

Assessing Groundwater Quality in Kewaunee County, Wisconsin

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Study Funding Sources

Wisconsin DNR

WI Groundwater Research Advisory Council

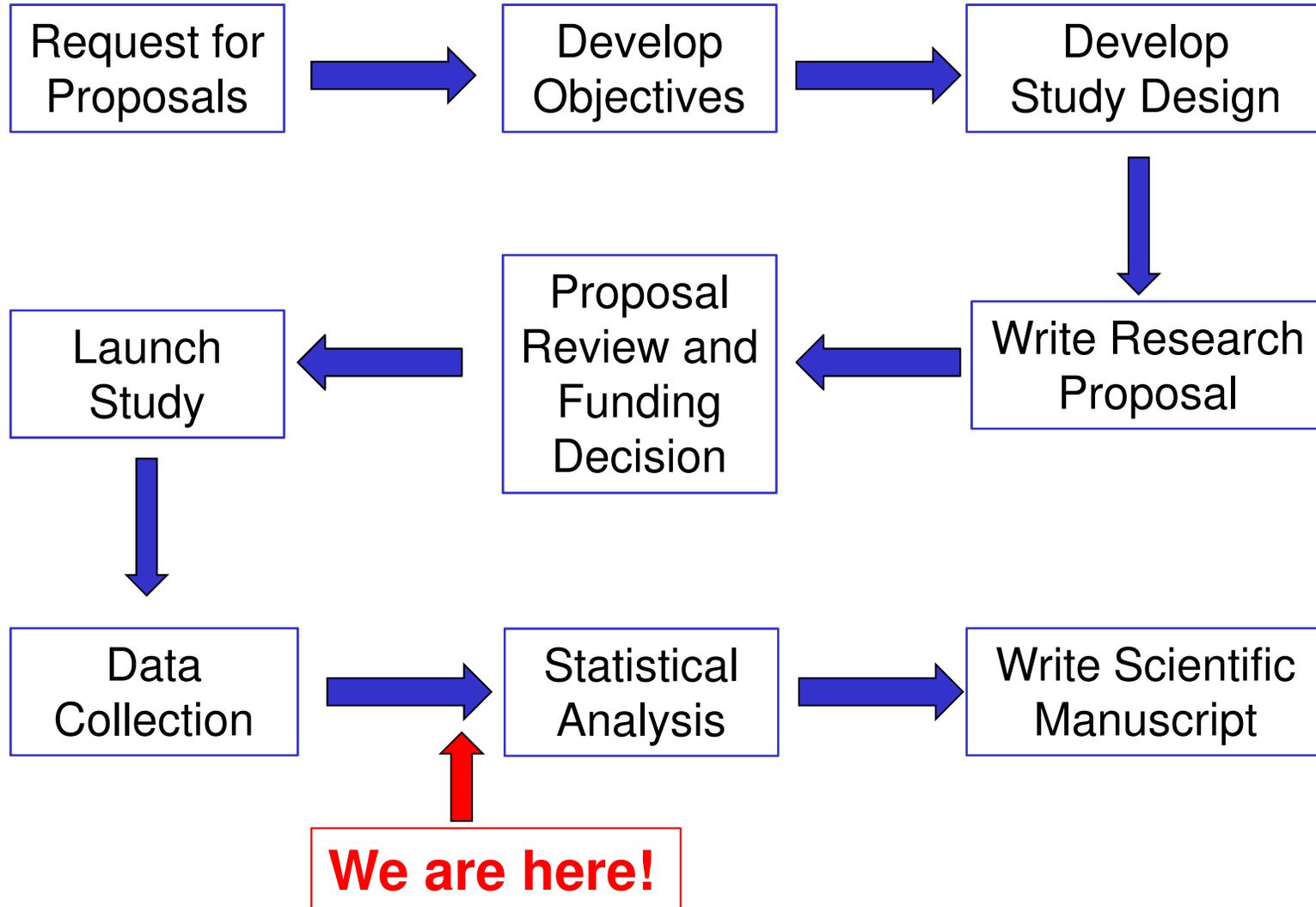
US Geological Survey

USDA - Agricultural Research Service

THANK YOU!

**621 Kewaunee County households
participated in the study**

Study Steps



Presentation Outline

- Introduction
- Hydrogeology of Kewaunee County
- Private well contamination and sources
- Contamination timing and variability
- What a private well owner can do
- Study next steps

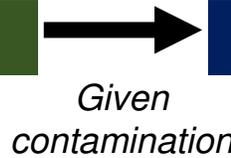
INSERT MOE'S HYDROGEOLOGY PRESENTATION

Research Objectives

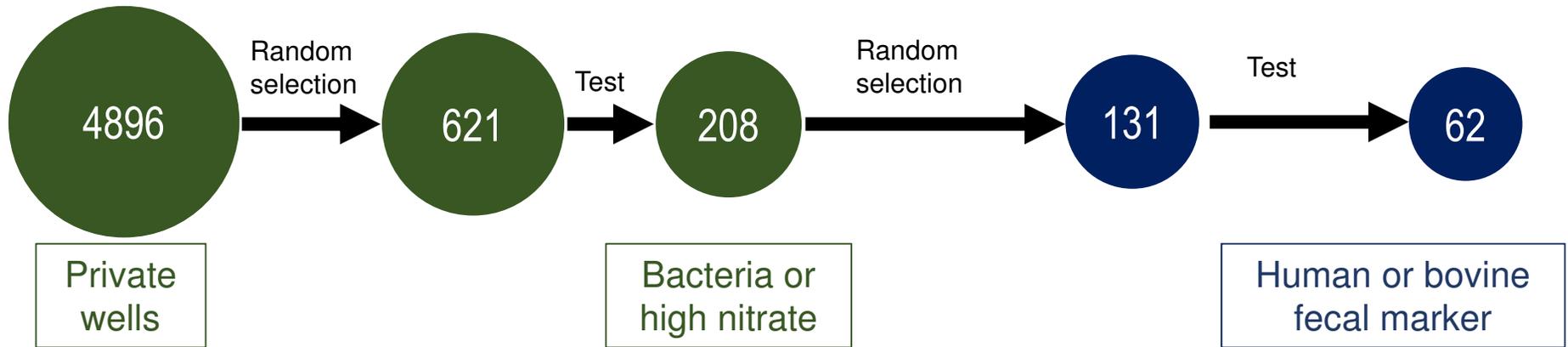
1. Design a county-wide randomized sampling plan, stratified by depth-to-bedrock, for nitrate and indicator bacteria
2. Sample once per season a subset of wells for viruses and fecal markers capable of distinguishing septic versus bovine sources of contamination
3. Install automated sampling systems on one or two wells to determine the timing of peak transport for viruses and indicator bacteria
4. Identify spatial and temporal patterns of contamination

Project objectives & study design

1. Measure total coliform, *E. coli*, nitrate



2. Determine fecal source

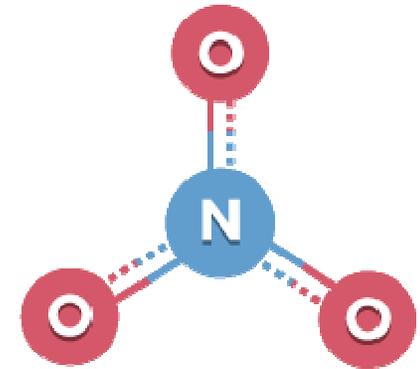


Outcome: County-wide occurrence as % wells contaminated

Outcome: Number of wells with human or bovine fecal markers

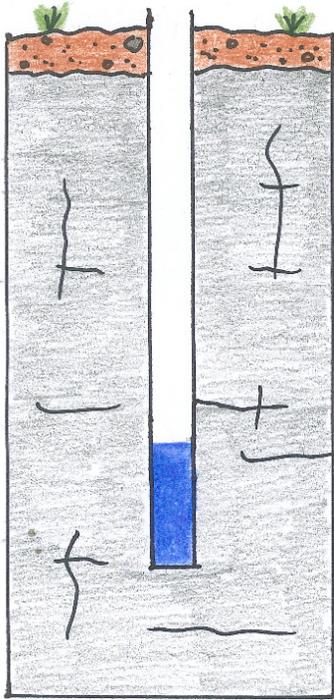
Objective I: Total Coliform, *E. coli*, Nitrate

- County-wide randomized sampling of private wells stratified by depth-to-bedrock: 0-5 ft, 5-20 ft, 20+ ft
- Participation rate ~ 50%
- Several day “Synoptic” sampling
- Recharge
 - November 2015
 - 317 wells in analysis
- No recharge
 - July 2016
 - 400 wells in analysis

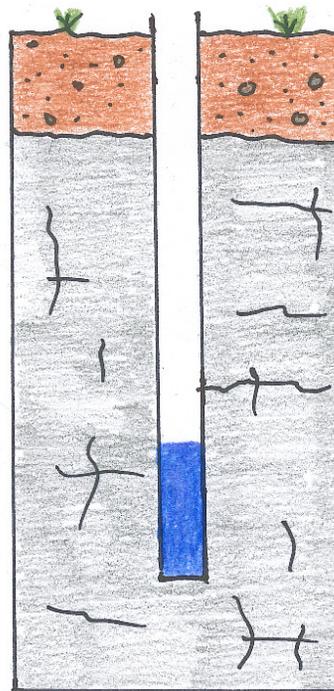


Total coliform in private wells by depth to bedrock

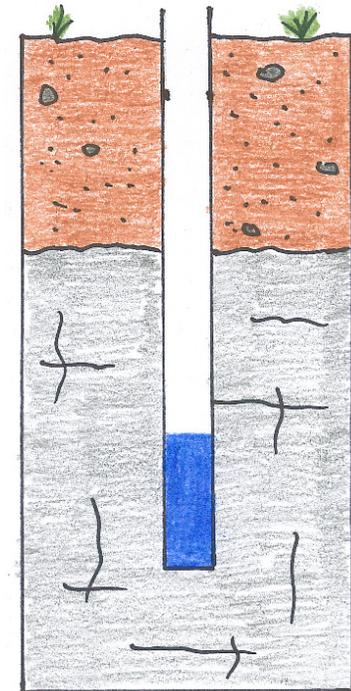
0 – 5 feet



5 – 20 feet



20 + feet



Total coliform (% positive wells)

Recharge **46**
No recharge **23**

28
29

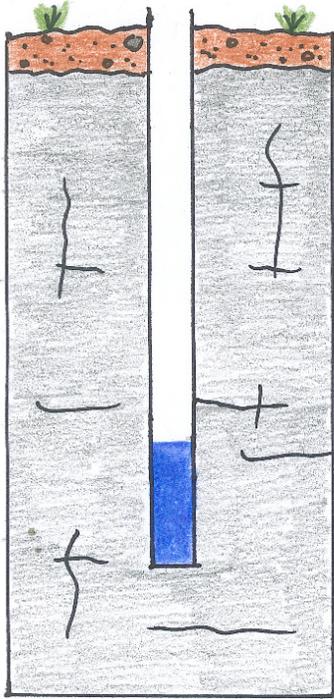
19
21

Wisconsin (all depths): **22.8**

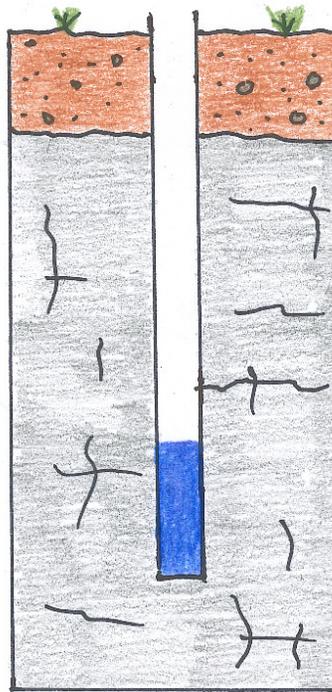
US General Accounting Office 1997

E. coli in private wells by depth to bedrock

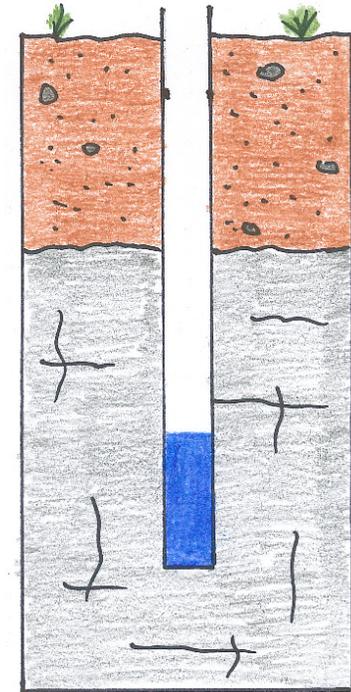
0 – 5 feet



5 – 20 feet



20 + feet



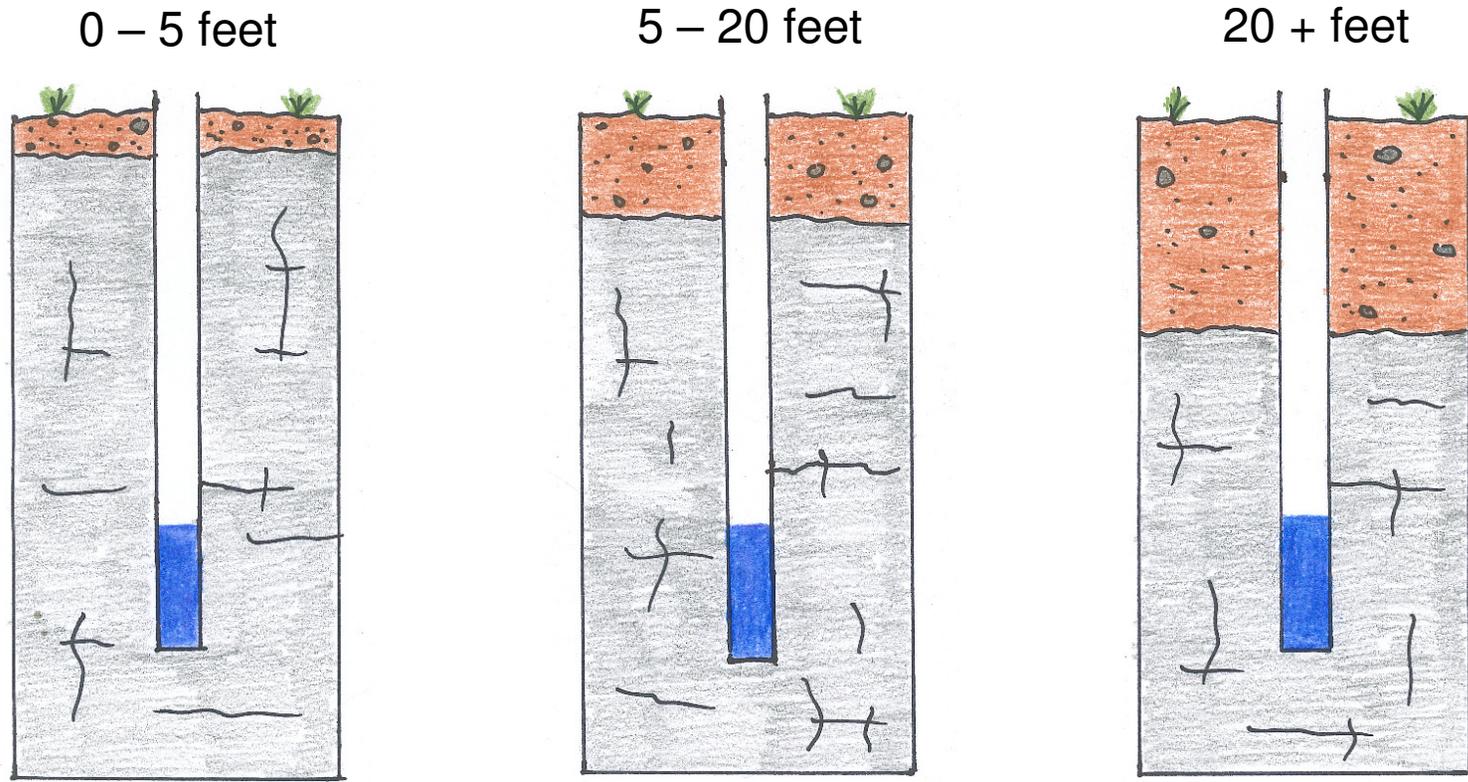
E. coli (% positive wells)

Recharge	4	1	0.3
No recharge	7	1	1

Wisconsin (all depths): **2.6**

US General Accounting Office 1997

High nitrate in private wells by depth to bedrock



High nitrate (% positive wells)

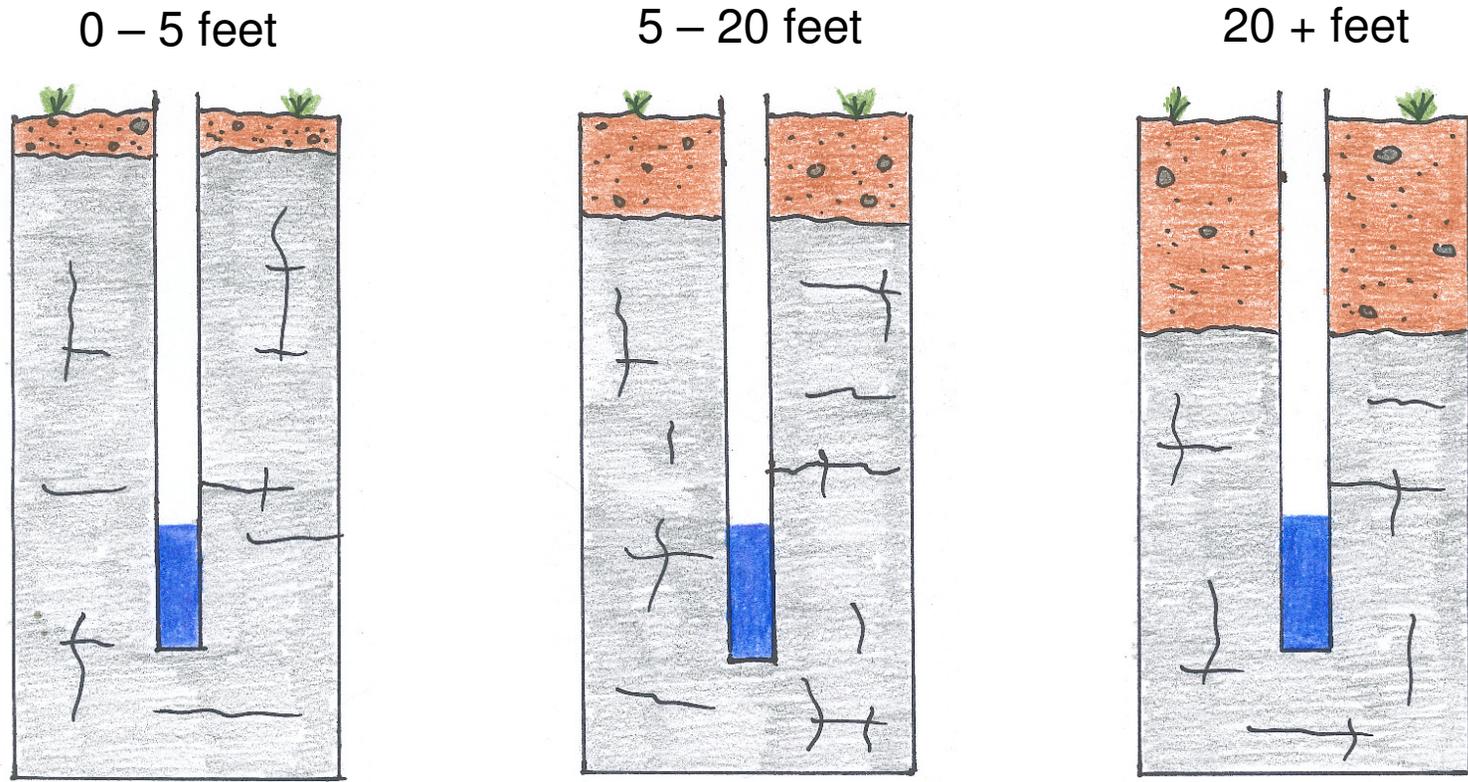
Recharge	7	20	6
No recharge	10	19	5

Wisconsin (all depths): **6.6**

US General Accounting Office 1997

High nitrate: exceeds health standard; $N-NO_3^- > 10$ ppm

Total coliform, *E. coli*, or high nitrate in private wells by depth to bedrock



Total coliform, *E. coli*, or high nitrate (% positive wells)

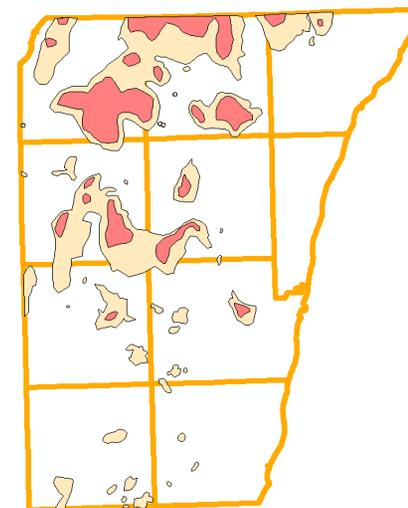
Recharge	50	42	23
No recharge	33	40	26

High nitrate: exceeds health standard; $N-NO_3^- > 10$ ppm

County-wide contamination rate; weighted by depth to bedrock

Percent wells contaminated

	Kewaunee County		Wisconsin*
	Recharge (n = 317)	No Recharge (n = 400)	(n = 534)
Total coliform	20.8	22.2	22.8
<i>E. coli</i>	0.4	1.2	2.6
High nitrate	7.4	6.8	6.6
Any of the 3 contaminants	26.4	27.6	NA



High nitrate: exceeds health standard; N-NO₃⁻ > 10 ppm

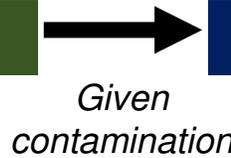
**private wells sampled; Information on the quality of water found at community water systems and private wells. United States GAO/RCED-97-123, June 1997*

Objective 2: Determine fecal source

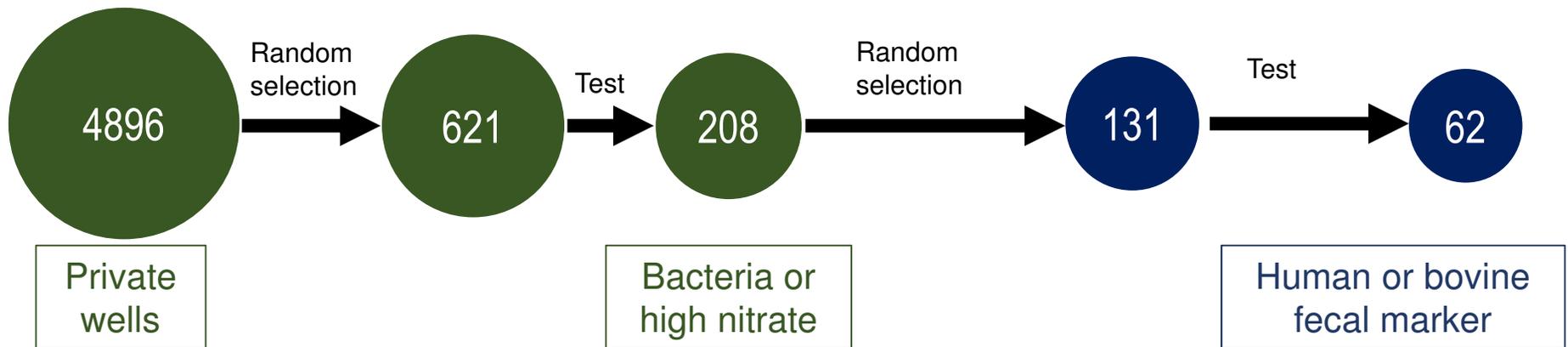
- Randomized stratified sampling from 208 wells positive for total coliform, *E. coli*, or high nitrate ($\text{N-NO}_3^- > 10 \text{ ppm}$)
- Five sampling rounds, all completed:
 - April, August, November, 2016
 - January and March, 2017

Project objectives & study design

1. Measure total coliform, *E. coli*, nitrate



2. Determine fecal source



Outcome: County-wide occurrence as % wells contaminated

Outcome: Number of wells with human or bovine fecal markers

Kewaunee County Cattle

- All cattle & calves in 2016 = 97,000
- Milk cows in 2013 = 45,500
- Milk cow herds in 2016 = 167
- Concentrated Animal Feeding Operations (CAFOs) 15 dairy, one beef
- Approximately 700 million gallons cattle manure per year



Kewaunee County Septic Systems

- 4822 septic systems in the county
- 540 holding tanks, 155 abandoned

Personal comm. Lee Luft, Kewaunee County Supervisor, March 7, 2017

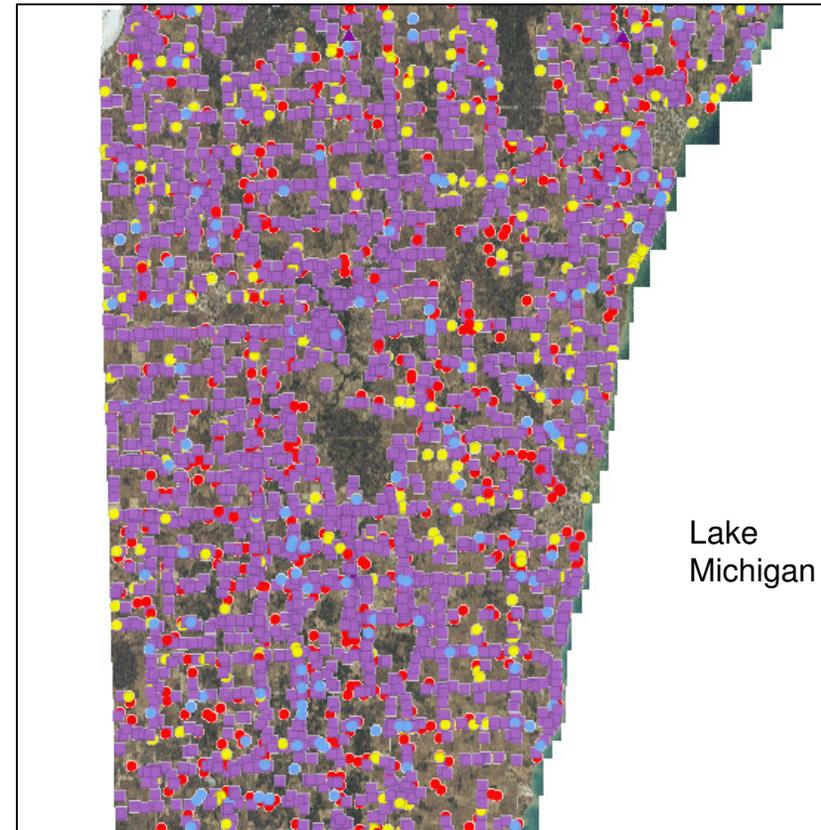
Legend

Purple = replaced or inspected

Red = not inspected

Yellow = holding tank

Blue = abandoned system



Kewaunee County septic systems

Approximately 200 million gallons septic effluent per year released to the subsurface

Study Sampling and Analyses

- Collected 138 samples from 131 household wells in Kewaunee County
- Pump ~800 L through hemodialysis filters
- Laboratory tests for genetic sequence unique to microorganism
 - Human-specific microbes
 - Bovine-specific microbes
 - Non-specific microbes (pathogens of both people and cattle)



Microbes: Identifying the Fecal Source

(n = 138 samples from 131 wells) (red font indicates pathogenic)

Host	Microorganism	Wells	Concentration (gene copies/L)
Human-specific	Adenovirus A	1	1
	<i>Bacteroidales</i> -like Hum M2	7	< 1 – 1050
	Human <i>Bacteroides</i>	27	< 1 – 34
	<i>Cryptosporidium hominis</i>	1	qualitative
	All	29	
Bovine-specific	<i>Bacteroidales</i> -like Cow M2	2	29 - 915
	<i>Bacteroidales</i> -like Cow M3	4	3 – 49818
	Bovine <i>Bacteroides</i>	36	< 1 – 42398
	Bovine polyomavirus	8	< 1 – 451
	Bovine enterovirus	1	2
All	40		

Not detected: [human-specific] adenovirus B & C, D, F, enterovirus, human polyomavirus, norovirus GI & GII
 [bovine-specific] coronavirus, bovine diarrheal virus 1 & 2

Wells with human or bovine microorganisms (62 of 131 tested)

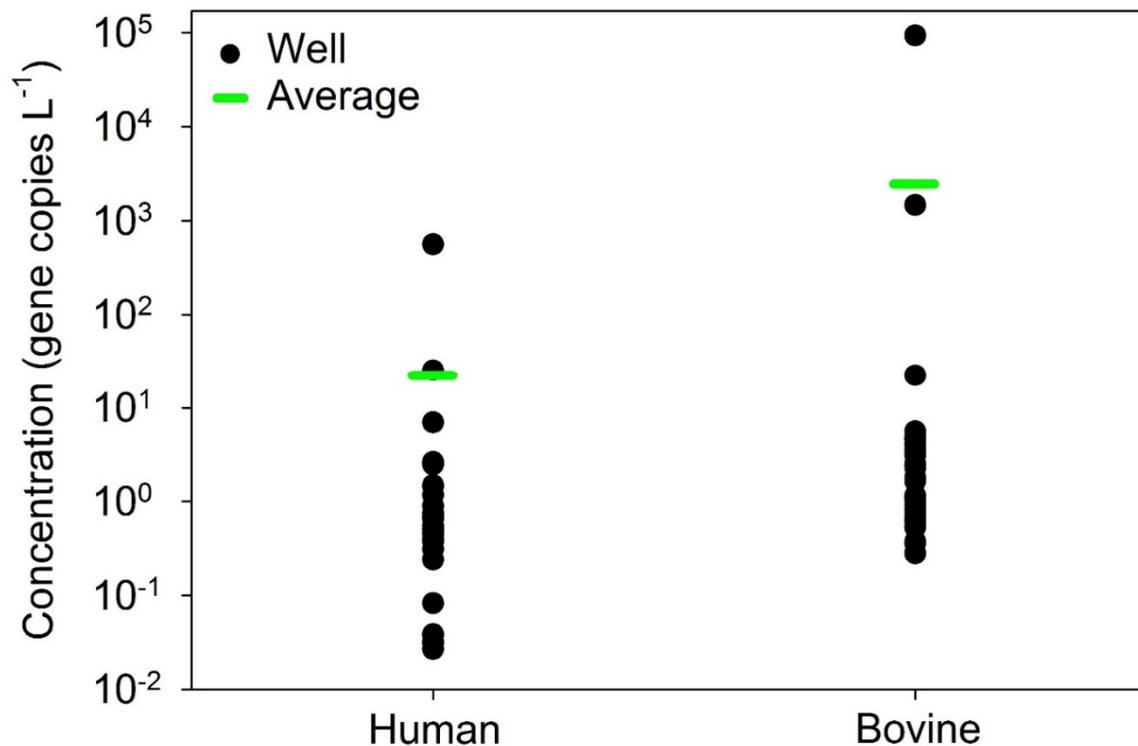
Number of wells with human or bovine microorganisms:

Human: 29

Both: 7

Bovine: 40

Concentrations of microorganisms in wells



Concentration is sum of human- or bovine-specific microorganisms in a positive well; displayed on a log₁₀ scale

Host	Microorganism	Wells	Concentration (gene copies/L)
	<i>Campylobacter jejuni</i>	1	< 1
	<i>Cryptosporidium parvum</i>	13	qualitative
	<i>Cryptosporidium</i> spp.	16	< 1 – 3
	<i>Giardia lamblia</i>	2	< 1
	Pathogenic <i>E. coli</i> (<i>eae</i> gene)	1	4
	Pathogenic <i>E. coli</i> (<i>stx1</i> gene)	1	16
Non-specific	Pathogenic <i>E. coli</i> (<i>stx2</i> gene)	1	1
	Pepper mild mottle virus	13	2 - 3811
	Rotavirus A (<i>NSP3</i> gene)	17	< 1 – 4481
	Rotavirus A (<i>VP7</i> gene)	7	< 1 – 732
	Rotavirus C	3	45 – 1301
	<i>Salmonella</i> (<i>invA</i> gene)	3	< 1 – 13
	<i>Salmonella</i> (<i>ttr</i> gene)	5	5 – 59
	All	44	
Total positive wells		79	< 1 - 49818

Wells with human or bovine rotavirus group A (17 of 131 tested)

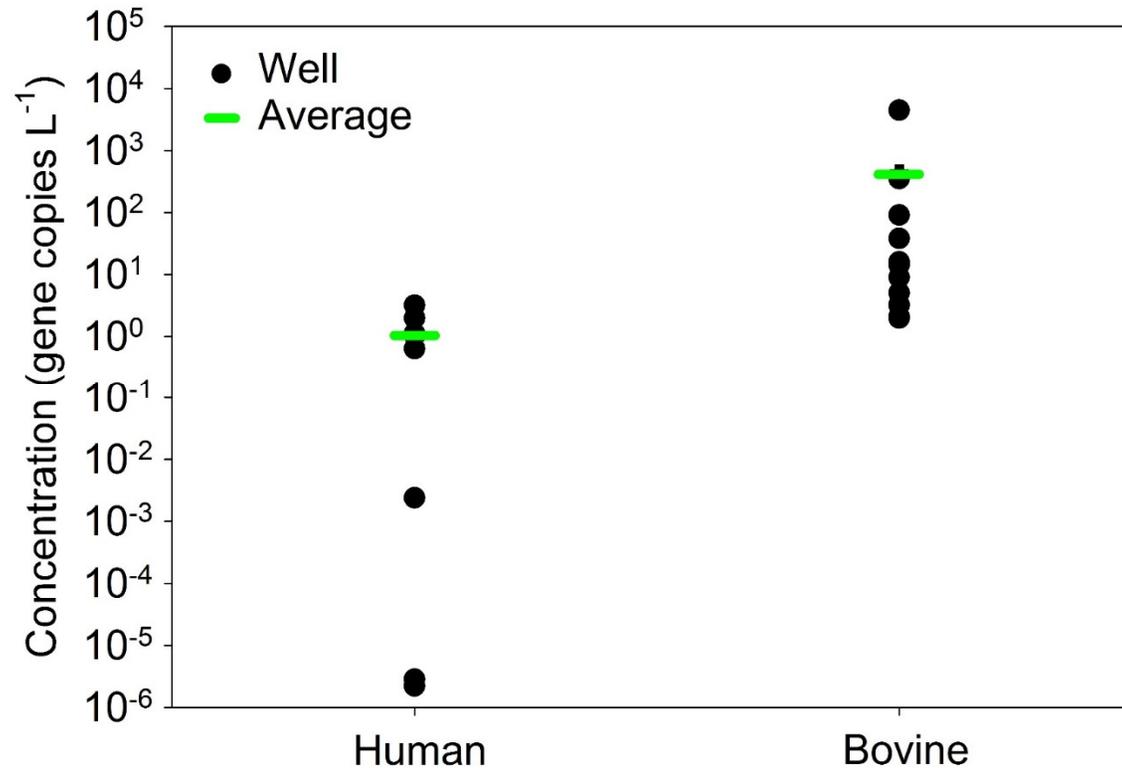
Number of wells with human or bovine rotavirus group A:

Human: 7

Both: 2

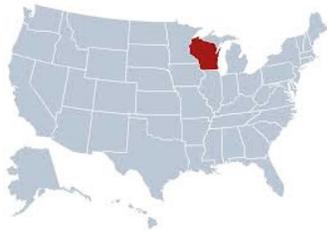
Bovine: 12

Concentrations of rotavirus group A in wells



Concentration is displayed on a log₁₀ scale

Pathogens & fecal markers in Kewaunee County: Comparison to other studies



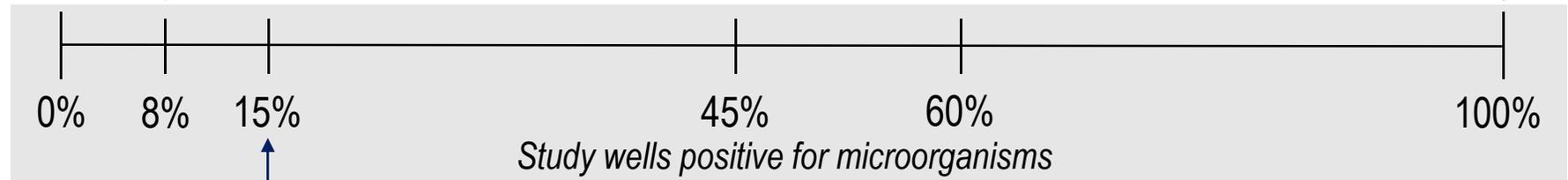
Wisconsin 2003:
Private wells
50 tested



Ontario 2017:
Private wells
11 tested



Pennsylvania 2017
Private wells
5 tested



Canada & USA 1990 – 2013
Public & private wells
12,616 tested



Kewaunee County
Private wells
131 tested



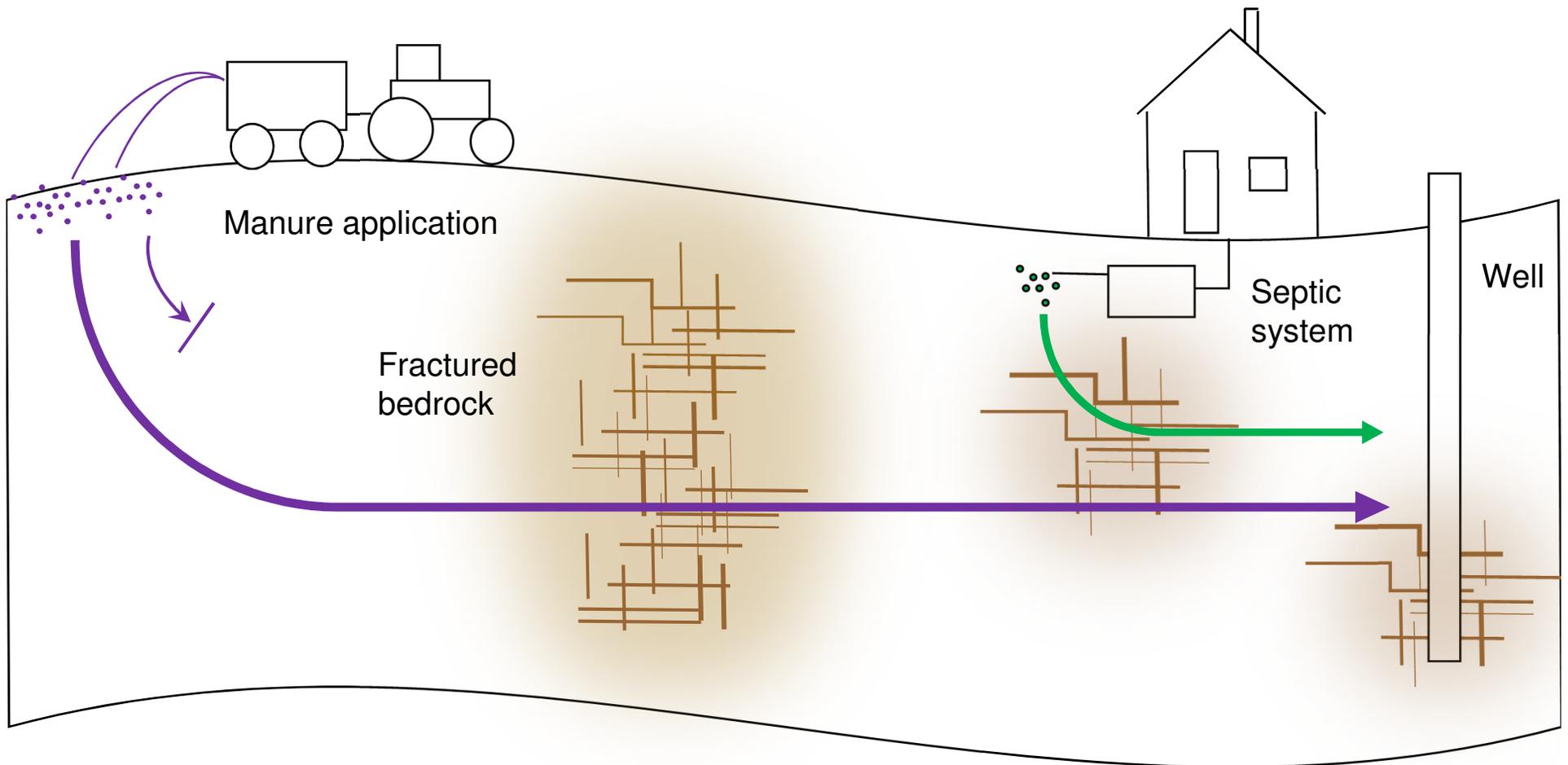
Conceptual Model of Fecal Contamination in Kewaunee County - 1

Bovine pathogen source

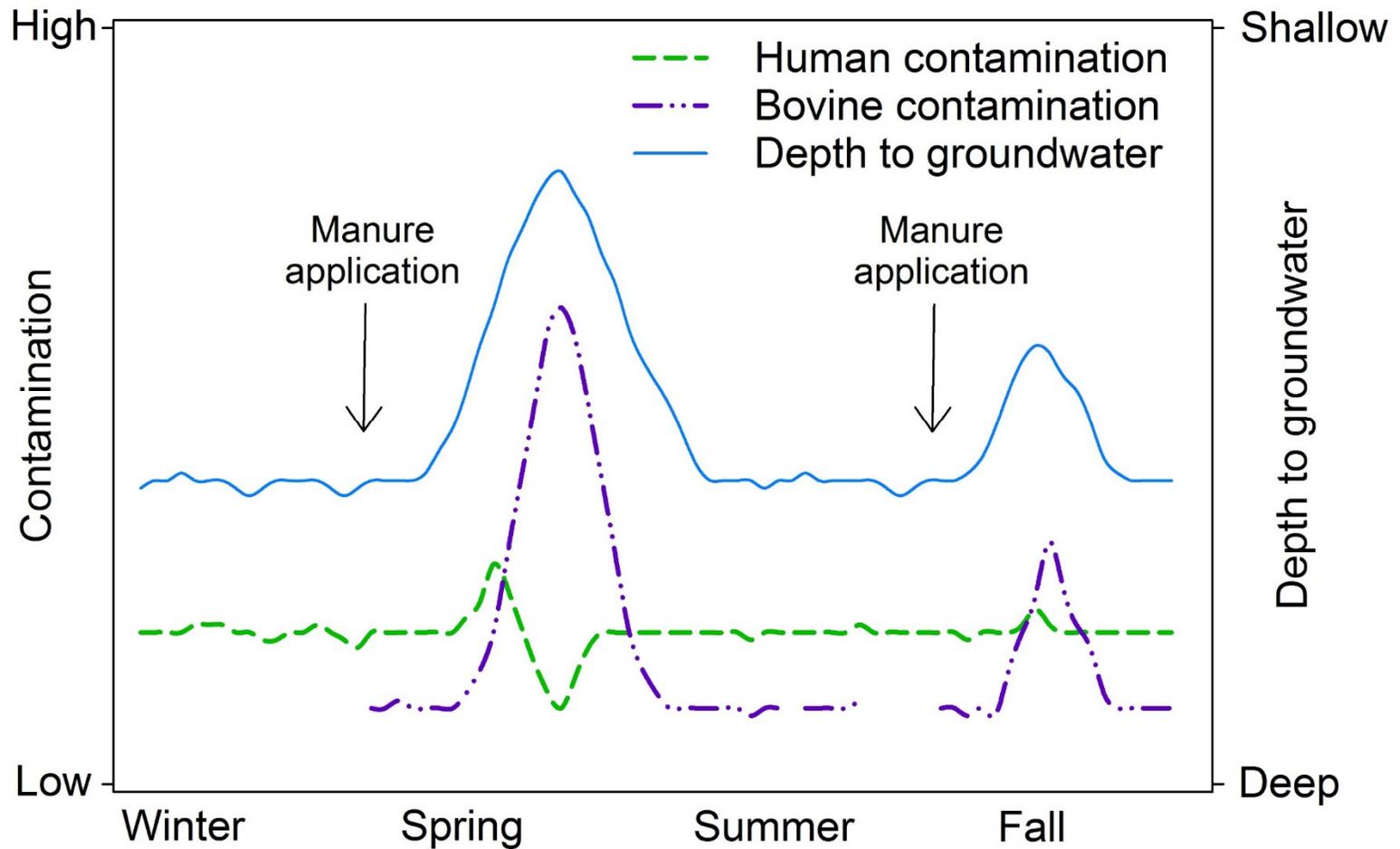
- Large fecal source
- Surface applied periodically
- Episodic infiltration

Human pathogen source

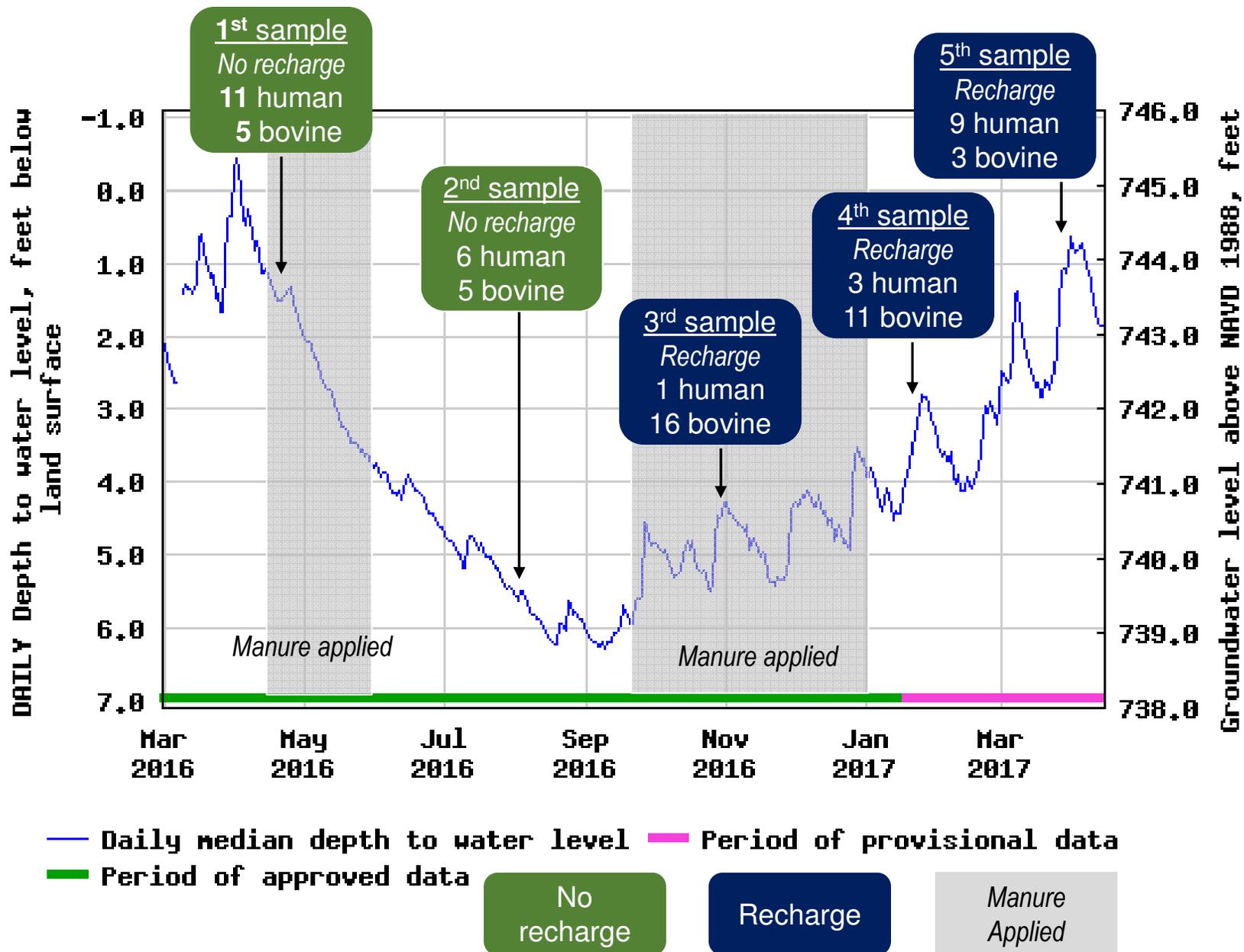
- Small fecal source
- Sub-surface release continuously
- Continuous infiltration



Conceptual Model of Fecal Contamination in Kewaunee County - 2



Groundwater levels during sampling for pathogens & fecal indicators



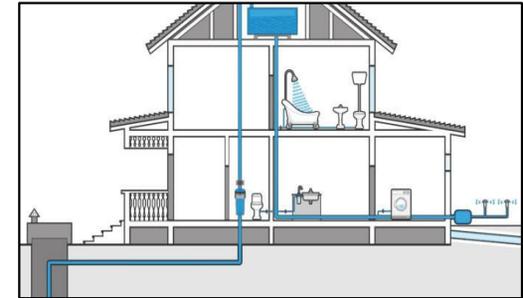
From Farm Field to Household Well



Manure applied Oct 25, 2016



> 1 inch rain Oct 26, 2016



House near field

Farm field sampled Oct 27, 2016



Bovine Bacteroides
Bovine enterovirus
Bovine polyomavirus
M2 Bacteroides-like
M3 Bacteroides-like

Rotavirus A NSP3
Rotavirus A VP7
Rotavirus C

Tap water Oct 27, 2016

Bovine Bacteroides
Bovine enterovirus
Bovine polyomavirus
M2 Bacteroides-like
M3 Bacteroides-like
Campylobacter jejuni
Cryptosporidium
Rotavirus A NSP3
Rotavirus A VP7
Rotavirus C



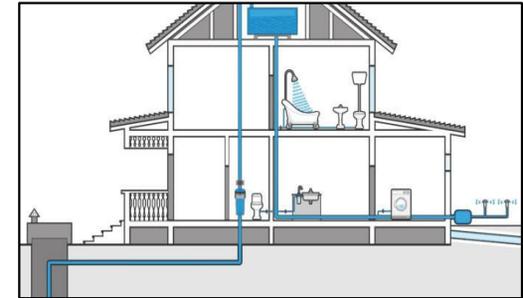
From Farm Field to Household Well



Manure applied Oct 25, 2016

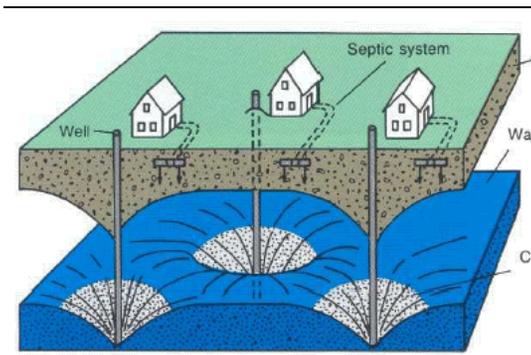


> 1 inch rain Oct 26, 2016



House near field

Neighbor's well sampled Oct 31, 2016



Bovine Bacteroides
 Bovine polyomavirus
 M2 Bacteroides-like
 M3 Bacteroides-like

 Rotavirus A NSP3
 Rotavirus A VP7
 Rotavirus C

Tap water Oct 27, 2016

Bovine Bacteroides
 Bovine enterovirus
 Bovine polyomavirus
 M2 Bacteroides-like
 M3 Bacteroides-like
 Campylobacter jejuni
 Cryptosporidium
 Rotavirus A NSP3
 Rotavirus A VP7
 Rotavirus C



Do people get sick from drinking contaminated private well water?

- Consider one pathogen: *Cryptosporidium parvum*
- Confirmed cryptosporidiosis cases in Kewaunee County reported to State:
 - 2 to 9 cases per year (2010 to 2016)
- Under-reporting of cryptosporidiosis cases in the USA is estimated to be 100-fold (Centers for Disease Control and Prevention, 2012)
- Therefore, in Kewaunee County there are likely 200 to 900 cryptosporidiosis cases per year

How many of these cases are from private wells?

Estimate of Kewaunee County *Cryptosporidium parvum* infections from private wells

	People	Calves
Population using private wells	12,200	17,300
Wells contaminated by <i>C. parvum</i>	3.1%	3.1% (assumed)
Population exposed per day	380	540
Infections per exposure	10 infections per 10,000 people	85 infections per 10,000 calves
Total infections per year	140	1,700

Summary

- On a county-wide basis 26% to 28% of private wells are positive for total coliforms, *E. coli*, or nitrate-N > 10 ppm.
- At depths to bedrock less than 20 feet contamination rates generally exceed statewide averages.
- Well contamination results from both human and bovine fecal sources.
- The primary source of fecal contamination in the wells, bovine or human, appears to vary with groundwater recharge and the timing of manure application.
- Wells are contaminated with pathogens of significant concern: *Salmonella*, EHEC, *Cryptosporidium*, rotavirus.
- We estimate contaminated private wells are responsible each year in Kewaunee County for 140 people and 1,700 calves infected with *Cryptosporidium parvum*.

INSERT MOE'S AUTO-SAMPLER PRESENTATION

Living in Kewaunee County with a private well

- Water treatment by reverse osmosis or ultraviolet light
- Maintain water treatment equipment
- Be aware of heavy rainfall and snowmelt as times when wells are most vulnerable to contamination
- Monitor the USGS monitoring well in Kewaunee County for groundwater recharge
- Be careful to avoid contaminated drinking water exposure to young children, elderly, and people with altered immune systems

Study Next Steps

- Determine how fecal source, pathogen types, and pathogen concentrations are associated with well construction, hydrogeological, and environmental variables
- Prepare scientific manuscript for peer-review

Wish List

- Estimate risk of illness from private well water by risk assessment or epidemiological methods
- Develop health-risk based well vulnerability tool
- Develop early warning system for pathogen contamination of private wells
- Use nano-scale pathogen transport models to predict well contamination