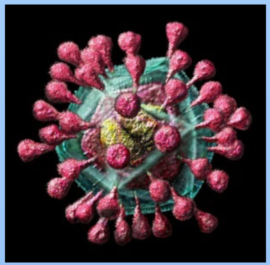 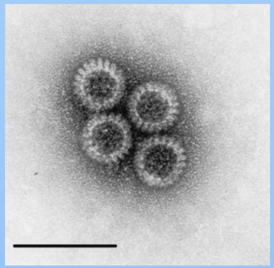  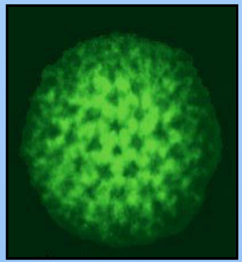 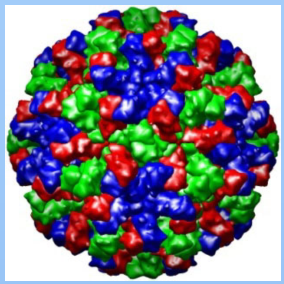

Viruses in Groundwater: From Disease Outbreaks to Sporadic Illness

Mark Borchardt, Ph.D.

USDA-Agricultural Research Service

US Geological Survey Wisconsin Water Science Center

Marshfield, Wisconsin USA

Minnesota Ground Water Association Spring Conference

April 24th, 2013

Groundwater-Borne Disease Outbreaks in the USA

Wisconsin WAHTER Study

- From 1971 to 2006 there were nearly 750 outbreaks associated with an infectious agent in drinking water; 60% of the outbreaks were attributable to groundwater
- In 2007-2008, 36 drinking water outbreaks, 22 (61%) from groundwater systems, of which in five outbreaks the cause was virus contamination

Summarized from CDC reports, e.g., MMWR, 2011, 60(12);38-68.

Groundwater Virus Studies in Wisconsin

Environ. Sci. Technol. **2010**, *44*, 7956-7963

Assessment of Sewer Source Contamination of Drinking Water Wells Using Tracers and Human Enteric Viruses

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Received March 3, 2010. Revised manuscript received August 16, 2010. Accepted August 18, 2010.

Sand/gravel sandstone aquifers

APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Feb. 2003, p. 1172–1180 Vol. 69, No. 2
0099-2240/03/$08.00+0 DOI: 10.1128/AEM.69.2.1172–1180.2003

Incidence of Enteric Viruses in Groundwater from Household Wells in Wisconsin

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Received 29 May 2002/Accepted 20 November 2002

Private domestic wells

APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Oct. 2004, p. 5937–5946 Vol. 70, No. 10
0099-2240/04/$08.00+0 DOI: 10.1128/AEM.70.10.5937–5946.2004

Vulnerability of Drinking-Water Wells in La Crosse, Wisconsin, to Enteric-Virus Contamination from Surface Water Contributions

Mark A. Borchardt,[1]* Nathaniel L. Haas,[1,2] and Randall J. Hunt[3]

Marshfield Clinic Research Foundation, Marshfield,[1] Department of Microbiology, University of Wisconsin—La Crosse, La Crosse,[2] and the United States Geological Survey, Middleton,[3] Wisconsin

Received 11 December 2003/Accepted 27 May 2004

Municipal wells in an alluvial aquifer

Environ. Sci. Technol. **2007**, *41*, 6606–6612

Human Enteric Viruses in Groundwater from a Confined Bedrock Aquifer

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KENNETH R. BRADBURY,‡
MADELINE B. GOTKOWITZ,‡
JOHN A. CHERRY,¶ AND
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Marshfield Clinic Research Foundation, Marshfield, Wisconsin, 54449, Wisconsin Geological and Natural History Survey, University of Wisconsin Extension, Madison, Wisconsin, 53705, and Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada

Even in a confined aquifer

ground water

Case Study/

Norovirus Outbreak Caused by a New Septic System in a Dolomite Aquifer

by Mark A. Borchardt[1], Kenneth R. Bradbury[2], E. Calvin Alexander Jr.[3], Rhonda J. Kolberg[4], Scott C. Alexander[3], John R. Archer[5], Laurel A. Braatz[6], Brian M. Forest[7], Jeffrey A. Green[8], and Susan K. Spencer[9]

Door County restaurant well

Virus Attributes Relevant to Groundwater Contamination

- Non-living packets of protein and nucleic acid (e.g. DNA); cannot replicate in the environment
- Often, virus types are specific to their host
- Small size (~ 50 nm) and negative charge favor movement through soil
- Viruses are often much smaller than fracture apertures or rock pores.
- Survivability favored by low temp, moisture, and absence of UV light
- Cause a variety of illnesses along a health effects spectrum from asymptomatic infection to death

Wisconsin WAHTER Study

Enteric Viruses – Clinical Significance

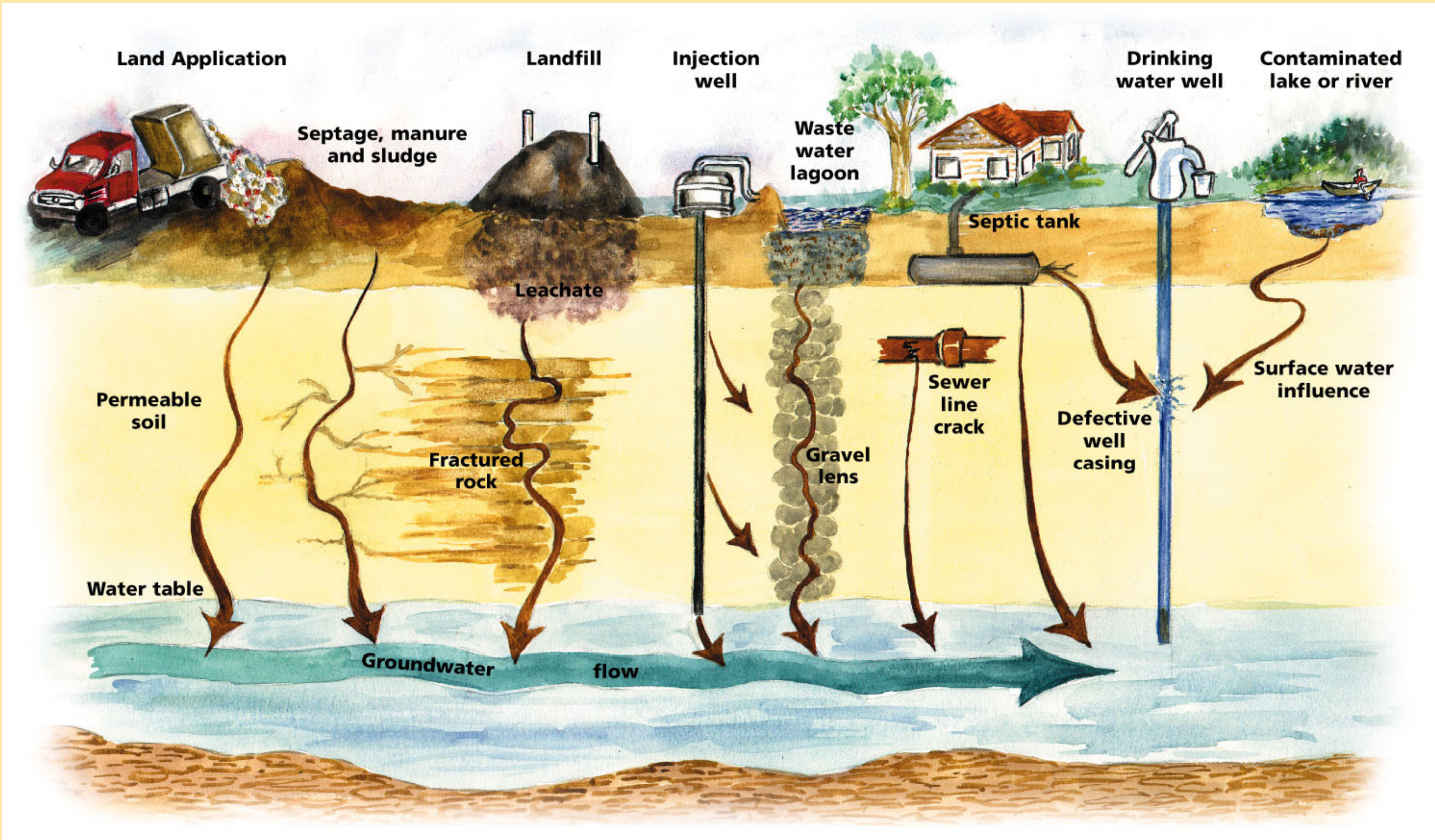
- **Enteroviruses:** fever, “summer cold”, diarrhea, hand, foot, mouth disease, conjunctivitis, meningitis, myocarditis, poliomyelitis, diabetes? chronic fatigue syndrome?
- **Rotavirus:** severe diarrhea and vomiting, 50,000 hospitalizations/year in US
- **Hepatitis A virus:** gastroenteritis, hepatitis, fatality rate of 2.7% in people > 49 years of age
- **Noroviruses:** gastroenteritis, “the flu”
- **Adenoviruses:** diarrhea, acute respiratory illness, pneumonia, conjunctivitis, neurological diseases, obesity?

Factors that Enhance Virus Subsurface Transport

- Large human fecal contamination source
- High water table, i.e., short unsaturated zone
- Alkaline pore water pH
- Coarse sediment texture
- Low ionic strength
- High precipitation
- High dissolved organic matter and surfactant concentrations

Wisconsin WAHTER Study

Virus Sources and Infiltration Routes into Groundwater



Modified from Keswick and Gerba 1980

Wisconsin WAHTER Study

Health Risk or Non-Issue?

- So viruses are present in public water supply and domestic wells …
- Does it matter?
- Is there any effect on public health?

Wisconsin WAHTER Study

Study Objectives

1) Find the association between tap water virus concentrations and community rates of acute gastrointestinal illness (AGI)
   - ➢ Published in Environmental Health Perspectives 2012

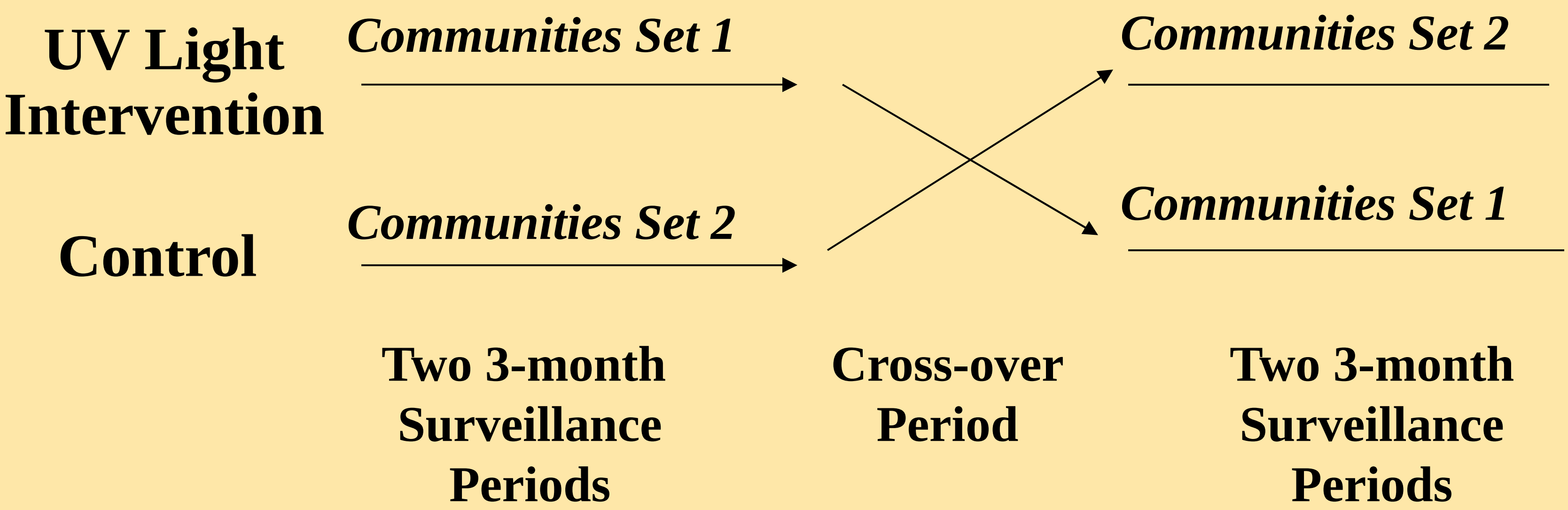
2) Estimate AGI risk from drinking non-disinfected municipal water from groundwater sources
   - ➢ Manuscript in preparation

3) Estimate AGI risk from viruses directly entering and contaminating distribution systems without residual chlorine
   - ➢ Published in Environmental Science & Technology 2012

4) Find the association between viruses in distribution systems and utility O & M procedures
   - ➢ Published in Journal of Water and Health 2011

Wisconsin WAHTER Study Design

Intervention trial in 14 groundwater-source communities



Wisconsin WAHTER Study

WAHTER Study Participating Communities

Populations: 1,200 – 8,300

Number Wells: 2 – 5

Pumpage: 0.13 – 2.1 MGD

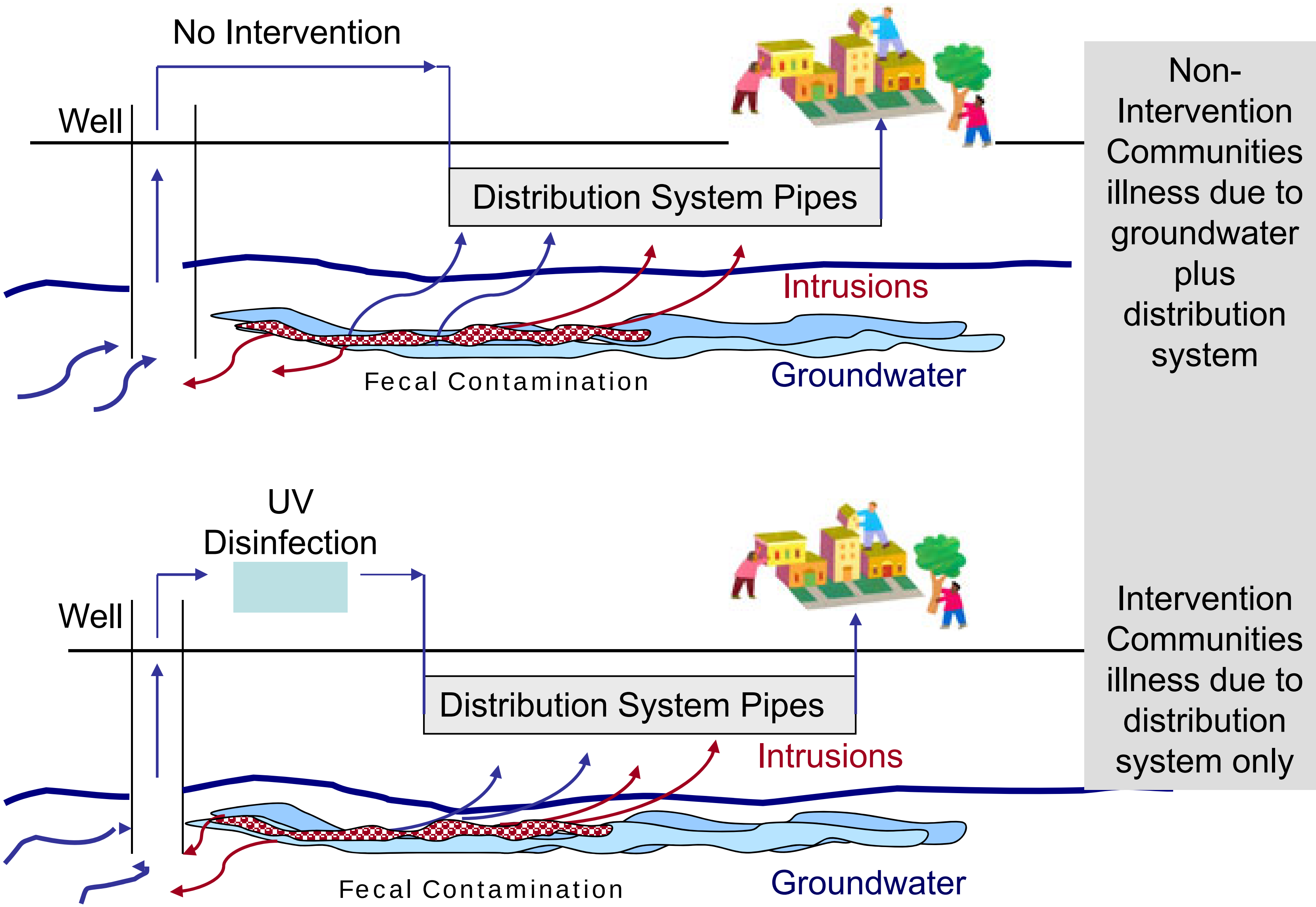
Hydrogeology: sand, sandstone, limestone

No surface water influence

No disinfection

UV dose = 50 mJ/cm2

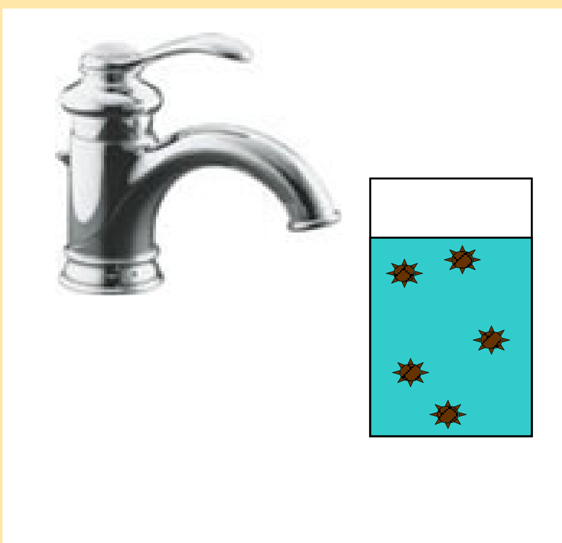
UV Intervention Effect



Wisconsin WAHTER Study

Tap Water Sampling

- Goal was to characterize virus exposure in a community’s drinking water
- Sampled 5 to 8 household taps per community; every community sampled once per month
- Households selected using utility-provided maps of water mains



- Viruses captured by glass wool filtration
- Viruses analyzed by qPCR
- In addition, enteroviruses and adenoviruses analyzed by cell culture

Wisconsin WAHTER Study

Virus Types, Frequencies, and Concentrations in Tap Water

Virus Type	Number qPCR Positive Samples	Virus Concentration Genomic copies/L		Number Culture Positive Samples
		Mean	Maximum	
Adenovirus	157 (13%)	0.07	9.5	40/157 (25%)
Enterovirus	109 (9%)	0.8	851.1	31/109 (28%)
GI Norovirus	51 (4%)	0.6	115.7	
GII Norovirus	0 (0%)	0	0	
Hepatitis A	10 (1%)	0.006	4.1	
Rotavirus	1 (0.1%)	2×10^{-5}	0.03	
All Viruses	287 (24%)	1.5	853.6	

N = 1,204 samples

- 41 samples (3%) were positive for two or more virus types

Wisconsin WAHTER Study

Epidemiological Study Design

- Acute gastrointestinal illness (AGI) surveillance for four 12 week periods, spring and autumn 2006 and 2007
- Participants submitted an illness symptom checklist every week
- AGI defined as ≥ three episodes loose watery stools OR ≥ one episode vomiting in 24 hour period
- Person-time estimated from nights slept away from home, self-reported on symptom checklist
- Outcome measure: Number AGI episodes/person-year for each community and surveillance period

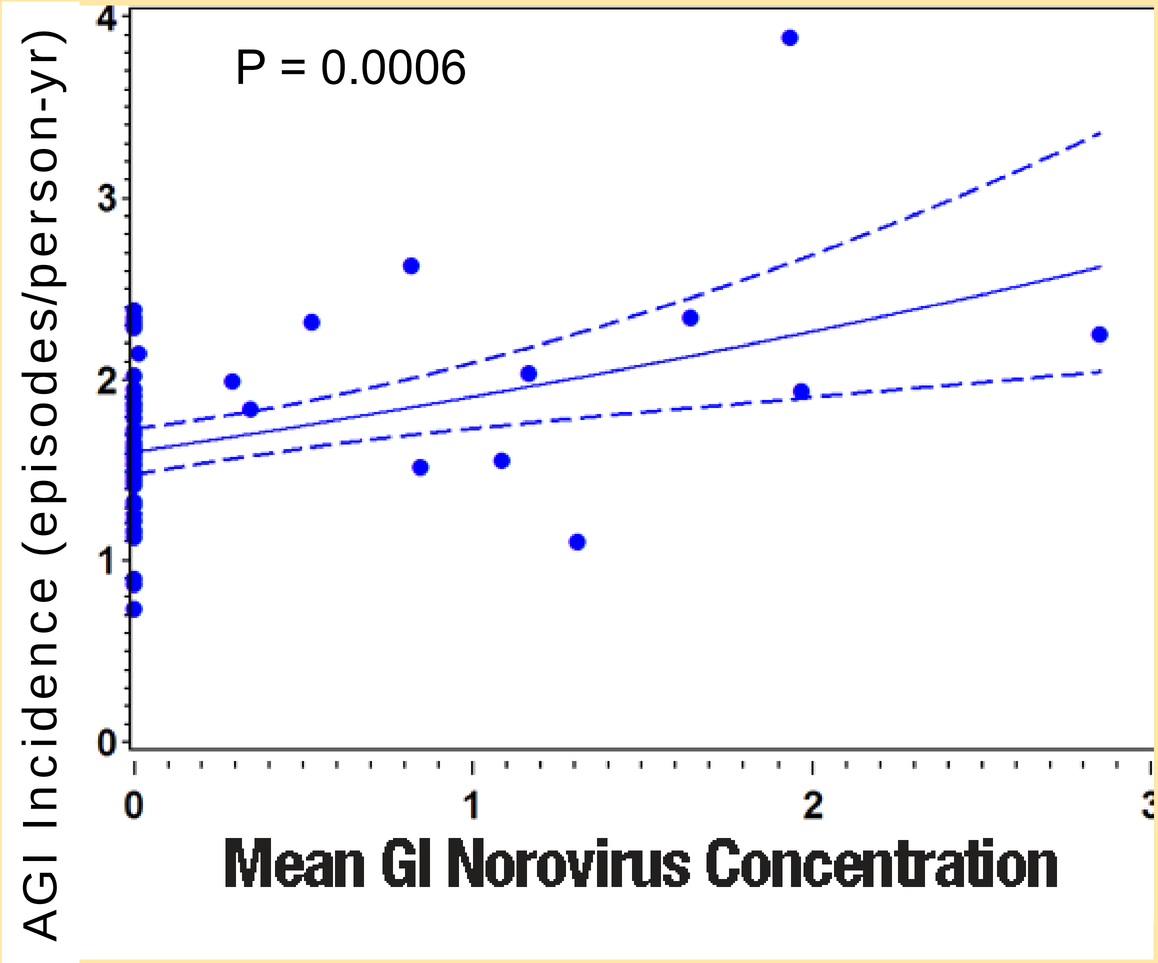
Wisconsin WAHTER Study

Participating Households' Characteristics

Characteristic	Number	%
Household size (no. of persons)		
2	17	(3)
3	159	(26)
4	246	(40)
5	136	(22)
≥6	63	(10)
Residence type		
Single family home	572	(92)
Apartment or condo	43	(7)
Other	6	(1)
Faucet or plumbing filtering device		
Yes	73	(12)
No	547	(88)
Don't know	1	(<1)
Primary drinking water source		
Municipal	1546	(93)
Bottled water	58	(3)
Other	1	(<1)
Missing	54	(3)

- **Beginning enrollment: 621 households**
- **Ending enrollment: 440 households**
- **Beginning enrollment: 1,079 children, 580 adults**
- **Ending enrollment: 765 children, 413 adults**

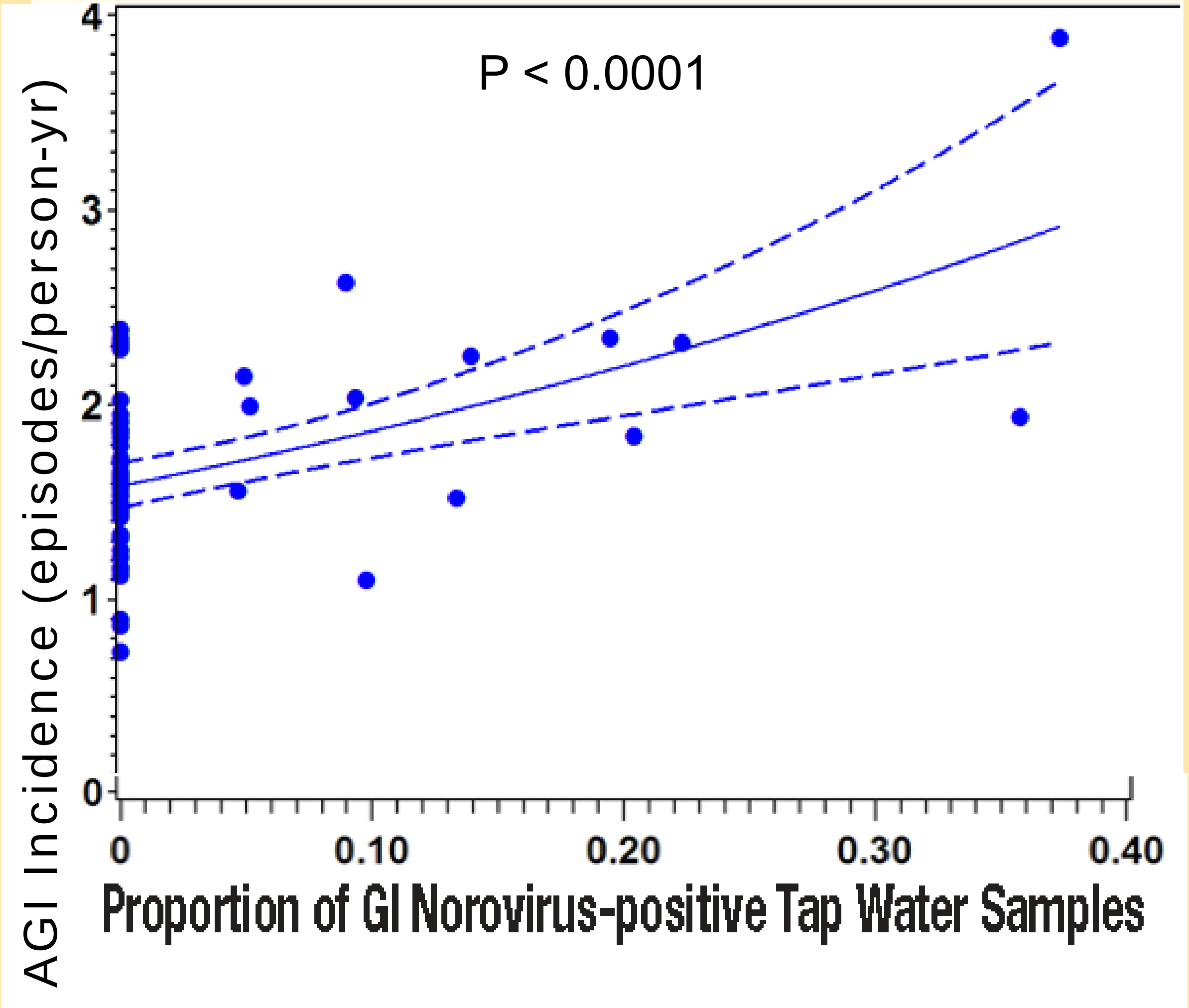
G1 Norovirus Concentration in Tap Water and AGI Incidence



Wisconsin WAHTER Study

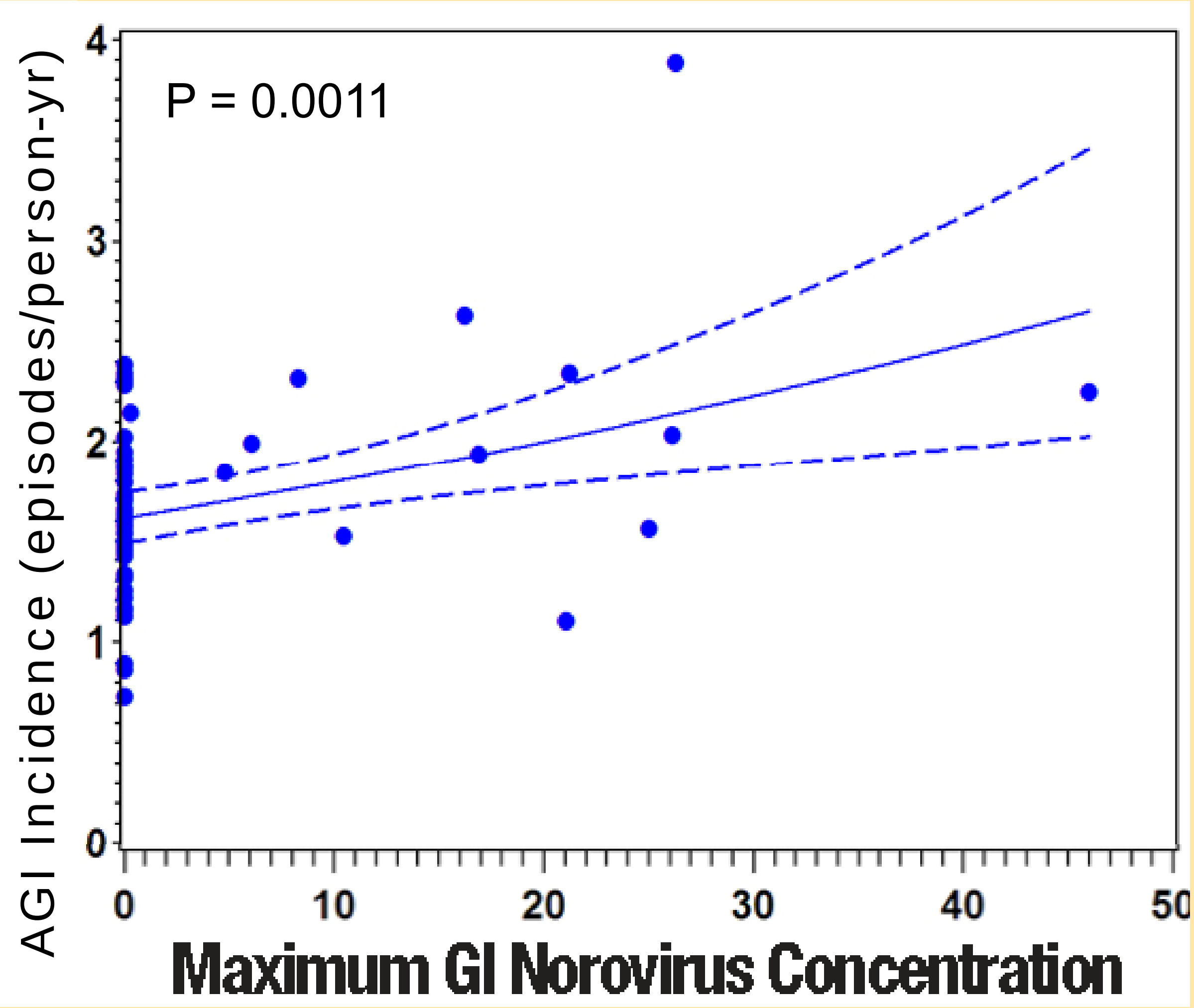
Proportion of G1 Norovirus-Positive Tap Water Samples and AGI Incidence

Wisconsin WAHTER Study



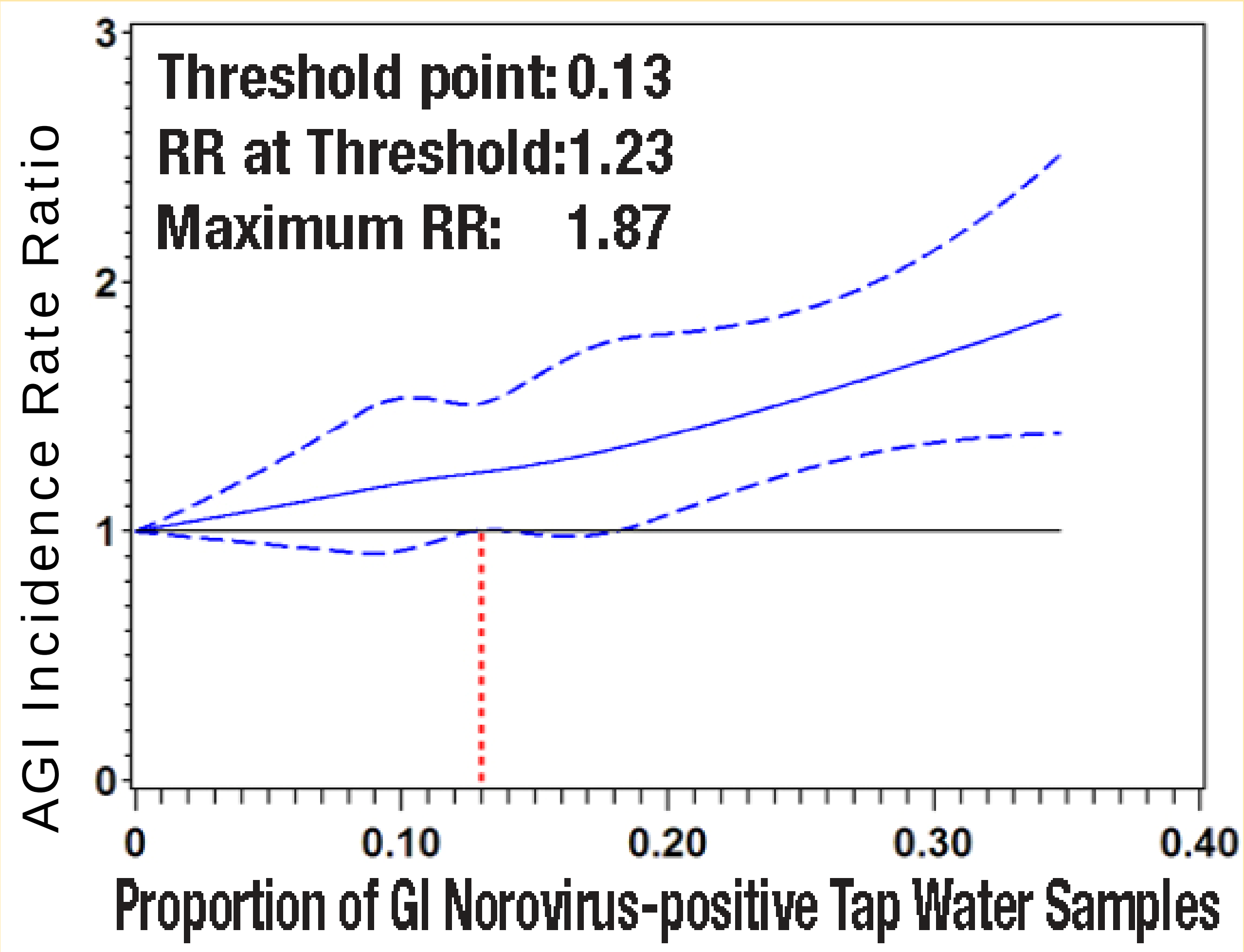
Maximum G1 Norovirus Concentration and AGI Incidence

Wisconsin WAHTER Study



Wisconsin WAHTER Study

AGI Relative Risk (RR) as Related to the Proportion of Tap Water Samples Positive for G1 Norovirus



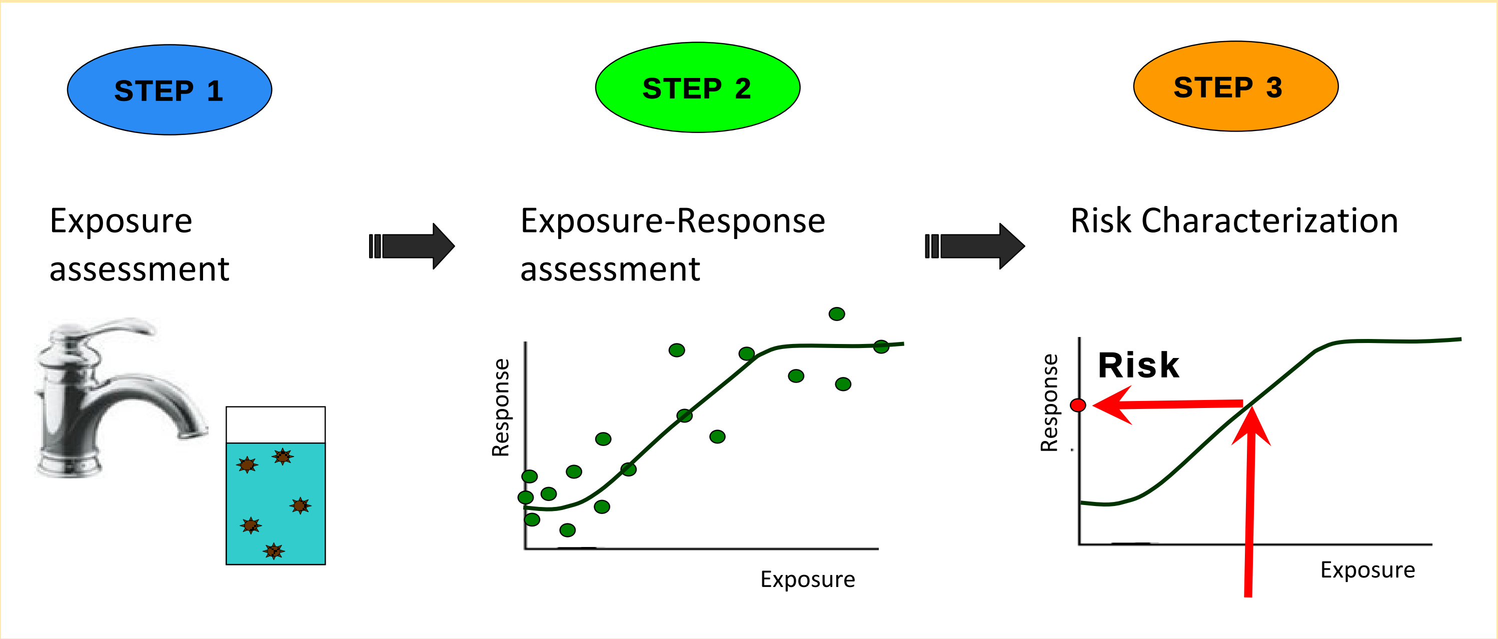
Wisconsin WAHTER Study

Results Summary

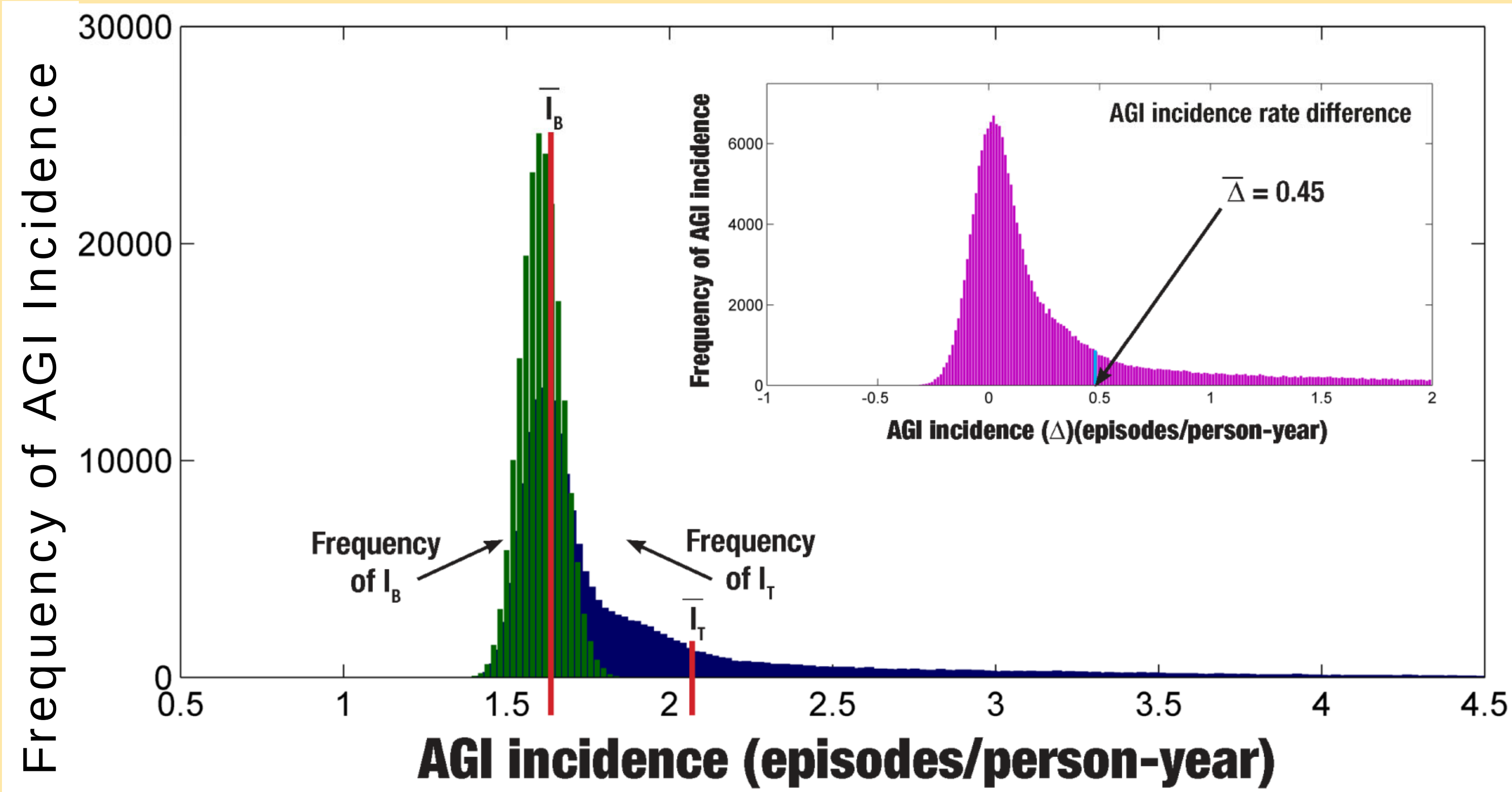
Virus Group	Predictor Variables	Age Group Most Affected	Maximum Increase in Relative Risk
All viruses combined	Mean Concentration Maximum Concentration	Adults	105%
Enterovirus	Mean Concentration Maximum Concentration Proportion samples +	Adults	84%
G1 Norovirus	Mean Concentration Maximum Concentration Proportion samples +	All ages	161%

Wisconsin WAHTER Study

Quantitative Microbial Risk Assessment Overview



Estimating the Fraction of AGI from Drinking Water Using Quantitative Microbial Risk Assessment

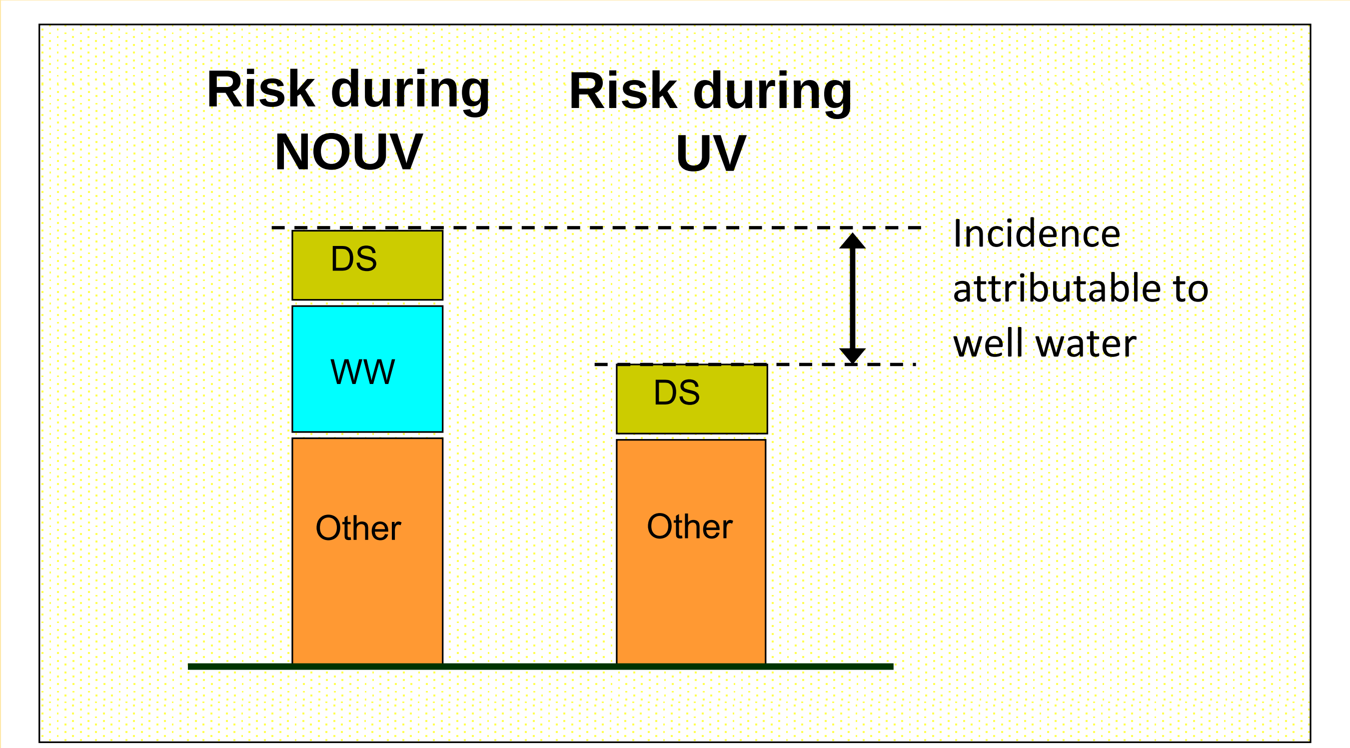


- Virus exposure – AGI model: mean concentration GI norovirus, all ages
- 22% of the AGI in the study communities was from virus-contaminated tap water
- For children < 5 yrs, in the spring of 2006, the fraction of AGI from drinking water was 63%!

Wisconsin WAHTER Study

Objective 2

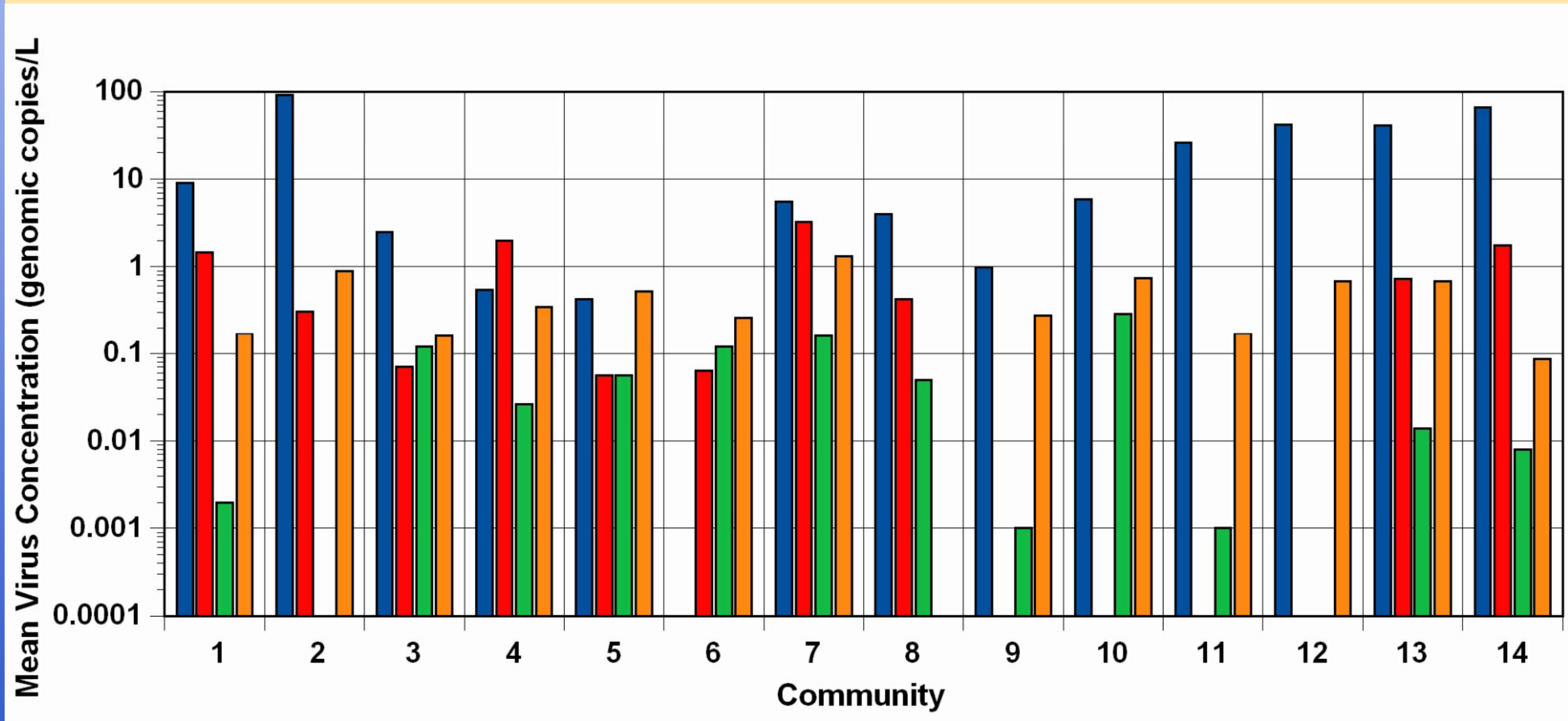
Estimate the risk of acute gastrointestinal illness (AGI) from drinking non-disinfected municipal water from groundwater sources



Wisconsin WAHTER Study

Viruses in the Study Wells

In the 14 study communities, of all 36 wells tested, 34 were virus-positive (139 positive samples out of 392 (36%))



Wisconsin WAHTER Study

Intervention Effect (i.e., Attributable Risk) for Groundwater-borne AGI

Age Group	UNADJUSTED ANALYSES			ADJUSTED ANALYSES*		
	Attributable Risk (# illness/ person-year)	P-value	95% CI	Attributable Risk (# illness/ person-year)	P-value	95% CI
All Ages	-0.02	0.58	-0.3 – 0.45	-0.01	0.52	-0.20 – 0.19
Adults	0.11	0.29	-0.33 – 0.56	0.14	0.17	-0.16 – 0.44
Children	-0.10	0.81	-0.34 – 0.14	-0.09	0.82	-0.3 – 0.11
Children <5 yrs	-0.14	0.68	-0.75 – 0.47	-0.26	0.81	-0.87 – 0.35

All analyses weighted by sample size (i.e., person-time)

*Adjusted for age, gender, day care attendance, year, season, and virus concentrations in the communities' wells

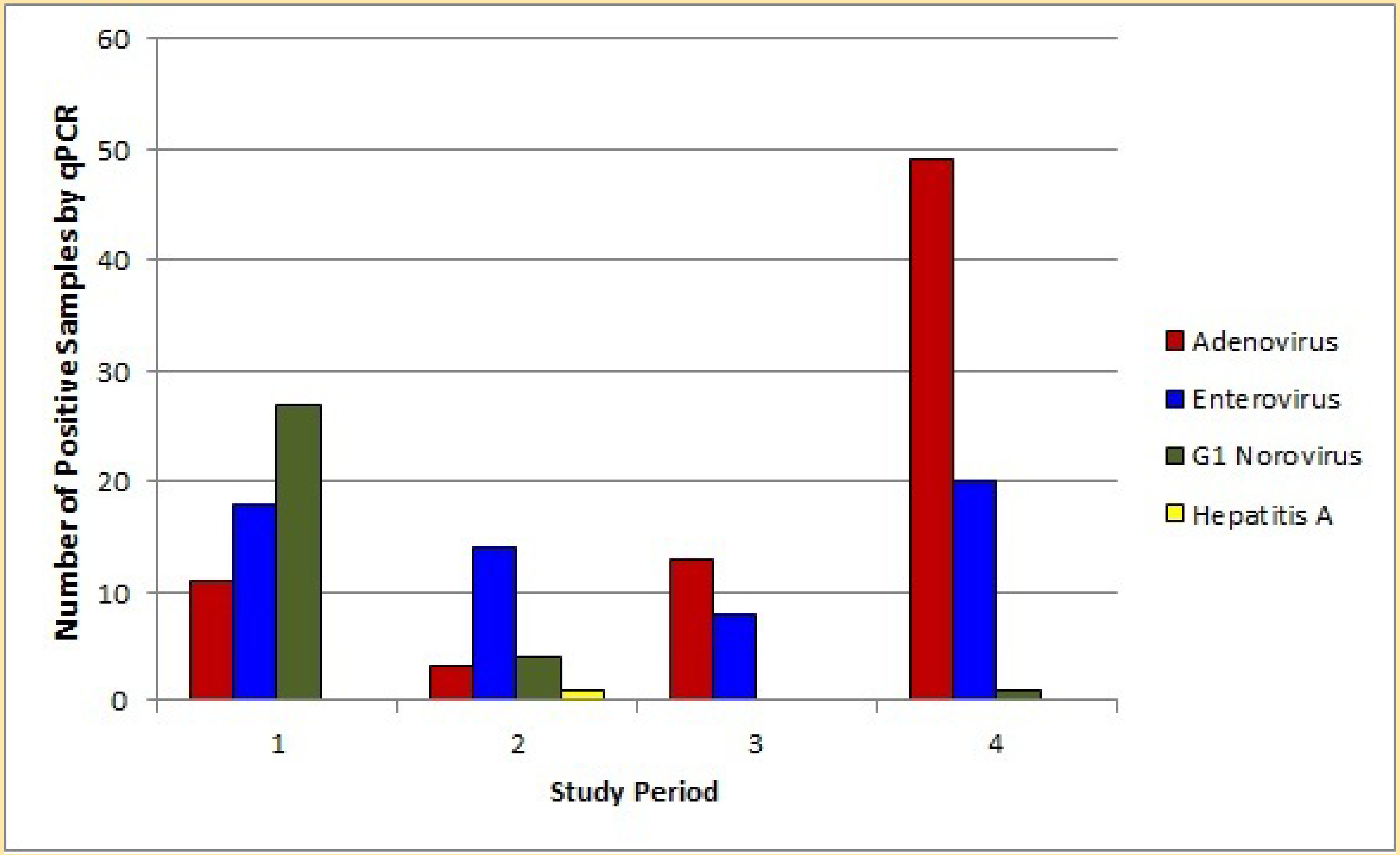
Wisconsin WAHTER Study

Intervention Effect Explanations

- Groundwater-borne transmission was zero to minimal
- Statistical power insufficient
- Viruses contaminated drinking water in the distribution system downstream of the UV intervention
- The level of virus exposures from well water differed by study year and season

Wisconsin WAHTER Study

Virus Types Detected in the Communities' Wells



Reduction in AGI from the UV Disinfection Intervention

Adults, Periods 3 and 4

AGI reduced by 13%
95% Confidence Interval: 0% - 22%

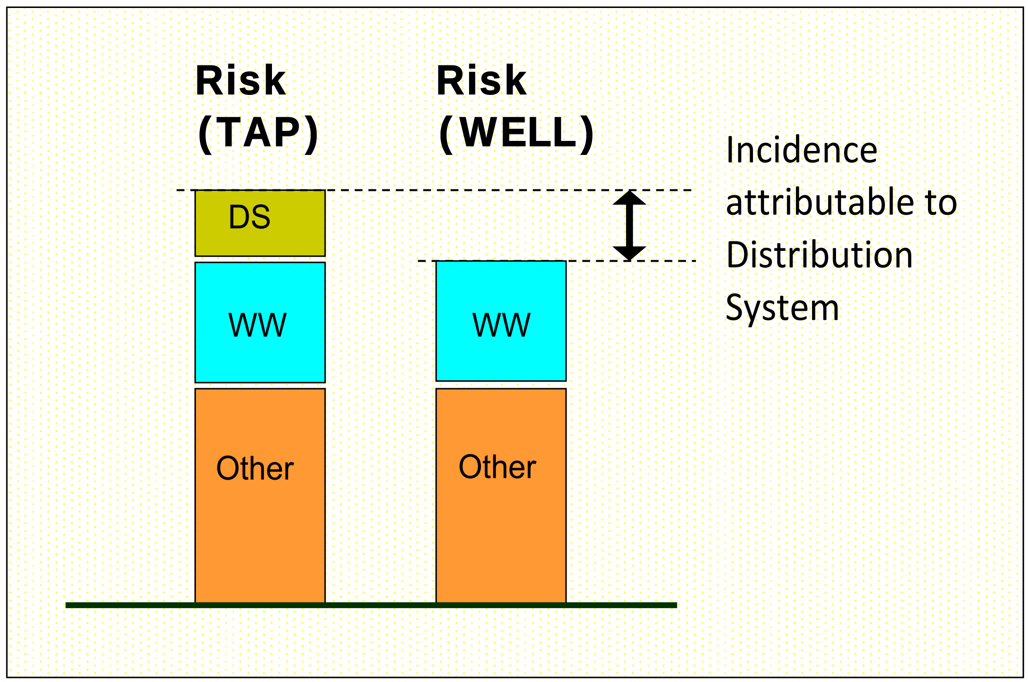
Children <5, Period 1

AGI reduced by 13%
95% Confidence Interval: 0% - 41%

Wisconsin WAHTER Study

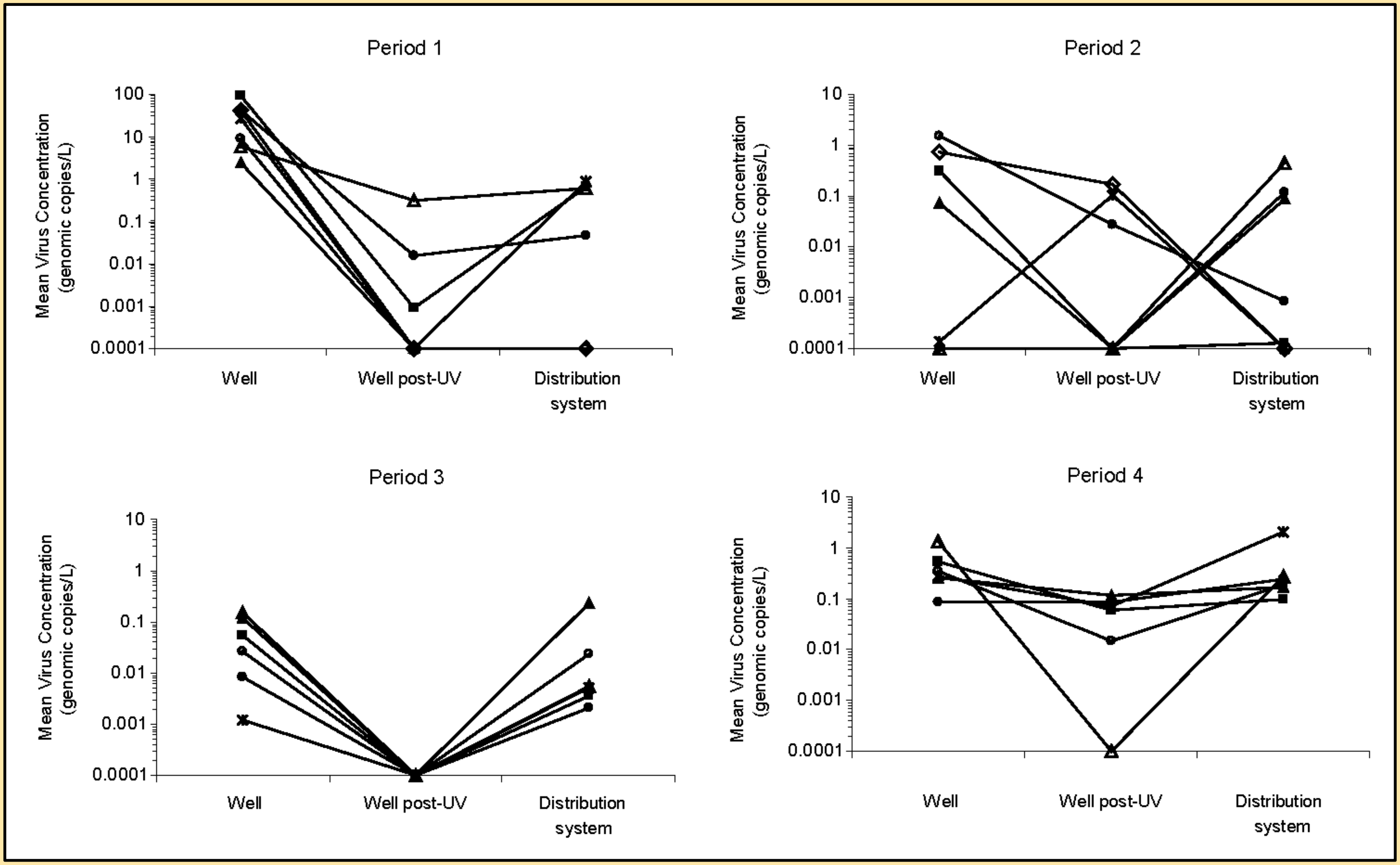
Objective 3

Estimate the AGI risk contributed solely by contaminated distribution systems



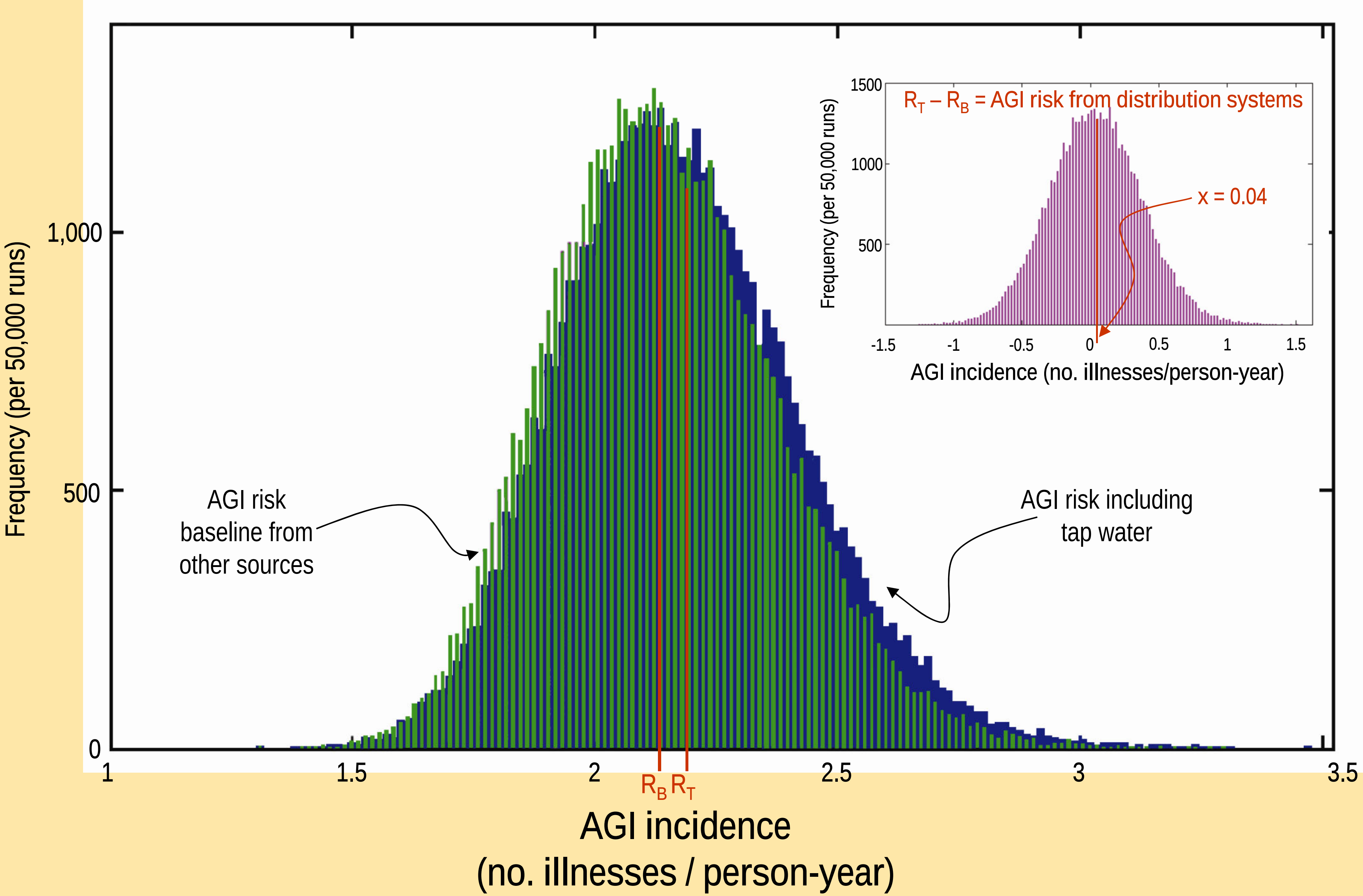
Wisconsin WAHTER Study

Virus Intrusions into Distribution Systems

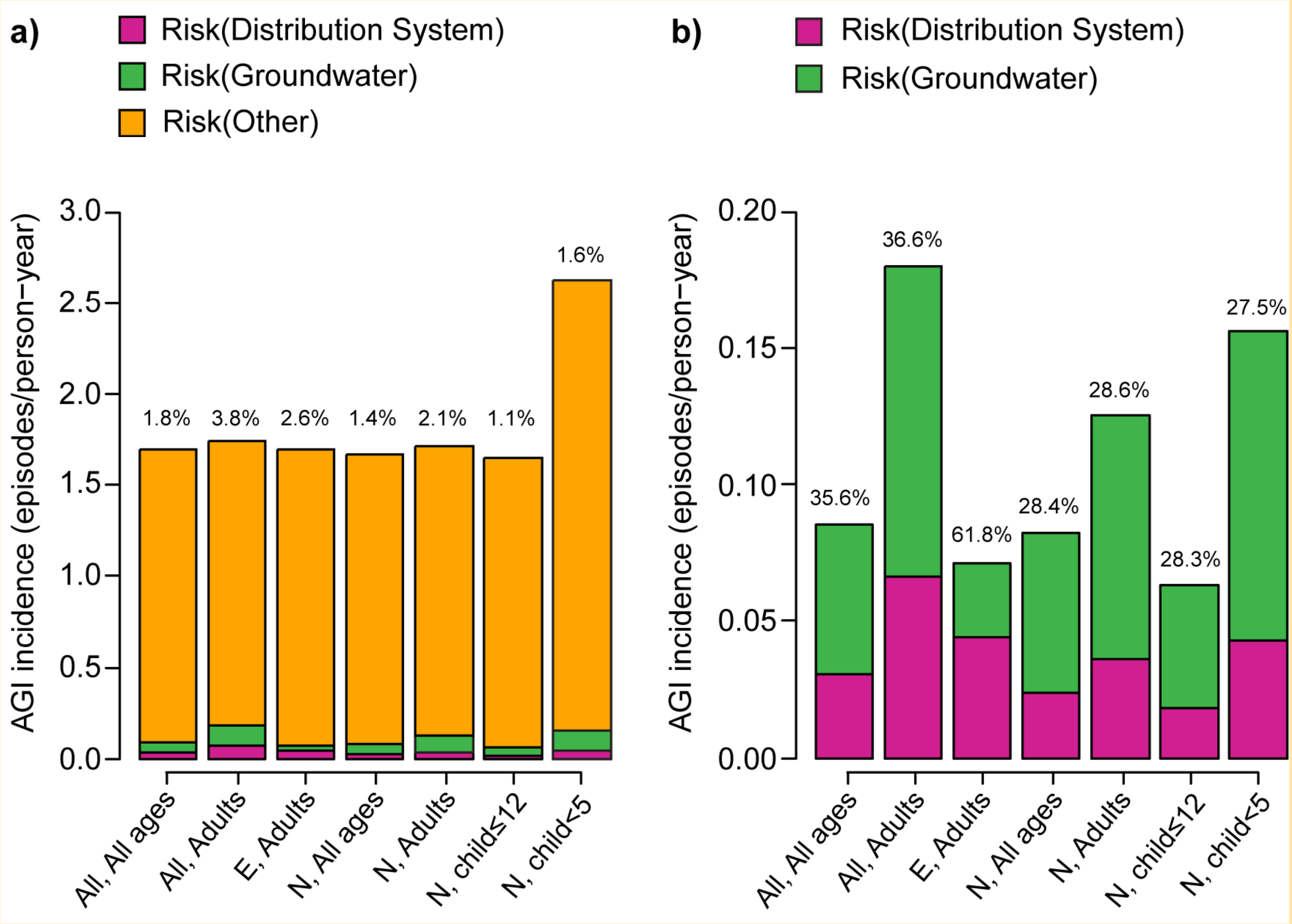


Lambertini et al. 2011 Journal of Water and Health, 9:799-812

Distribution System Risk – Approach 1 With UV



AGI Attributable Risk Percent for Distribution Systems, Approach 1 with UV



Wisconsin WAHTER Study

Does Groundwater-borne Illness Risk Meet US EPA Standards?

- Acceptable EPA risk for waterborne disease is 1 infection in 10,000 people/year
- Assume every infection leads to an illness, then the acceptable illness rate is 0.0001 illness/person-year
- Our modeling using quantitative microbial risk assessment indicates norovirus in drinking water was responsible 0.45 AGI episodes/person-year
- 4,500 times higher than EPA acceptable risk

Wisconsin WAHTER Study

Effect of WAHTER Study on State and National Policies

In Wisconsin…

WI Code NR 810 was revised to require disinfection of municipal water supplies in July 2010, but then this requirement was reversed by law in May 2011.

In the USA…

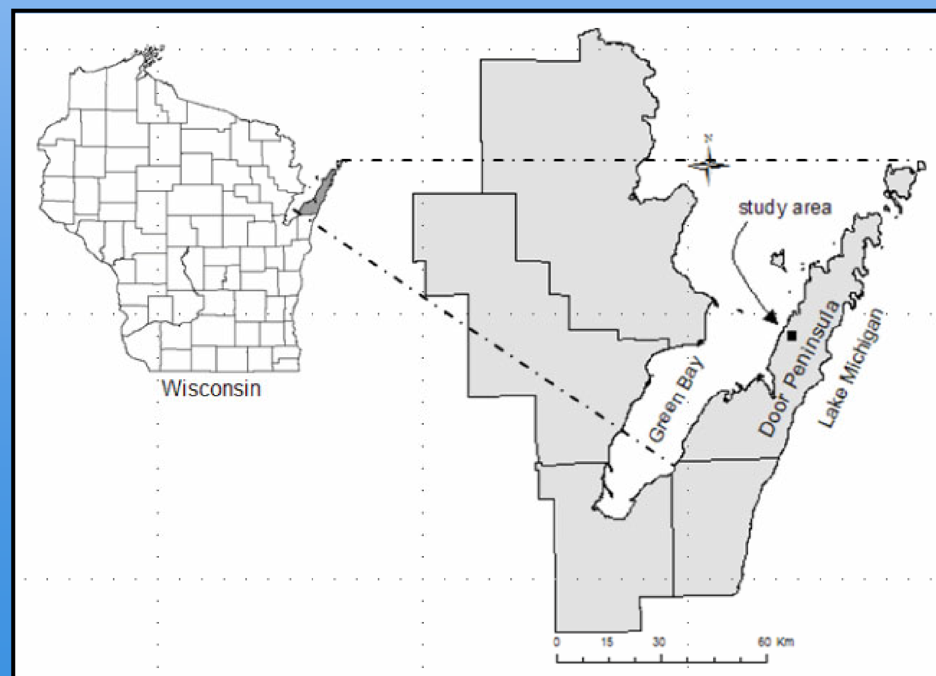
The third Unregulated Contaminant Monitoring Rule (UCMR) will conduct monitoring in 2013 – 2015 for enterovirus and norovirus from 800 groundwater-source public water systems that do not disinfect.

ground water

Case Study/

Norovirus Outbreak Caused by a New Septic System in a Dolomite Aquifer

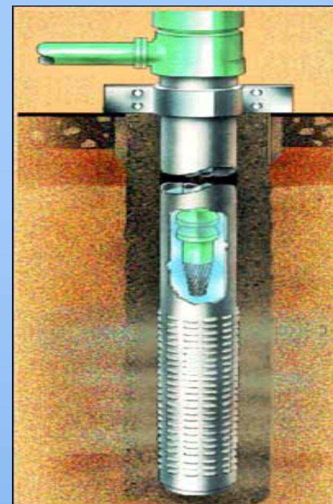
by Mark A. Borchardt[1], Kenneth R. Bradbury[2], E. Calvin Alexander Jr.[3], Rhonda J. Kolberg[4], Scott C. Alexander[3], John R. Archer[5], Laurel A. Braatz[6], Brian M. Forest[7], Jeffrey A. Green[8], and Susan K. Spencer[9]



Outbreak Background

- In early June, 2007, 229 patrons and employees of a new restaurant in Door County were affected by severe acute gastrointestinal illness, 6 people hospitalized
- New well and conventional drain-field septic system, both conforming to State code
- Hydrogeologic setting: shallow soil over densely fractured dolomite
- Epidemiologic case-control analysis indicated the restaurant’s well water was associated with illness

Norovirus Transmission Cycle



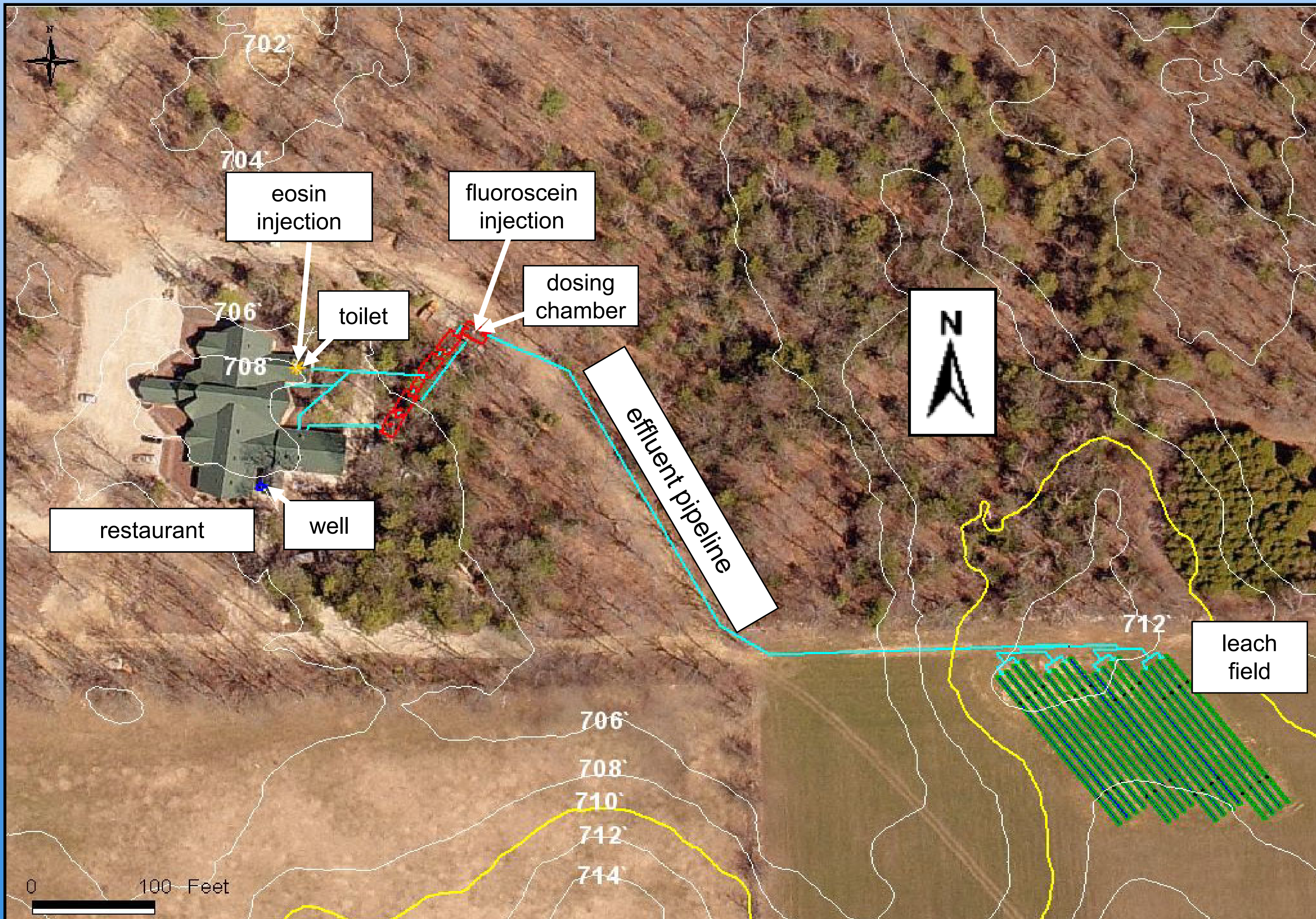
Tap water from well:
50 genomic copies/L

Norovirus isolates from 3 sources had identical 327 bp polymerase gene sequences

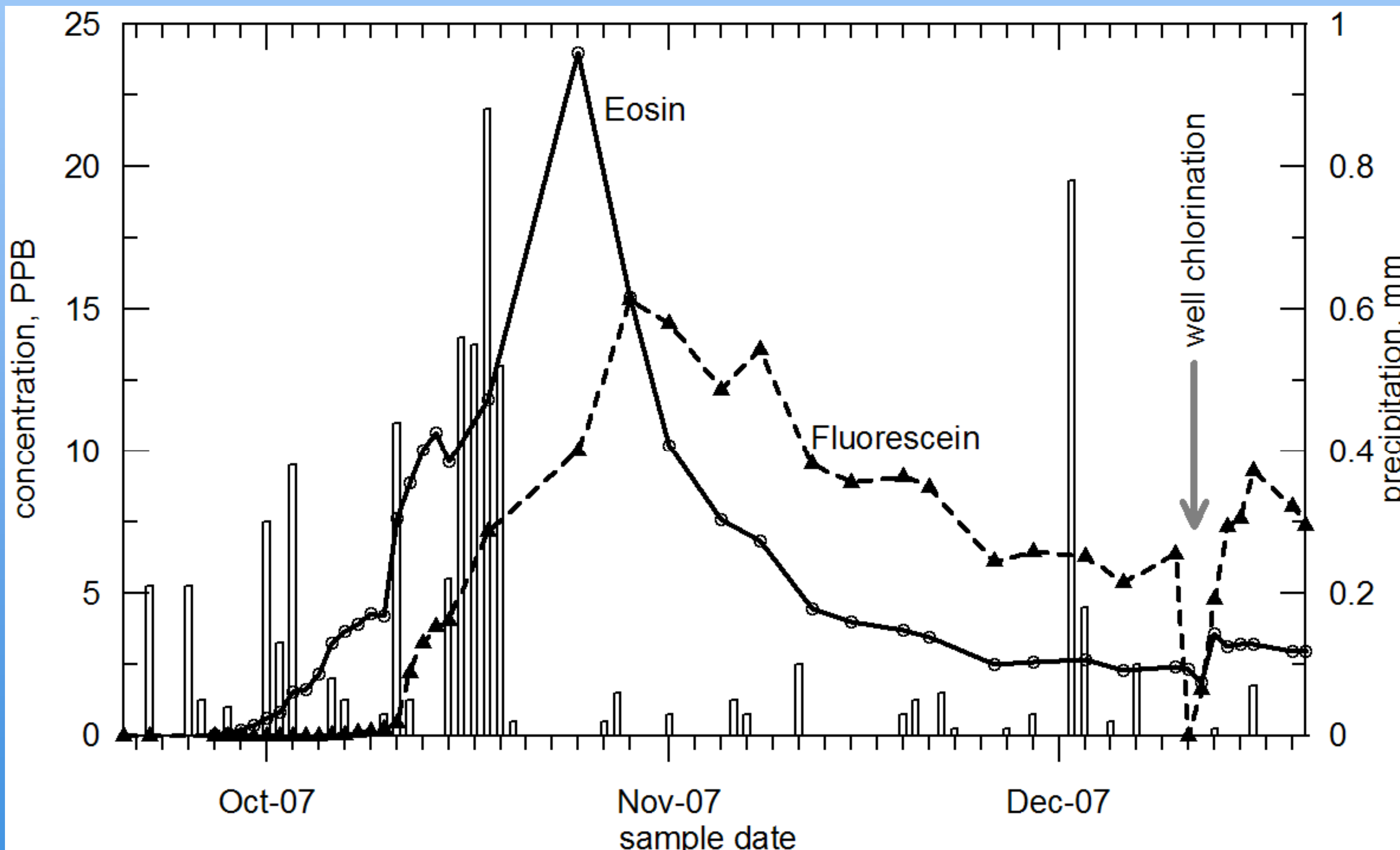
Restaurant patrons: $10^4 - 10^8$ gc /gm stool

Septic tank: 79,600 genomic copies/L

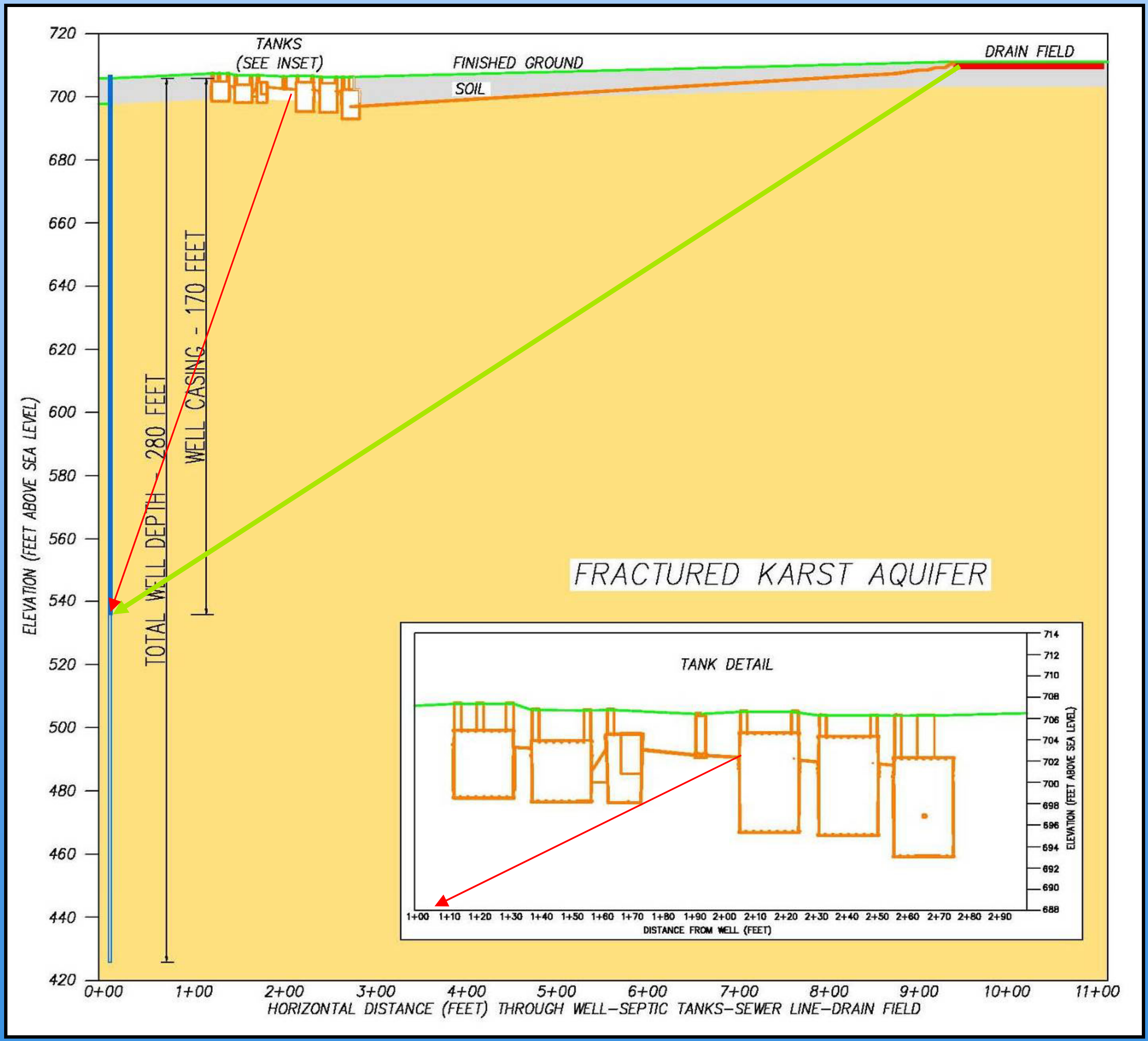
Restaurant - As Built Septic System and Well

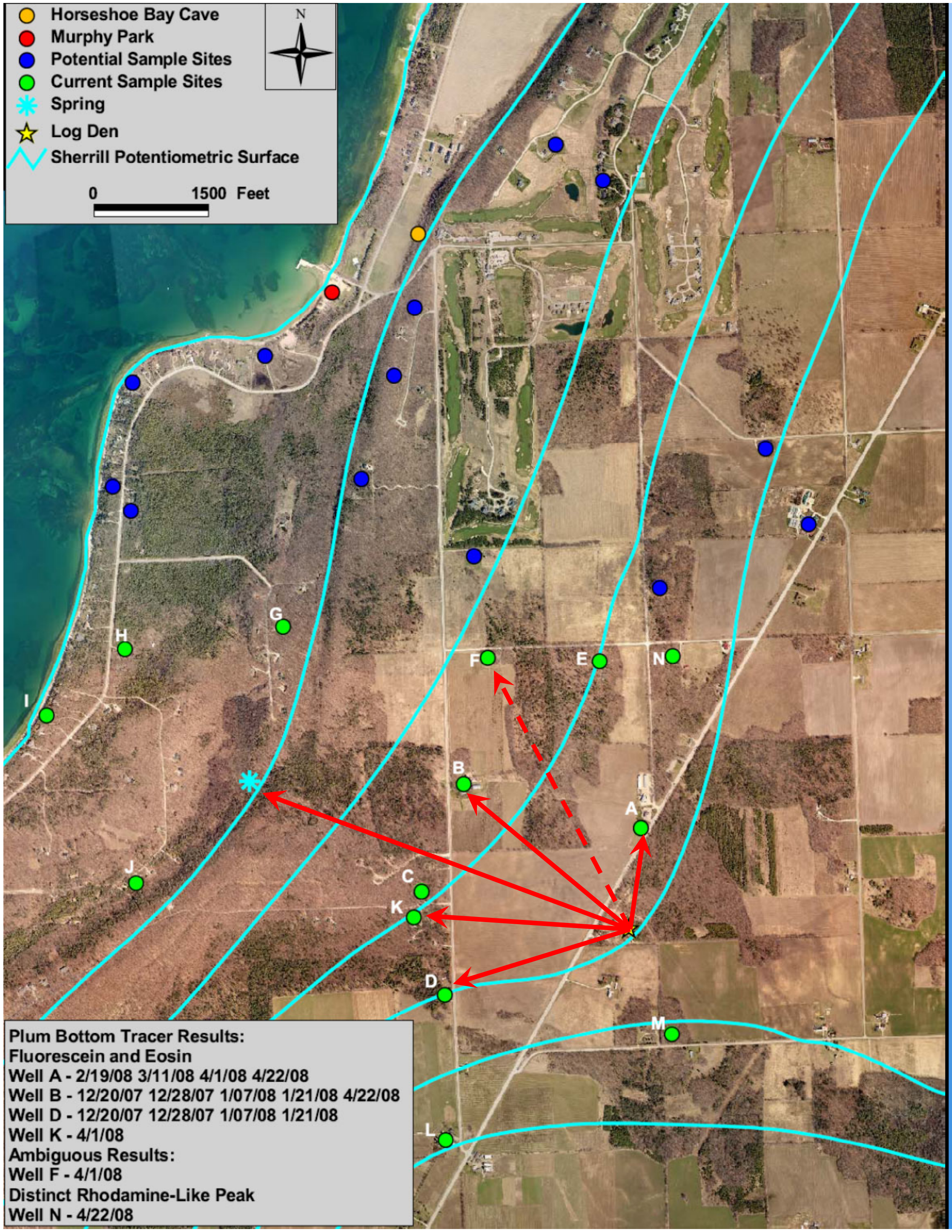


Tracer concentrations in the restaurant supply well



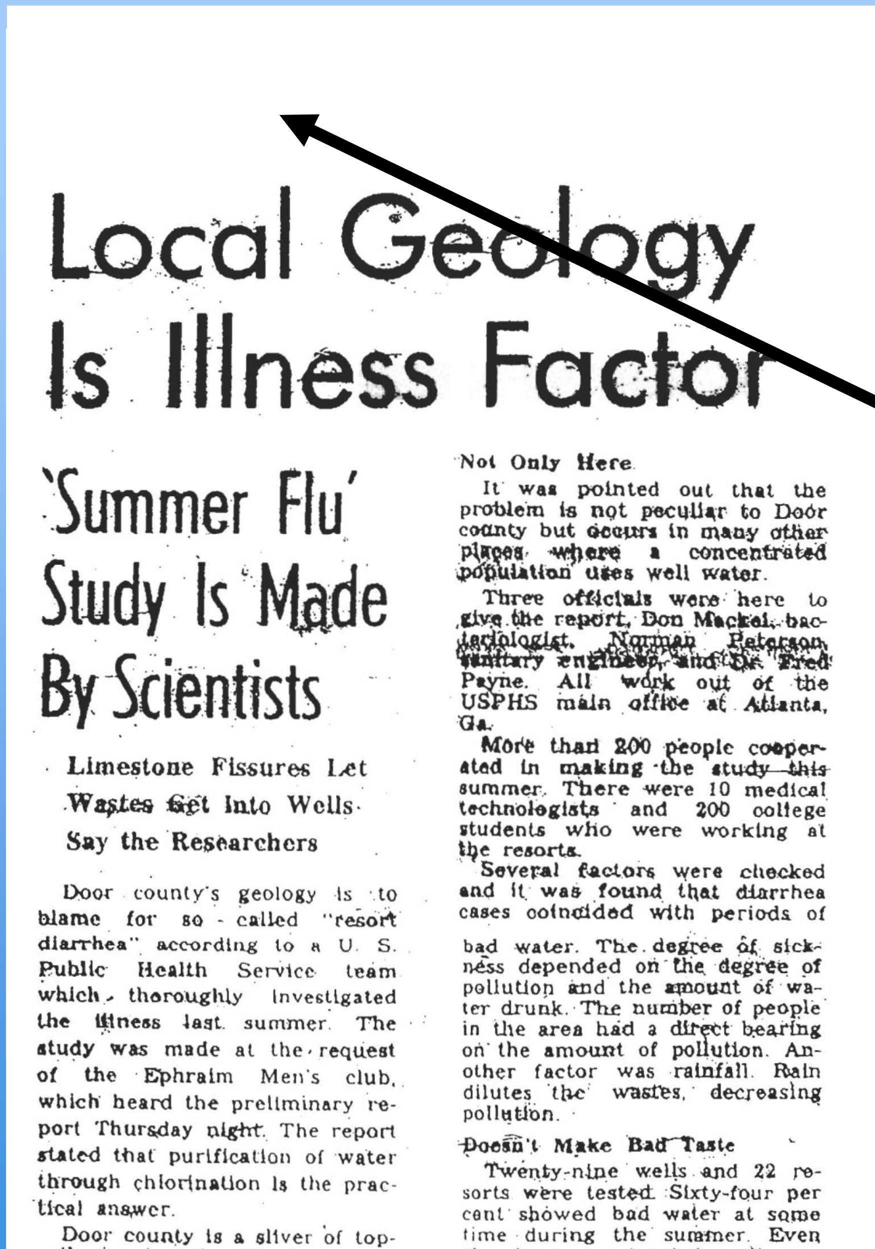
Restaurant Cross Section





Regional Scale Movement of Dye from the Restaurant

Tracer velocities to offsite wells B and D are in the range of 7 to 8 m/d.



Local Geology Is Illness Factor

'Summer Flu' Study Is Made By Scientists

Limestone Fissures Let Wastes Get Into Wells Say the Researchers

Door county's geology is to blame for so - called "resort diarrhea" according to a U. S. Public Health Service team which thoroughly investigated the illness last summer. The study was made at the request of the Ephraim Men's club, which heard the preliminary report Thursday night. The report stated that purification of water through chlorination is the practical answer.

Door county is a sliver of top-

Not Only Here

It was pointed out that the problem is not peculiar to Door county but occurs in many other places where a concentrated population uses well water.

Three officials were here to give the report, Don Mackel, bacteriologist, Norman Peterson, sanitary engineer, and Dr. Fred Payne. All work out of the USPHS main office at Atlanta, Ga.

More than 200 people cooperated in making the study this summer. There were 10 medical technologists and 200 college students who were working at the resorts.

Several factors were checked and it was found that diarrhea cases coincided with periods of bad water. The degree of sickness depended on the degree of pollution and the amount of water drunk. The number of people in the area had a direct bearing on the amount of pollution. Another factor was rainfall. Rain dilutes the wastes, decreasing pollution.

Doesn't Make Bad Taste

Twenty-nine wells and 22 resorts were tested. Sixty-four per cent showed bad water at some time during the summer. Even

1955!

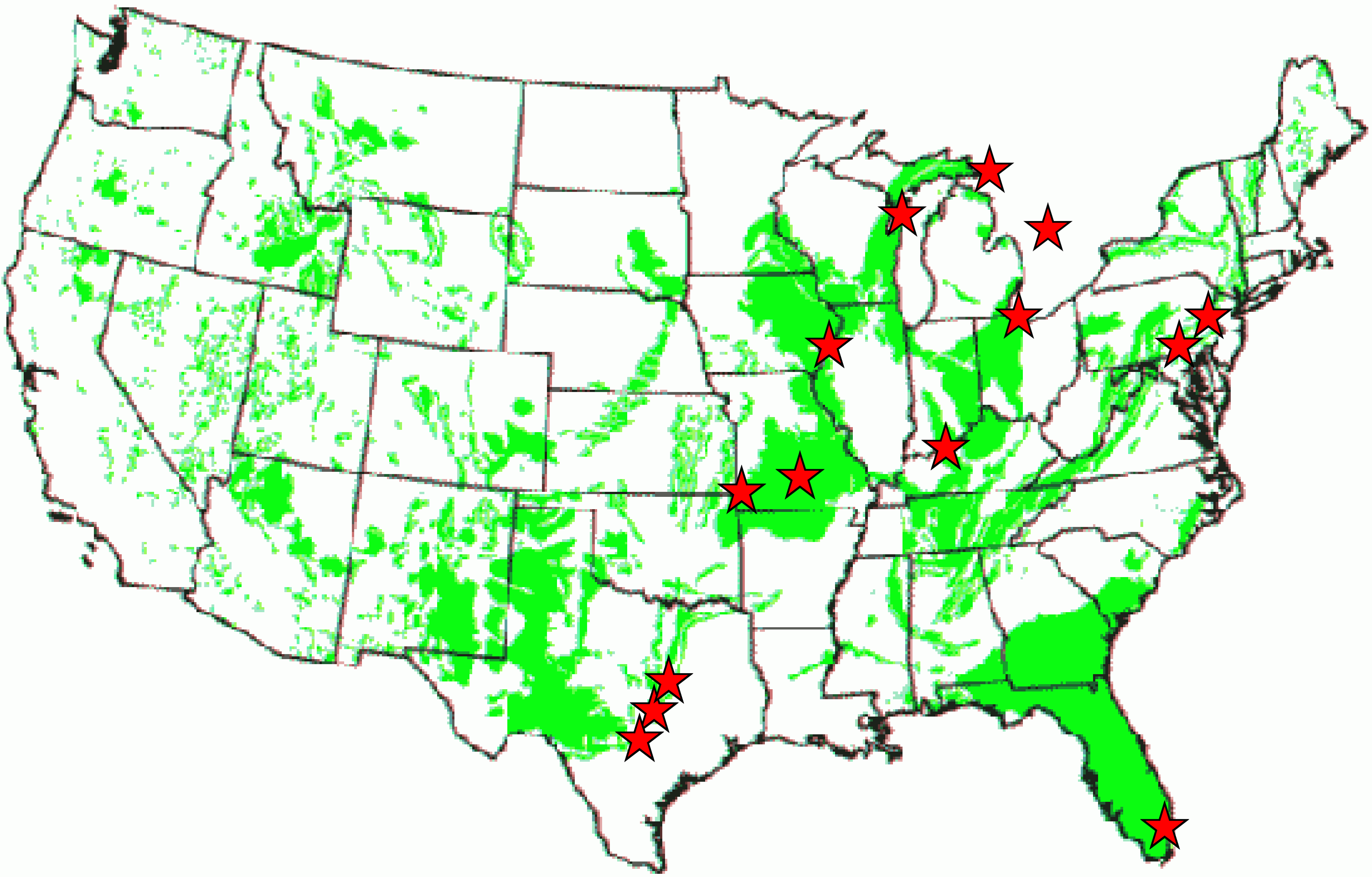
Article in the Door County Advocate

Policy "Lapse"

WI Septic System Code Comm 83 allows 24" minimum distance between drainfield and groundwater table or bedrock, regardless of bedrock type.

Groundwater-borne Outbreaks in Karst, USA

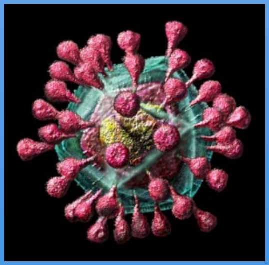
http://water.usgs.gov/ogw/karst/kig2002/jbe_map.html

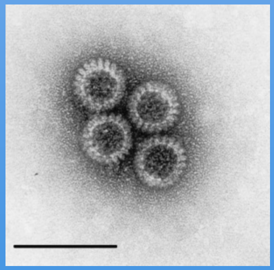


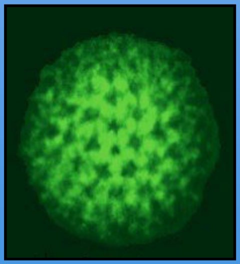
P. Berger (2008), table 1

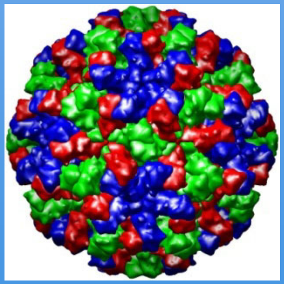
Questions?

Comments?









Wisconsin WAHTER Study

Acknowledgments

Laboratory

Susan Spencer
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Matt Volenec

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Vicki Allison
Carol Beyer
Jordon Ott
Marilyn Bruger
Deb Kempf
Cathy Schneider
Amy Kieke

Biostatistics

Burney Kieke, Jr.
Carla Rottscheit
Richard Berg

Risk Assessment

Frank Loge, Ph.D.
Elisabetta Lambertini

EPA

Angela Page
Cynthia Nolt-Helms
Shay Fout, Ph.D.
Phil Berger