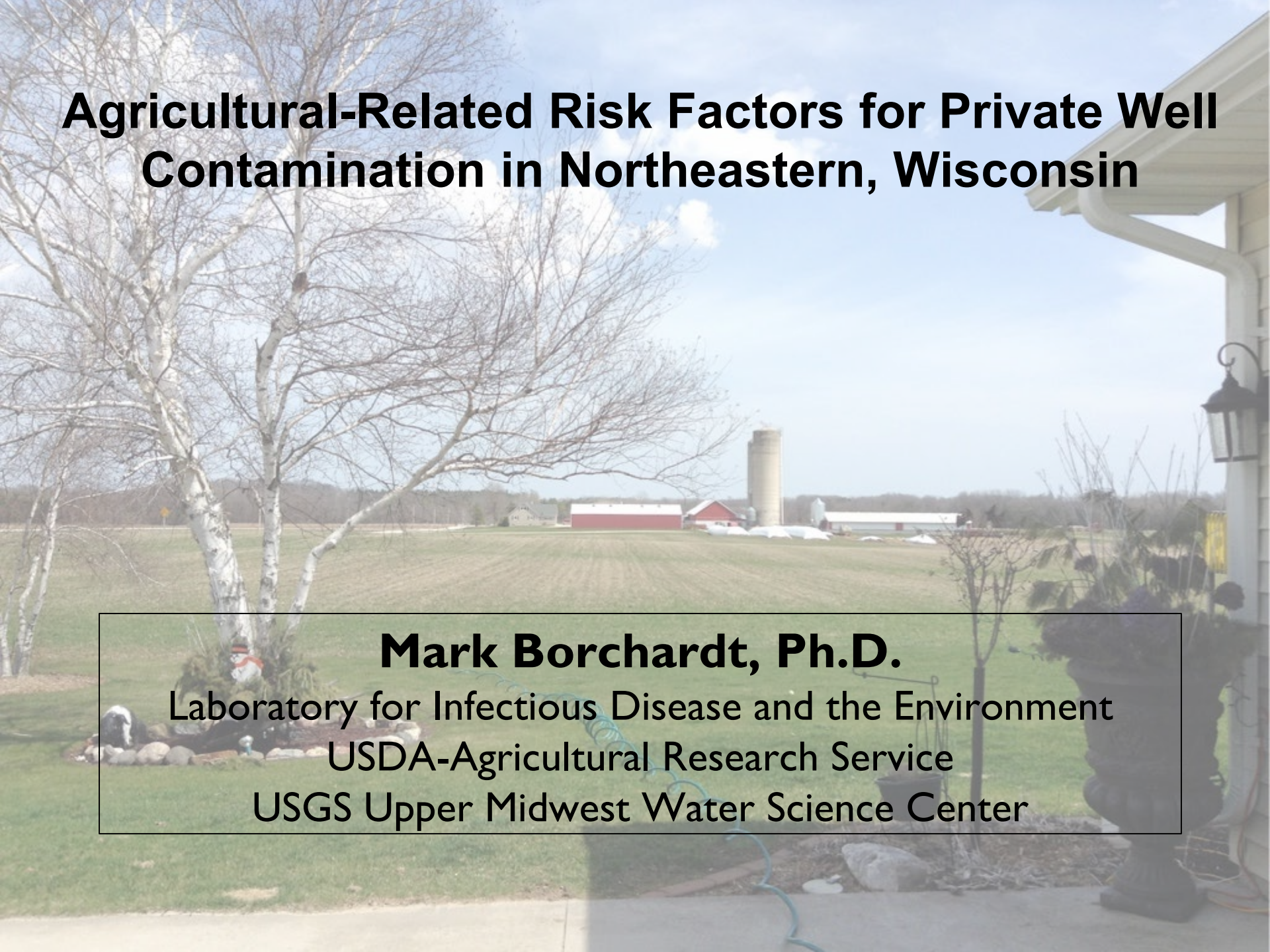
Agricultural-Related Risk Factors for Private Well Contamination in Northeastern, Wisconsin



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

L·I·D·E
LABORATORY FOR INFECTIOUS DISEASE AND THE ENVIRONMENT

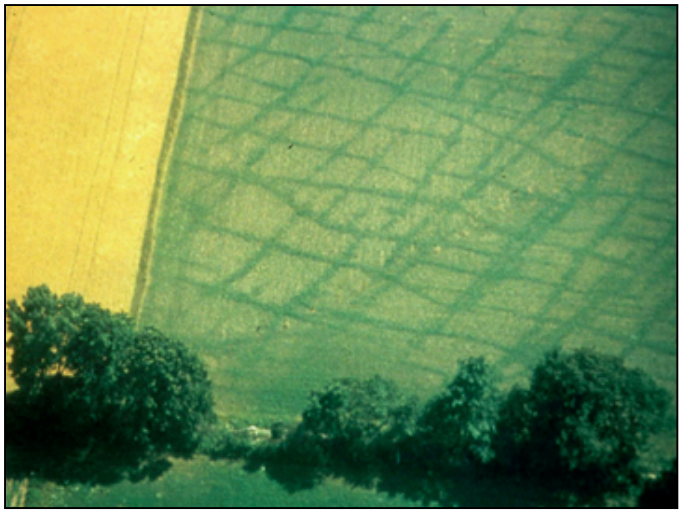
USGS science for a changing world

Brown Water Events in Northeast Wisconsin

- Groundwater recharge, especially spring snow melt, can generate brown water events
- Several outbreaks associated with these events e.g., EHEC, *Campylobacter jejuni*
- This well is code compliant, 123 ft deep, cased to 63 ft

Photos courtesy of Chuck Wagner

Silurian Dolomite Aquifer



Photos courtesy of Ken Bradbury and Maureen Muldoon

Kewaunee County Cattle

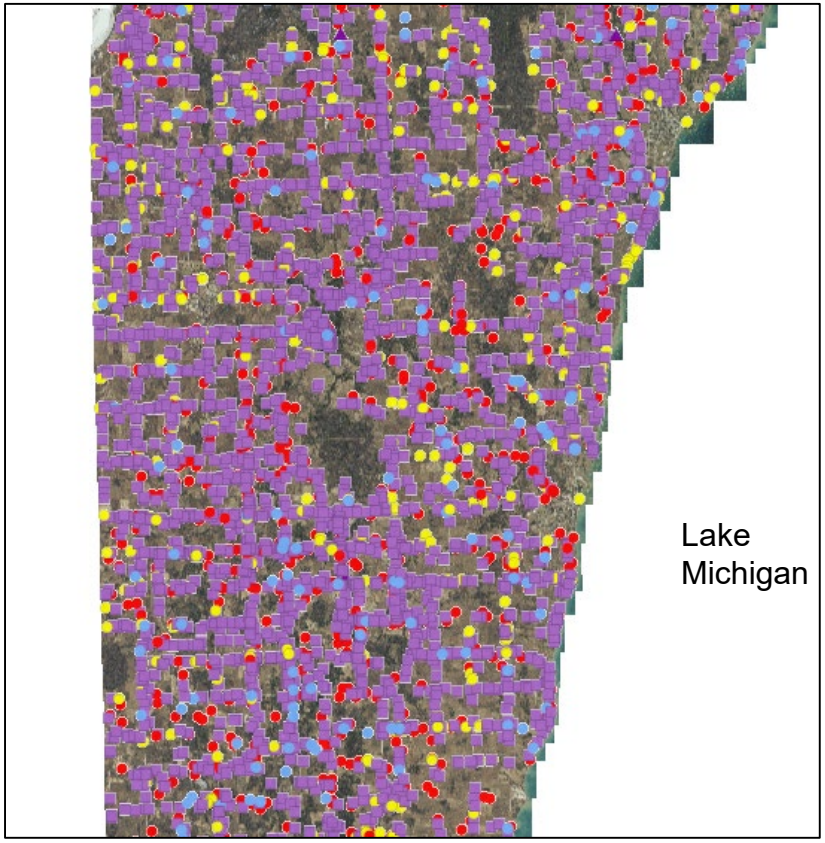
- All cattle & calves in 2016 = 97,000
- Milk cows in 2013 = 45,500
- Milk cow herds in 2016 = 167
- Concentrated Animal Feeding Operations (CAFOs) 15 dairy, one beef
- Approximately 700 million gallons cattle manure per year

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

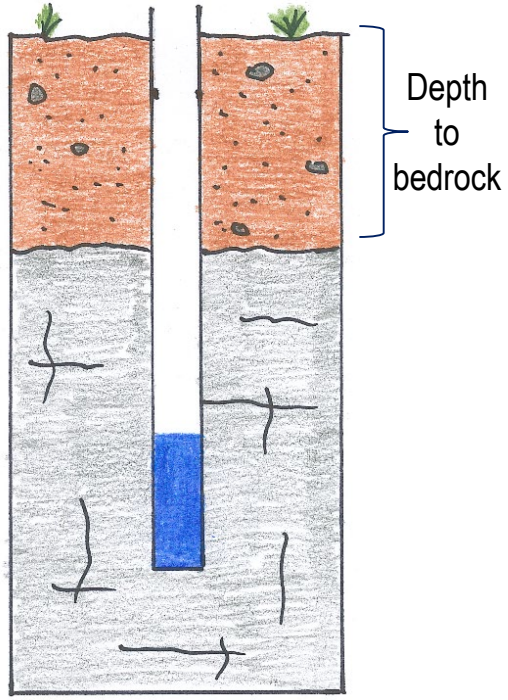
Approximately 200 million gallons septic effluent per year released to the subsurface

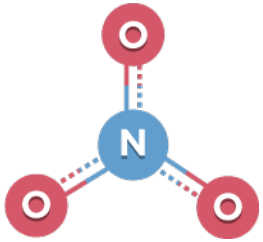
Research Objectives

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

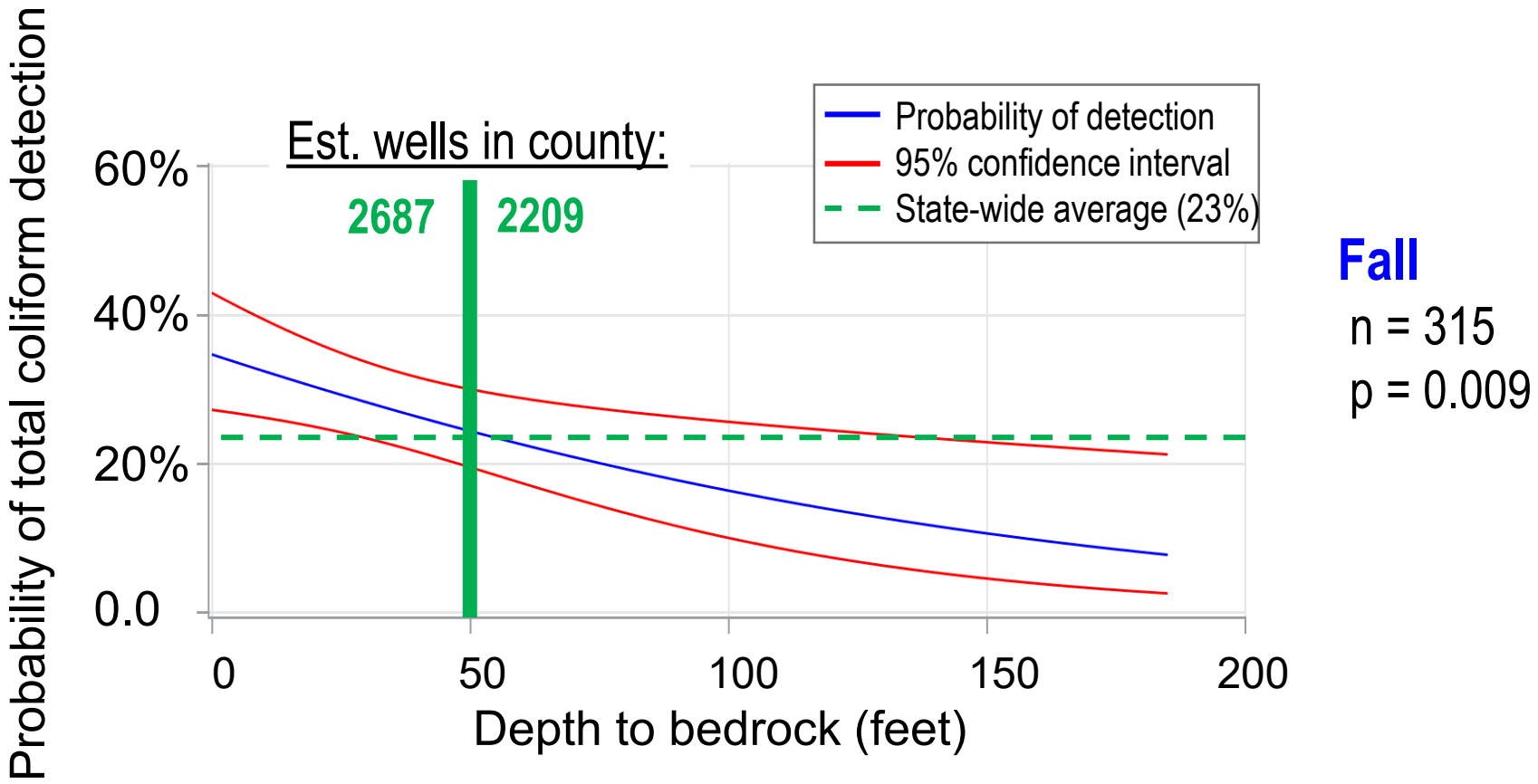
Objective 1: Total Coliform, *E. coli*, Nitrate

- County-wide randomized sampling of private wells – 4,896 in county
- Stratified by depth-to-bedrock: 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





Effect of depth to bedrock on total coliform contamination

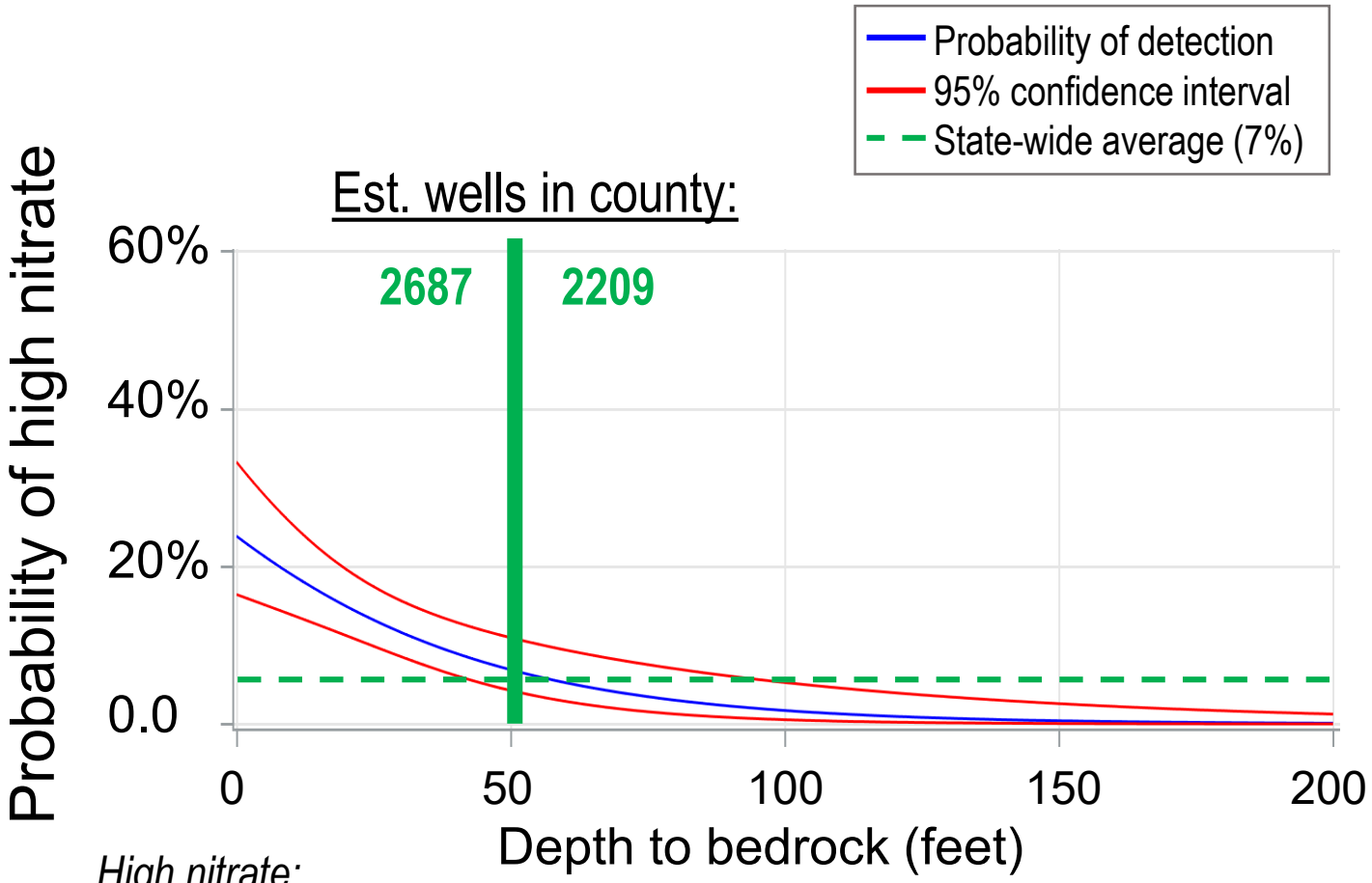


Fall

n = 315

p = 0.009

Effect of depth to bedrock on nitrate contamination



Summer

n = 399

p < 0.0001

High nitrate: exceeds health standard

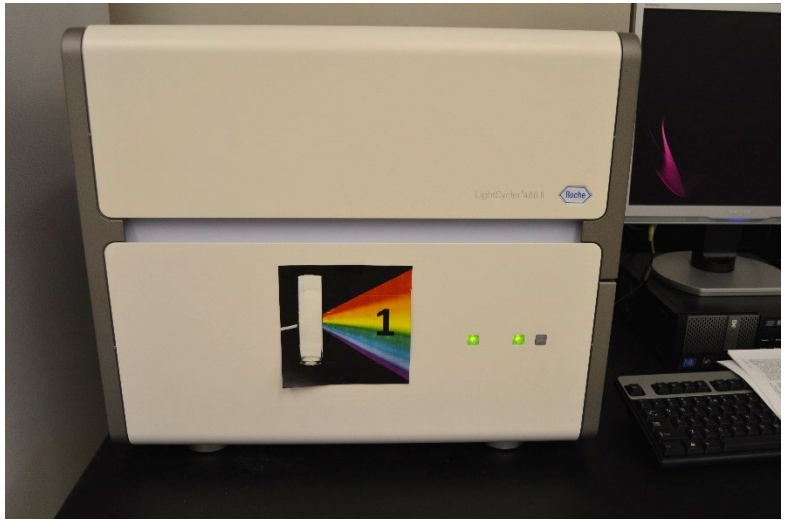
$N\text{-}NO_3^-$ > 10 ppm

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	Concentration (gene copies/L)
Human-specific	Adenovirus A	1	1
	Bacteroidales-like Hum M2	7	< 1 – 1050
	Human *Bacteroides*	27	< 1 – 34
	Cryptosporidium hominis	1	qualitative
	Rotavirus A (G1 P[8])	7	qualitative
	All	**33**	

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

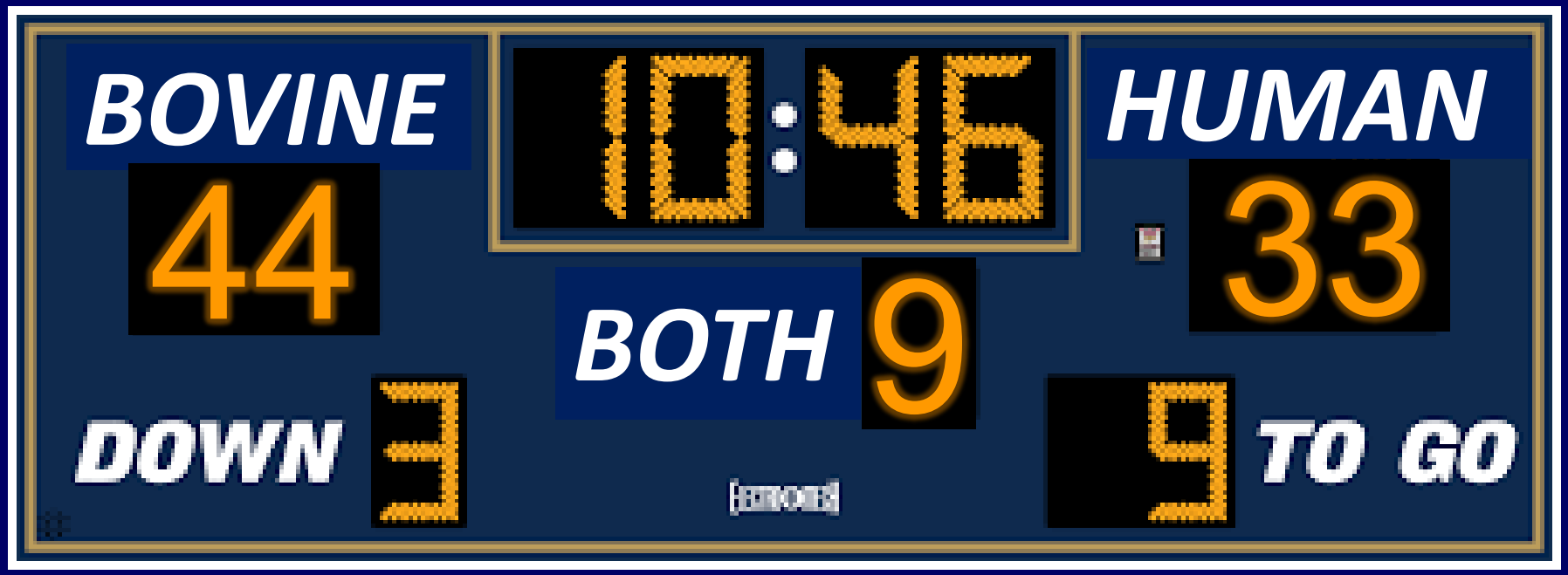
Microbes: Identifying the Fecal Source

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

Host	Microorganism	Wells	Concentration (gene copies/L)
Bovine-specific	*Bacteroidales*-like Cow M2	2	29 - 915
	Bacteroidales-like Cow M3	4	3 – 49,818
	Bovine *Bacteroides*	36	< 1 – 42,398
	Bovine polyomavirus	8	< 1 – 451
	Bovine enterovirus	1	2
	Rotavirus A (G10 P[11])	12	qualitative
	All	**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



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

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

Agricultural fields

Fields with NMPs

Manure storages

Septic Systems

All septic types

Drain fields

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*

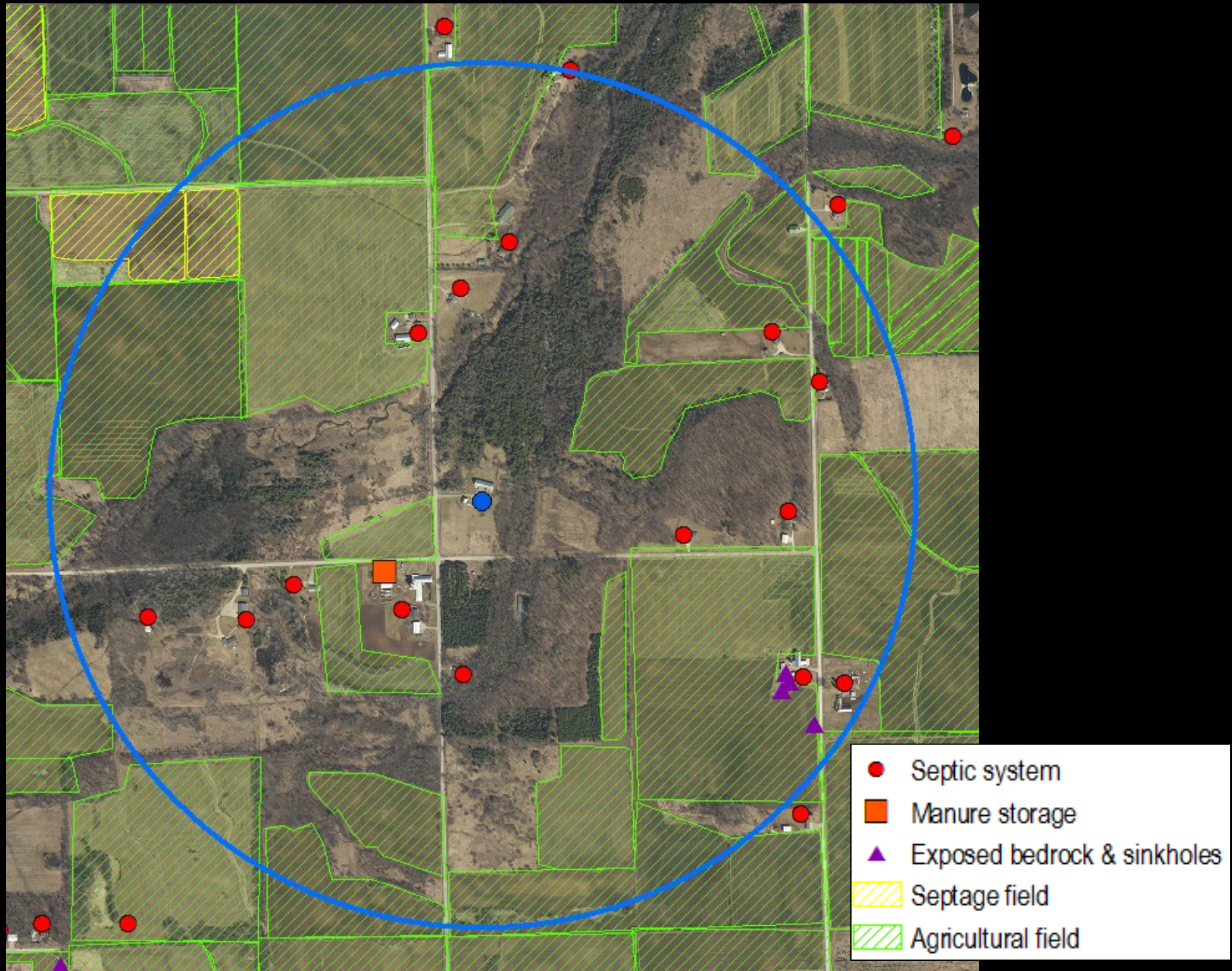
Rainfall (cumulative, no snowfall)

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

Groundwater recharge (cumulative)

Depth to groundwater (median & minimum)

Depth to Bedrock

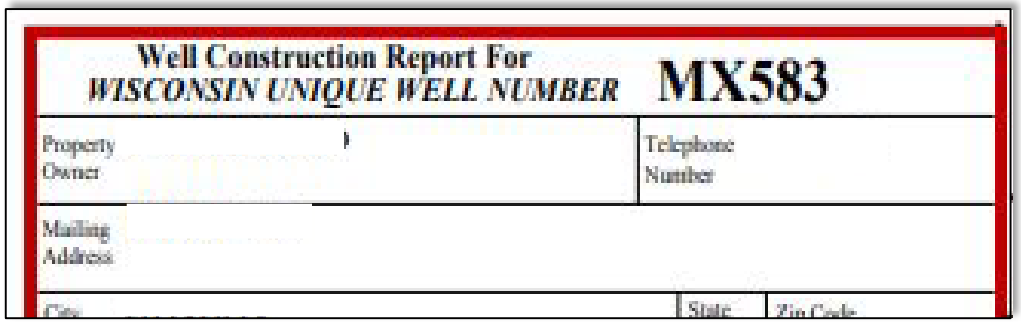

Septic system
Manure storage
Exposed bedrock & sinkholes
Septage field
Agricultural field

Risk Factor Data Sources

Groundwater depth (monitoring well)

Rainfall data

Well characteristics (construction report)



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

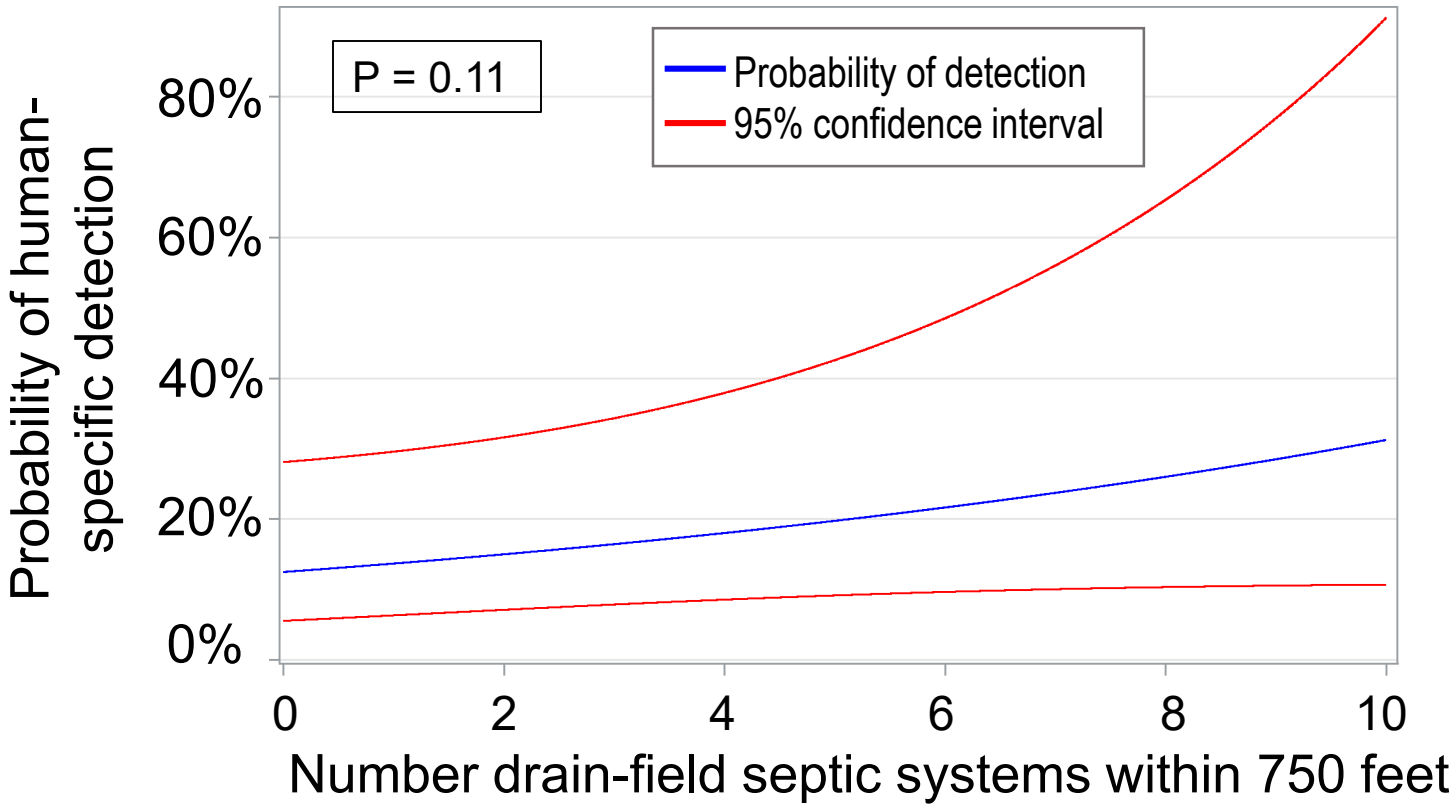
Property Owner	Telephone Number
Mailing Address	
City	State / Zip Code

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

Probability of Human-Specific Microbes in Private Wells



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

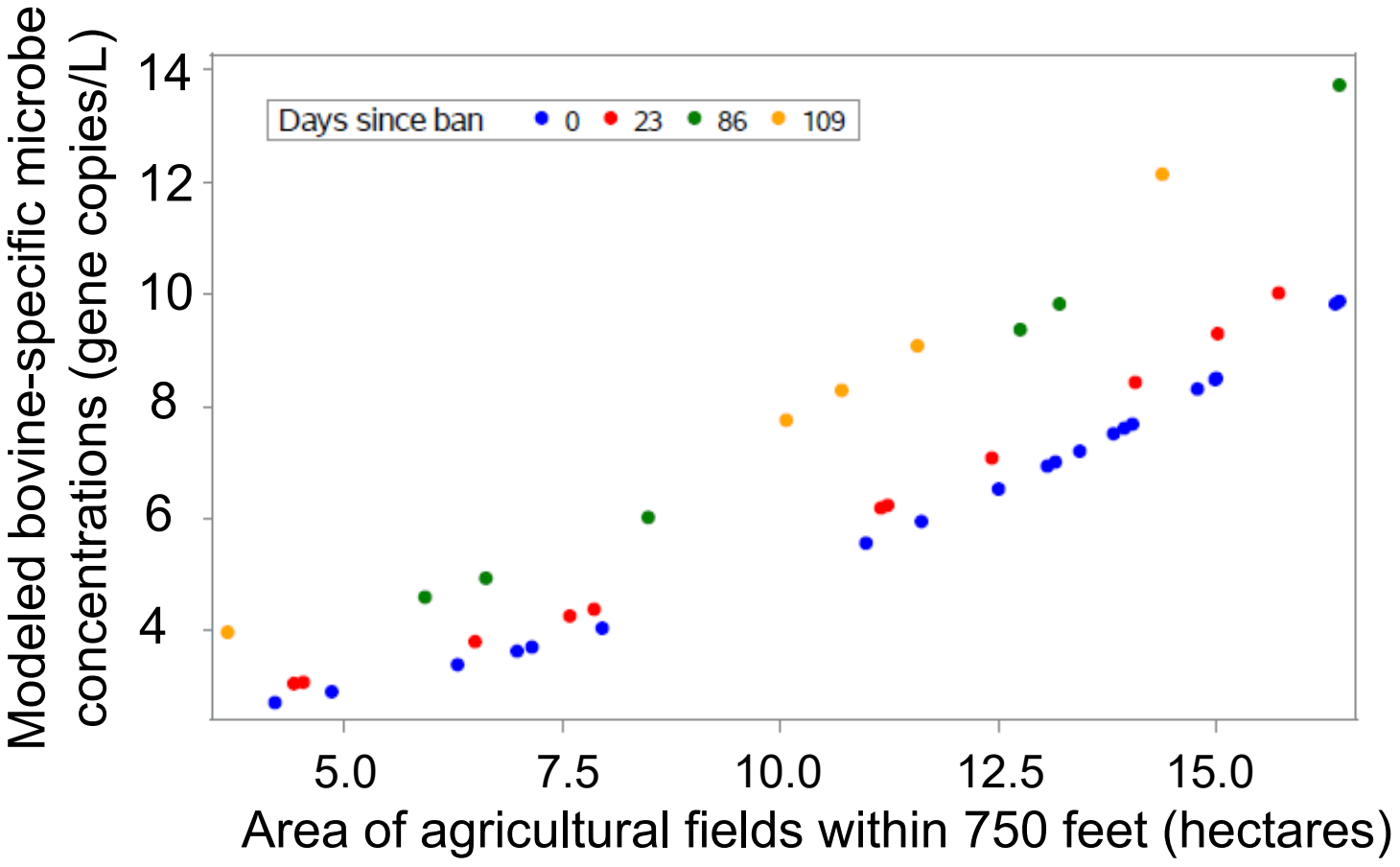
Surprising unimportant factors

- 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

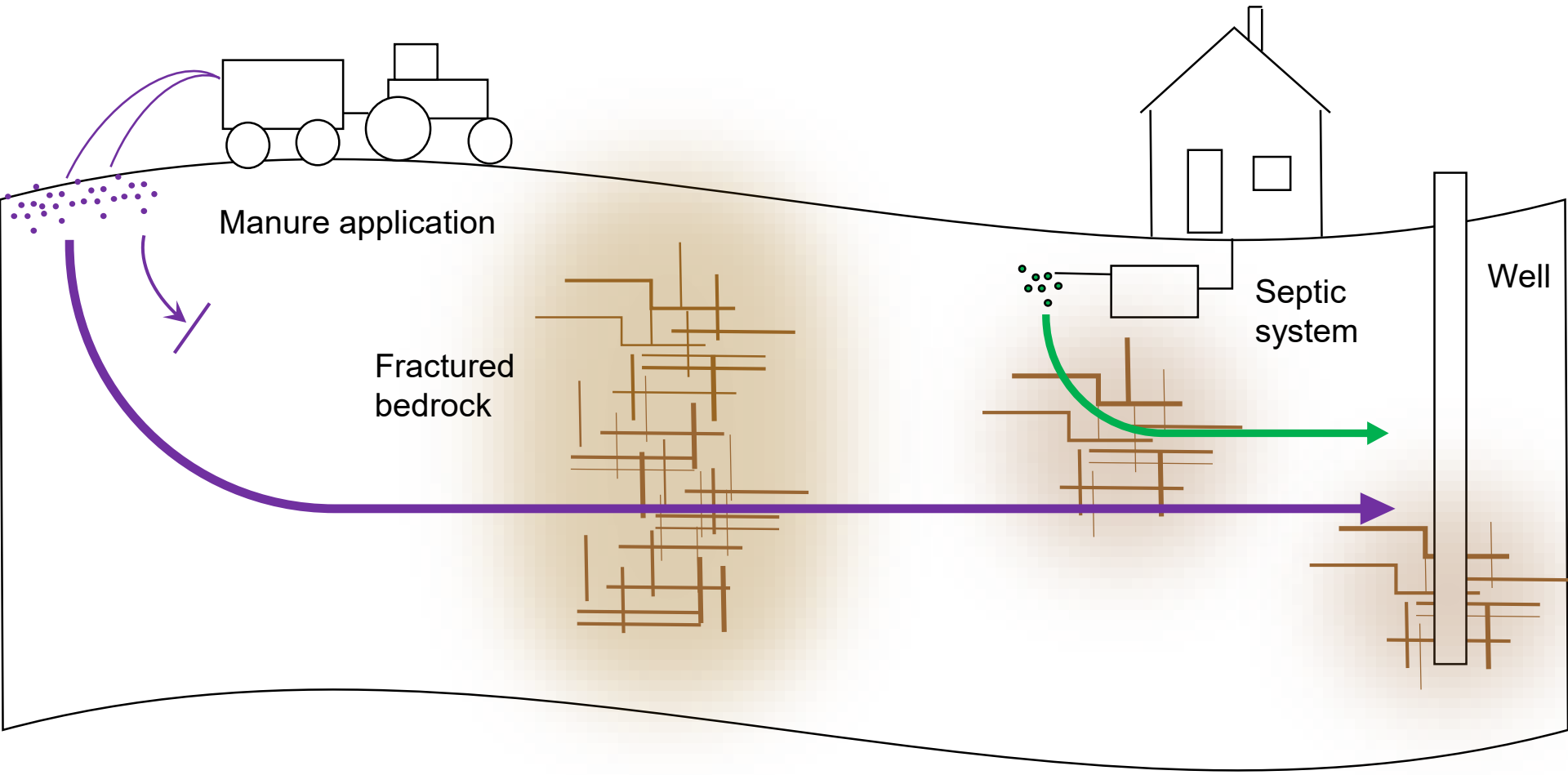
Concentration of Bovine-Specific Microbes in Private Wells Related to Agricultural Field Area



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

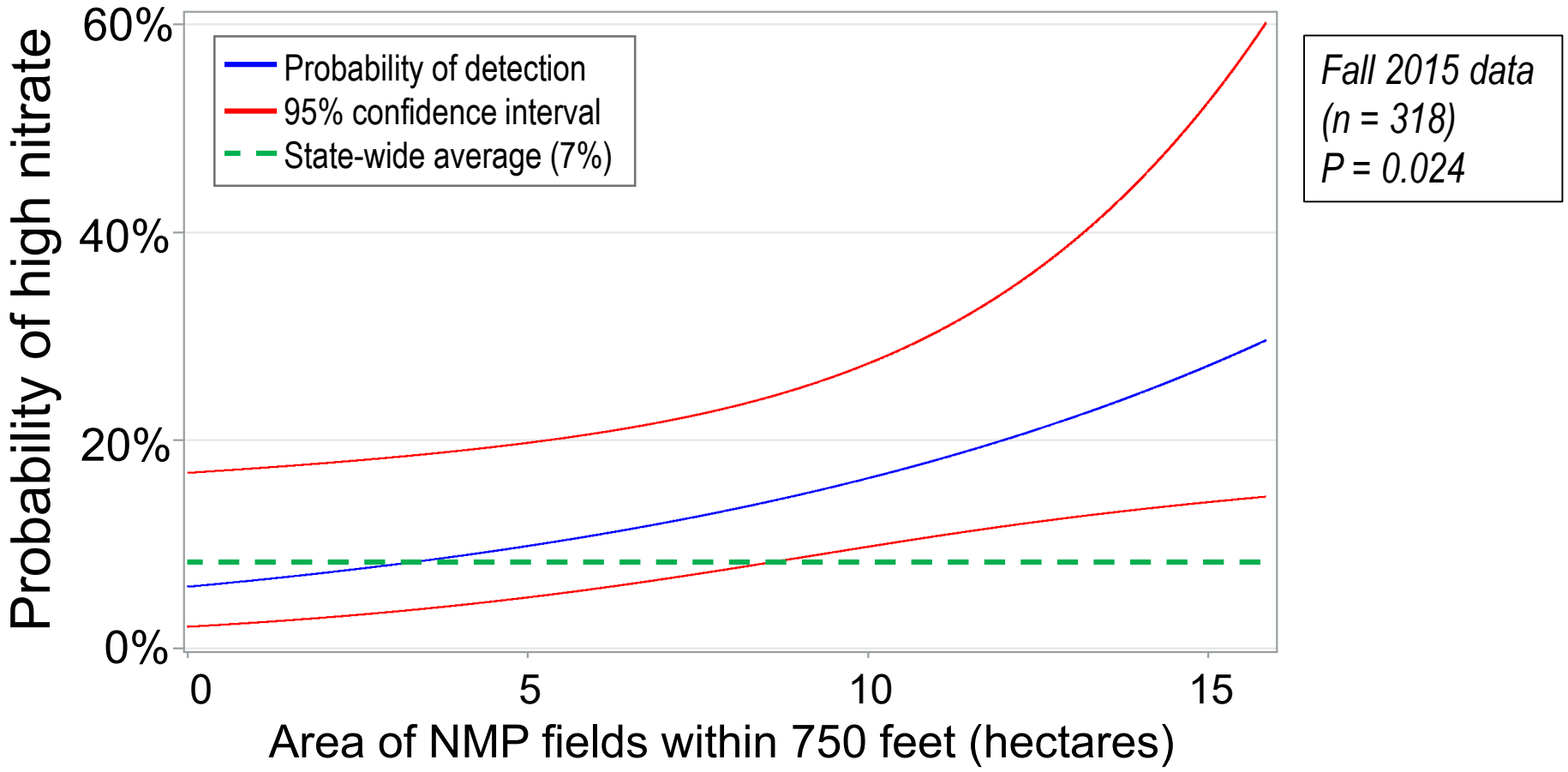
Important factors

- Distance to nearest agricultural field
- Distance to nearest manure lagoon
- Distance to nearest field with nutrient management plan
- Area of fields (acres) with NMP within 750 feet of well
- Area of fields (acres) with NMP within 1500 feet of well
- Depth to bedrock

Unimportant factors

- Septic system variables were all not significant

Area of NMP fields within 750 feet of well is related to high nitrate detection (*N-NO_3^- > 10 ppm)*



Model accounts for the effects of:

Distance to nearest field with an NMP

Distance to manure lagoon

Depth to bedrock

Risk Factors for Coliform Bacteria Detection - Fall and Summer Sampling

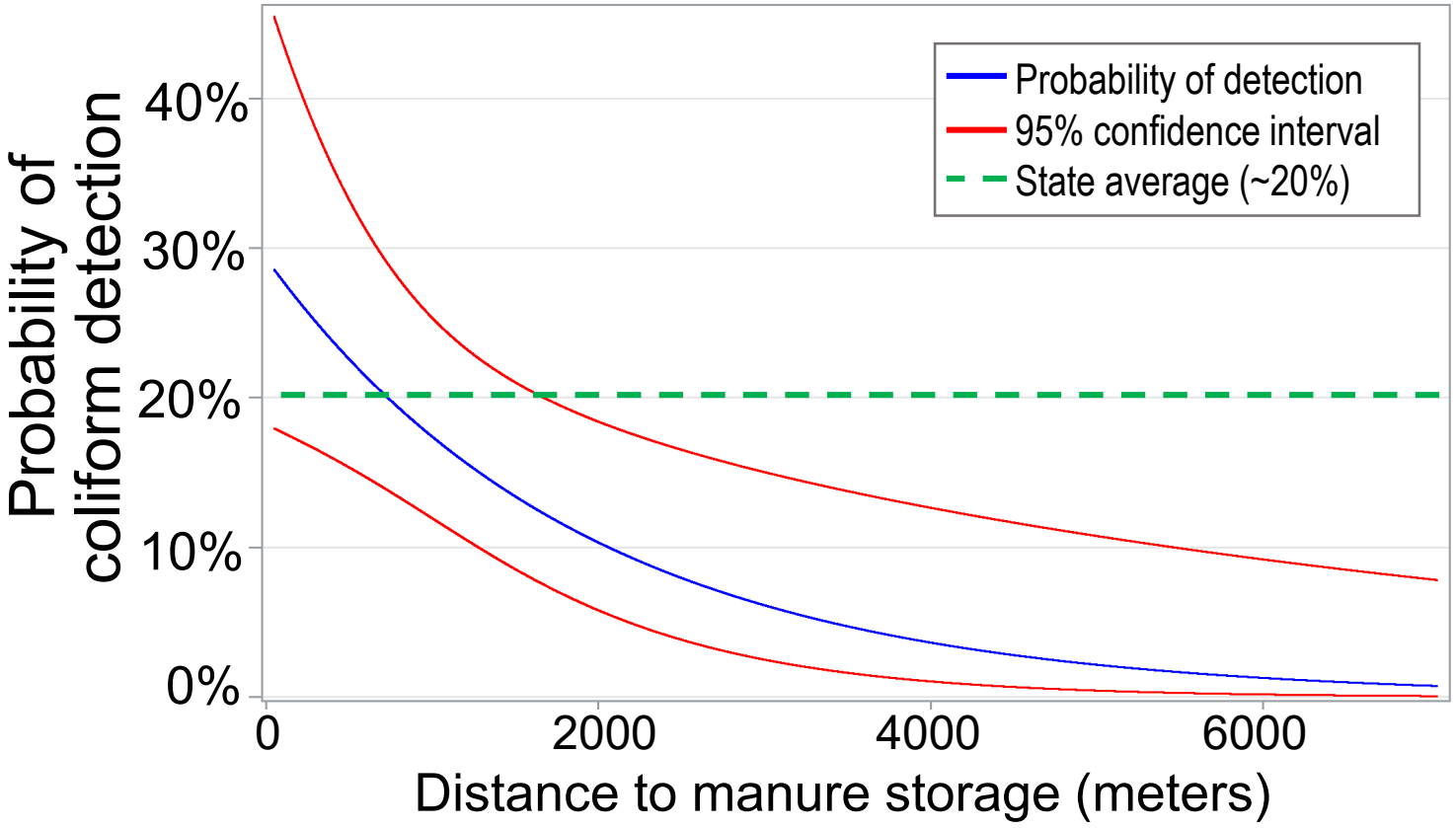
Important factors

- Distance to nearest manure lagoon
- Distance to nearest agricultural field
- Distance to nearest field with nutrient management plan
- Area of fields (acres) with NMP within 750 feet of well
- Area agricultural fields (acres) within 750 feet of well
- Depth to bedrock

Unimportant factors

- Septic system variables were all not significant

Manure Lagoon Distance and Coliform Detection



Summer 2016 data
(n = 395)
P = 0.006

Model accounts for the effects of:

Distance to nearest agricultural field

Area of fields with NMP within 750 feet of well

Depth to bedrock

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

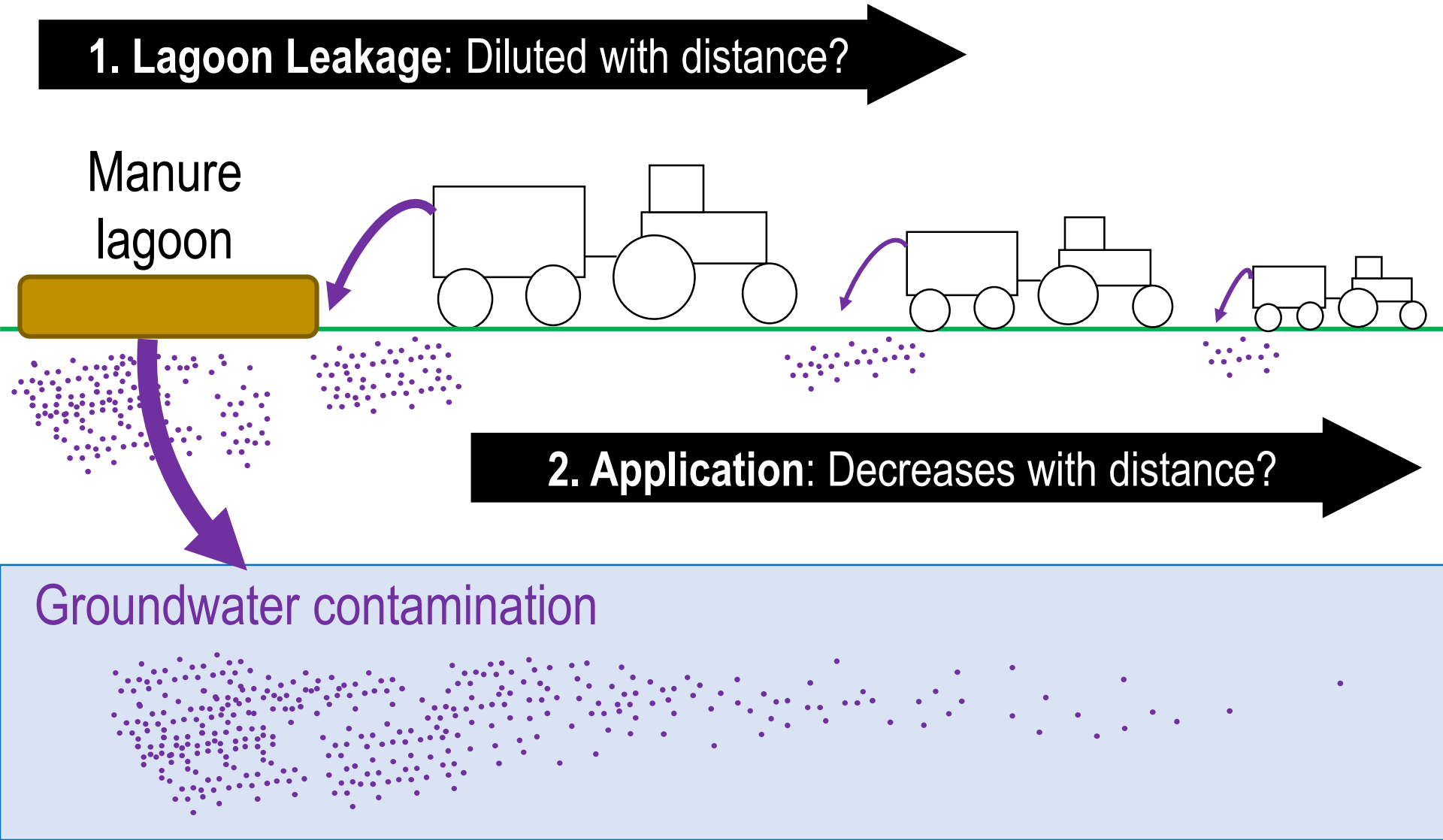
277 manure storage structures

- 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

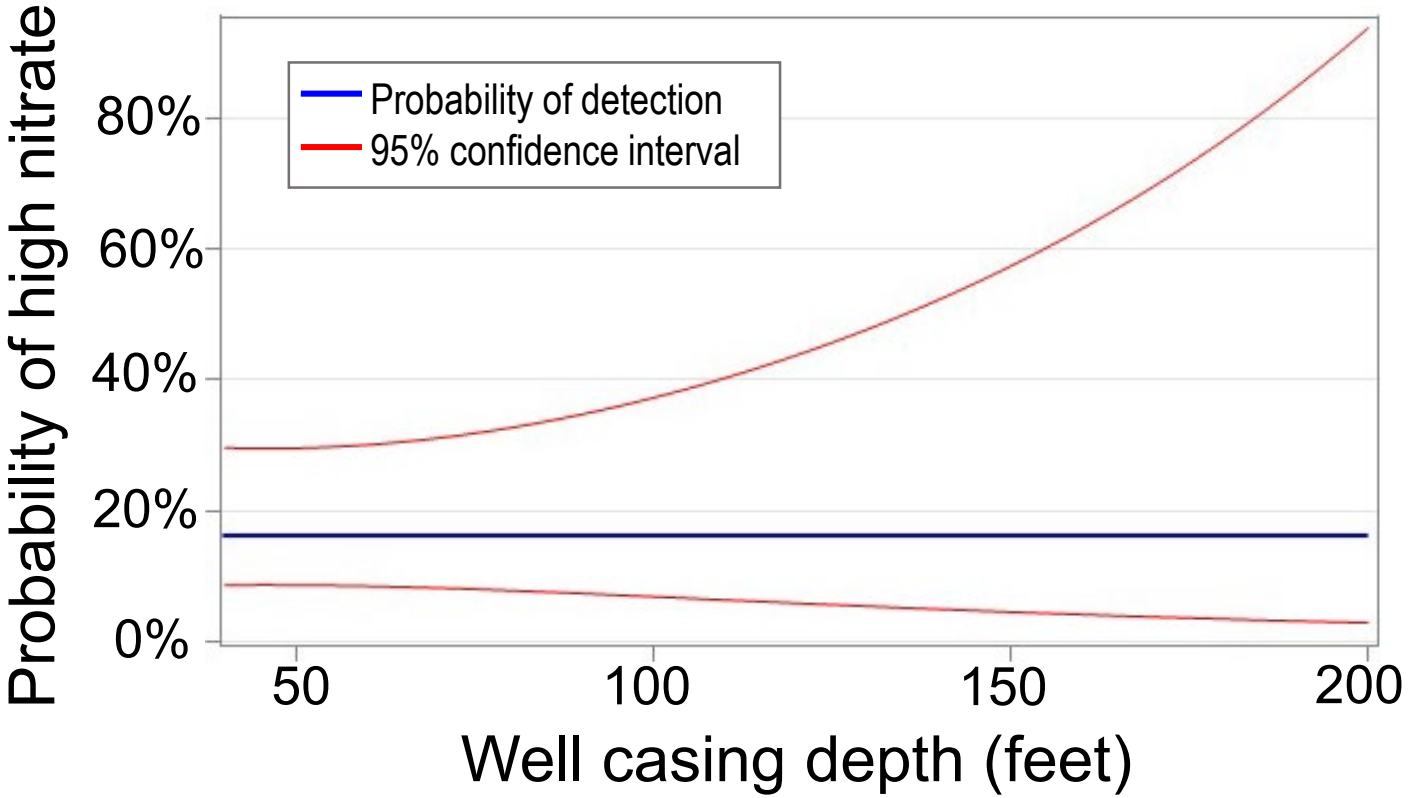
Groundwater contamination decreases with distance from manure lagoons: *Why?*



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)*



Summer 2016
(n = 252)
P = 0.99

Model accounts for the effects of:
Depth to bedrock

Data restricted to casing depths between 40 and 200 feet

Highlights

- Well contamination is from both human and bovine fecal sources.
- Septic system drainfields increasing from 10 to 0 within 750 feet of a well increases contamination risk by 2.5 times for human fecal contamination.
- Fields under nutrient management plans increasing to 40 acres from 0 acres within 750 feet of a well increases risk 5-times for high nitrate
- Manure lagoon distance from a well is inversely related to coliform contamination; 3 miles distance gives 10% of the risk compared to wells located closest to lagoons (150 feet in this study).
- Well construction factors are not as important as other risk factors for contamination

Questions?

Comments?