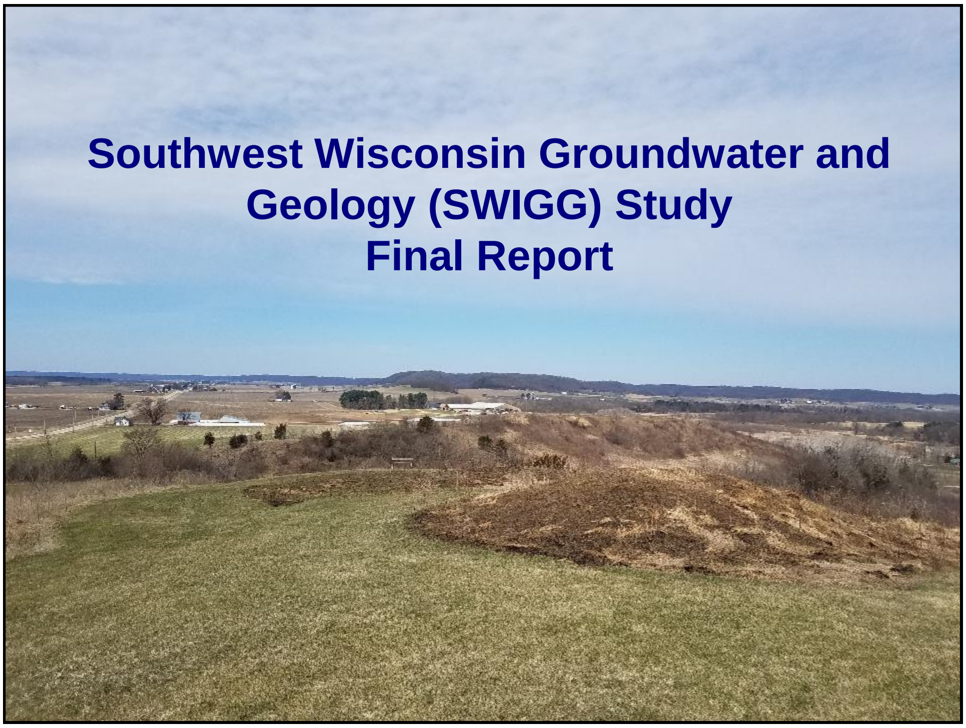


1

Study Researchers

<u>Tonight's Presenters</u>

Mark Borchardt, PhD (USDA-ARS)
Study background and scientists' role

Maureen Muldoon, PhD (WGNHS)
Hydrogeology of southwest Wisconsin

Joel Stokdyk, (USGS)
Groundwater quality and risk factors for contamination

Ken Bradbury, PhD (WGNHS)
Information for private well owners

Burney Kieke (Marshfield Clinic Research Institute)
Statistical models

2

Study Background and scientists' roles

Mark Borchardt, Ph.D.
Emeritus, Research Microbiologist
USDA-Agricultural Research Service

3

Study Team

County Conservationists
- Lynda Schweikert, Chippewa County
- Katie Abbott, Iowa County
- Terry Loeffelholz, Iowa County
- Erik Heagle, Grant County
- Erica Sauer, Lafayette County

Laboratory and Field Sampling
- Aaron Firnstahl, U.S. Geological Survey
- Susan Spencer, USDA Agricultural Research Service

Support
- Scott Laeser, Clean Wisconsin

Lafayette County | IOWA County WISCONSIN GOVERNMENT | County of Grant State of Wisconsin | L•I•D•E LABORATORY FOR INFECTIOUS DISEASE AND THE ENVIRONMENT

USDA | USGS science for a changing world | Wisconsin Geological and Natural History Survey DIVISION OF EXTENSION UNIVERSITY OF WISCONSIN-MADISON

4

Acknowledgements

Well Geo-Locating
- Steve Mauel (WGNHS)
- Matt Rehwald (WGNHS)
- Chris Headlee (WGNHS)

Geographic Information Systems Data Layers
- Lauree Aulik (Lafayette County)
- Jaclyn Essandoh (Southwest WI Regional Planning)
- Terry Loeffelholz (Iowa County)

Septage and Sludge Records
- Steve Warrner (WI DNR)

Precipitation Data
- Dustin Goering (U.S. National Weather Service)

5

Study Funding

- Grant, Iowa, and Lafayette counties
- Lafayette Ag Stewardship Alliance
- Residents of Lafayette County
- Iowa County Uplands Watershed Group
- WI Department of Natural Resources
- US Geological Survey
- USDA-Agricultural Research Service
- WI Geological & Natural History Survey

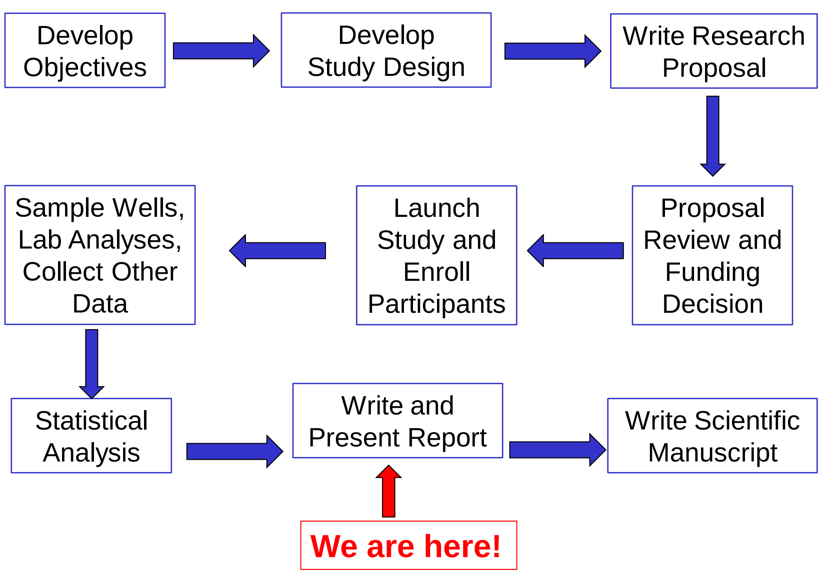
6

Background

- Jan. 2018, Grant County, Moratorium & Manure Spreading Restriction requests
- Drs. Mark Borchardt & Madeline Gotkowitz presented
- Invited Iowa & Lafayette Counties
- Grant County approved groundwater study
- Iowa & Lafayette counties participation

7

SWIGG Research Process



8

Kewaunee County Published Scientific Papers

Research

A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP7813.

Sources and Risk Factors for Nitrate and Microbial Contamination of Private Household Wells in the Fractured Dolomite Aquifer of Northeastern Wisconsin

Mark A. Borchardt,[1] Joel P. Stokdyk,[2] Burney A. Kieke Jr.,[3] Maureen A. Muldoon,[4] Susan K. Spencer,[1] Aaron D. Firnstahl,[2] Davina E. Bonness,[5] Randall J. Hunt,[6] and Tucker R. Burch[1]

[1]Environmentally Integrated Dairy Management Research Unit, U.S. Dairy Forage Research Center, U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS), Marshfield, Wisconsin, USA
[2]Upper Midwest Water Science Center, U.S. Geological Survey, Marshfield, Wisconsin, USA
[3]Center for Clinical Epidemiology and Population Health, Marshfield Clinic Research Institute, Marshfield, Wisconsin, USA
[4]Wisconsin Geological and Natural History Survey, Madison, Wisconsin, USA
[5]Kewaunee County Department of Land and Water Conservation, Luxemburg, Wisconsin, USA
[6]Upper Midwest Water Science Center, U.S. Geological Survey, Middleton, Wisconsin, USA

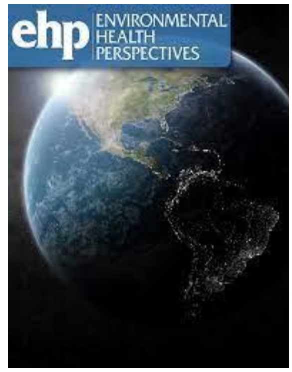
Research

A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP7815.

Quantitative Microbial Risk Assessment for Contaminated Private Wells in the Fractured Dolomite Aquifer of Kewaunee County, Wisconsin

Tucker R. Burch,[1] Joel P. Stokdyk,[2] Susan K. Spencer,[1] Burney A. Kieke Jr.,[3] Aaron D. Firnstahl,[2] Maureen A. Muldoon,[4] and Mark A. Borchardt[1]

[1]Environmentally Integrated Dairy Management Research Unit, U.S. Dairy Forage Research Center, U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS), Marshfield, Wisconsin, USA
[2]Upper Midwest Water Science Center, U.S. Geological Survey, Marshfield, Wisconsin, USA
[3]Center for Clinical Epidemiology and Population Health, Marshfield Clinic Research Institute, Marshfield, Wisconsin, USA
[4]Wisconsin Geological and Natural History Survey, University of Wisconsin-Madison Division of Extension, Madison, Wisconsin, USA



9

SWIGG and Kewaunee Studies were Designed to Achieve Two Goals…

- A state-of-the-art assessment of private well contamination
- Findings that help identify ways to address contamination

10

Scientists' Role

We do…
- Design study to meet specific questions and objectives
- Apply appropriate technologies to address objectives
- Strive for objectivity and transparency
- Provide and interpret scientific results

We do NOT…
- Make policy or management recommendations
- Advocate for certain viewpoints or actions

11

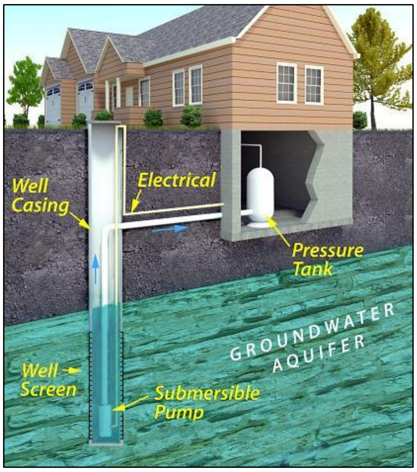
Scientists' Motivation

Research locally, publish globally
- Local research provides information that is beneficial to the residents of southwest Wisconsin
- Global publishing advances groundwater science and allows others around the world to use the findings

Uniqueness
- SWIGG is only the second study to relate microbial contamination of private wells to risk factors, like land use

12

Gratitude for Study Participants



816 households with private wells participated in the SWIGG study

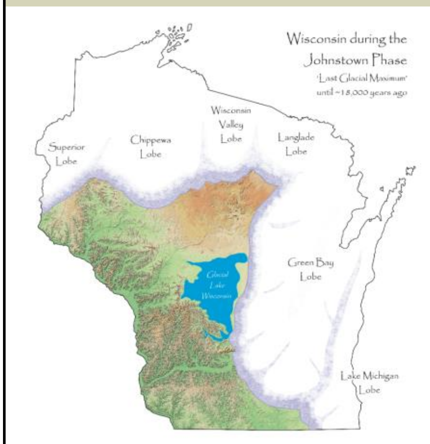
13

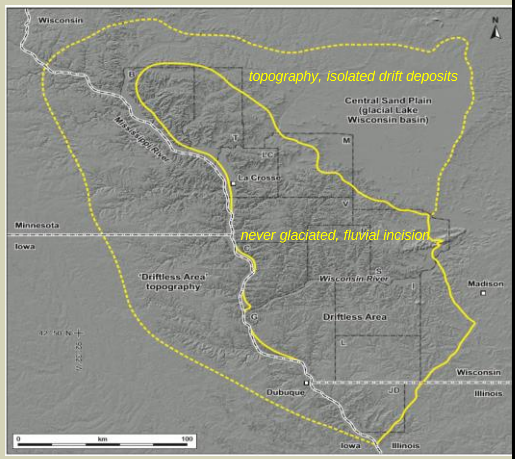
Hydrogeology of SW Wisconsin

Maureen Muldoon, Ph.D.
Hydrogeologist
Wisconsin Geological & Natural History Survey

14

Wisconsin's Driftless Area





From Carson and others, 2019

Wisconsin's Karst

- Karst -- a landscape created when water dissolves rocks such as dolomite and limestone

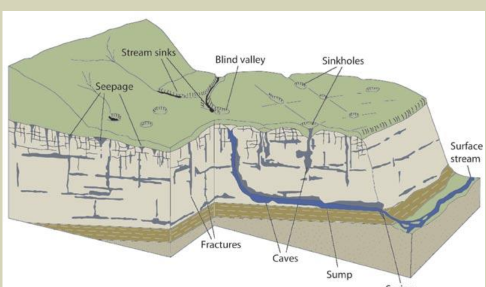
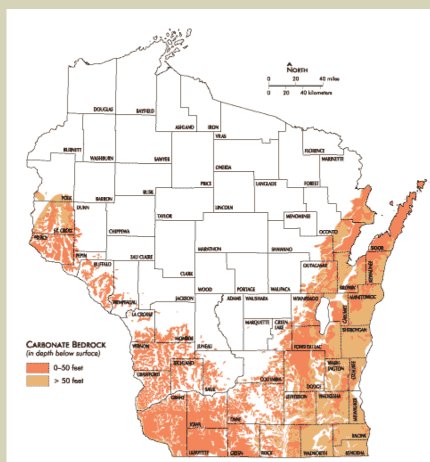


Image courtesy of Tony Runkel, MN Geological Survey



https://wgnhs.wisc.edu/catalog/publication/000905/resource/fs02

Karst & Surficial Geology

- Karst features
  - Sinkholes, conduits, caves
- Surficial Geology
  - Residuum – reddish clay from weathered carbonate bedrock, locally known as the 'Rountree Formation'
  - Loess (wind-blown sediment) that is silt-sized and is the parent material for many soils in the region


Sinkhole near Blue Mounds, WGNHS photo

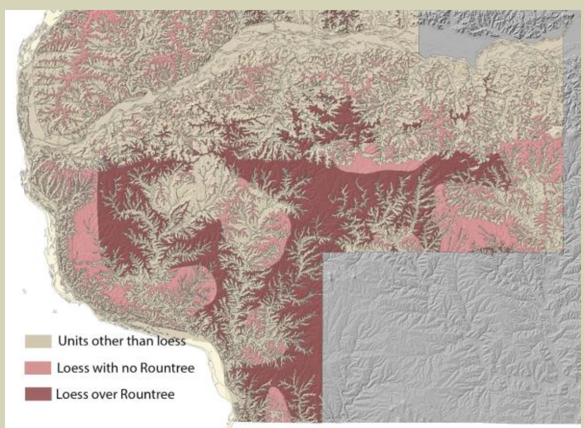

Photo by Eric Carson, WGNHS


Conduit in 151 roadcut, WiDOT photo

17

Southwest Wisconsin Surficial Geology

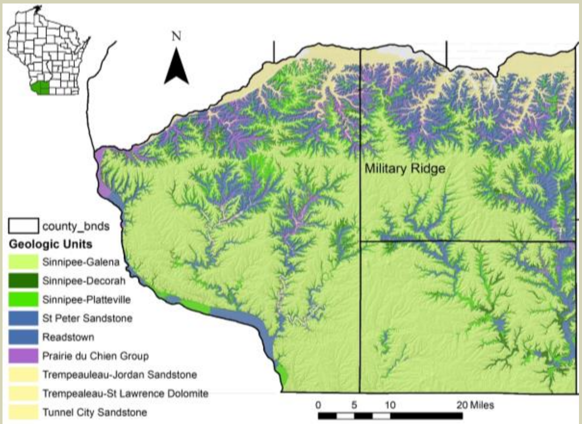
- Rountree Formation
  - Not present everywhere
  - Ranges from clayey to sandy
  - Generally less than 5 feet in thickness
  - If present, it is overlain by loess



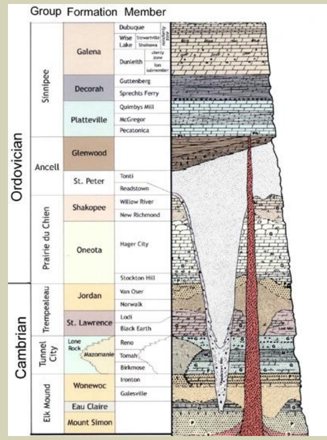
Preliminary map of the distribution of the Rountree Fm in Grant and Iowa Counties
From Eric Carson, WGNHS

18

Southwest Wisconsin Bedrock Geology



Geology from WGNHS bedrock mapping projects currently underway in SW WI. Eric Stewart and others



"Bedrock Stratigraphic Units of Wisconsin" https://wgnhs.wisc.edu/catalog/publication/000200/resource/es051

19

Water Cycle

- Processes
  - Evaporation
  - Transpiration
  - Precipitation
  - Infiltration
  - Groundwater flow
  - Overland flow
  - Stream runoff

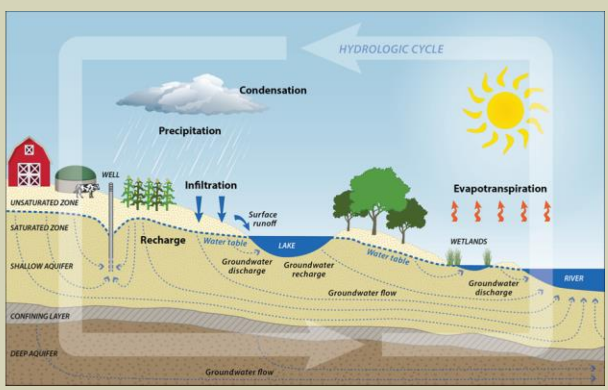
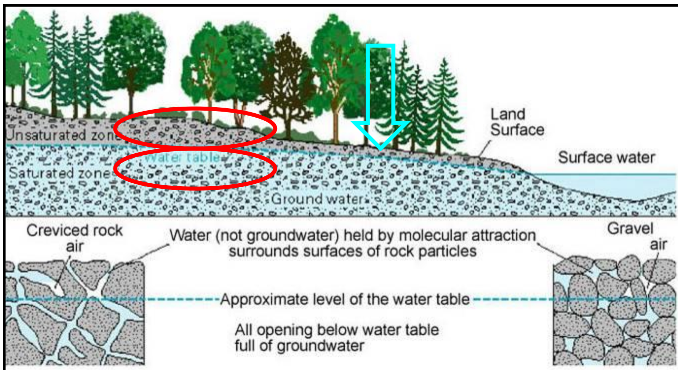


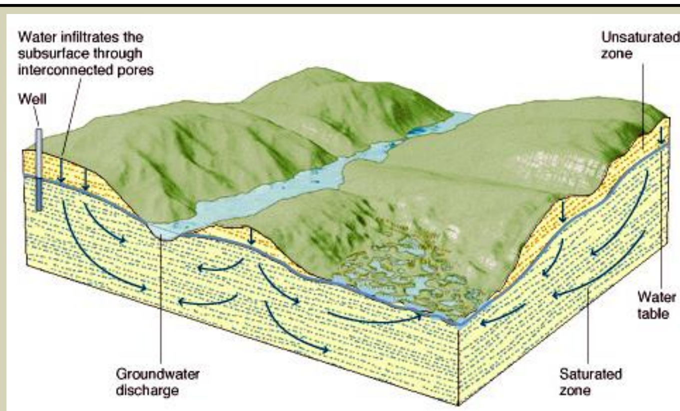
Figure from WI Geological and Natural History Survey

20



- Aquifer – a geologic unit that can store and transmit usable quantities of water to a well
- Water table is boundary between the unsaturated and saturated zones
  - Unsaturated zone - pores spaces contain both air and water
  - Saturated zone - pores spaces are filled with water
- Groundwater Recharge – water that seeps past the root zone and makes it to the water table (top of the saturated zone)

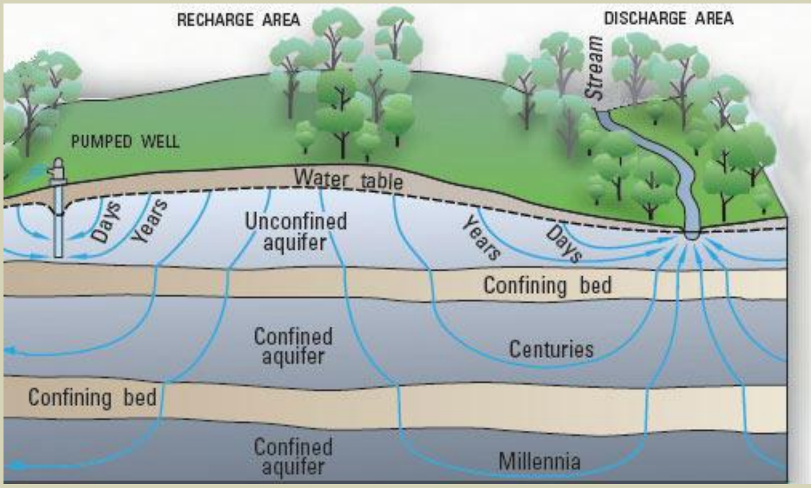
21



- Groundwater flow is from areas of higher hydraulic head to areas of lower hydraulic head.
- Recharge area -- area where precipitation infiltrates and moves into the groundwater flow system. Groundwater flow is generally downward in these areas.
- Discharge area -- area where water exits the aquifer. In this diagram streams and lakes are the discharge areas.

22

Groundwater Flow in Multi-Aquifer Systems

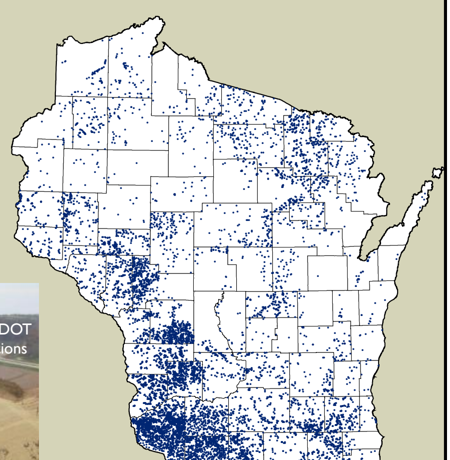


- Different rock layers have differing abilities to transport water
- Shale layers often serve to separate aquifers

23

Flow Patterns in Southwestern Wisconsin

- Short flow paths from ridgetop to adjacent creek or river
- Different rock layers can cause perching and significant lateral movement of water
- Springs common

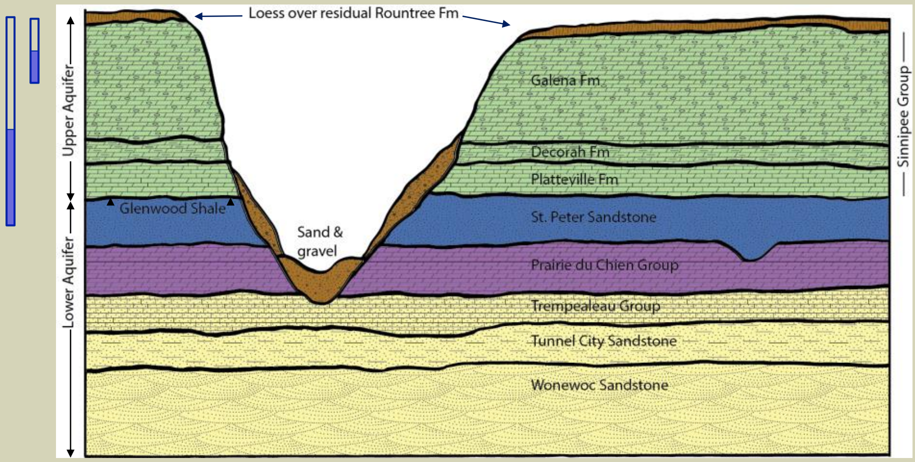


WGNHS Springs database

Above is modified from "Bedrock Stratigraphic Units of Wisconsin"
https://wgnhs.wisc.edu/catalog/publication/000200/resource/es051

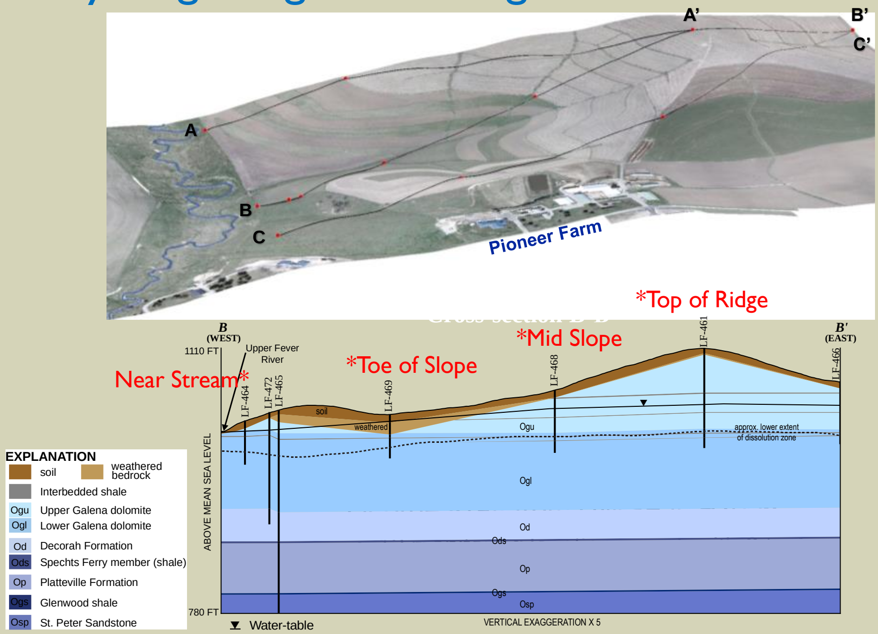
24

Multiple Aquifers in Southwestern WI

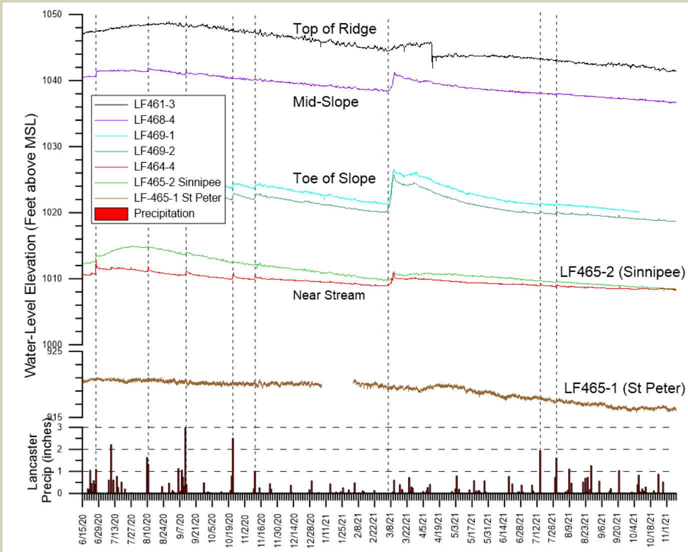


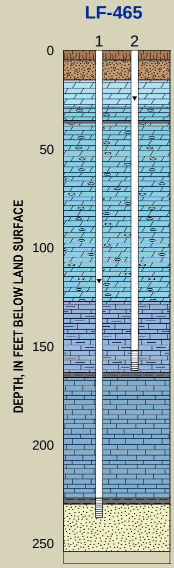
- Upper Aquifer consists of the Sinnipee Group (Galena, Decorah, & Platteville Fm)
- Separated from Lower Aquifer by the Glenwood Shale
- Lower Aquifer includes the St Peter sandstone, Prairie du Chien dolomite and underlying Cambrian sandstones

Hydrogeological Investigations: Pioneer Farm



Hydrogeological Investigations: Pioneer Farm





- Recharge to the upper aquifer is rapid
- Significant difference in water levels from upper to lower aquifer

27

Groundwater quality and risk factors for contamination

Joel Stokdyk
U.S. Geological Survey
Laboratory for Infectious Disease & the Environment
Marshfield, WI

28

Study design & objectives

Objectives

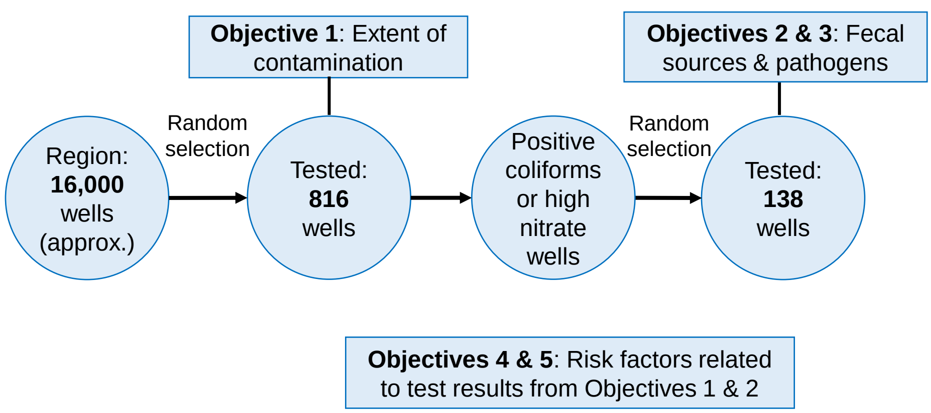
1) Determine the extent of contamination
2) Identify fecal sources
3) Test for pathogens
4) Assess well & geologic risk factors
5) Assess land use risk factors

Presentation organized by objective

- Approach
- Key findings
- Context & interpretation

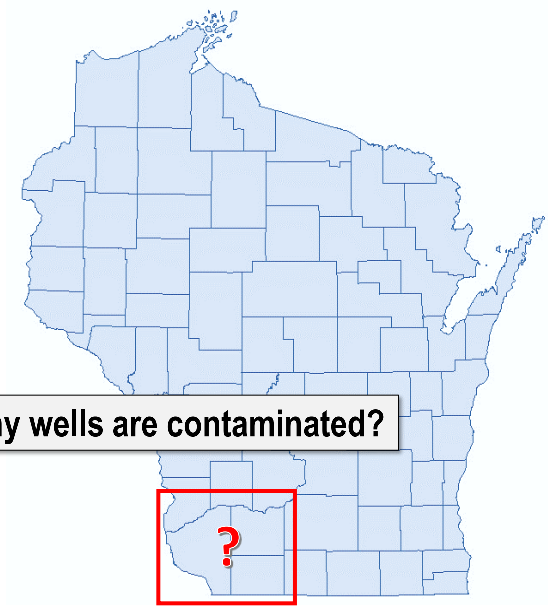
29

Study design & objectives



30

Objective 1: Extent of private well contamination



31

Objective 1: Approach

Random selection across the 3 counties

- Similar geology & land use
- Represent the 3-county region

Two 2-day synoptic events ("snap-shots")

- Nov. 2018 & Apr. 2019
- 3,333 total solicitations, 25% participation
- 840 total samples

Total coliform bacteria, *E. coli*, & nitrate

- Analyzed by UW-Stevens Point WEAL
- Homeowner collection; free to participants

32

Objective 1: Approach

Nitrate
- Source: manure, wastewater, chemical fertilizers
- Groundwater quality standard: 10 mg NO_3^--N/L (10 ppm)

Total coliforms
- Source: fecal & non-fecal
- Groundwater quality standard: 0 per 100 mL

E. coli
- Source: fecal
- Groundwater quality standard: 0 per 100 mL

All 3 are commonly used to assess private well water quality

Wisconsin groundwater quality standards for bacteria & nitrate are consistent with US EPA standards for public water supplies. WDNR (2021) Groundwater quality standards, § NR 140.10. USEPA (2022), National primary drinking water regulations, 40 CFR Part 141.

33

Objective 1: Key findings

42% of wells in November & 27% of wells in April were positive for total coliforms or had high nitrate.

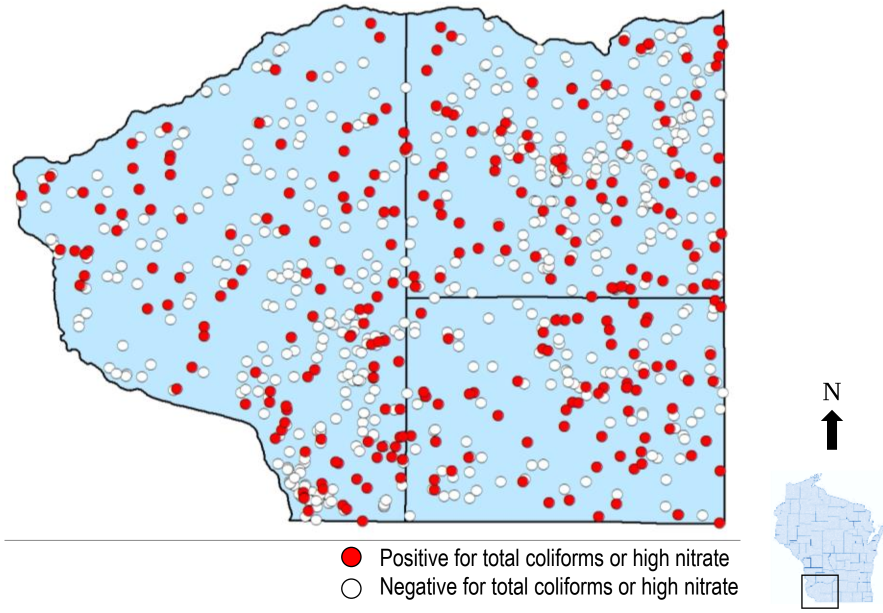
Private wells	Wells sampled	Total coliform	*E. coli*	High nitrate*
SWIGG: November 2018	**301**	**34%**	**4%**	**16%**
SWIGG: April 2019	**539**	**16%**	**2%**	**15%**
Statewide 1997[a]	534	23%	3%	7%
Statewide 2013[b]	3838	18%	-	10%
Statewide 2017[c]	401	-	-	8%

*High nitrate: NO_3^--N > 10 mg/L. "-" indicates data were not reported.

[a] US General Accounting Office. 1997. Information on the quality of water found at community water systems and private wells. United States GAO/RCED-97-123.
[b] Knobeloch L., Gorski P., Christenson M., and Anderson H. 2013. Private drinking water quality in rural Wisconsin. Journal of Environmental Health 75:16-20.
[c] Agricultural chemicals in Wisconsin groundwater. 2017. Wisconsin Department of Agriculture, Trade, and Consumer Protection, ARM-PUB-264.indd.

34

Positive wells were geographically distributed



35

Objective 1: Context & interpretation

1. Comparison to statewide private well data

2. Groundwater contamination can change
   - Contaminant sources & weather change
   - Synoptic events: 2 snap-shots with different conditions

3. Representative assessment using standard tests
   - Random selection, many wells, geographically distributed
   - Facilitates comparison, provides benchmark

36

Objective 2: Fecal sources

Septic systems: 16,000
Septage/sludge: 449 permitted fields

Hogs & pigs: 77,600
Cattle & calves: 368,128

Identifying the fecal source:
"Microbial Source Tracking"

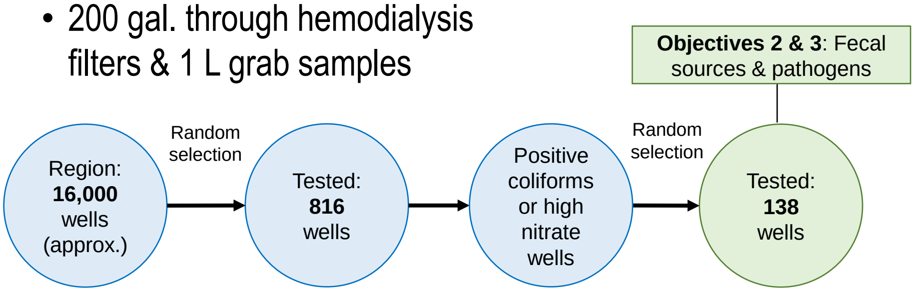
Data from County records; WI DNR; USDA National Agriculture Statistics Service 2017 Census of Agriculture, AC-17-A-51, Washington DC.

37

Objective 2: Approach

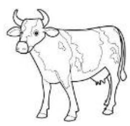
Sample collection

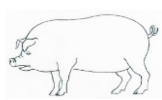
- Random selection from wells positive for total coliforms, *E. coli*, or high nitrate
- 34 or 35 wells per season, 138 wells total
- 200 gal. through hemodialysis filters & 1 L grab samples



38

Microbes specific to fecal sources





Fecal source	Fecal microbe
Human wastewater	*Bacteroidales-like Hum M2*
	Cryptosporidium hominis
	Human adenovirus groups A-F
	Human enterovirus
	Human polyomavirus
	Norovirus genogroup I
	Human *Bacteroides*
Cattle/ruminant manure	*Bacteroidales*-like cow M2
	Bacteroidales-like cow M3
	Bovine adenovirus
	Bovine enterovirus
	Bovine polyomavirus
	Ruminant *Bacteroides*
Pig manure	Pig-1-*Bacteroidales*
	Pig-2-*Bacteroidales*
	Porcine adenovirus
	Porcine epidemic diarrhea virus

39

Objective 2: Key findings

Human wastewater & livestock manure contribute to private well contamination, & human wastewater was more common.

Wells positive for fecal microbes (138 tested)

Fecal source	No. positive wells
Human wastewater	64
Cattle/ruminant manure	33
Pig manure	13

26 wells were positive for multiple fecal sources.

40

Objective 2: Context & interpretation

1. Few private well studies for comparison

- Human or livestock fecal microbes in 0 – 61% of wells
- Kewaunee County
  - Human: 33 of 131 wells (25%)
  - Bovine: 44 of 131 wells (34%)

2. Common fecal sources

- Septic systems: Continuous, subsurface
- Manure: Intermittent/variable

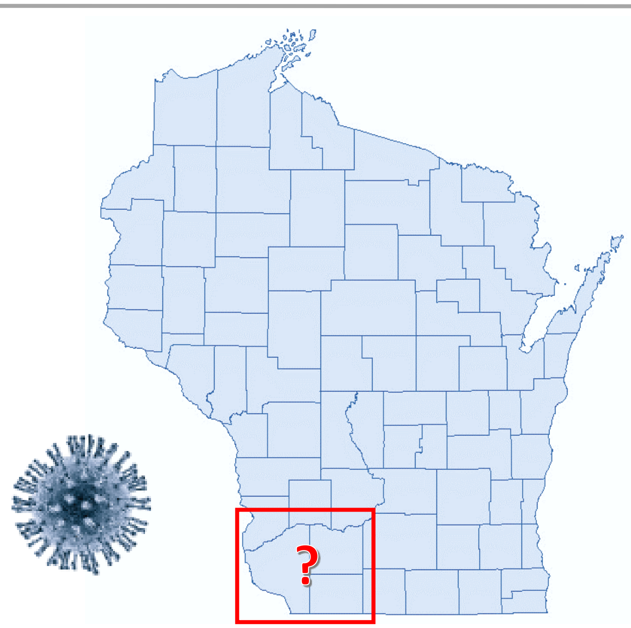
Take note!

Fecal source tests don't identify sources of nitrate & total coliforms.

1. Non-fecal sources possible
2. Multiple sources possible
3. Sources can change

41

Objective 3: Pathogens



42

Objective 3: Approach

138 wells from Objective 2

- Random selection from wells positive for total coliforms, *E. coli*, or high nitrate

19 genetic tests for pathogens

- Viruses, bacteria, & protozoa
- Human & zoonotic

Take note!

Zoonotic pathogens can be passed between animals & humans.

43

Pathogen genes detected in 66 of 138 wells.

Type	Pathogen	No. positive Wells
	Cryptosporidium hominis	8
	Human adenovirus A-F	2
Human	Human enterovirus	1
	Human polyomavirus	0
	Norovirus genogroup I	0
	Campylobacter jejuni	3
	Cryptosporidium parvum	8
	Cryptosporidium spp.	29
	Giardia duodenalis	1
	Hepatitis E virus	0
Zoonotic or not host-specific	Norovirus genogroup II	2
	Pathogenic *E. coli*	0
	Rotavirus A (2 tests)	9
	Rotavirus C	2
	Salmonella (2 tests)	13
	Shiga toxin 1-producing bacteria	1
	Shiga toxin2-producing bacteria	0

44

Objective 3: Context & interpretation

1. Health risk depends on pathogen type, amount, water treatment, susceptibility

2. Pathogen sources
- Wastewater, manure, & other feces
- Source unknown for zoonotic pathogens

3. Comparison to other studies

Take note!

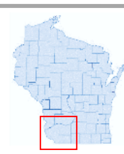
Genetic tests don't distinguish between living & dead pathogens, but they do:
1. Show pathogen contamination is possible
2. Correspond to other tests
3. Correspond to illness

Allen et al. 2017. Hydrogeol. J. 25(4); Borchardt et al. 2021. Env. Health Persp. 129(6) p.067004; Borchardt et al. 2003. Appl. Env. Micro. 69(2); Hynds et al. 2014, PLoS One. 9(5), p.e93301; Stokdyk et al. 2020, Water Res. 178 p115814

45

Pathogens in wells: Comparison to other studies

Kewaunee Co. 2021
Private wells
131 tested



SWIGG 2022
Private wells
138 tested

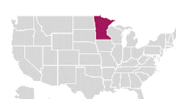
0% 15% 24% 45% 48% 70%

Study wells positive for pathogens

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

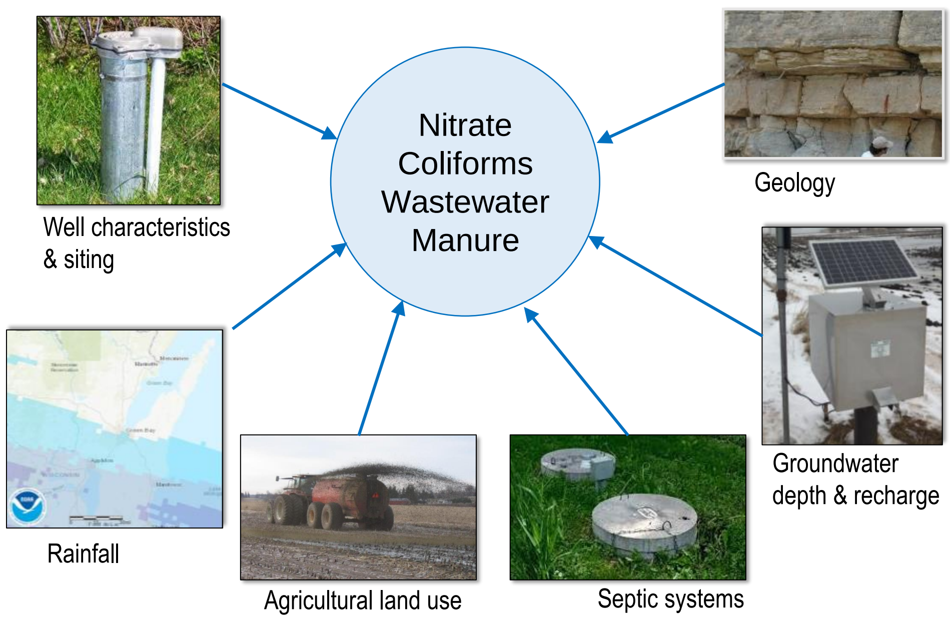
Ontario 2017
Private wells
11 tested

Minnesota 2020
Public wells
145 tested



46

Objectives 4 & 5: Factors associated with contamination



47

Objective 4: Risk factors investigated

Well characteristics
Well age
Well depth
Casing depth
Groundwater depth at construction
Casing length below water table
Casing length into bedrock
Open interval length
Specific capacity

Well siting
Slope (within 750, 1500, & 3000 ft)
Soil hydrologic group
Surficial sediment type
Well elevation

Geology
Bedrock depth
Open interval geology
Topmost geology

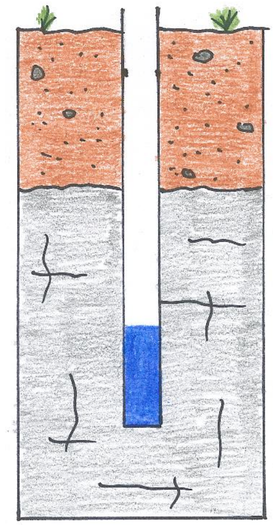
Groundwater & rainfall
2, 7, 14, 21 days prior to sampling:
- Groundwater depth
- Groundwater recharge
- Rainfall

Data sources
Well construction reports
Geologic maps & soil survey
Digital elevation model
National Weather Service (QPE)
Groundwater monitoring wells

48

Well characteristics were important

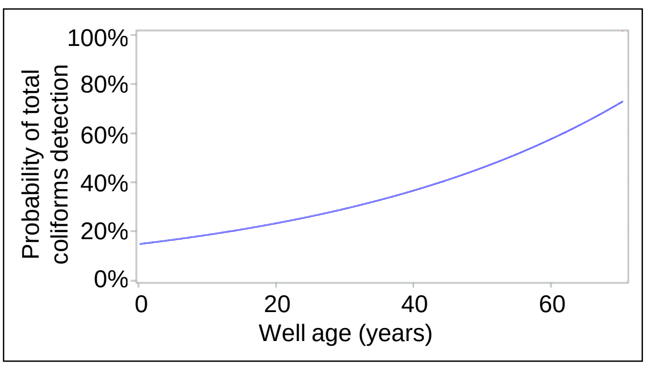
Significant factors (one or more contaminants)
- Well age
- Well depth
- Casing depth
- Open interval length
- Casing length into bedrock
- Casing length into groundwater
- Slope
- Elevation
- Soil


Cross-section of well

49

Examples of important well risk factors

Probability of total coliforms contamination increases with well age

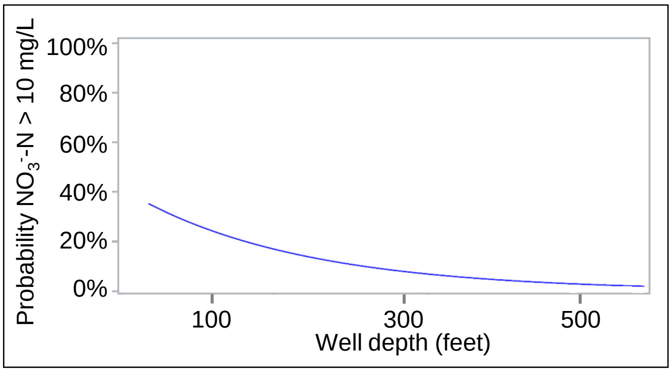


The plot shown is for the November synoptic event.

50

Examples of important well risk factors

Probability of high nitrate contamination decreases with well depth



The plot shown is for the April synoptic event.

51

Geology was important

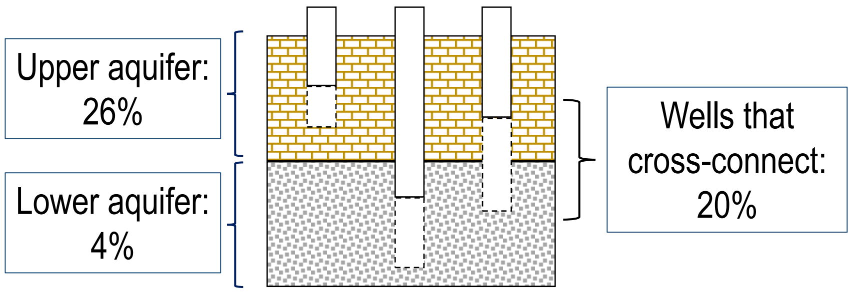
Significant factors (one or more contaminants)

- Open interval geology
- Topmost geology
- Bedrock depth

52

Example of geology factors

Open interval geology: Probability of high nitrate is greater for the upper aquifer



The data shown are for the November synoptic event.

53

Rainfall & groundwater depth were important

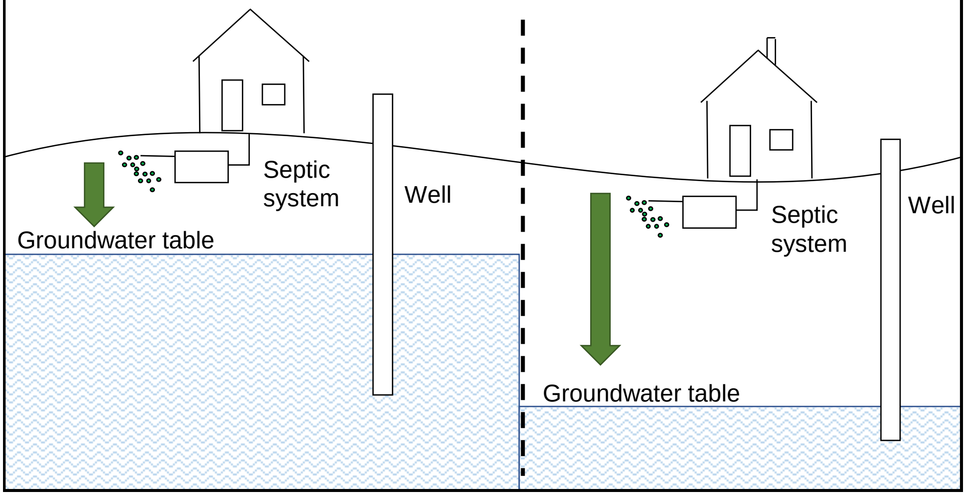
Significant factors for wastewater contamination

- Rainfall
- Groundwater depth

54

Example of rainfall & groundwater factors

Wastewater contamination is more likely when groundwater is shallow.



55

Objective 5: Risk factors investigated

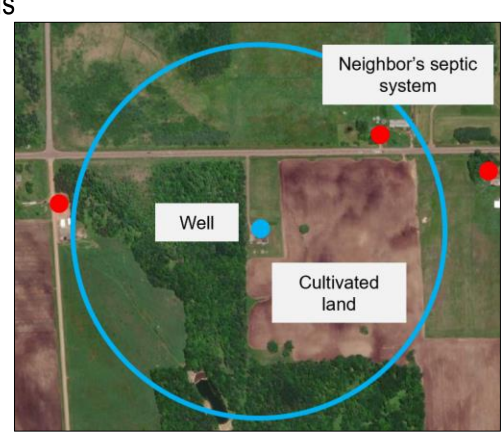
Land use

Distance; count or acres within 750, 1500, & 3000 ft of well

- Cultivated land
- Livestock farms
- Septage/municipal sludge fields
- Septic systems
- Drainfield septic systems

Data sources

USDA Cultivated Land Layer
WI DNR
Aerial imagery
County records



56

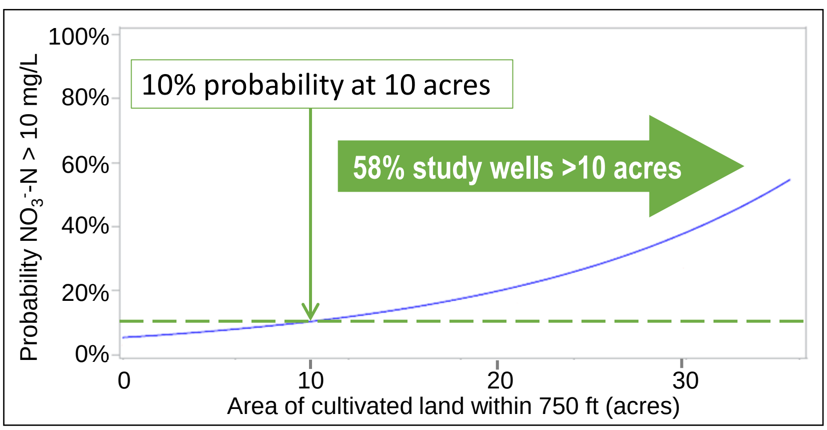
Land use was important

Agricultural factors were associated with nitrate, total coliforms, & manure

- Area of cultivated land nearby
- Distance to cultivated land
- Distance to livestock farm

57

Example: Probability of high nitrate increased with the area of cultivated land nearby



750 ft radius around well = 40 ac

Statewide (10%)
Knobeloch et al. 2013. J Environ Health

The plot shown is for the November synoptic event.

58

Land use was important

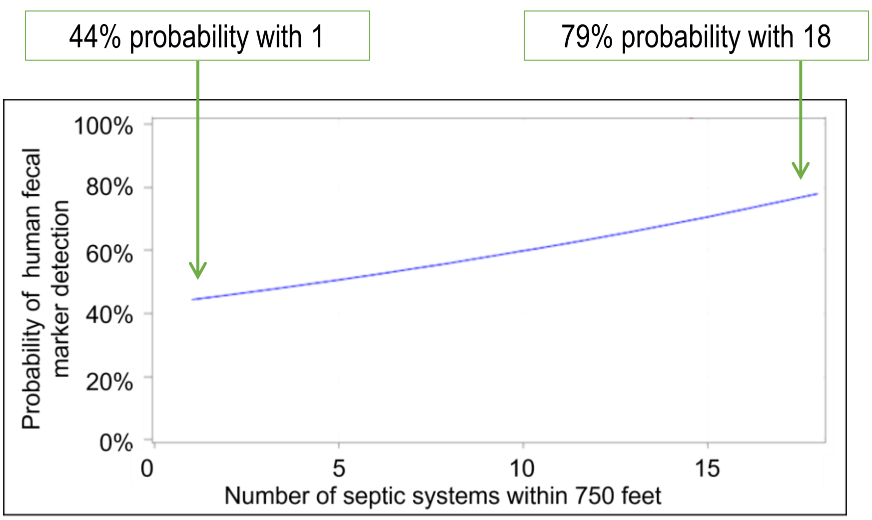
Septic system factors were associated with human wastewater

- Number of septic systems nearby
- Distance to neighbor's septic system

Septic system factors were not associated with nitrate & total coliforms

59

Example: Probability of human wastewater contamination increased with the number of septic systems nearby



60

Two study goals

An assessment of private well contamination

- Extent of contamination (Obj. 1)
- Pathogens were detected (Obj. 3)

Findings that help identify potential ways to address contamination

- Contamination from wastewater & manure (Obj. 2)
- Well, geology, & land use factors were important (Obj. 4 & 5)

61

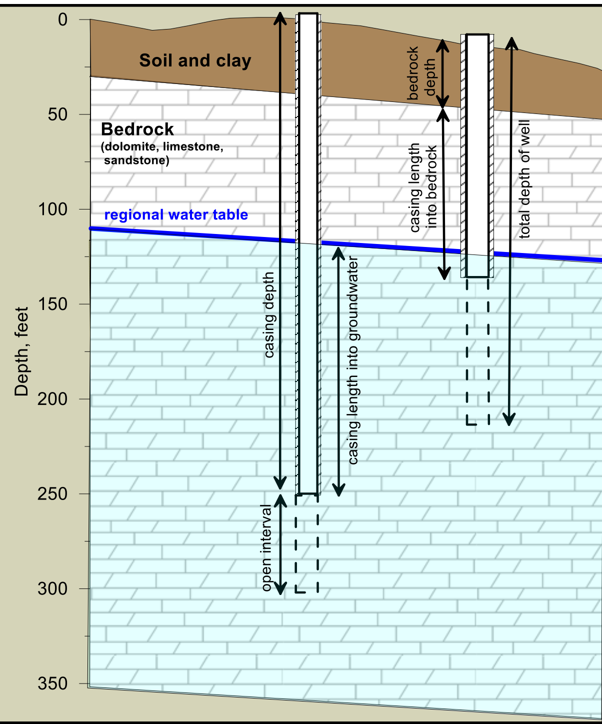
Understanding wells and what a private well owner can do

Ken Bradbury, Ph.D.
State Geologist and Director
Wisconsin Geological & Natural History Survey

62

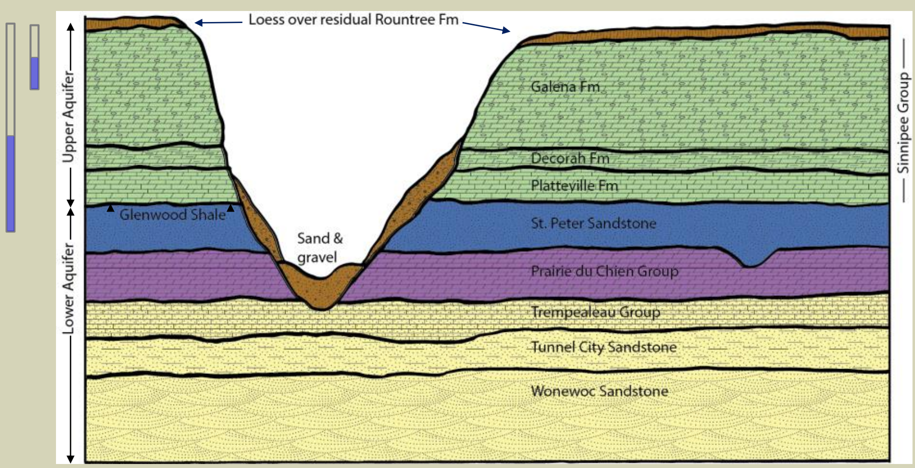
Well Construction

Definitions of measures used in the report



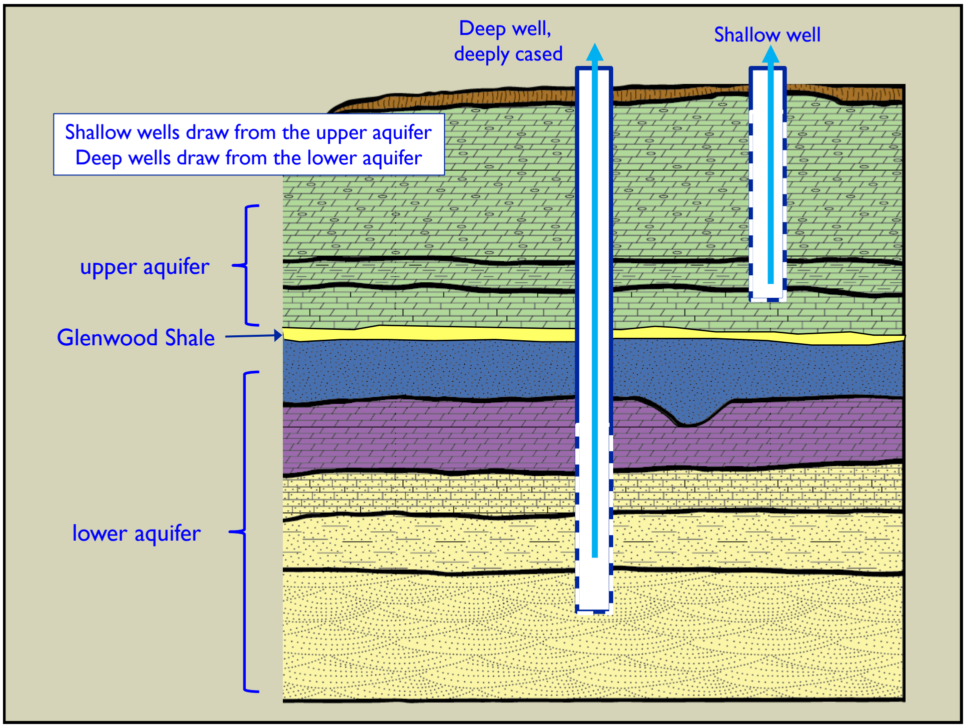
63

Multiple Aquifers in Southwestern WI

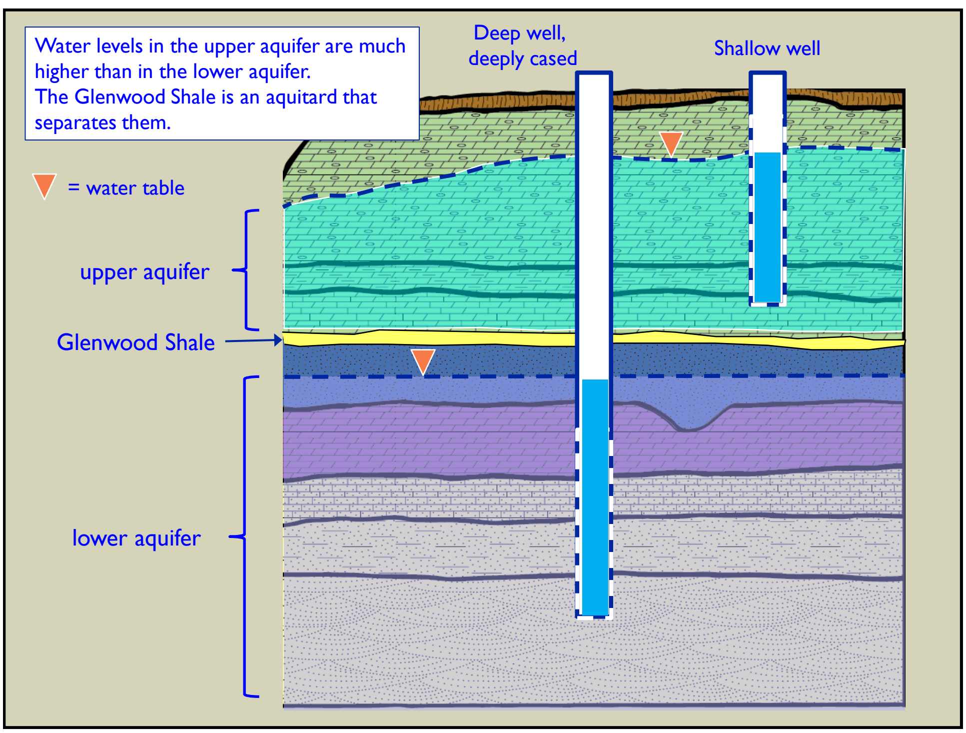


- Upper Aquifer consists of the Sinnipee Group (Galena, Decorah, &Platteville Fm)
- Separated from Lower Aquifer by the Glenwood Shale
- Lower Aquifer includes the St Peter sandstone, Prairie du Chien dolomite and underlying Cambrian sandstones

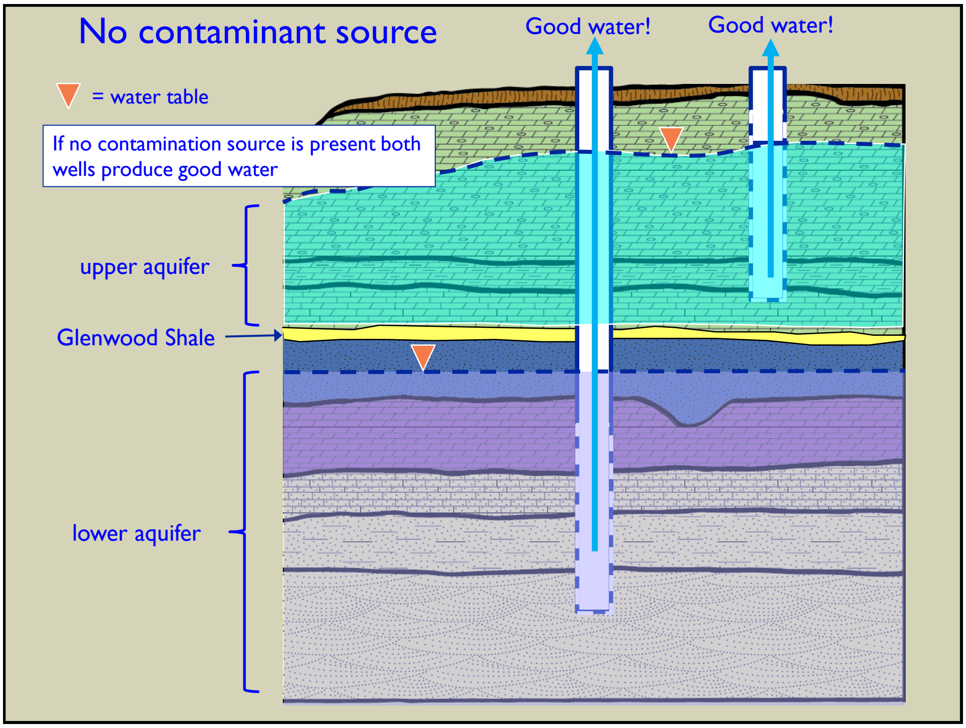
64


Deep well,
deeply cased
Shallow well
Shallow wells draw from the upper aquifer
Deep wells draw from the lower aquifer
upper aquifer
Glenwood Shale
lower aquifer

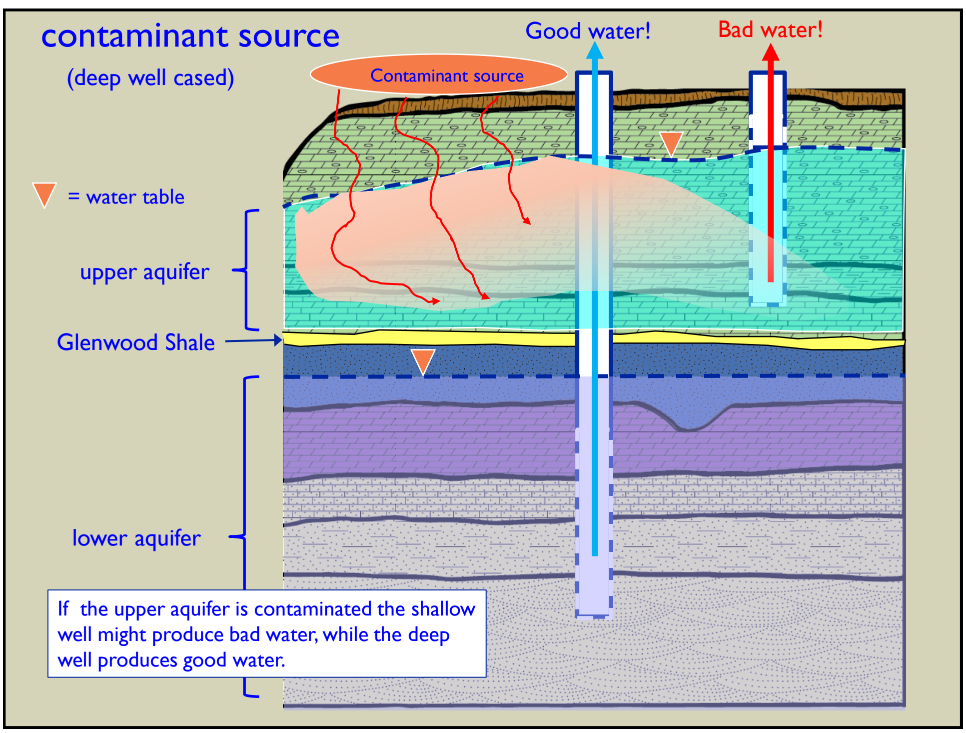
65


Water levels in the upper aquifer are much higher than in the lower aquifer.
The Glenwood Shale is an aquitard that separates them.
Deep well,
deeply cased
Shallow well
= water table
upper aquifer
Glenwood Shale
lower aquifer

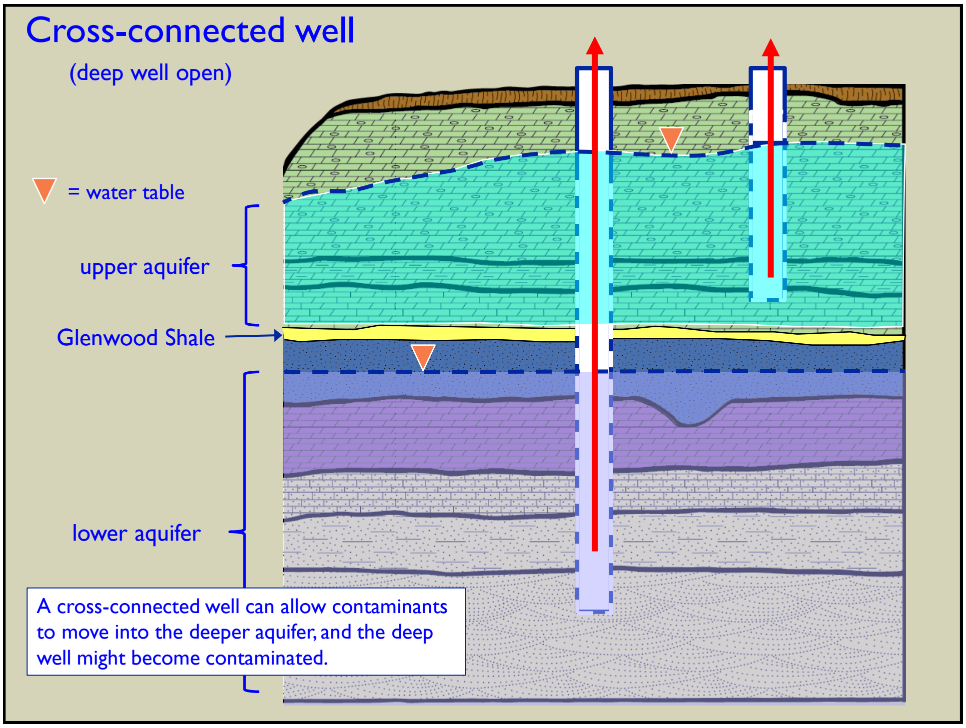
66


No contaminant source
Good water!
Good water!
= water table
If no contamination source is present both wells produce good water
upper aquifer
Glenwood Shale
lower aquifer

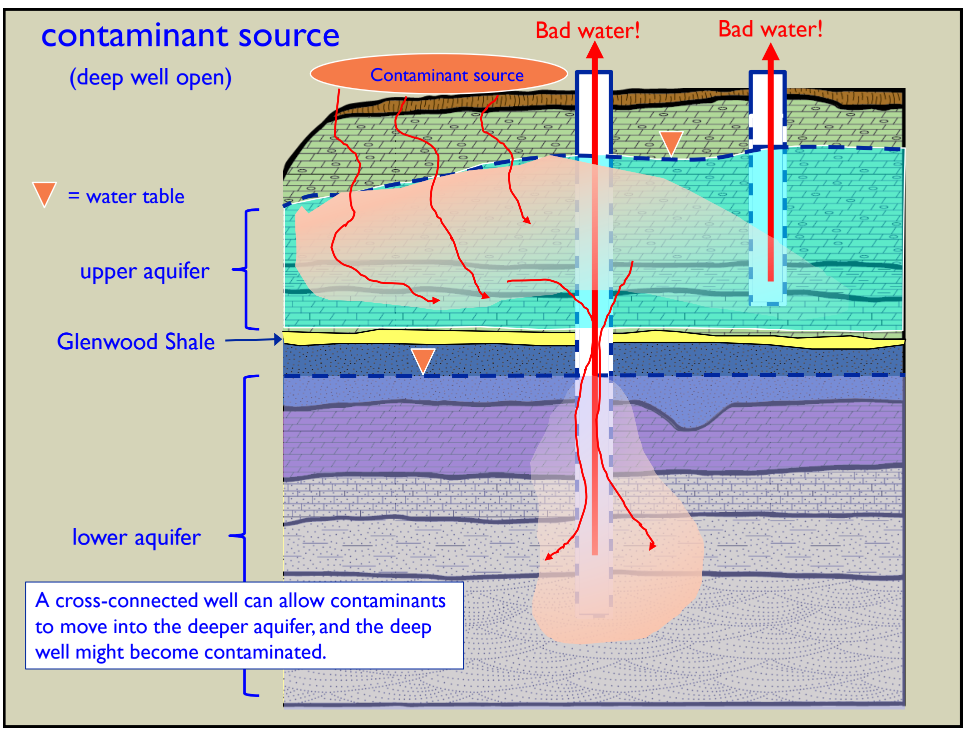
67


contaminant source
(deep well cased)
Good water!
Bad water!
Contaminant source
= water table
upper aquifer
Glenwood Shale
lower aquifer
If the upper aquifer is contaminated the shallow well might produce bad water, while the deep well produces good water.

68

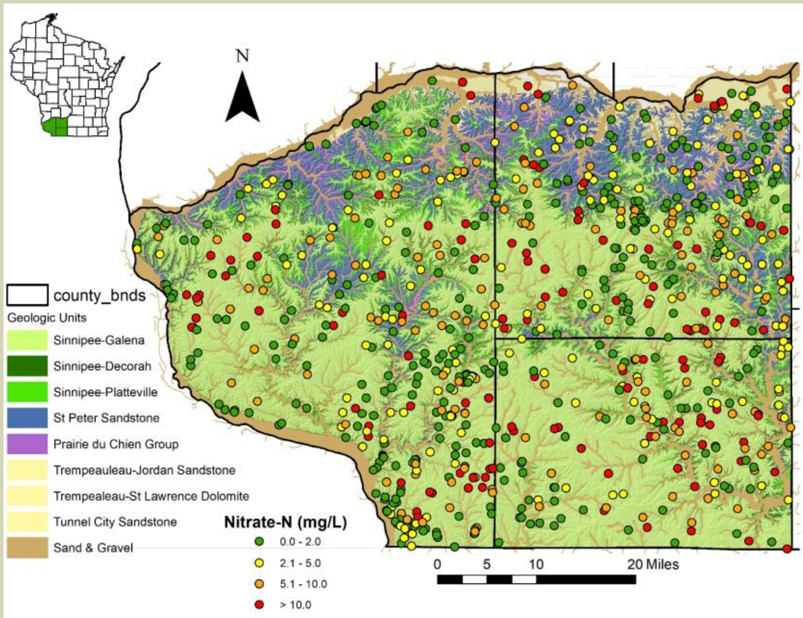

Cross-connected well
(deep well open)
= water table
upper aquifer
Glenwood Shale
lower aquifer
A cross-connected well can allow contaminants to move into the deeper aquifer, and the deep well might become contaminated.

69


contaminant source
(deep well open)
Bad water!
Bad water!
Contaminant source
= water table
upper aquifer
Glenwood Shale
lower aquifer
A cross-connected well can allow contaminants to move into the deeper aquifer, and the deep well might become contaminated.

70

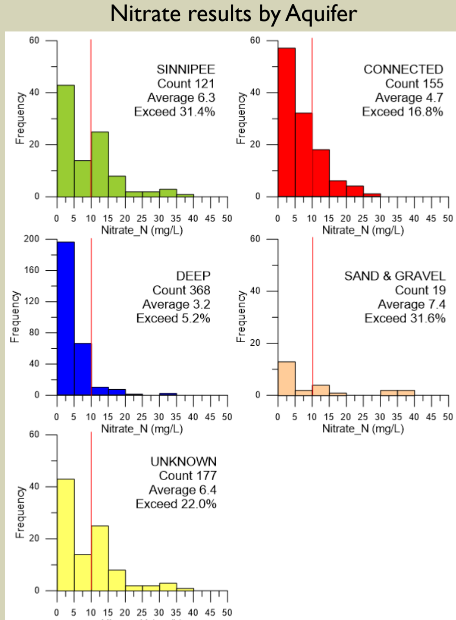
Geology and Water Quality



71

Geology and Water Quality

Nitrate results by Aquifer



Nitrate data shown are for the November and April synoptic events combined.

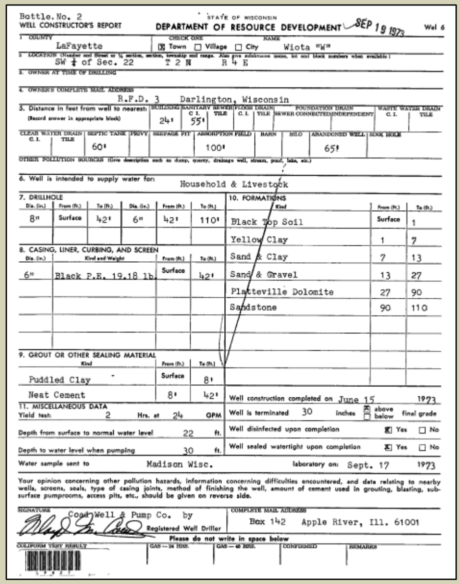
72

Information on Well Construction

Well construction reports (WCRs) contain information about private wells.

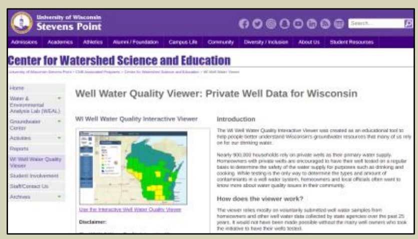
To find a well construction report visit the DNR website:

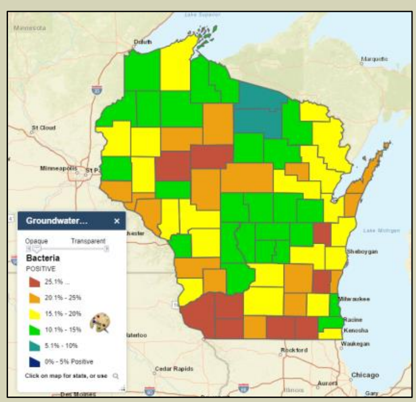
https://dnr.wi.gov/WellConstructionSearch/#!/PublicSearch/Index



Information on Groundwater Quality

- UW Stevens Point Center for Watershed Science
  - Interactive program that allows you to view groundwater quality data at a variety of scales





https://www3.uwsp.edu/cnr-ap/watershed/Pages/WellWaterViewer.aspx

Where to get help with your water

WISCONSIN DEPARTMENT OF NATURAL RESOURCES

HUNTING FISHING PARKS CLIMATE ENVIRONMENT FORES

Open all private well owners resources

Contact information for licensed well drillers and pump installers +

Test your private well –

- Test your private well water annually
- Tests for drinking water from private wells [PDF]
- Laboratories certified to test private well drinking water for:
  - bacteria
  - other contaminants

Your well's water quality and possible water problems –

- What's wrong with my water? — pinpoint your water problem and what can be done about it.
- Identify your water's symptoms — does your water smell, look, taste or feel funny?
- Statewide water quality viewer [exit DNR]
- Water quality and contamination
- Arsenic in drinking water [PDF]
- Bacteria in drinking water [PDF]
- Nitrate in drinking water [PDF]
- Manure and drinking water
- Flooded wells

The WDNR has a variety of publications

https://dnr.wisconsin.gov/topic/Wells/homeowners.html

75

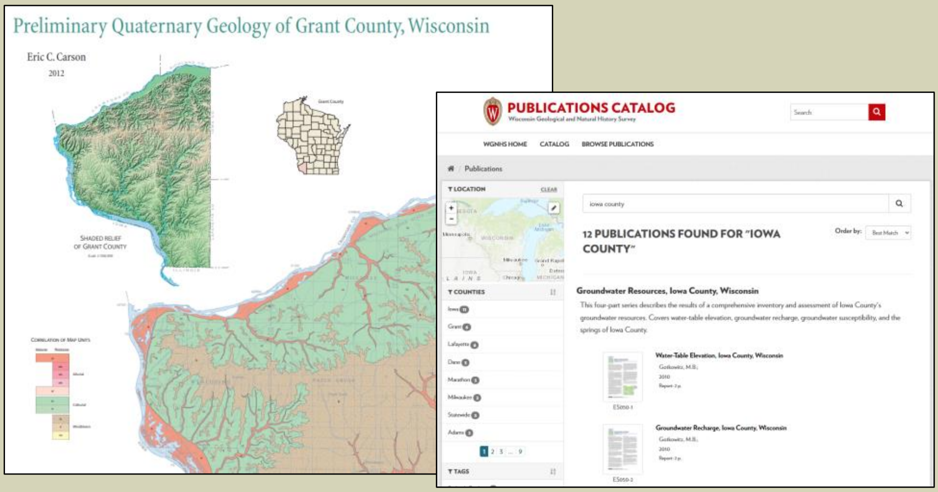
The Center for Watershed Science and Education at UW Stevens Point has numerous education resources about groundwater and wells

https://www3.uwsp.edu/cnr-ap/watershed/Pages/GWHome.aspx

76

The Wisconsin Geological and Natural History Survey provides maps, publications, and data about geology and groundwater

https://wgnhs.wisc.edu/



77