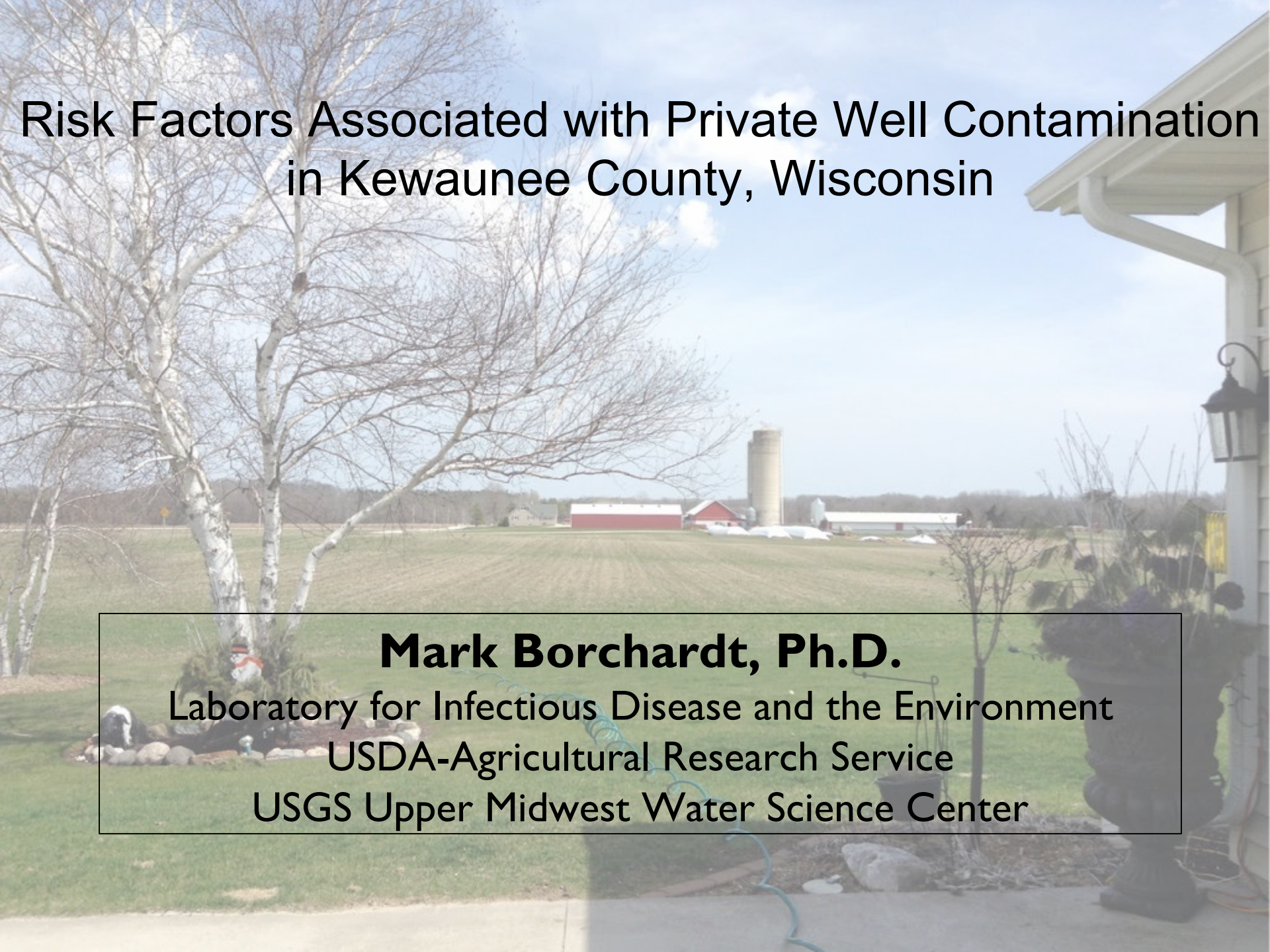
Risk Factors Associated with Private Well Contamination in Kewaunee County, Wisconsin



Mark Borchardt, Ph.D.
Laboratory for Infectious Disease and the Environment
USDA-Agricultural Research Service
USGS Upper Midwest Water Science Center

The Research Team

Sue Spencer, USDA-Agricultural Research Service

Maureen Muldoon, UW-Oshkosh Department of Geology

Randall Hunt, Joel Stokdyk, Aaron Firnstahl & Dave Owens
USGS Upper Midwest Water Science Center

Davina Bonness Kewaunee County Land and Water Conservation

Burney Kieke Marshfield Clinic Research Institute

USDA United States Department of Agriculture

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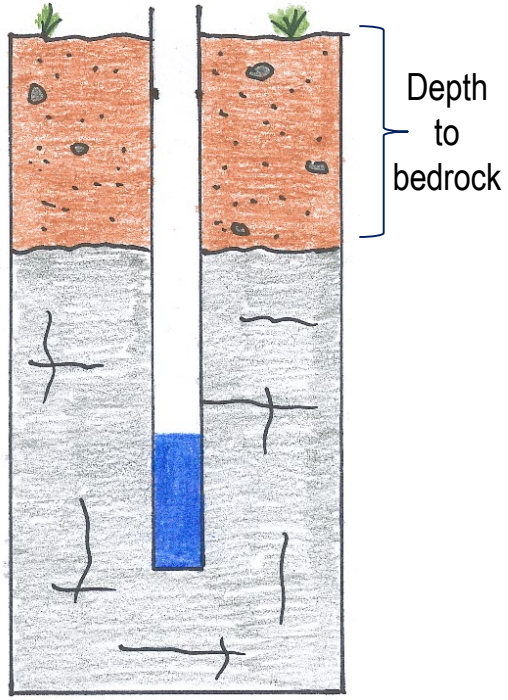
USGS science for a changing world

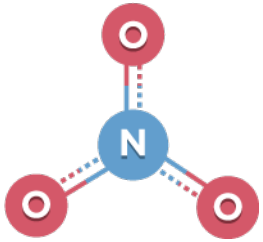
Research Objectives

1. Estimate county-wide contamination rate for nitrate and indicator bacteria as related to depth-to-bedrock
2. Determine source of fecal contamination using viruses and fecal markers
3. Identify risk factors for private well contamination using statistical models

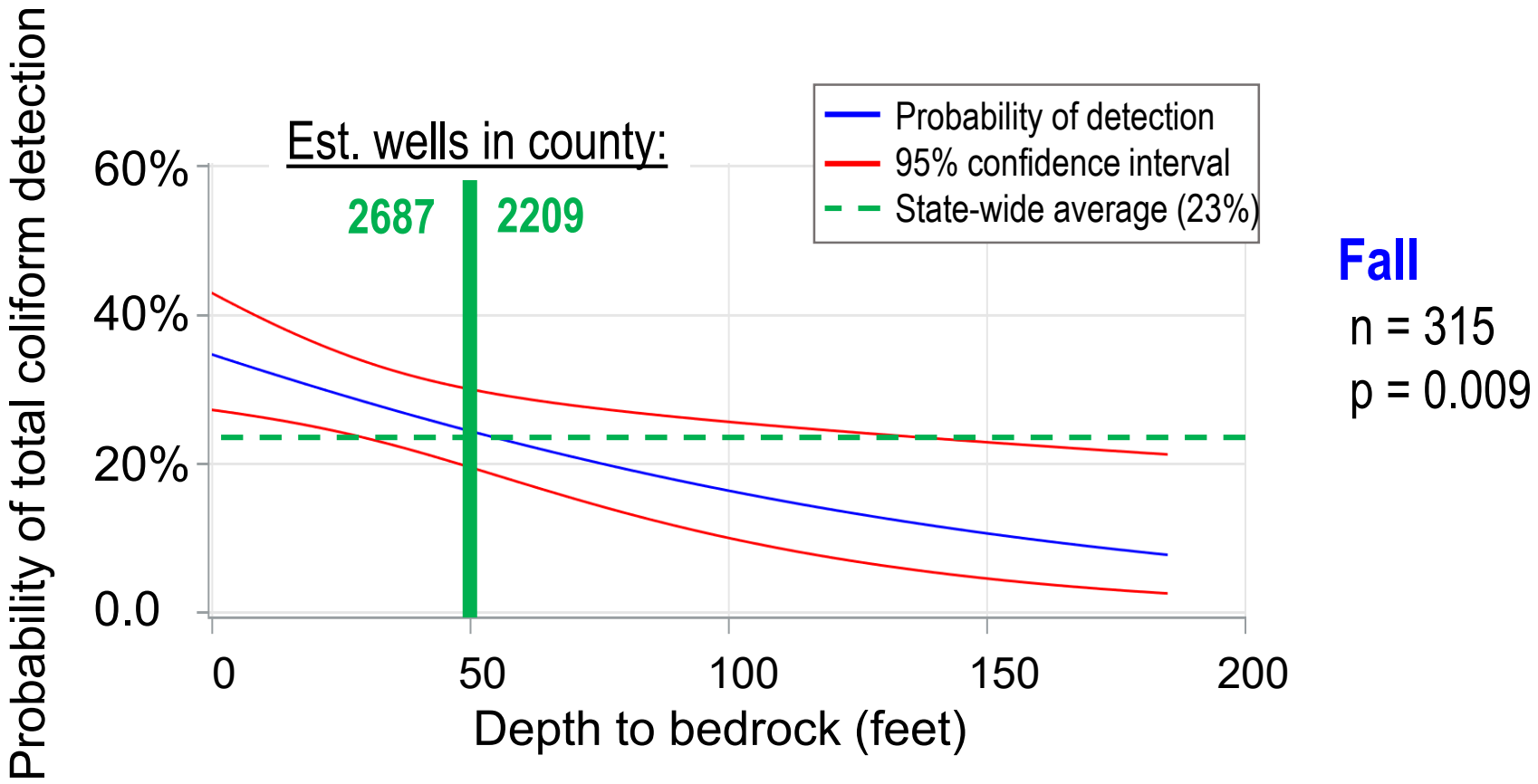
Objective 1: Total Coliform, *E. coli*, Nitrate

- County-wide randomized sampling of private wells – 4,896 in county
- Stratified by depth-to-bedrock:
  - Less than 5 feet
  - 5-20 feet
  - Greater than 20 feet
- Participation rate ~ 50%
- Sampled twice:
- November 2015
  - 317 wells in analysis
- July 2016
  - 400 wells in analysis





Effect of depth to bedrock on total coliform contamination

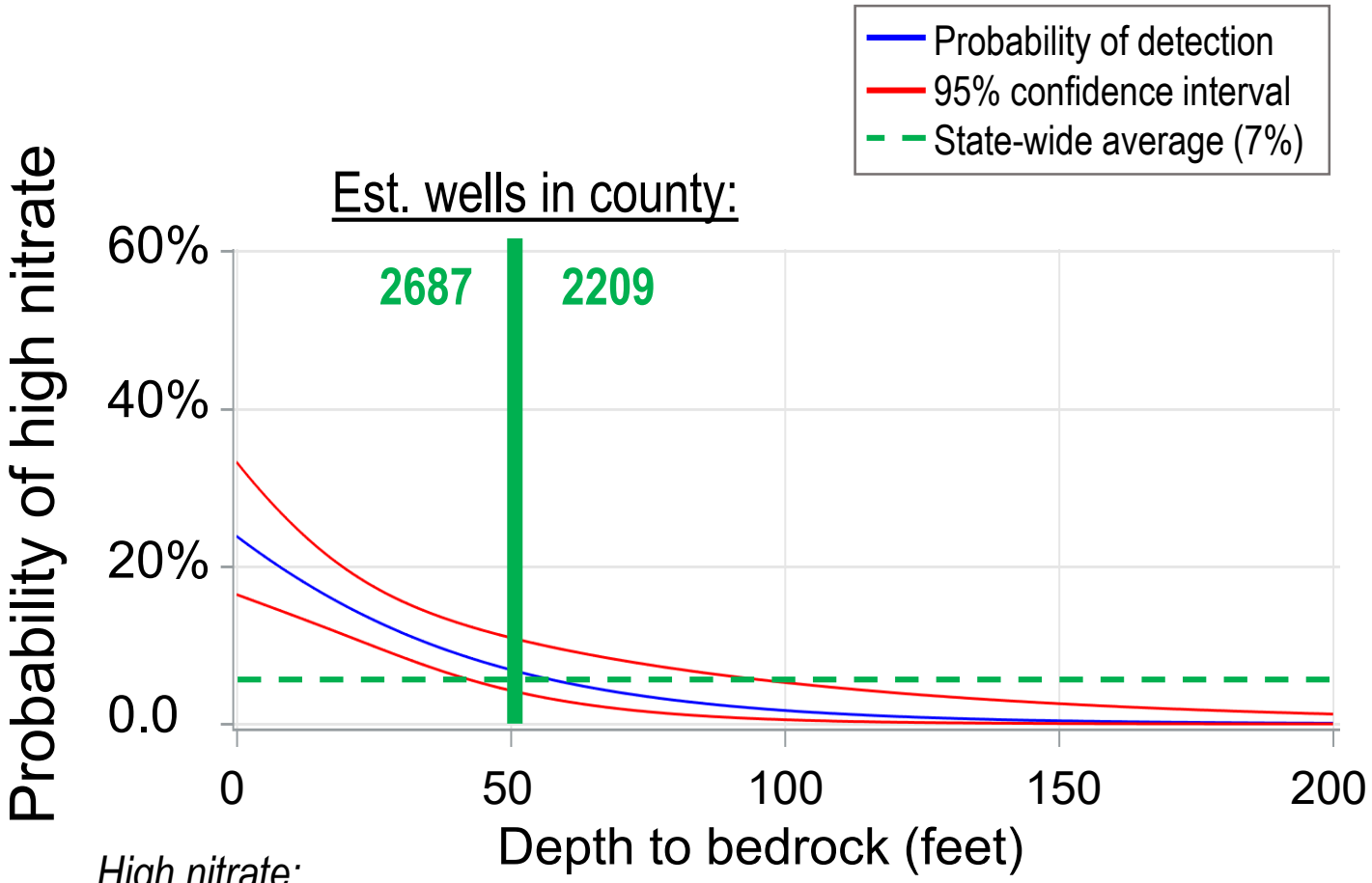


Fall

n = 315

p = 0.009

Effect of depth to bedrock on nitrate contamination



Summer

n = 399

p < 0.0001

High nitrate: exceeds health standard

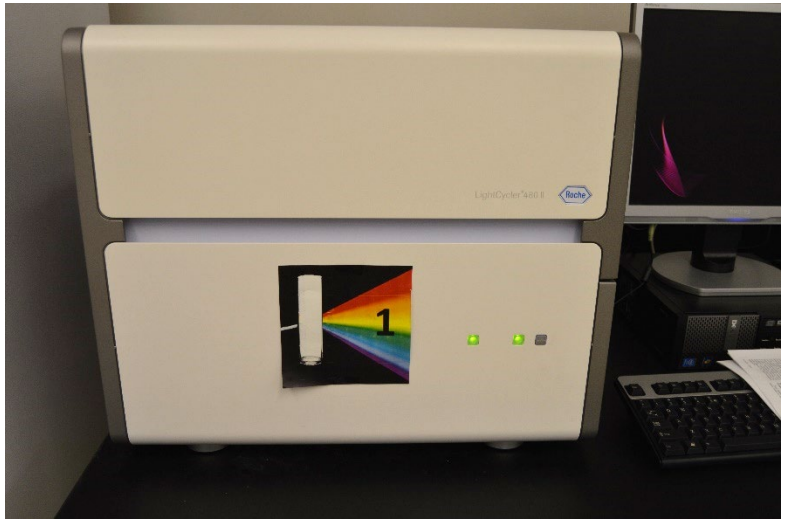
$N\text{-}NO_3^-$ > 10 ppm

Objective 2: Determine fecal source

- Randomized stratified sampling from 208 wells positive for total coliform, *E. coli*, or high nitrate ($N\text{-}NO_3^-$ > 10 ppm)
- Five sampling rounds:
    - April, August, November, 2016
    - January and March, 2017

Study Sampling and Analyses

- Collected 138 samples from 131 household wells in Kewaunee County
- Pump ~800 L through hemodialysis filters
- qPCR for microbial genetic targets
  - 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
Human-specific	Adenovirus A	1
	Bacteroidales-like Hum M2	7
	Human *Bacteroides*	27
	Cryptosporidium hominis	1
	Rotavirus A (G1 P[8])	7
	Any human microbe	**33**

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

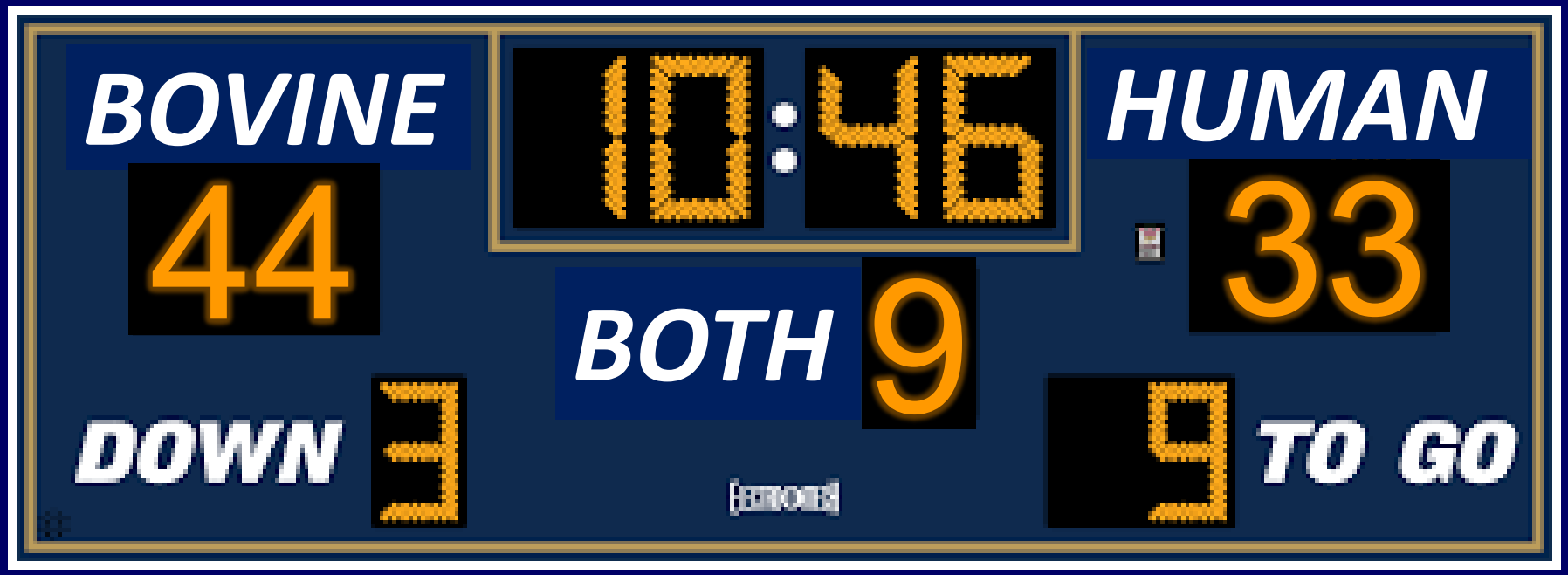
Microbes: Identifying the Fecal Source

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

Host	Microorganism	Wells
Bovine-specific	*Bacteroidales*-like Cow M2	2
	Bacteroidales-like Cow M3	4
	Ruminant *Bacteroides*	36
	Bovine polyomavirus	8
	Bovine enterovirus	1
	Rotavirus A (G10 P[11])	12
	Any bovine microbe	**44**

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

Well Contamination Scoreboard



Other Fecal Microbes (red font indicates pathogenic)

Host	Microorganism	Wells
Non-specific	*Campylobacter jejuni*	1
	Cryptosporidium parvum	13
	Cryptosporidium spp.	2
	Giardia lamblia	2
	Pathogenic *E. coli* (*eae* gene)	1
	Pathogenic *E. coli* (*stx1* gene)	1
	Pathogenic *E. coli* (*stx2* gene)	1
	Pepper mild mottle virus	13
	Rotavirus C	3
	Salmonella (*invA* gene)	3
	Salmonella (*ttr* gene)	5
	Any non-specific microbe	**37**
	Total fecal positive wells	**79**

Objective 3: Identify Contamination Risk Factors

Why do this?

- Understand what might be the causes of contamination
- Understand how a change in risk factor magnitude affects the magnitude of contamination
- Provide policymakers and stakeholders with options for contamination prevention; Examples:
  - Setback distances
  - Allowable density or number of contamination sources
  - Vulnerable periods related to weather
  - Well construction best practices

Risk Factors Investigated

Land Use – *Distance; count or acres within 750, 1500, 3000 feet of well*

Agricultural	*Septic Systems*
Agricultural fields	All septic types
Fields with NMPs	Drain fields
Manure storages	Not inspected systems
	Septage-applied fields

Bedrock Features – *Count within 750, 1500 and 3000 feet of well*

Sinkholes

Bedrock ledges at the surface

Precipitation – *2, 7, 14, 21 days prior to sampling*

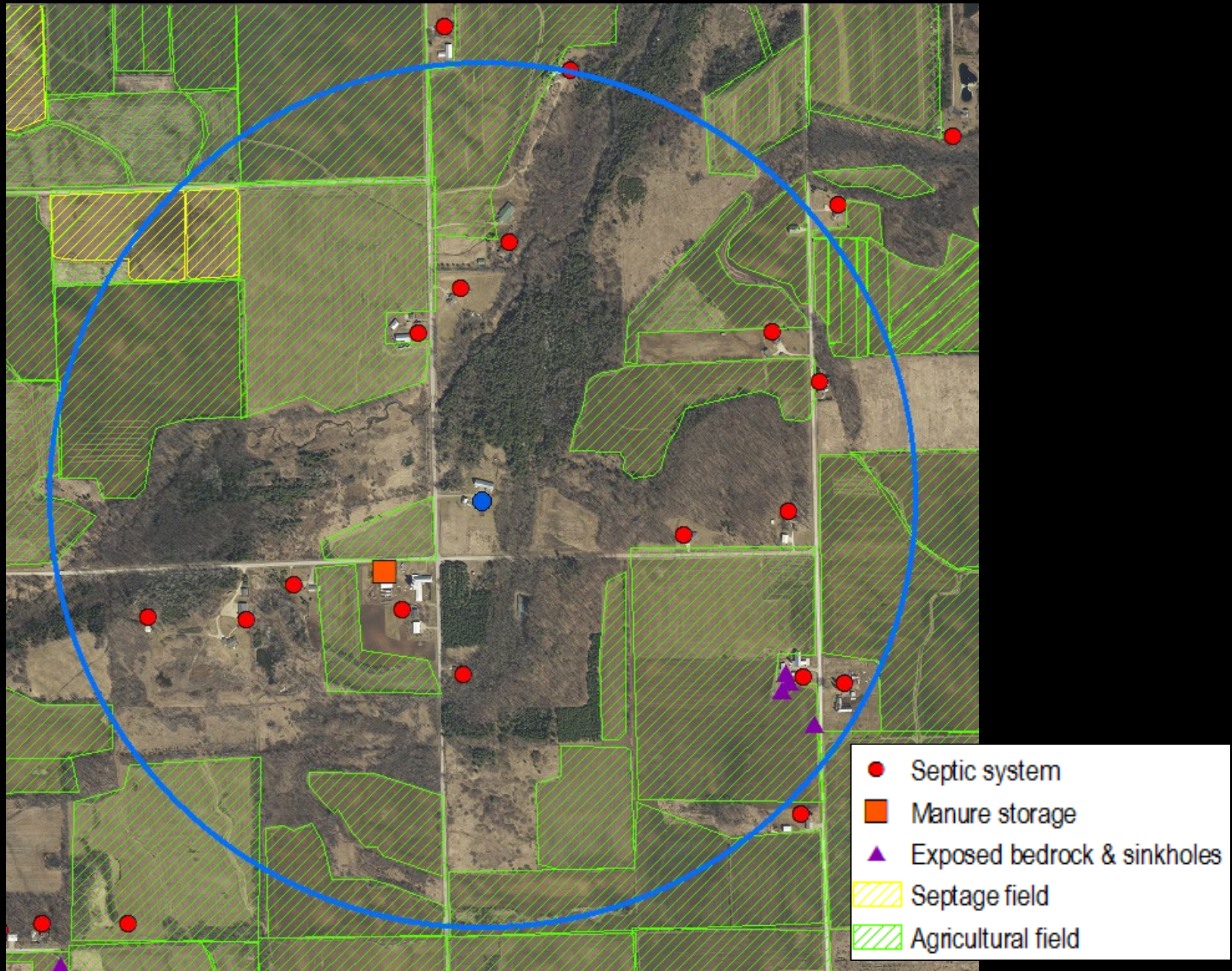
Rainfall (cumulative, no snowfall)

Groundwater Recharge – *2, 7, 14, 21 days prior to sampling*

Groundwater recharge (cumulative)

Depth to groundwater (median & minimum)

Depth to Bedrock

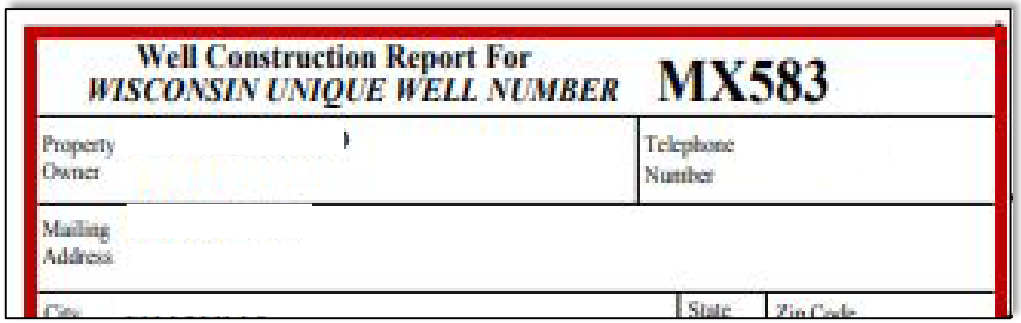

Septic system
Manure storage
Exposed bedrock & sinkholes
Septage field
Agricultural field

Risk Factor Data Sources

Groundwater depth (monitoring well)

Rainfall data

Well characteristics (construction report)



Well Construction Report For
WISCONSIN UNIQUE WELL NUMBER **MX583**

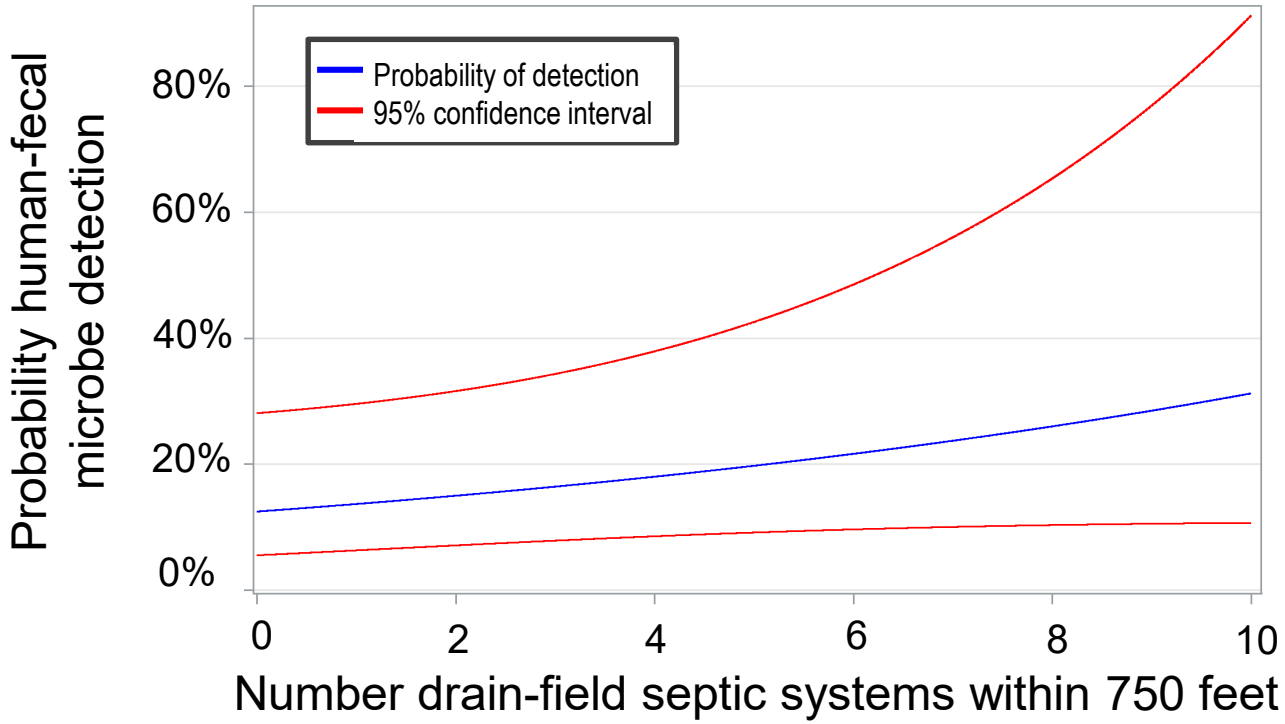
Property Owner	Telephone Number
Mailing Address	
City	State / Zip Code

Risk Factors for Human Fecal Contamination – Detection Probability

Four Significant Risk Factors

1. Number of septic system drain-fields within 750 feet of well
2. Rainfall total previous 2 days
3. Depth to groundwater previous 14 days
4. Depth to bedrock

More septic systems around a well means greater risk for contamination by human fecal microbes



Model accounts for the effects of:

Rainfall total previous 2 days

Depth to groundwater previous 14 days

Depth to bedrock

Risk Factors for Dairy Manure Contamination

Risk Factors – Detection of Manure Microbes

- Groundwater recharge total previous 7 days

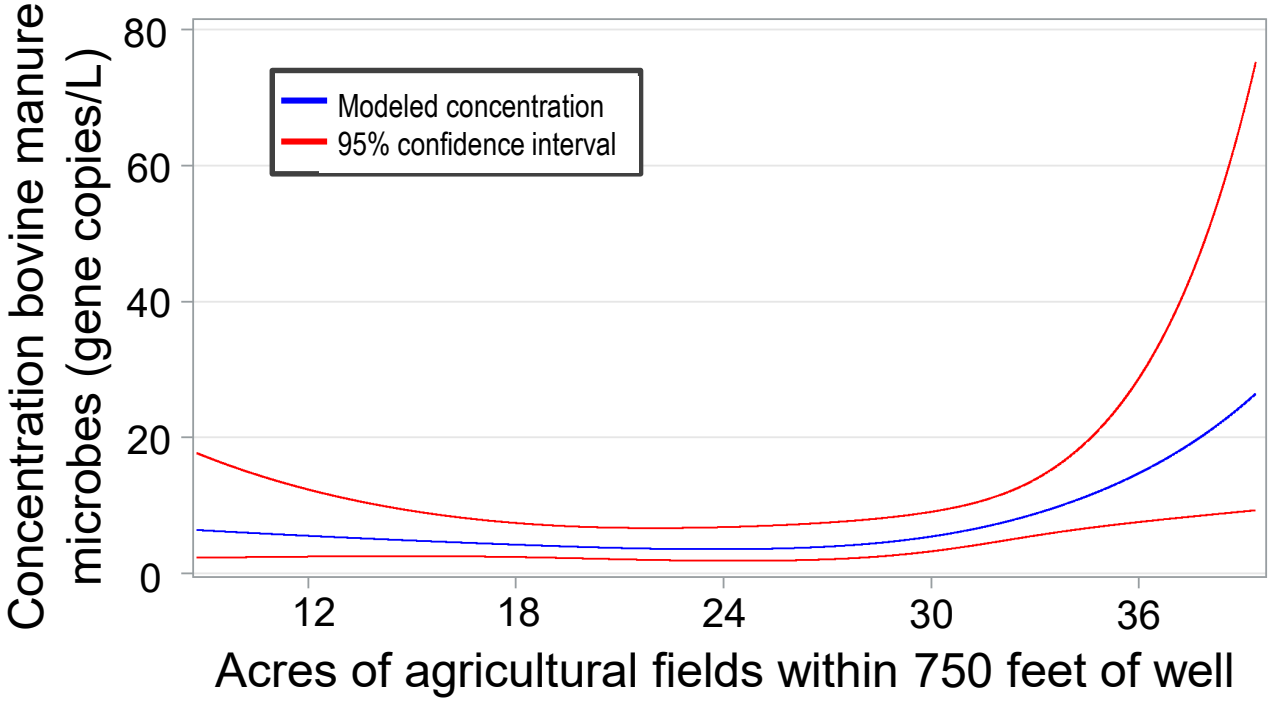
Surprising unimportant factors

- Agricultural-related risk factors were not significant

Risk Factors - Concentration of Manure Microbes in Wells

- Agricultural field area (number of acres) within 750 feet of well
- Depth to bedrock

Exceeding 30 acres of ag fields around a well is associated with higher concentrations of manure microbes in well water

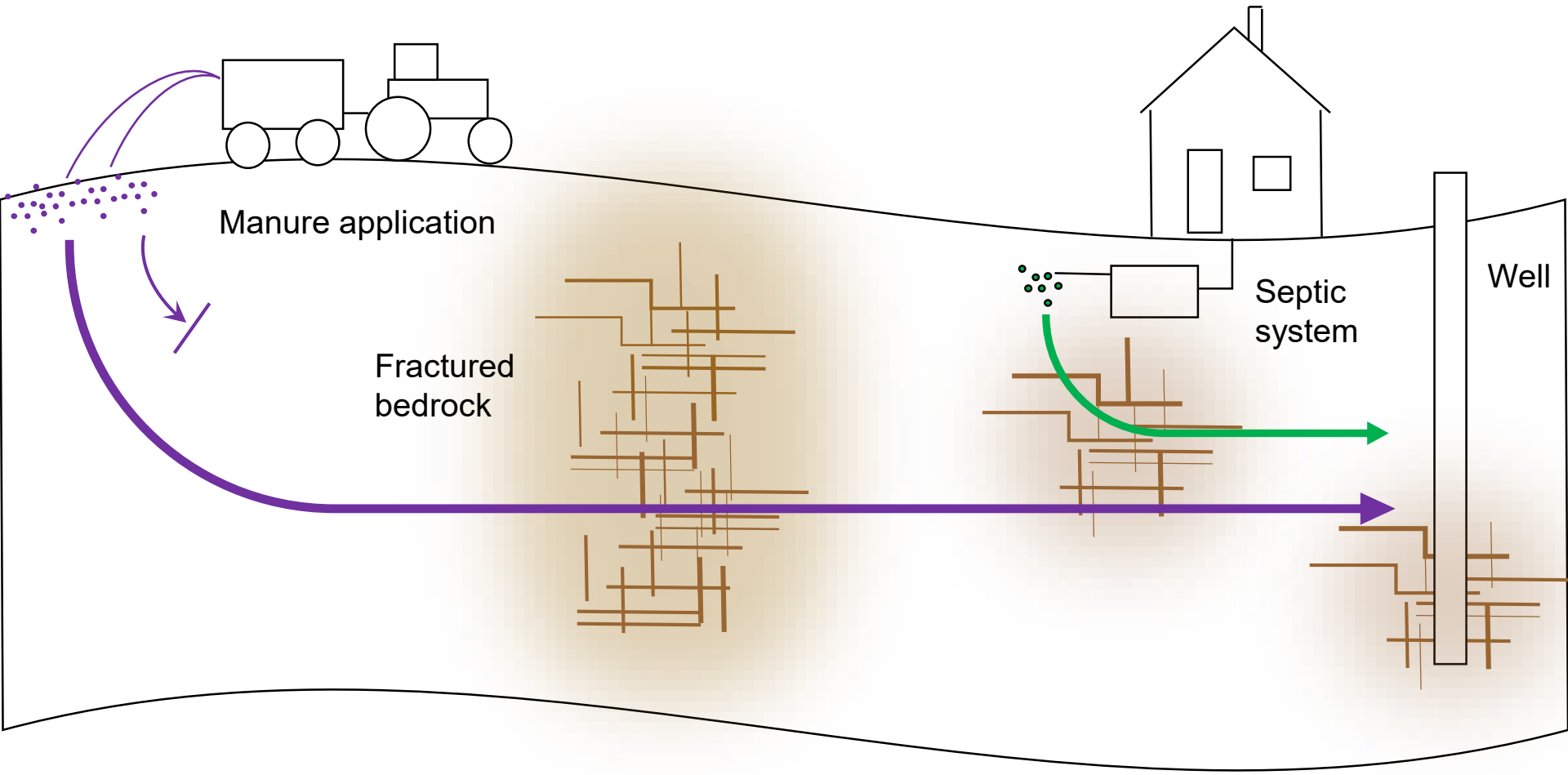


Model accounts for the effect of:
Depth to bedrock

Manure Application vs Septic Systems as Contamination Sources

Manure Source
- Large fecal source
- Surface applied
- Variable application location, timing, and infiltration

Septic System Source
- Small fecal source
- Sub-surface release
- Constant location and release



Risk Factors for High Nitrate Detection - Fall and Summer Sampling

High nitrate: exceeds health standard; $N\text{-}NO_3^-$ > 10 ppm

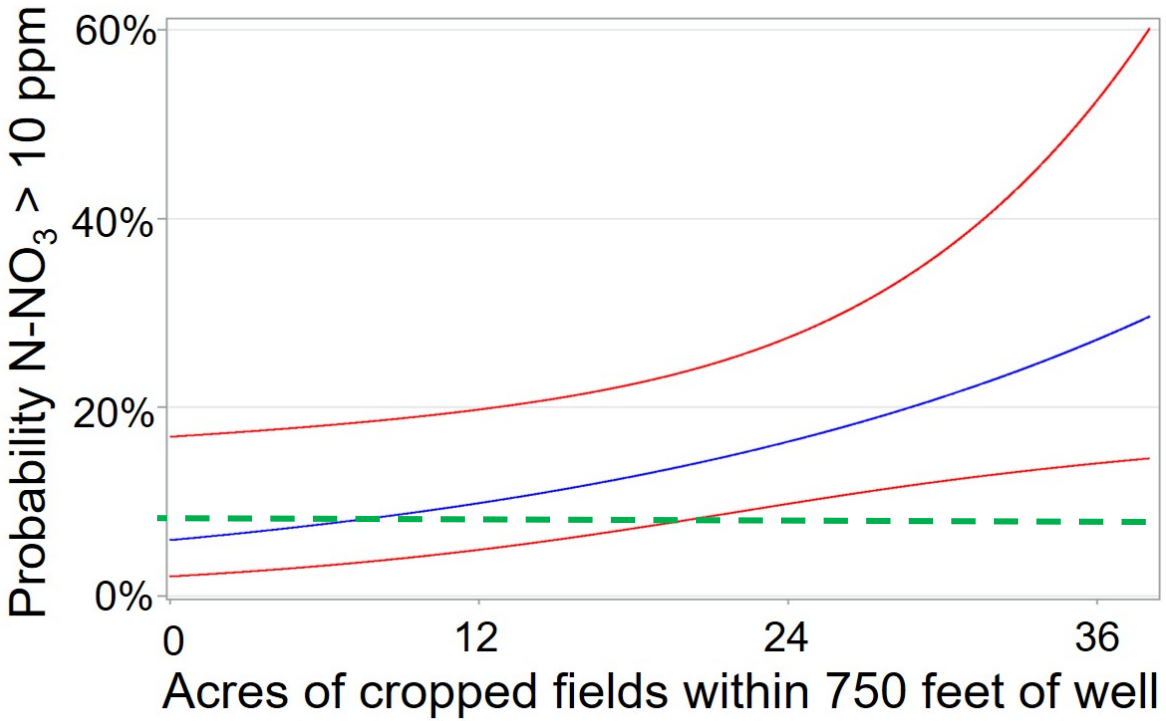
Important factors

- Distance to nearest agricultural field
- Distance to nearest manure lagoon
- Distance to nearest cropped field
- Area of cropped fields (acres) within 750 feet of well
- Area of cropped fields (acres) within 1500 feet of well
- Depth to bedrock

Unimportant factors

- Septic system variables were all not significant

More crop land around a well means greater risk for contamination by high nitrate



Model accounts for the effects of:
Distance to nearest cropped field
Distance to manure lagoon
Depth to bedrock

Probability of detection
95% confidence interval
State-wide average (7%)

Risk Factors for Coliform Bacteria Detection - Fall and Summer Sampling

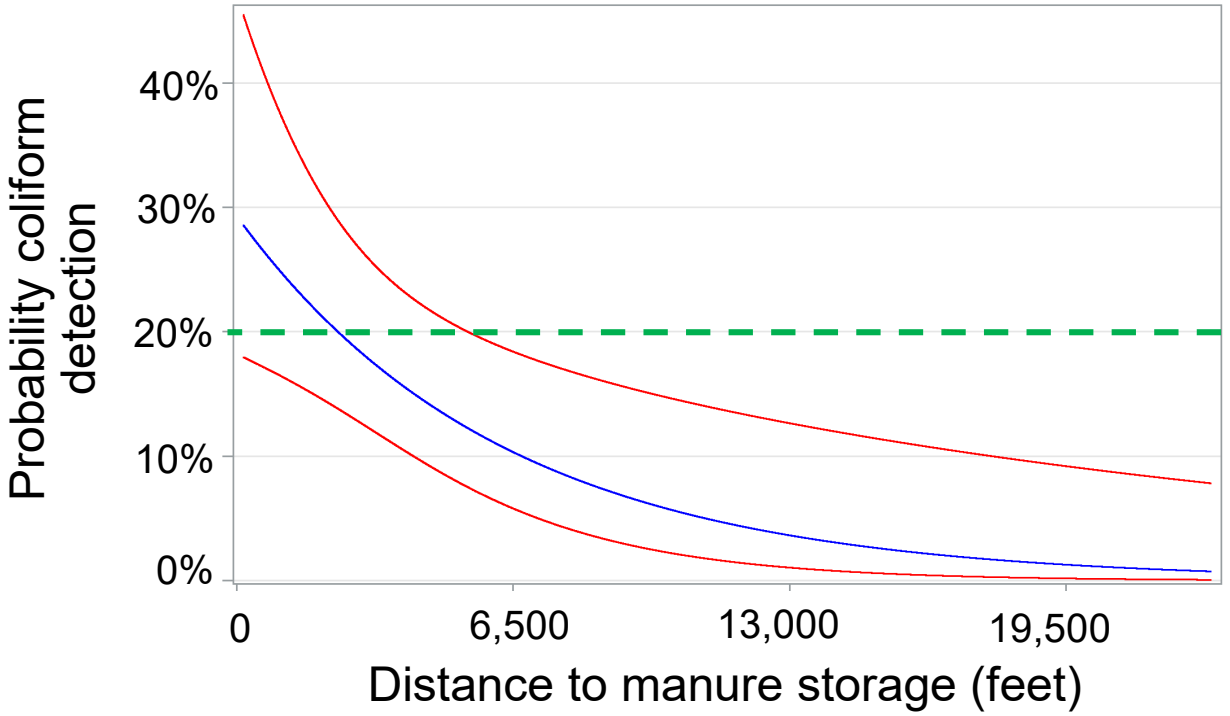
Important factors

- Distance to nearest manure lagoon
- Distance to nearest agricultural field
- Area agricultural fields (acres) within 750 feet of well
- Distance to nearest cropped field
- Area of cropped fields (acres) within 750 feet of well
- Depth to bedrock

Unimportant factors

- Septic system variables were all not significant

Wells located farther from manure storage are less likely to be contaminated with coliform bacteria



Model accounts for the effects of:
Distance to nearest agricultural field
Area of cropped fields within 750 feet of well
Depth to bedrock

Probability of detection
95% confidence interval
State average (~20%)

Private Well Contamination by **Any** Fecal Microbe is Related to:

- Distance to manure storage
- Number septic drain fields within 750 feet
- Rainfall total the previous 2 days
- Depth to bedrock

Kewaunee County Manure Storage

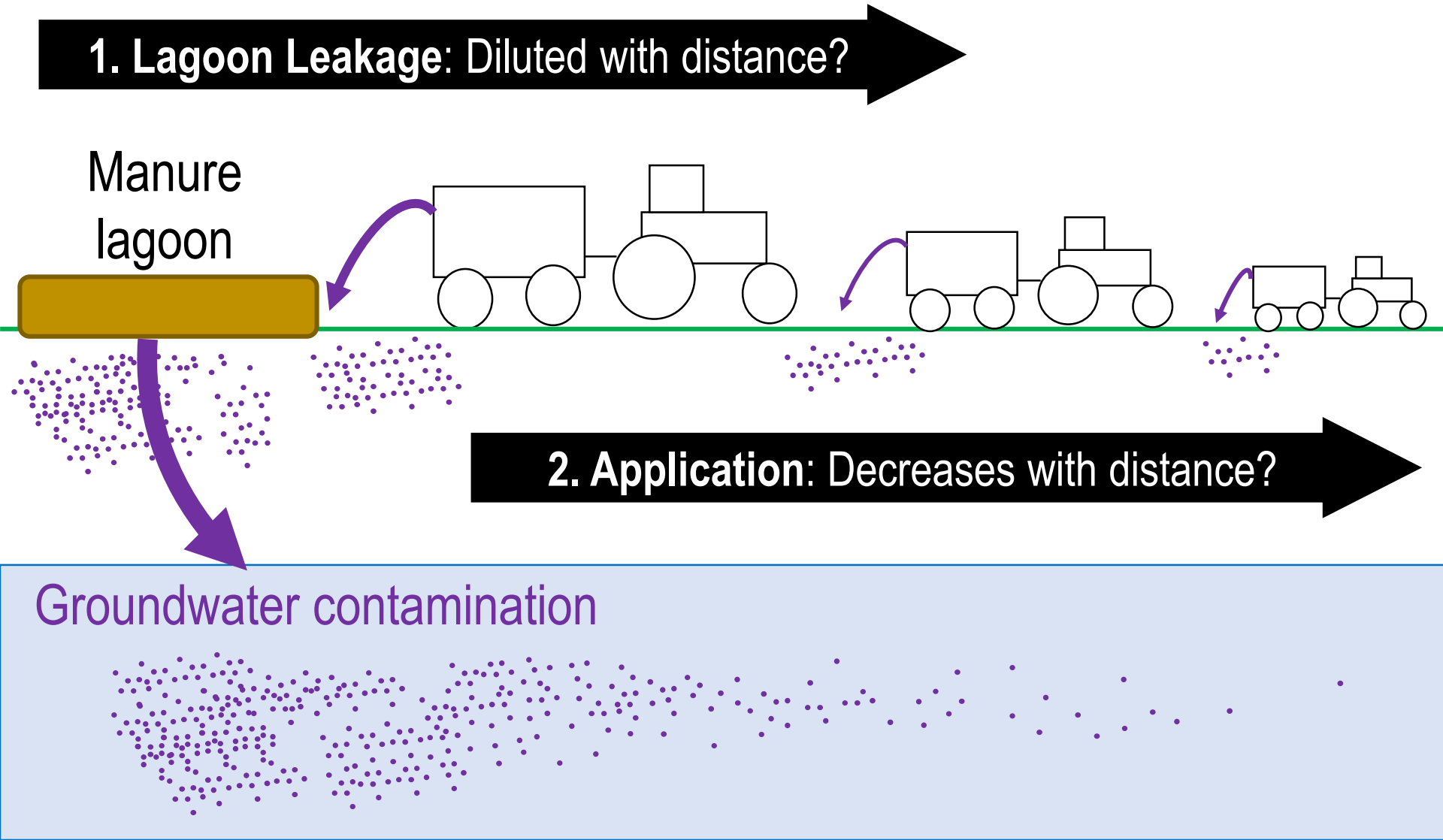
277 manure storage structures

- 219 lagoons
  - 150 lagoons (approximately) are earthen
- 51 other types (e.g., under barn, wood wall)
- 7 storage type not specified

Estimated manure volume for 242 storages (gallons)

- Range: 13,000 to 20 million
- Mean = 2.1 million

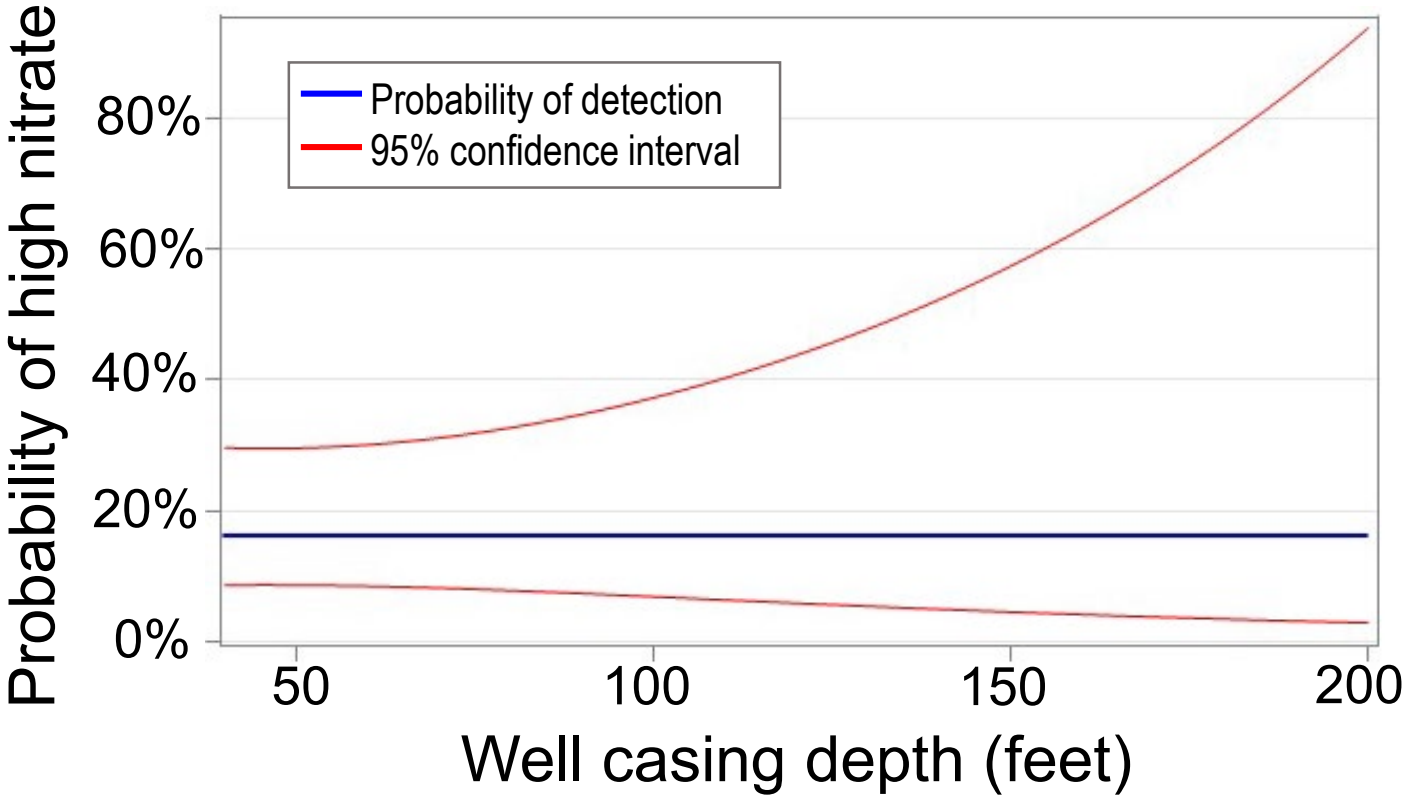
Groundwater contamination decreases with distance from manure lagoons: *Why?*



Well Construction and Siting Risk Factors Investigated

- Well age
- Well depth
- Casing depth
- Length of casing into bedrock
- Length of casing below water table
- Open interval length
- Depth to groundwater at time of well construction
- Depth to bedrock
- Elevation at site
- Soil drainage at site

Well casing depth is NOT related to high nitrate detection (*N-NO_3^- > 10 ppm)*



Model accounts for the effects of:
Depth to bedrock

Data restricted to casing depths between 40 and 200 feet

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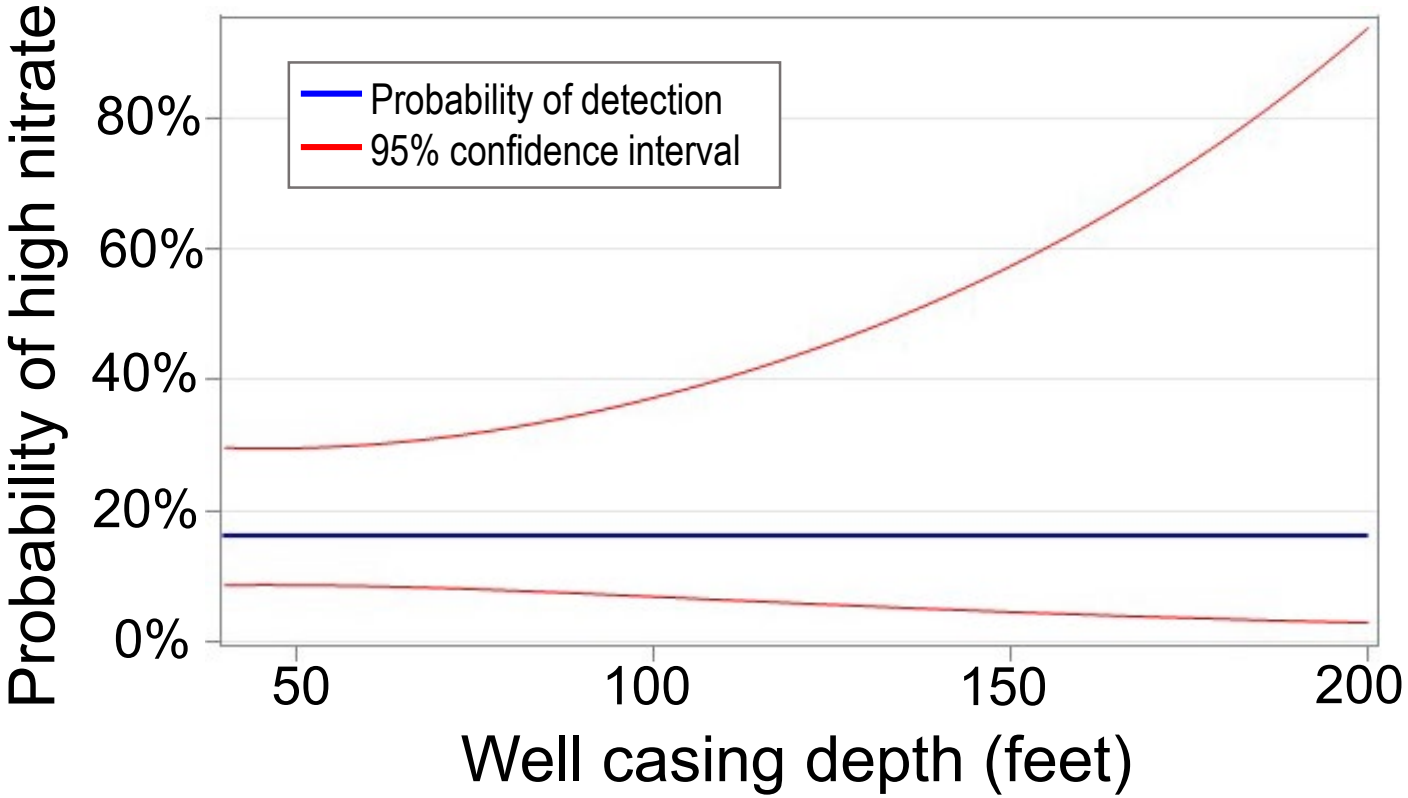

Model accounts for the effects of:
Depth to bedrock

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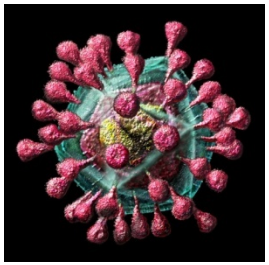
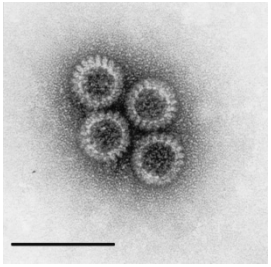
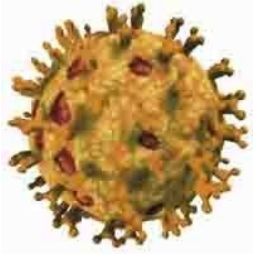
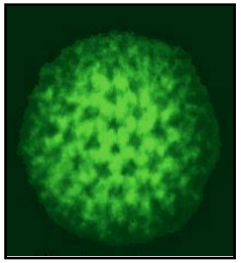
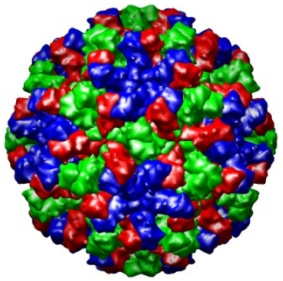
Summary

- Well contamination is from both human and bovine sources.
- Wells are contaminated with pathogens of significant concern: *Salmonella*, EHEC, *Cryptosporidium*, rotavirus.
- Depths to bedrock less than 50 feet means coliform bacteria and high nitrate contamination are more likely than statewide contamination rates.
- Risk factors for well contamination are: septic system density, agricultural land use, manure storage, groundwater recharge, depth to groundwater, precipitation.
- Well construction is not very important.

Questions?

Comments?

Risk Factor Highlights

- Septic system drain-fields within 750 feet of a well are related to human fecal contamination; an increase to 10 from 0 drain-fields increases contamination risk by 2.5-times.
- Field area under nutrient management plans (i.e. cropped field) within 750 feet of a well is related to nitrate contamination; an increase to 40 acres from 0 acres increases risk 5-times
- Manure lagoon proximity is related to coliform bacteria contamination; contamination risk 3 miles from a lagoon is 10% of the risk level at the closest distance measured in the study, 151 feet.
- Fecal microbe contamination (human, bovine, no specific host) is related to manure lagoon proximity and number of septic system drain-fields within 750 feet