% had concentrations at or above the EPA MCL for public water (10 mg/L NO_3-N). There were statistically significant associations between decreasing nitrate-N concentration and increasing well depth, and between sampling region and nitrate-N concentration, with high nitrate (≥10 mg/L) most prevalent in the northwest and southwest. The comparison of results for the 116 wells sampled in both SWRL and SWRL2 showed that there were significantly fewer nitrate-N detections during the SWRL2 sampling, and the median nitrate-N concentration was significantly lower in the SWRL2 sampling. Overall, the percent detections for nitrate-N was lower in SWRL2 (374 wells) than in SWRL (686 wells).

  Nitrate contamination of rural drinking water wells is mainly related to agricultural use of nitrogen fertilizers coupled with poorly constructed or poorly maintained wells in areas with shallow alluvial aquifers or in karst regions. The prevalence of high nitrate detections indicates a potential problem for families with very young children that may mix the water with infant formula. Long-term exposure to elevated nitrate-N concentrations in drinking water has been linked to cancer risk, although study findings are mixed (Ward et al., 2005).

  ***Recommendation*:** Continued emphasis on using Grants to Counties funds for annual nitrate testing of private wells, and dissemination of information on factors impacting nitrate contamination of wells and water treatment options are encouraged. While the decrease in the number of nitrate detections and lower median nitrate-N concentration in the 116 SWRL/SWRL2 wells are encouraging, the sample size was small. Regular repeated sampling of a larger subset of SWRL2 wells (perhaps every 3 years) would be useful in following trends for nitrate in private wells. Information on possible health effects from exposure to nitrate in drinking water is available at http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1310926;

Water treatment information can be found at
http://www.uhl.uiowa.edu/services/wellwater/homewater.pdf and at
http://www.nsf.org/consumer/drinking_water/dw_treatment.asp

- **Chloride**: The pervasiveness of chloride in Iowa groundwater was unexpected, as there is no natural source of chloride in groundwater (except for deep saline brine). It is likely that surface sources/activities (e.g., fertilizer salts, de-icing compounds) heavily impact chloride contamination of groundwater across the state*. Chloride concentration was associated with nitrate-N concentration, bacterial detections, and acetanilide herbicide degradate detections.

  Recommendation: Chloride might be considered as an indicator variable for the presence/concentration of contaminants of public health interest in Iowa groundwater. Investigation of the sources of chloride in Iowa groundwater supplies is warranted.

- **Herbicide degradates**: Herbicide degradates (of atrazine and the acetanilide herbicides) were much more prevalent in groundwater than their respective parent compounds: 11% of SWRL2 wells had detections of DEA (8% had atrazine), 11% had acetochlor ESA (<1% had acetochlor), 27% had alachlor ESA (<1% had alachlor), 33% had metolachlor ESA and 8% had metolachlor OXA (2% had metolachlor). There was a statistically significant association between the presence of herbicide degradates and well depth, shallower wells having more detections than deeper wells; there was also an association between the presence of total coliform bacteria and degradate detections. Although there was no association between degradate detections and sampling region, the widespread exposure of rural well water users to herbicide degradates (unknown toxicity) is a public health concern, as some of the parent compounds have known adverse reproductive or developmental effects.

  Recommendation: Identify populations at-risk of exposure by including analysis for herbicide degradates using Grants to Counties funds for wells with total coliform bacteria detections. Encourage partnerships between government, industry and academia to attempt to speed up the process for toxicity testing on the most commonly detected herbicide degradates, for sharing results of toxicity testing, and for increased monitoring for herbicide degradates.

- **Arsenic:** Forty-eight percent (48%) of SWRL2 wells had arsenic detections; 8% had arsenic concentrations at or above the EPA MCL for public water (0.01 mg/L). There was no association between arsenic concentration and well depth or sampling region; arsenic was most prevalent in the southwest, north-central, and northwest. While high arsenic (≥0.01 mg/L) was most common in wells in the north-central region, 30 counties had arsenic detections ≥0.01 mg/L. From a public health perspective, a large number of Iowa private well water users are potentially exposed to arsenic. Arsenic is a known carcinogen (lung, bladder), and exposure to high arsenic concentrations in drinking water has also been associated with non-cancer health effects including skin lesions and cardiovascular problems (ATSDR 2008).

  Recommendation: Identify populations at-risk of exposure by including analysis for arsenic in sampling and testing covered under Grants to Counties. An Iowa Arsenic Groundwater Monitoring Network is being planned that will initially conduct analysis of

factors that impact arsenic concentrations in groundwater. A second phase of that project will include a statewide education outreach program on arsenic in wells with information on well construction/geology/water use risk factors, health effects, and water treatment options to reduce or remove arsenic.

Other variables examined for possible relationships to contaminant presence/concentration in well water included well age (year constructed), sampling season (wet vs. dry months), and distance from septic system to well.

- **Well age (year constructed):** There was a statistically significant association between herbicide degradates and well age, with older wells (constructed before 1991) having more detections, and between total coliform bacteria and well age, again with older wells having more detections. There was no association between presence of enterococci or *E.coli* and well age, or between nitrate-N concentration or arsenic concentration and well age. These results are dependent on the definitions of "older" and "newer" wells, as different years could be used for that definition. Additional analyses could define "older wells as constructed prior to 1991 (Iowa developed mandatory well contractor certification requirements), prior to 1973 (most counties instituted environmental health offices to provide oversight on new well locations and well permitting), or prior to 1980 (implementation of basic well standards/rules and well grouting began statewide).

- **Sampling season:** There was a statistically significant association between presence of herbicide degradates (more detections) and sampling in dry months, and between the presence of enterococci (more detections) and sampling in wet months. There was a suggestive association between the presence of *E. coli* (more detections) and sampling in wet months. There was no association between presence of total coliform bacteria, nitrate-N concentration or arsenic concentration and sampling season. These results may be related to increased surface movement of contaminants to groundwater in wet periods compared to dry periods.

- **Distance from septic system to well:** There was a statistically significant association between the presence of bacteria (total coliforms, enterococci and *E. coli*) and distance from the septic system to the well, with more detections as the distance from the septic system to the well increased. There was no association between the number of nitrate-N detections or nitrate-N concentration and distance from the septic system to the well. While chloride concentration did not correlate with distance from the septic system to the well, the correlation between chloride concentration and bacterial detections suggests that bacteria are more regionally distributed instead of being from point sources; regional sources could include manure spreading and spreading of municipal wastes*.

[+] Personal communication with Nancy Hall, University Hygienic Laboratory.

* Personal communications with William Simpkins, Department of Geological and Atmospheric Sciences, Iowa State University

References

Agency for Toxic Substances and Disease Registry. 2008. Toxicological Profile: Arsenic http://www.atsdr.cdc.gov/toxprofiles/tp2.html

Casarett and Doull's Toxicology: the Basic Science of Poisons, 1996. CD Klaassen, editor. McGraw-Hill Health Professions Division, New York.

Chai Y, Wels BR, Bernholtz SG, Simmons DL. 2008. TP13B arsenic speciation with HPLC-ICPMS and its application to real-world samples. *UHL Technical Report*. University Hygienic Laboratory, Ankeny, IA.

Erickson ML, Barnes RJ. 2005. Glacial sediment causing regional-scale elevated arsenic in drinking water. *Ground Water* 43(6):796-805.

Iowa Department of Agriculture and Land Stewardship, Climatology Bureau. Iowa Monthly Weather Summaries, 2006 – 2008. Des Moines, IA

Iowa Department of Public Health, 2003. Hills, Iowa, Perchlorate Groundwater Contamination Site Fact Sheet. http://www.idph.state.ia.us/eh/common/pdf/env/perchlorate_fact_sheet.pdf

Iowa Geological Survey, Iowa Department of Natural Resources. May, 2009. Personal Communication.

Kolpin DW, Schnoebelen DJ, Thurman EM. 2004. Degradates provide insight to spatial and temporal trends of herbicides in groundwater. *Ground Water*. 42(4):601-608.

Kross BC, Hallberg GR, Bruner DR, et al. 1990. The Iowa State-wide Rural Well-Water Survey: Water Quality Data: Initial Analysis. Technical Information Series 19. Iowa Department of Natural Resources. Des Moines, IA.

Kross BC, Hallberg GR, Bruner DR, Cherryholmes K, Johnson JK. 1992. The nitrate contamination of private well water in Iowa. *Am J Public Health*. 83(2):270-272.

National Agricultural Statistics Service (NASS), 2009. http://www.nass.usda.gov/

Simpkins WW, Parkin TB. 1993. Hydrogeology and redox geochemistry of CH_4 in a late Wisconsinan till and loess sequence in central Iowa. *Water Resources Research* 29(11):3643-3657.

Ward MH, deKok TM, Lavallois P, Brender J, Gulis G, Nolan BT, VanDerslice J. 2005. Workgroup report: Drinking-water nitrate and health – recent findings and research needs. *Environ Health Perspec* 113(11):1607-1614.

List of Acronyms

As-III: Arsenic 3 (arsenite)
As-V: Arsenic 5 (arsenate)
CDC: Centers for Disease Control and Prevention
CMH: Cochran Mantel Haenszel statistic
DEA: desethylatrazine
DF: degrees of freedom
DIA: deisopropylatrazine
ESA: ethane sulfonic acid
GEOSAM: Geologic Sample Database
ICPWS: Iowa Community Private Well Water Study (2002–03)
IDALS: Iowa Department of Agriculture and Land Stewardship
IDNR: Iowa Department of Natural Resources
IDPH: Iowa Department of Public Health
MCL: Maximum Contaminant Level (for public water supplies)
MDL: Minimum Detection Limit
Mg/L: milligrams per liter, or parts per million
µg/L: micrograms per liter, or parts per billion
MPN: most probable number
NO_3-N: nitrate-nitrogen
OXA: oxanilic acid
OP: organophosphate
PWTS: Private Well Tracking System
SWRL: Iowa Statewide Rural Well Water Survey (1988–89)
SWRL2: Iowa Statewide Rural Well Water Survey Phase 2 (2006–08)
UHL: University of Iowa Hygienic Laboratory
USGS: United States Geological Survey

Appendix

UHL Analytical Methods

Common herbicides and organophosphate insecticides – EPA Method 507 - Nitrogen- and Phosphorus- Containing Pesticides by GC with a Nitrogen Phosphorus Detector, Rev 2.1 in Methods for the Determination of Organic Compounds in Drinking Water - Supplement III (EPA/600/R-95-131)

Acid herbicides – EPA Method 515.3, Chlorinated Acids using Liquid-Liquid Extraction, Derivatization and GC with Electron Capture Detection, Rev 1.0 in Methods for the Determination of Organic and Inorganic Compounds in Drinking Water, Volume 1 (EPA 815-R-00-014)

Anions (fluoride, nitrate and nitrite) – EPA Method 300.0, Inorganic Anions by Ion Chromatography, Rev 2.1 in Methods for the Determination of Inorganic Substances in Environmental Samples (EPA/600/R-93/100)

Total Coliform Bacteria and E. coli – Determined by Method 9223 B Chromogenic Substrate Test (Colilert®) in Standard Methods for the Examination of Water and Wastewater.

Ammonia – LAC10-107-06-1J based on EPA Method 350.1, Ammonia by Automated Colorimetry in Methods for the Determination of Inorganic Substances in Environmental Samples (EPA/600/R-93/100)

Perchlorate – EPA Method 314.0, Determination of Perchlorate in Drinking Water by Ion Chromatography

Phosphorous – ortho phosphate in drinking water, LAC-10-115-01-1A based on EPA Method 365.4, Phosphorus by Automated Colorimetry in Methods for the Chemical Analysis of Water and Wastes (MCAWW) (EPA/600/4-79/020).

Metals (Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Hg, Se and Tl) – EPA Method 200.8, Trace Elements by ICP/Mass Spectrometry, Rev 5.4 in Methods for the Determination of Metals in Environmental Samples Supplement 1 (EPA/600/R-94/111)

Viruses – Somatic Coliphage, EPA Method 1602, Single Agar layer Procedure.

UHL - Routine Quality Control Procedures

Quality control procedures was performed as appropriate and specified in the methods referenced. In general, precision was estimated by the preparation and analysis of duplicate samples or matrix spike and matrix spike duplicate samples. Analytical accuracy was estimated by the preparation and analysis of laboratory control samples (laboratory-fortified blanks), sample matrix spikes, and sample matrix spike duplicates. Method specifics vary, but duplicates and spikes or matrix spike, matrix spike duplicate samples were prepared and analyzed at a frequency of 5-10% of all samples analyzed in this study. Typically, method blanks and external reference standards were analyzed each day of analysis and results were within method specified or laboratory determined control limits. For confirmation of pesticide compounds determined using gas chromatography (GC) with electron capture detectors (GC/EC) or nitrogen-phosphorous detectors (GC/NP), sample extracts were split upon injection into two GC columns simultaneously. Each column provides an independent determination. Both columns must agree that the analyte is present and both must agree on the concentration within a margin of error before an analyte is reported. This additional confirmation is not necessary with methods utilizing mass spectrometry for detection.