Iowa DNR Ambient Groundwater Quality Monitoring Program Summary for Fiscal Year 2017

The purpose of the Iowa DNR's ambient groundwater monitoring program is to document the quality of water in Iowa's major aquifers. While public drinking water supplies are required to test for contaminants in finished water, the Iowa DNR's ambient program tests raw (untreated) water, most of which is currently collected from individual public water supply wells. Results of these analyses help us to understand which natural and anthropogenic contaminants are present, how they are distributed across the state, and whether their concentrations change over time. The ambient groundwater quality monitoring effort in fiscal year (FY) 2017 was designed to continue annual sampling for nitrate, and to repeat and expand the 2013 statewide survey for viruses and bacterial pathogens in public wells representing all major aquifers in Iowa. In addition, the ambient groundwater quality monitoring program has provided support for continuous monitoring of nitrate in Big Spring in a cooperative program with IIHR – Hydroscience & Engineering at the University of Iowa, which put a sensor at the Manchester hatchery. These sensors have been in place since December of 2015.

Wells: From October 2016 to February 2017, untreated groundwater samples were collected from 94 public water supply wells in Iowa (Figure 1). Fifty-three wells are considered highly vulnerable to contamination from surface activities because they have less than 50 feet (ft) of confining layer thickness above the screened interval. Thirty-three of these highly vulnerable wells are alluvial wells, and the other highly vulnerable wells are Silurian-Devonian or shallow Cambrian-Ordovician wells in northeast Iowa. Seventeen wells (18%) were of intermediate vulnerability (50 - 99 ft), and 24 wells are considered low vulnerability wells (≥ 100 ft). Most wells (98%) were sampled between October to December, and 2 samples (2%) were collected in early February. Sampling was conducted by staff from the Iowa DNR and the State Hygienic Laboratory (SHL). Well water was analyzed for temperature, pH, turbidity, and dissolved oxygen in the field, and grab samples were transported on ice to SHL where they were analyzed for total suspended solids, chloride, nitrate + nitrite as nitrogen, ammonia as nitrogen, and the indicator bacteria, total coliform and *Escherichia coli* (*E. coli*). Table 1 summarizes the results of these analyses.

Nitrogen: Groundwater samples were analyzed for two forms of nitrogen (N): nitrate + nitrite as N (referred to as nitrate from this point on) and ammonia as N. Thirty-nine of the wells sampled (41%) had detectable levels of nitrite, and fifty-three (56%) of the samples contained nitrogen in the form of ammonia (Table 1). With only four exceptions, wells that contained nitrate did not contain ammonia and vice versa. The FY17 sample set contained a greater percentage of low vulnerability wells compared to FY16, therefore, it is not surprising that a smaller percentage of the samples from FY17 (41%) contained nitrate than in FY16 (60%). The mean (average) concentration of nitrate in samples with detections was 7.0 mg/L. The maximum concentration of nitrate (40 mg/L) was found in a well with known point-source contamination in an alluvial aquifer. In FY17, seven (7%) samples contained nitrate concentrations at or above the drinking water standard of 10 mg/L, and 18 (19%) of samples exceeded 5.0 mg/L nitrate as N. The mean concentration of ammonia as N in groundwater samples with detections was 0.95 mg/L. The maximum concentration of ammonia as N was 6.8 mg/L, which is likely to be derived from the rock that forms the Silurian-Devonian aquifer rather than being caused by surface contamination.

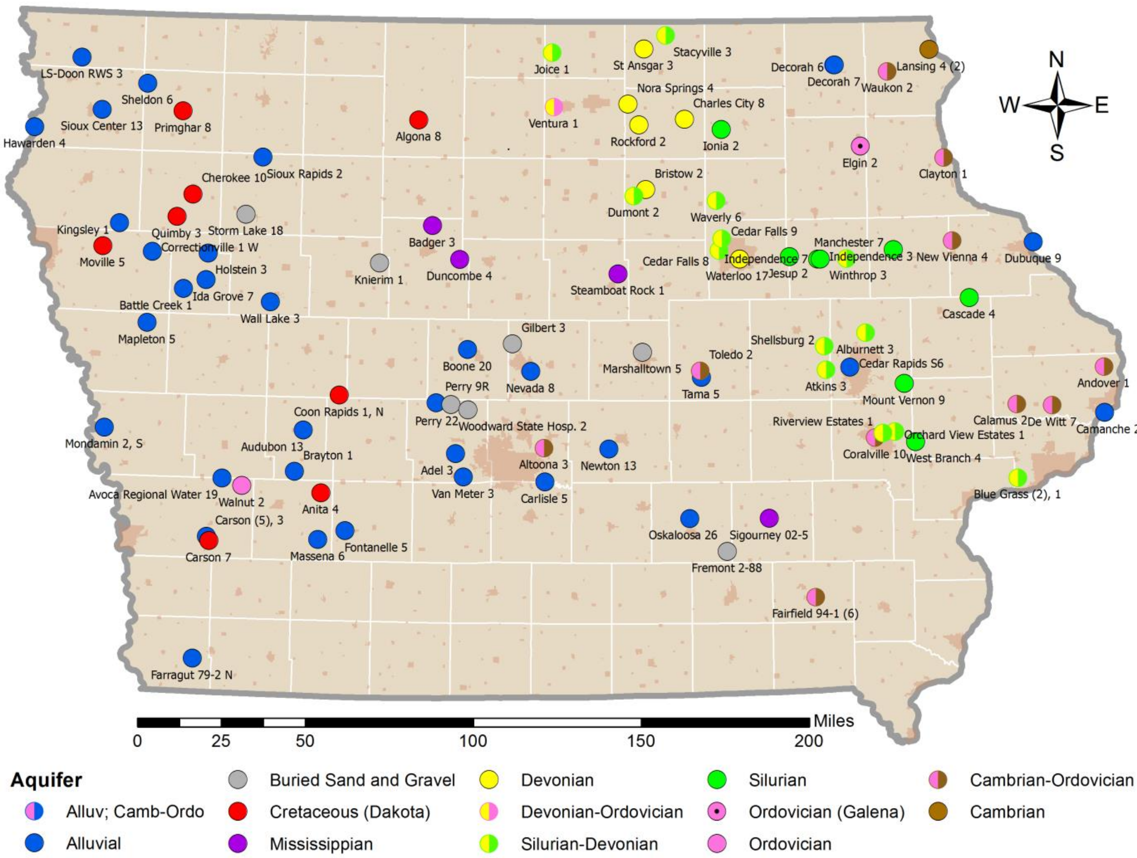

Figure 1. Ambient groundwater quality monitoring sites for FY2017 by aquifer.

Table 1. Summary statistics for field and laboratory parameters analyzed by the State Hygienic Laboratory for groundwater samples collected in FY2017.

	Analyte	Limit of Detection	Units	Method	N	Number of Detections	Percent Detections	Mean of Detections	Median of all values	Maximum
Field	pH			SM 4500 H+ B	94	94	100%	7.28	7.28	7.90
	Turbidity	1	NTU	SM 2130 B	94	55	59%	4.2	0.4	36
	Dissolved Oxygen	0.1	mg/L	ASTM D 888-09 C	94	92	98%	3.4	2.8	9.0
Laboratory	Total Suspended Solids	1	mg/L	USGS I-3765-85	94	37	39%	5.51	ND	34
	Chloride	1	mg/L	EPA 300.0	94	85	90%	28.9	15	230
	Nitrate + Nitrite nitrogen as N	0.1	mg/L	LAC 10-107-04-1J	94	39	41%	7.0	ND	40
	Ammonia Nitrogen as N	0.05	mg/L	LAC 10-107-06-1J	94	53	56%	0.95	0.11	6.8
	Total Coliform	1	MPN/100ml	SM 9223B	94	14	15%	47	ND	540ǂ
	Escherichia coli	1 (10)	MPN/100ml	SM 9223B	94	1	1%	1	ND	1

ǂ - After notification, the water operator collected a new sample for analysis, which had a reported concentration of <1 MPN/100ml.

Microbial Indicators: Two groups of microorganisms, total coliforms and *E. coli*, were analyzed in FY17 using enzyme substrate tests (SM 9223B). Total coliforms were detected in 14 (15%) of wells at concentrations ranging from 1 to 540 most probable number (MPN) per 100 milliliters (ml). Twelve out of the fourteen (86%) detections of total coliforms occurred in samples from wells where the estimated confining layer thickness was less than 100 feet, and ten (71%) of these detections occurred in wells with confining layers less than 50 feet thick. Iowa DNR immediately notified the water operator of the sample containing 540 MPN/100ml. He then collected an additional sample, which was negative for total coliforms. The water sample collected at the same time as the high total coliform sample was not found to contain any viruses or bacterial pathogens. *E. coli* was only detected (at 1 MPN/100ml) in one sample from a carbonate (Silurian-Devonian) aquifer, which also contained 3.1 MPN/100ml total coliforms, but was negative for all of the viruses and bacterial pathogens assessed.

Access to Data: Currently, all ambient groundwater monitoring data supplied by the State Hygienic Laboratory from 2002 – 2017 is housed in the Iowa DNR's EQuIS database and is available on the IASTORET website: https://programs.Iowadnr.gov/iastoret/. Users who search by "Station" can select "Iowa Groundwater Data" from the organization drop-down list, and then they can choose the station and date range of interest. Pharmaceutical and pesticide data analyzed by the USGS for the 2013 study can be found in the USGS NWIS database. Virus data from 2013 and FY2017 will be available in IASTORET in the near future.

Testing for Viruses: Testing for viral and bacterial pathogens required filtration of large volumes (>800 liters) of water. Sterilized tubing was connected directly to sample taps and water was directed through ultrafilters until the target volume was reached, or until the filter became clogged. Filters were shipped overnight to the Laboratory for Infectious Disease and the Environment, and interagency laboratory between USDA-ARS and the USGS Wisconsin Water Science Center in Marshfield, Wisconsin. Samples were analyzed for ten viral pathogens and three bacterial pathogens using quantitative polymerase chain reaction (qPCR) methodology as described in Borchardt et al. (2012).[1] Results of these analyses are summarized in Table 2, where virus and bacteria concentrations are reported in genomic copies per liter (gc/L). Detection limits for qPCR vary depending on the exact procedure that is used (including sample volumes, extraction volumes, template volumes, and replications). Using probit analysis of the proportion of known positive replicate samples that are detected, a 95% limit of detection (95% LOD) can be calculated for the entire analytical procedure. The 95% LOD is the lowest concentration at which there is a 95% probability of detecting a positive sample. Concentrations measured below the 95% LOD are not false-positives, but there is a lower probability of detecting them. In Table 2, we report the 95% LOD determined by Stokdyk et al. (2016)[2] for a waterborne DNA virus (adenovirus), RNA virus (enterovirus), and bacterium (*Salmonella*), which were performed in the same laboratory as our project's analyses. In addition, we report the 95% LOD for the qPCR reaction in genomic copies reaction (gc/rxn) as determined specifically for this project. Standard curve quality assurance parameters will be made available upon request.

Table 2. Summary of virus and bacterial pathogen results for FY2017 (number of samples = 93).

Microorganism	Host	Type	Target	Full Process 95% LOD (gc/L)*	Assay 95% LOD (gc/rxn)ǂ	Detection Frequency (%)	Maximum (gc/L)
Adenovirus group A	Human	DNA virus	Hexon gene	1.5	2.4	0%	-
Adenovirus group B	Human	DNA virus	Hexon gene	1.5	4.5	0%	-
Adenovirus groups C,D,F	Human	DNA virus	Hexon gene	1.5	3.9	1%	0.09
Enterovirus	Human	RNA virus	UTR region	4	2.6	0%	-
Norovirus genogroup I & II	Human	RNA virus	ORF1-ORF2	4	5.9	0%	-
Norovirus genogroup II	Human	RNA virus	ORF1-ORF2	4	5.7	0%	-
Human polyomavirus	Human	DNA virus	T antigen	1.5	3.3	0%	-
Bovine polyomavirus	Bovine	DNA virus	VP1 gene	1.5	3.5	1%	1.8
Hepatitis E virus	Swine	RNA virus	ORF3	4	4	0%	-
Avian influenza A	Birds	RNA virus	matrix gene	4	4.4	0%	-
Pepper mild mottle virus	Peppers	RNA virus	replication protein	4	32.2	4%	26.7
Salmonella sp.	Non-specific	bacterium	invA gene	1.3	8.5	0%	-
Campylobacter jejuni	Non-specific	bacterium	mapA gene	1.3	3.3	0%	-
Enterrohemorrhagic *E. coli*	Non-specific	bacterium	eae gene	1.3	3.6	0%	-

* - As reported by Stokdyk et al. (2016)[2] for a waterborne DNA virus (adenovirus), RNA virus (enterovirus), and bacterium (*Salmonella*).
ǂ - As determined for this study.

As with 2013, the most commonly detected virus was the pepper mild mottle virus (PMMV), which is a plant virus that is not known to infect humans, but is found in high concentrations in human waste due to ingestion of pepper products, such as hot sauce. In FY2017, PMMV was detected in four (4%) samples, with a maximum concentration of 26.7 genomic copies per liter (gc/L). PMMV was detected in two highly vulnerable alluvial wells with no documented confining materials (at 9.4 and 14.4 gc/L), one

Dakota sandstone well with 27 feet of confining material (at 11.2 gc/L), and one Cambrian-Ordovician (Jordan) well with greater than 200 feet of confining material (at 26.7 gc/L). The presence of PMMV does not necessarily indicate that human waste is leaking into groundwater, but it does indicate that some contamination from human or animal waste sources may be occurring.

In this broad survey of Iowa's aquifers, rates of detection and concentrations of human and animal pathogens were lower than what has been found in surface-waters in the Midwest[3,4,5] and in wells in highly vulnerable aquifers in Wisconsin.[6] In FY2017, there was one detection of a human virus (adenovirus C, D, F), which was found at a very low concentration (0.09 gc/L) in a deep, highly-confined (>400 ft) Jordan well in central Iowa. This concentration was below the estimated 95% LOD and was not found in a duplicate sample obtained simultaneously. There was also one detection of bovine polyomavirus at a concentration of 1.76 gc/L in a highly vulnerable (no confining material present) Jordan well in NE Iowa. Bovine polyomavirus is often carried by cattle but is not associated with a specific illness. Unlike 2013, GII norovirus, human polyomavirus, and *Campylobacter* were not detected in FY2017. Adenovirus A, adenovirus B, enterovirus, GI norovirus, swine hepatitis E, *Salmonella*, and enterohemorrhagic *E. coli* were not detected in either 2013 or FY2017. The avian influenza A virus, which was associated with the massive outbreak that occurred in 2015, was not found in any of the groundwater samples in FY2017. A recent publication by Borchardt et al. (2017) did detect avian influenza A in well water from an Iowa farm eight days after the outbreak was first detected at that site.[7] Therefore, it is important to consider that groundwater used for washing trucks or watering birds during an outbreak has the potential to spread the disease.

Duplicate samples were obtained at nine wells. Duplicates were obtained by splitting the hose attached to the sample spigot and running the water through two filters at once. At two sites, viruses were detected in one sample, but not in the duplicate sample. Since viruses and bacteria are not spread evenly throughout the water like dissolved contaminants usually are, it is possible that a "clump" of the viruses was captured by one filter and not the duplicate. For concentrations reported below the 95% LODs, it is also possible that viral genetic material was present at concentrations too low to be detected. No false positives were found for any of the negative controls run during the secondary concentration, extraction, reverse transcription, or qPCR steps of the analyses, with the exception of one detection of PMMV. In this case, the sample was re-extracted and reanalyzed. This sample was then confirmed positive and all the negative controls were compliant. Contamination during sampling is also possible; however, no viruses or bacteria were detected in the two field blanks, which were run with sterilized water.

The overall frequency of detection of pathogenic organisms was lower in 2017 (6%) than in 2013 (23%). Although recharge events did occur in Iowa during the 2017 sampling period, most locations around the state were experiencing declining shallow groundwater levels, as illustrated by groundwater level data from Crawford County in western Iowa provided by the USGS (Figure 2). The results of Iowa's monitoring for viruses and bacterial pathogens are consistent with recent groundwater studies in Minnesota and Wisconsin, which show that pathogen occurrence is intermittent, and is likely to be influenced by hydrological parameters, including recharge rate and groundwater temperature.[8,9]

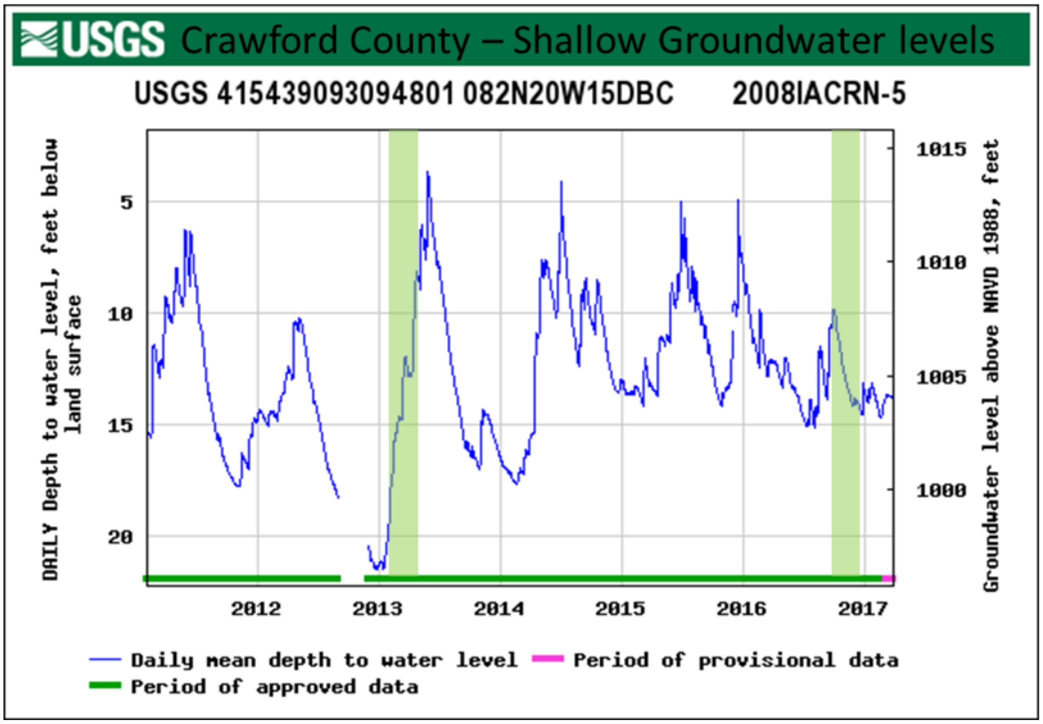

Figure 2. Shallow groundwater levels in Crawford County, Iowa, from 2011 through 2017. Periods of sampling for viruses and pathogenic bacteria are highlighted in green. Data provided by the USGS.

All of the municipalities that cooperated with this monitoring currently disinfect their water, with the exception of four systems: two that did not have any microbial detections, and two other systems that are not operating, but continue to maintain their wells. Even if the water treatment systems failed, the virus monitoring results revealed no immediate threats to human health. However, these results do indicate that it is possible for microbial pathogens to be transported to groundwater, even to aquifers, like the Cambrian-Ordovician (Jordan) aquifer, traditionally considered to be protected from surface contamination. Other studies indicate that deep wells can become contaminated by viruses that are transported through poorly constructed or aging well casings, or preferential pathways, such as bedding-planes or fractures.[10] Users of private wells should be aware of the potential for transport of viruses and bacteria to groundwater, and should consider additional treatment especially when users are vulnerable due to age or medical conditions.

Springs: Continuous monitoring data from two springs in NE Iowa allow for comparison between variations in nitrate concentrations in groundwater influenced by a high number of sinkholes in the Ordovician Galena limestone (Big Spring) versus a spring draining Silurian dolomite bedrock in an area with very few sinkholes (Manchester). Both locations drain landscapes dominated by row-crop agriculture. Results of the continuous nitrate monitoring at Big Spring and Manchester hatcheries can be found at the IIHR's Iowa Water Quality Information System (IWQIS) website: http://iwqis.iowawis.org/. Nitrate + Nitrite as N concentrations at Big Spring have generally varied between 10 – 15 mg/L since December, 2015, with a few sharp dips as low as 3.8 mg/L in response to precipitation or snowmelt events (Figure 3). In contrast, nitrate in the spring at the Manchester hatchery has varied between 15 – 25 mg/L, with the highest concentrations recorded in December of 2015 (Figure 3) following a warm and wet fall. Dissolved oxygen concentrations, first reported in January 2017, are higher at Big Spring (7.7 – 9.3 mg/L) than at Manchester (6.6 – 7.6 mg/L). Continuous monitoring of specific conductance, pH, and water temperature are also available for these sites and efforts to verify discharge data are ongoing.

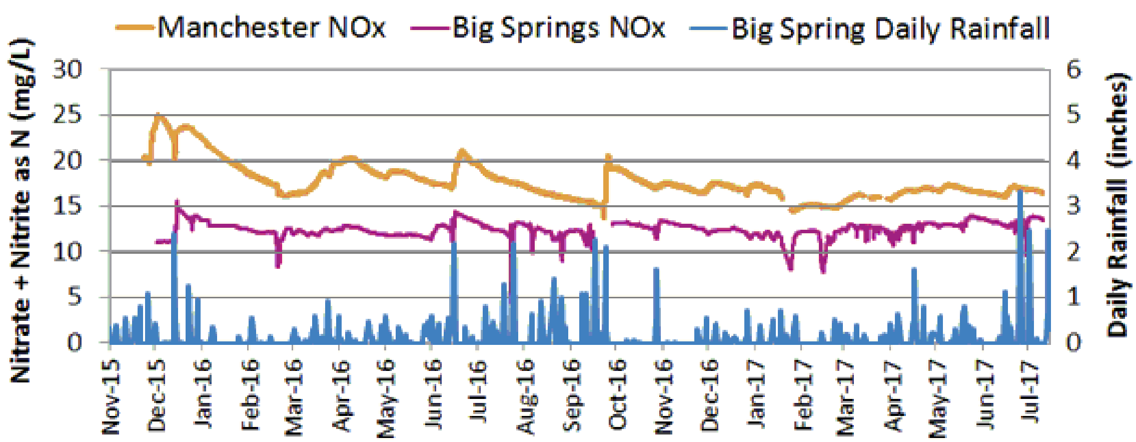

Figure 3. Nitrate + nitrite as N at Manchester and Big Spring Fish Hatchery's springs from November 2015 to July 2017 (data from IIHR) and daily rainfall data for Big Springs (from the Iowa Environmental Mesonet).

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References:

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