Groundwater Quality in the Valley and Ridge: Relation to Karst Features and Topographic Setting

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GROWING COMMUNITIES ON KARST 2010

GREAT VALLEY WATER RESOURCES SCIENCE FORUM

Overview: Is water quality in the Valley and Ridge unique?

- We will compare water quality in the Valley and Ridge carbonate-rock aquifers to:
  - Other aquifers in the United States
  - Other carbonate-rock aquifers in the nation
  - Other aquifers in the Valley and Ridge

Overview

- Issues related to water quality in karst – from the obvious to the less obvious
  - Land use near the well
  - Density of sinkholes near the well (karst is more than just sinkholes)
  - Position of the well along the flow path or topographic position

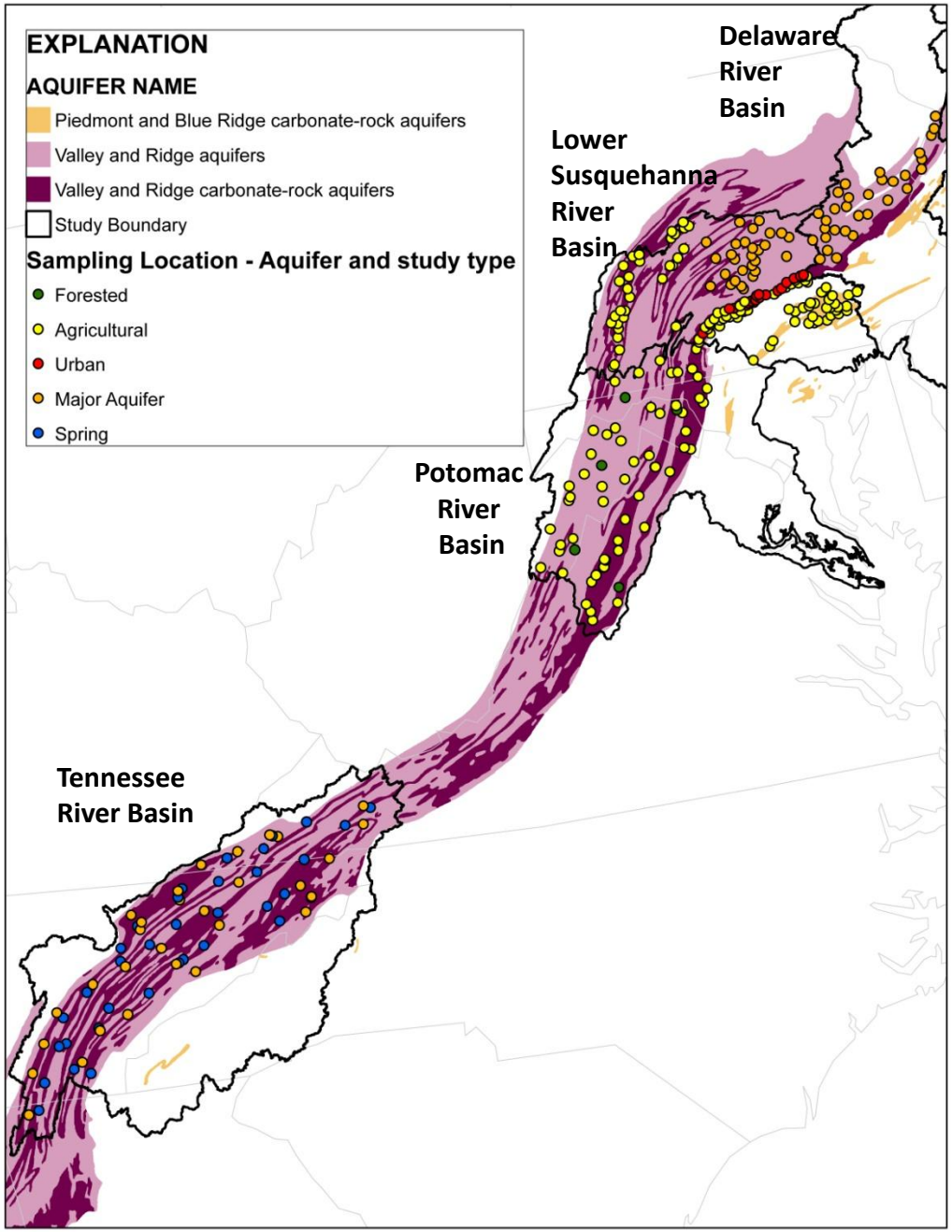
Generalizing about karst?

One thing you can count on:

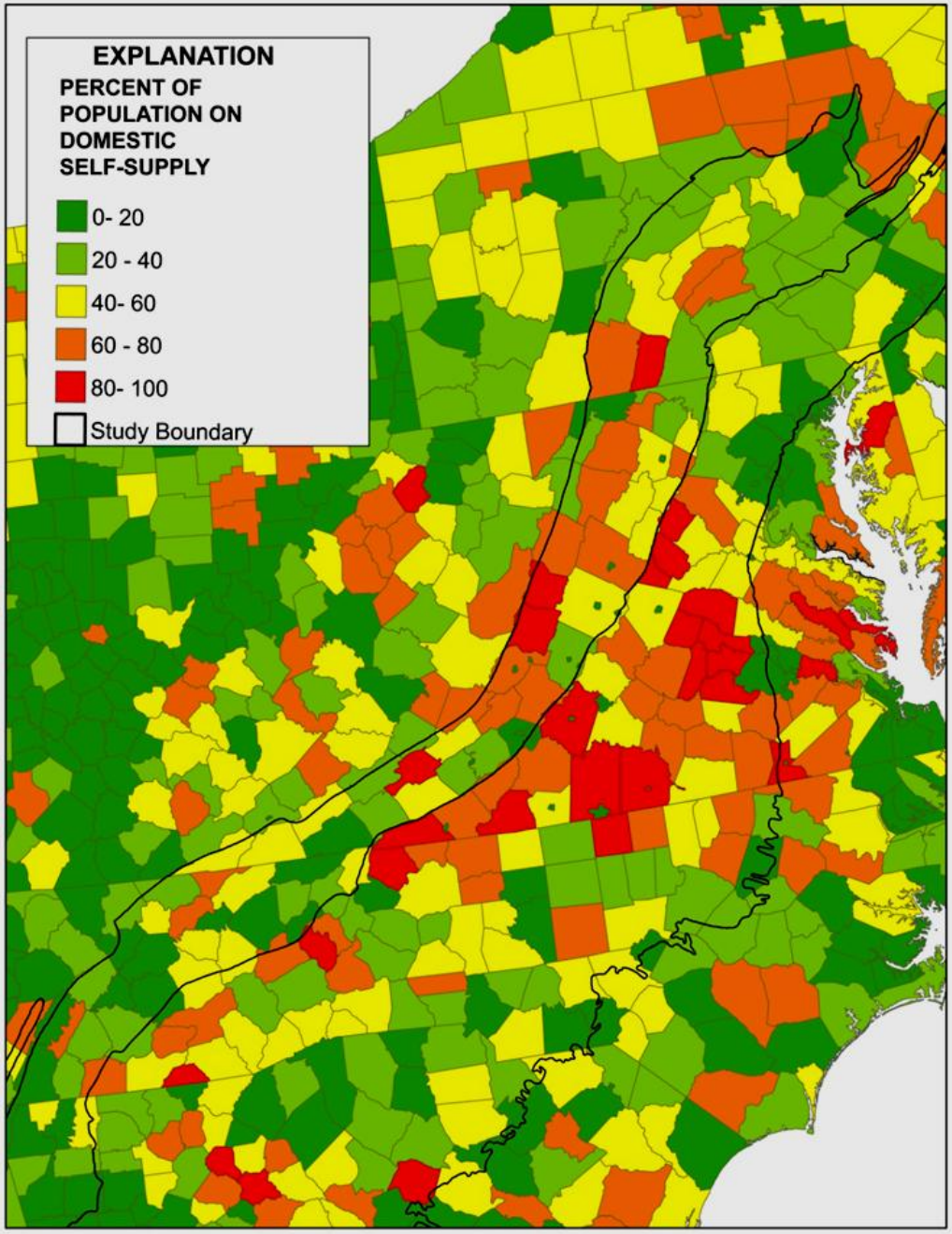
There are *ALWAYS* going to be exceptions!

General tendencies that follow are presented in that context.

Locations of studies and wells



Reliance on domestic self-supply (private wells) is very high in Piedmont and Valley and Ridge aquifers



Data from Hutson and others, 2004

Comparison to national studies: Of the networks with the highest concentrations of nitrate (of 133 networks total), the Piedmont or Valley and Ridge carbonate-rock aquifers ranked among the highest.

Study area abbreviation	Network type	Number of wells sampled	Median nitrate concentration, in mg/L as N	Median well depth below water level, in ft	National Rank
Long Island-New Jersey	Agricultural Land Use	15	13	12	1
Puget Sound	Agricultural Land Use	22	13	17	2
Susquehanna	**Piedmont carbonate**	**30**	**11**	**130**	**3**
San Joaquin	Agricultural Land Use	20	10	106	4
South Platte	Agricultural Land Use	30	9.4	9	5
Susquehanna	**Valley and Ridge carbonate**	**30**	**9.1**	**83**	**6**
Susquehanna	**Valley and Ridge carbonate**	**30**	**8.6**	**87**	**7**
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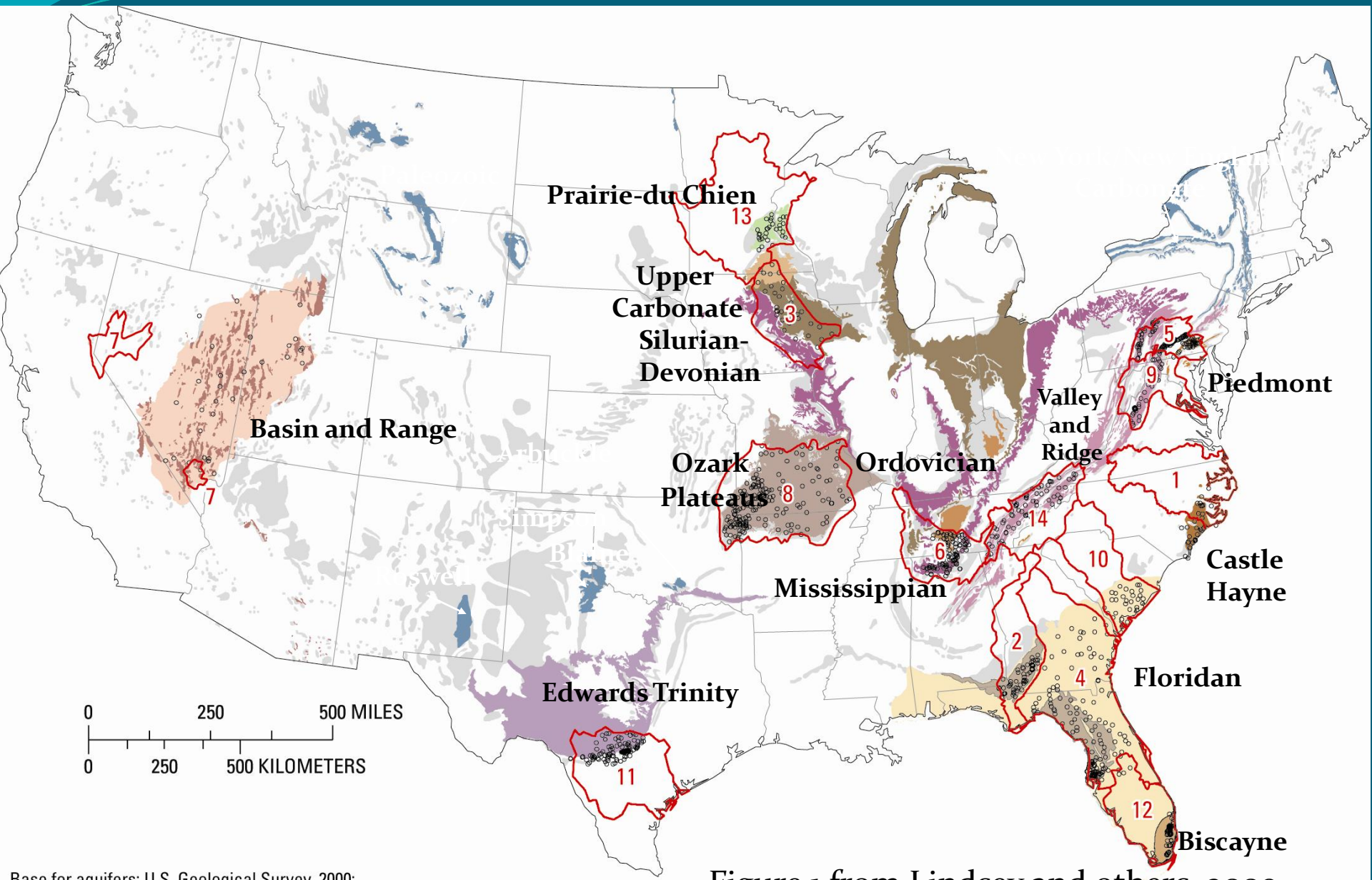
Potomac	**Valley and Ridge Carbonate**	**28**	**4.6**	**101**	**30**
Susquehanna	**Valley and Ridge Carbonate Urban**	**20**	**3.5**	**81**	**36**

Table S1 from Burow et al, 2010

Locations of Carbonate Aquifers



Base for aquifers: U.S. Geological Survey, 2000;
Base for other Carbonate Geology: Weary and others, 2006

Figure 1 from Lindsey and others, 2009

Nitrate concentrations were highest in Piedmont and Valley and Ridge carbonate-rock aquifers when compared to other carbonate aquifers

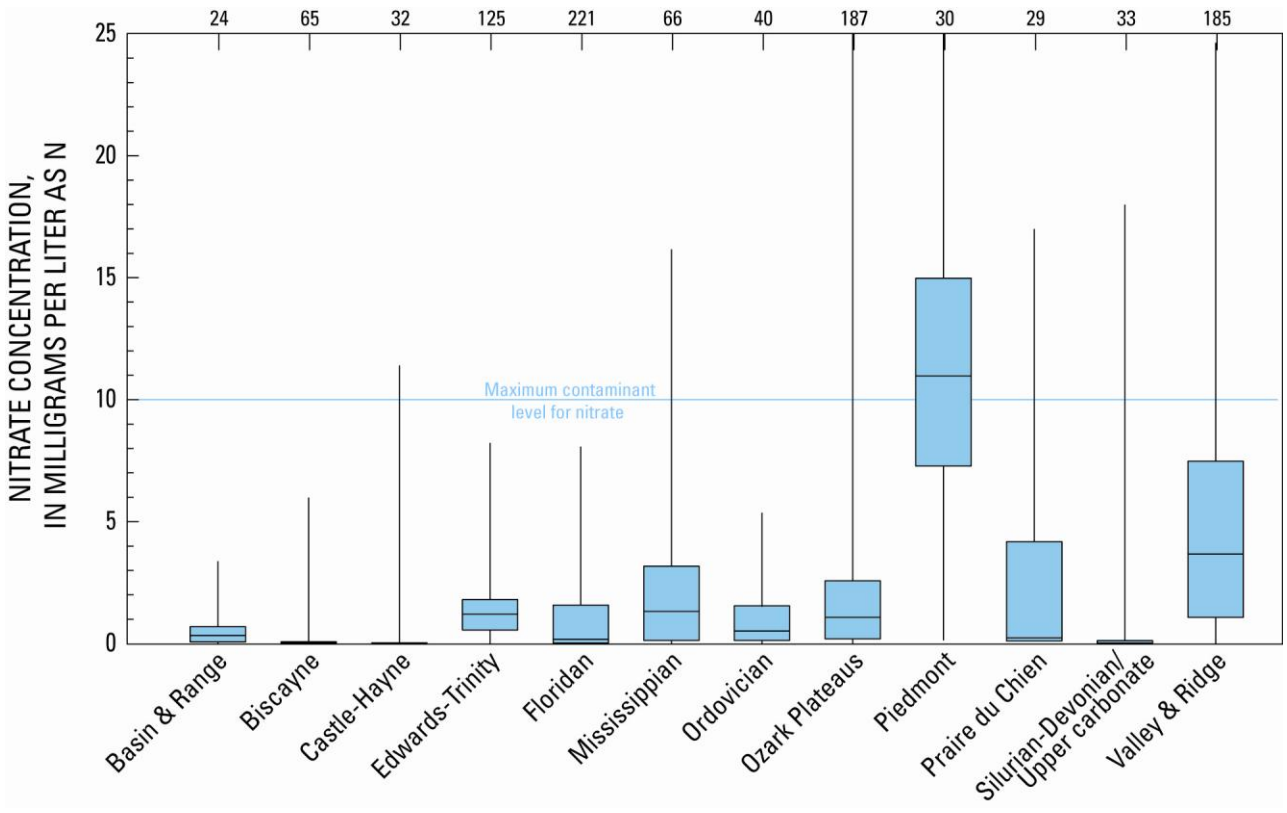
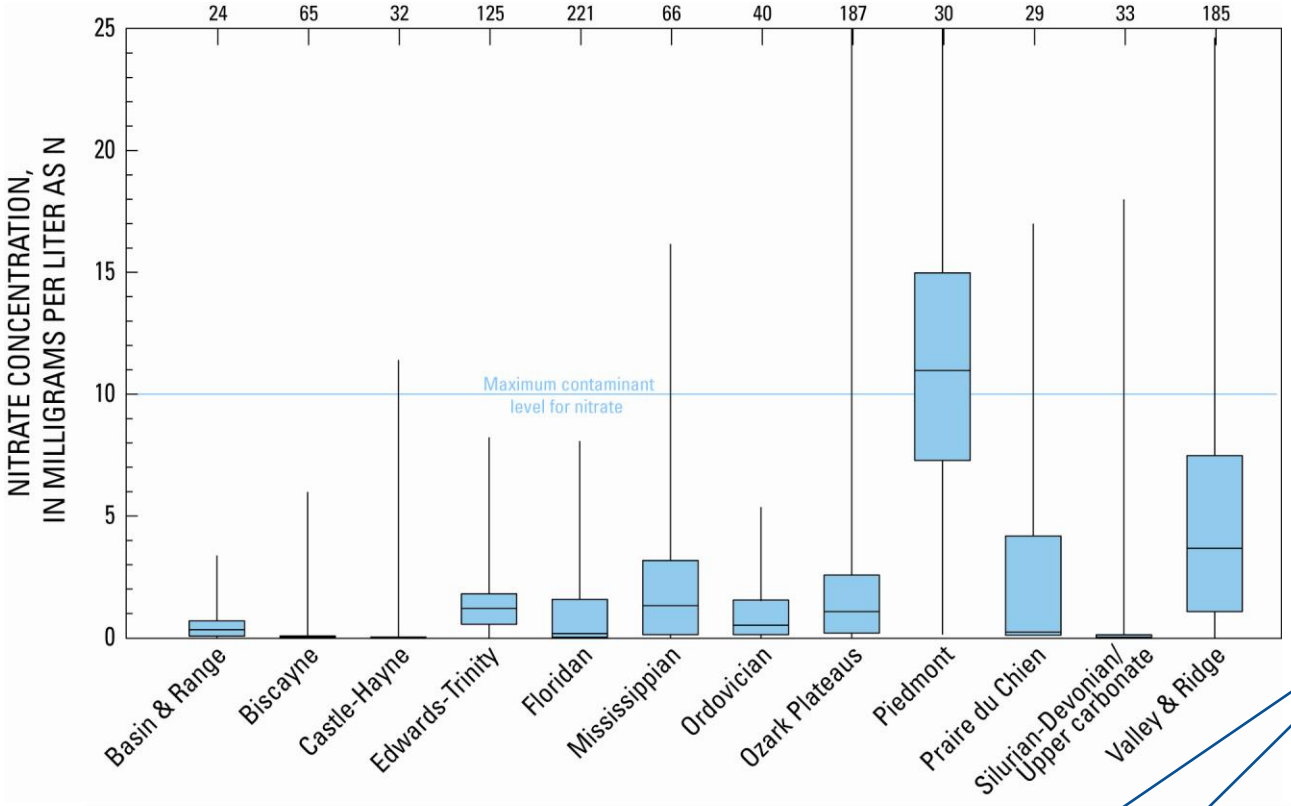
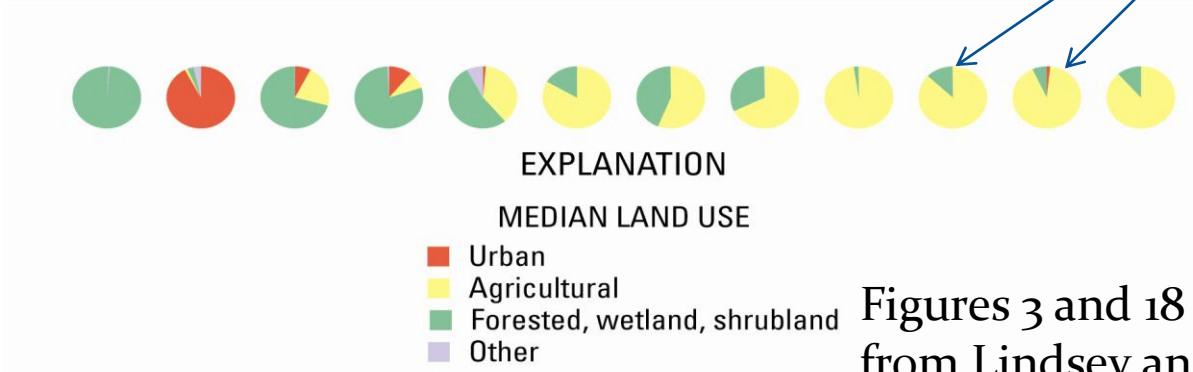


Figure 18 from Lindsey and others, 2009

How does water quality in the Valley and Ridge carbonate-rock aquifers compare to other carbonate-rock aquifers, and is the relation of land use to water quality consistent?



The high percentage of agricultural land use, but low median nitrate concentration is related to confinement and denitrification



Figures 3 and 18
from Lindsey and others, 2009

Reasons for high nitrate concentrations in Piedmont and Valley and Ridge:

- High input of nitrogen
- Oxic groundwater (allows nitrate to move without degrading)
  - Lacks organic carbon that would promote denitrification
  - Groundwater residence time is short
- Lacks protective confining layer, and in some cases, even soils are very thin.
- Karst features – sinkholes, conduits, caverns.

Hypothesis for Lindsey and others, 2010: Sinkholes contribute to degraded water quality

Photograph by W.E. Kochanov, Pennsylvania Geological Survey

Issues about sinkhole-density data

Photograph by W.E. Kochanov, Pennsylvania Geological Survey

- Not every feature was identified
- Not every feature that was located has the same potential effect on water quality
- Data were collected for different reasons, by different agencies, in different states
- But on a broad scale, it seems be a good explanatory variable for water quality

Sinkhole density and water quality

- Sinkhole data sets for 4 states (Missouri, Pennsylvania, Florida, Tennessee/Alabama) used to classify sinkhole density as high, medium, and low

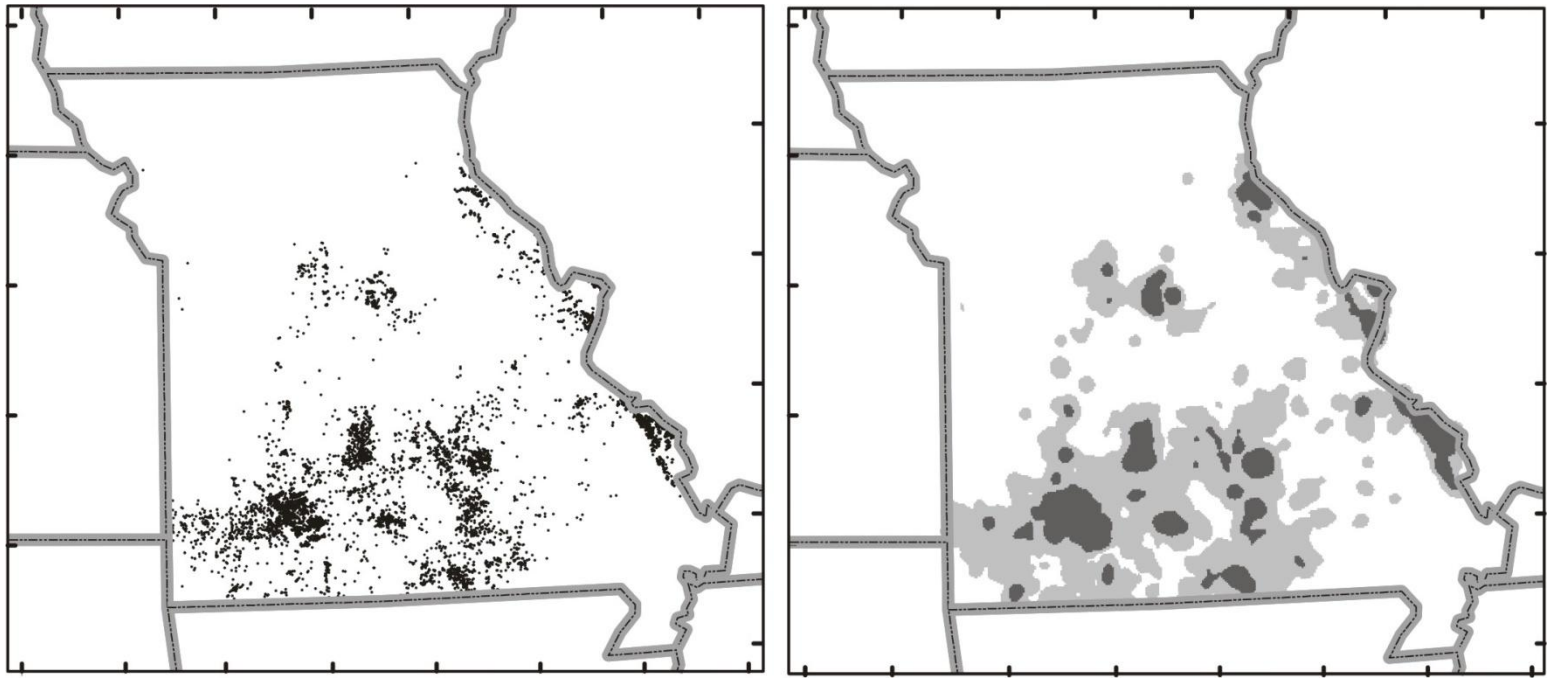


Figure 1 from Lindsey and others, 2010

Sinkhole density and water quality

- High sinkhole density was related to higher nitrate concentrations

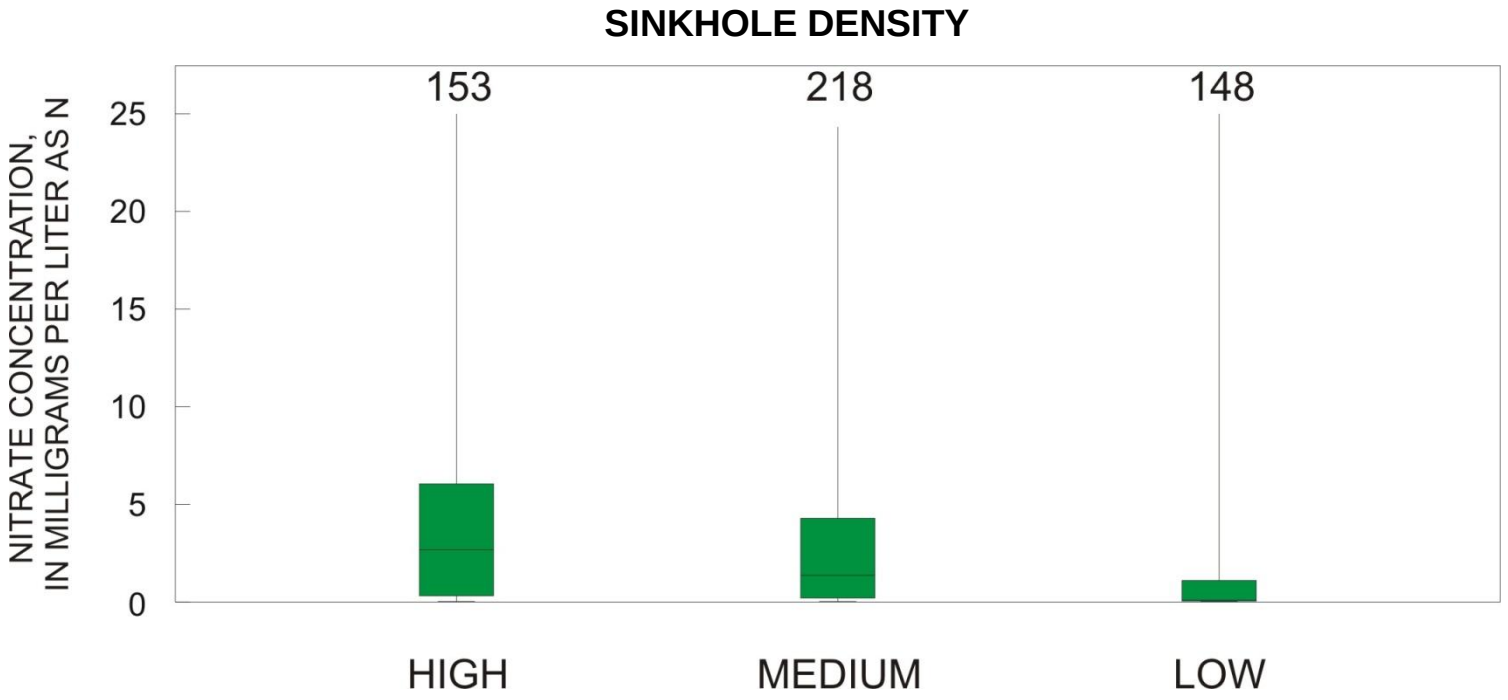


Figure 3 from Lindsey and others, 2010

Sinkhole density and water quality

- Sinkhole density was not a significant explanatory variable for nitrate concentrations in the Valley and Ridge

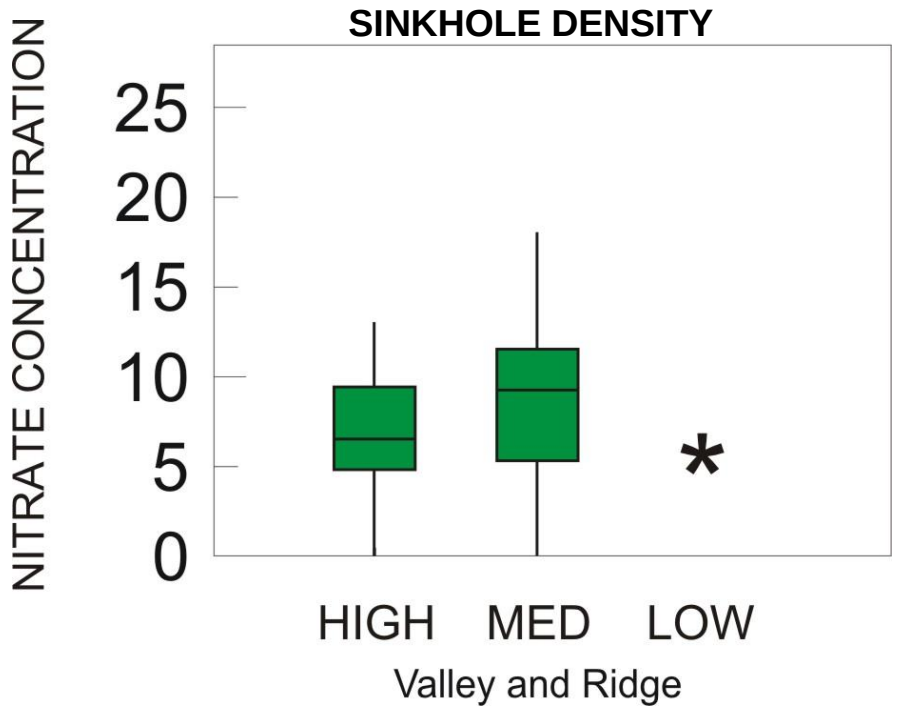


Figure 5 from Lindsey and others, 2010

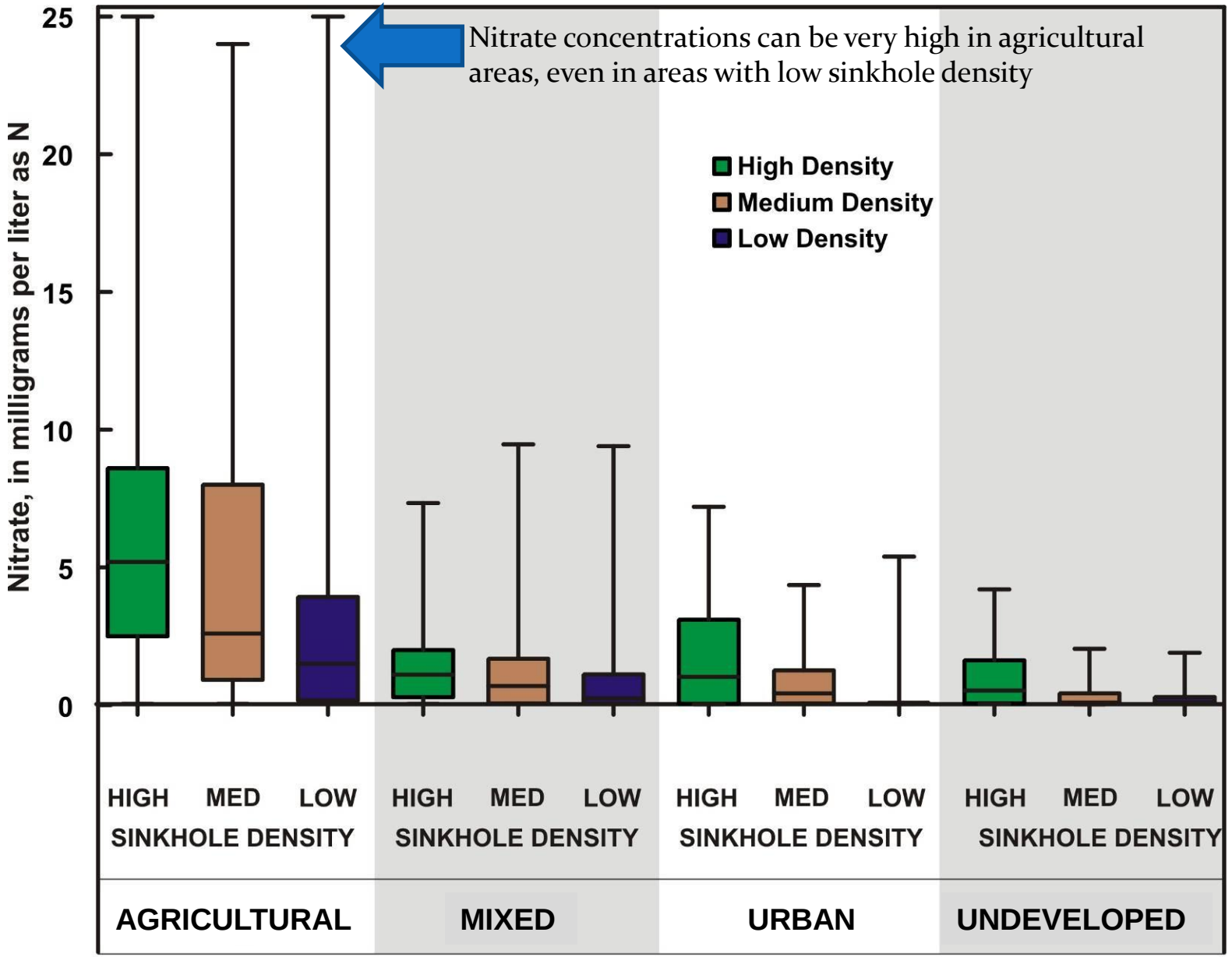


Figure 4 from
Lindsey and others, 2010

In the Valley and Ridge, pesticide detection frequency was related to sinkhole density for some pesticides.

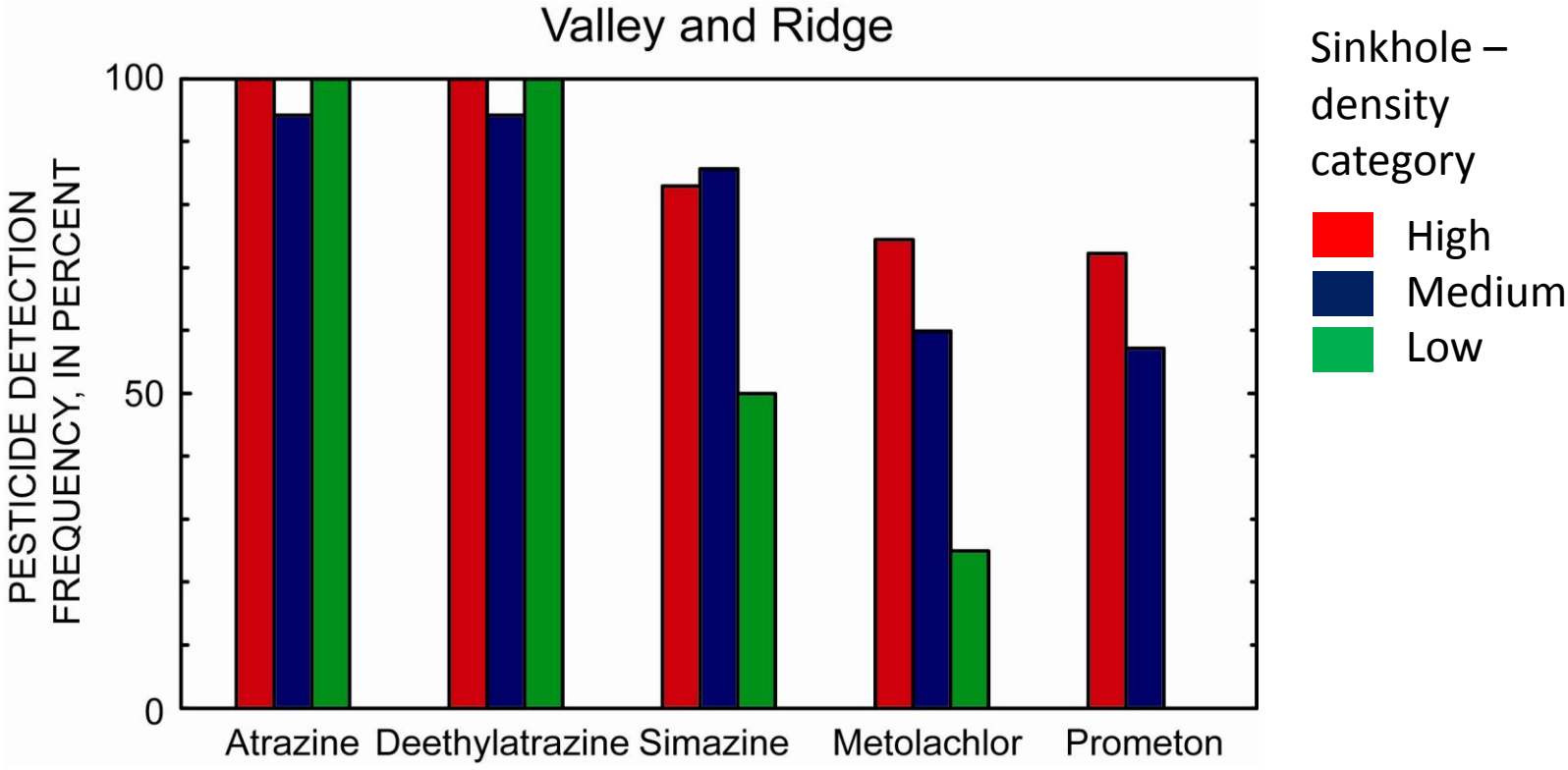
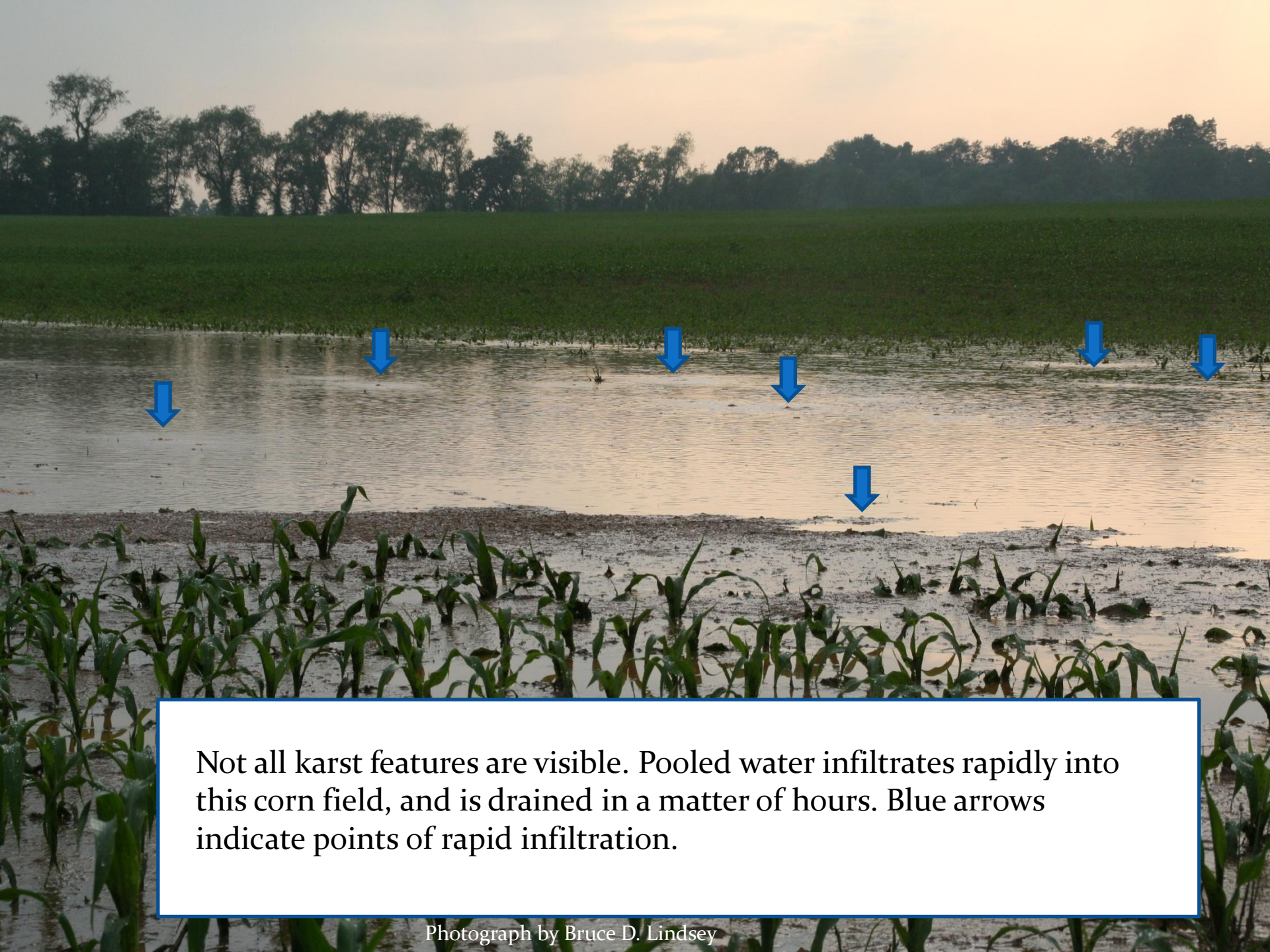


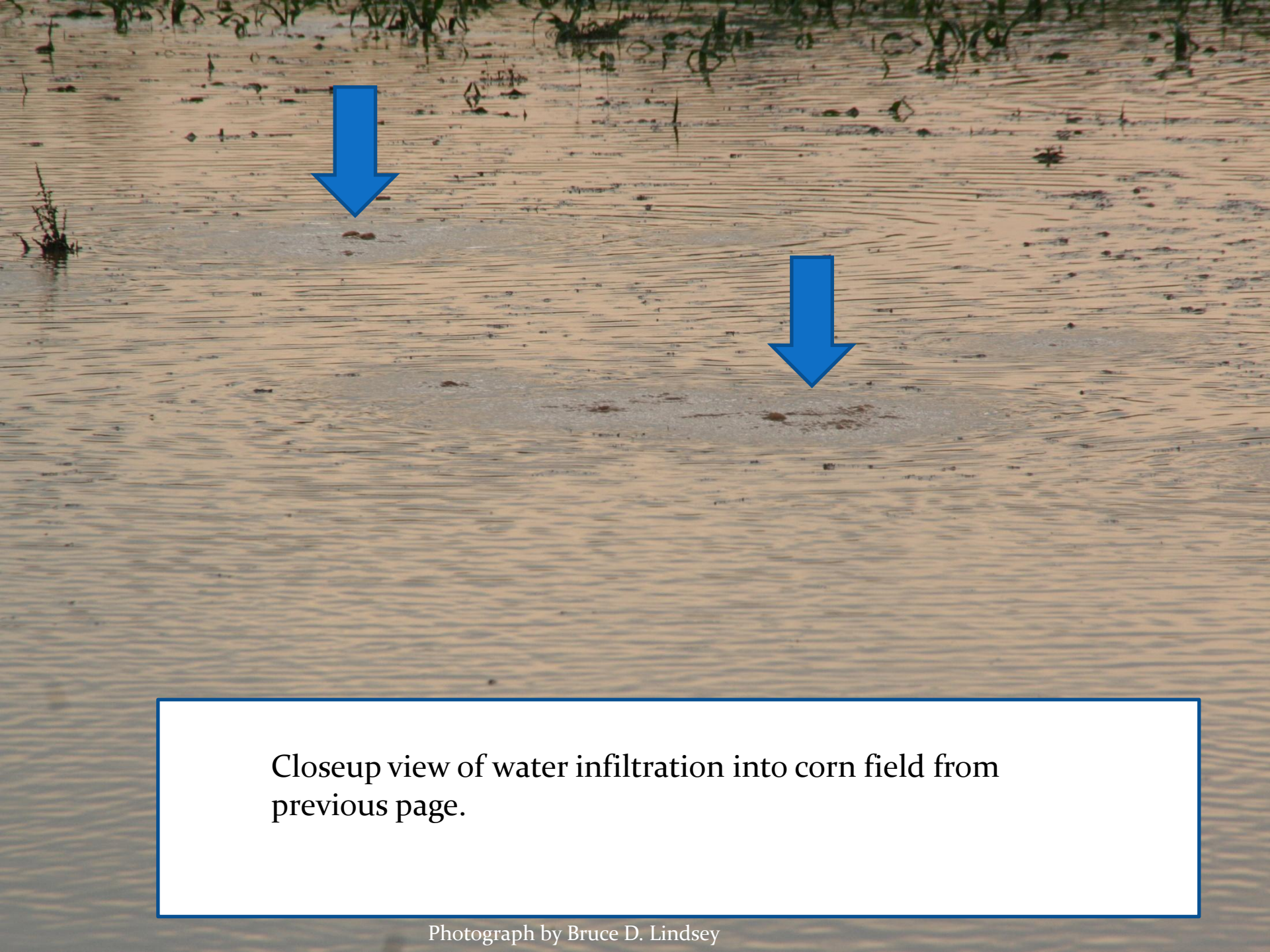
Figure 8 from
Lindsey and others, 2010

Bedrock outcrops are an example of other karst features that may affect water quality.



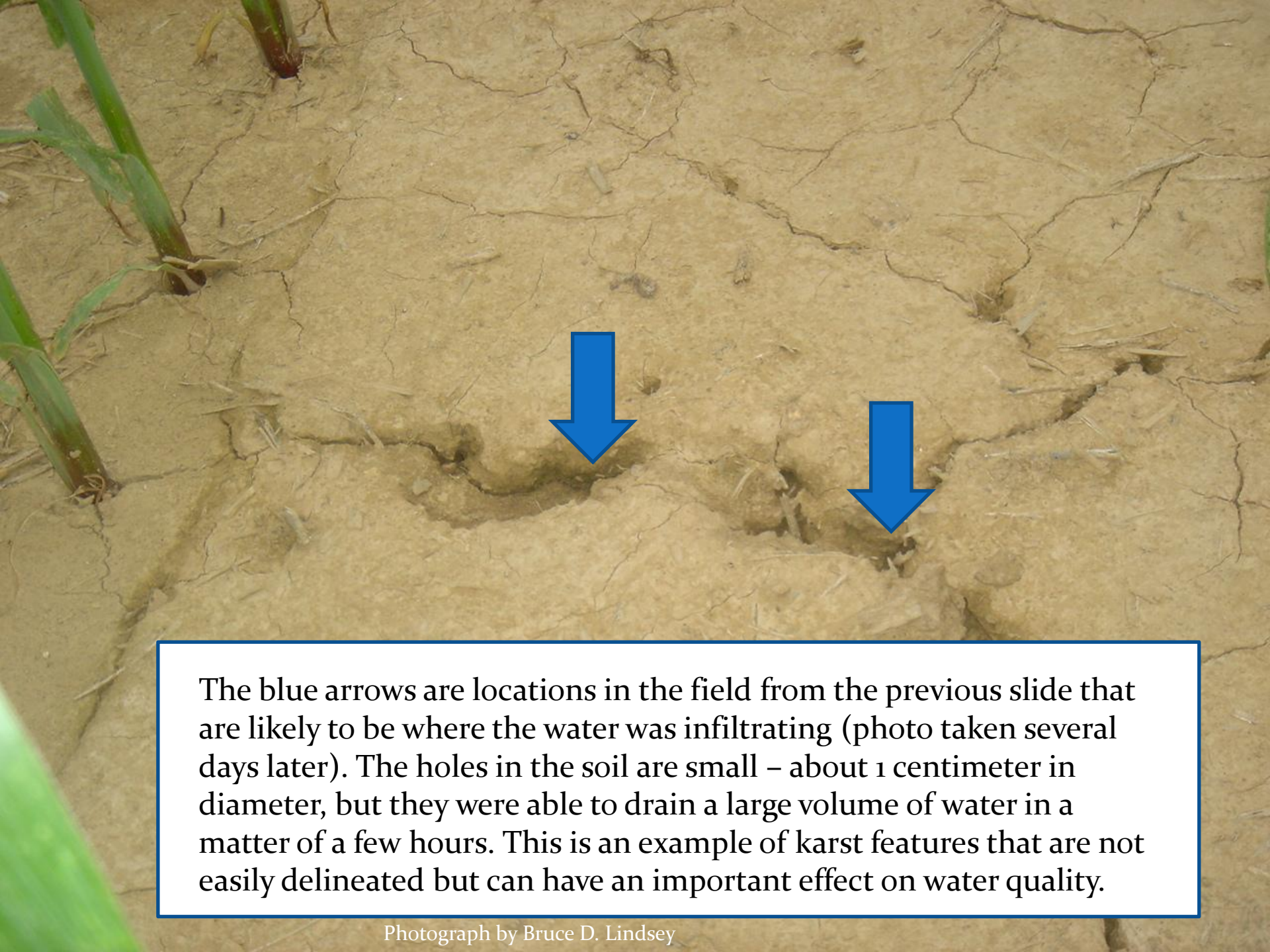
Not all karst features are visible. Pooled water infiltrates rapidly into this corn field, and is drained in a matter of hours. Blue arrows indicate points of rapid infiltration.

Photograph by Bruce D. Lindsey



Closeup view of water infiltration into corn field from previous page.

Photograph by Bruce D. Lindsey

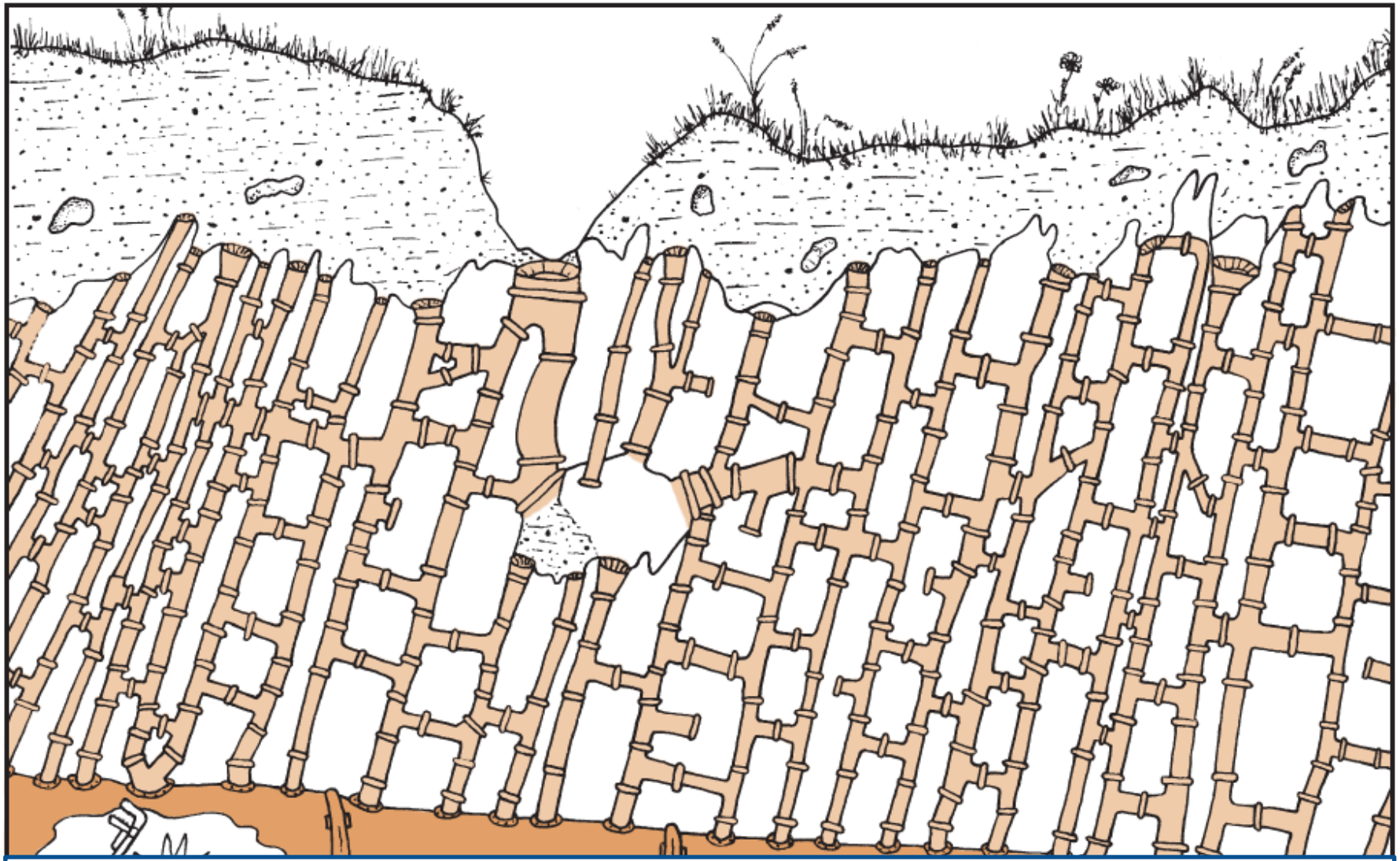


The blue arrows are locations in the field from the previous slide that are likely to be where the water was infiltrating (photo taken several days later). The holes in the soil are small – about 1 centimeter in diameter, but they were able to drain a large volume of water in a matter of a few hours. This is an example of karst features that are not easily delineated but can have an important effect on water quality.

Photograph by Bruce D. Lindsey

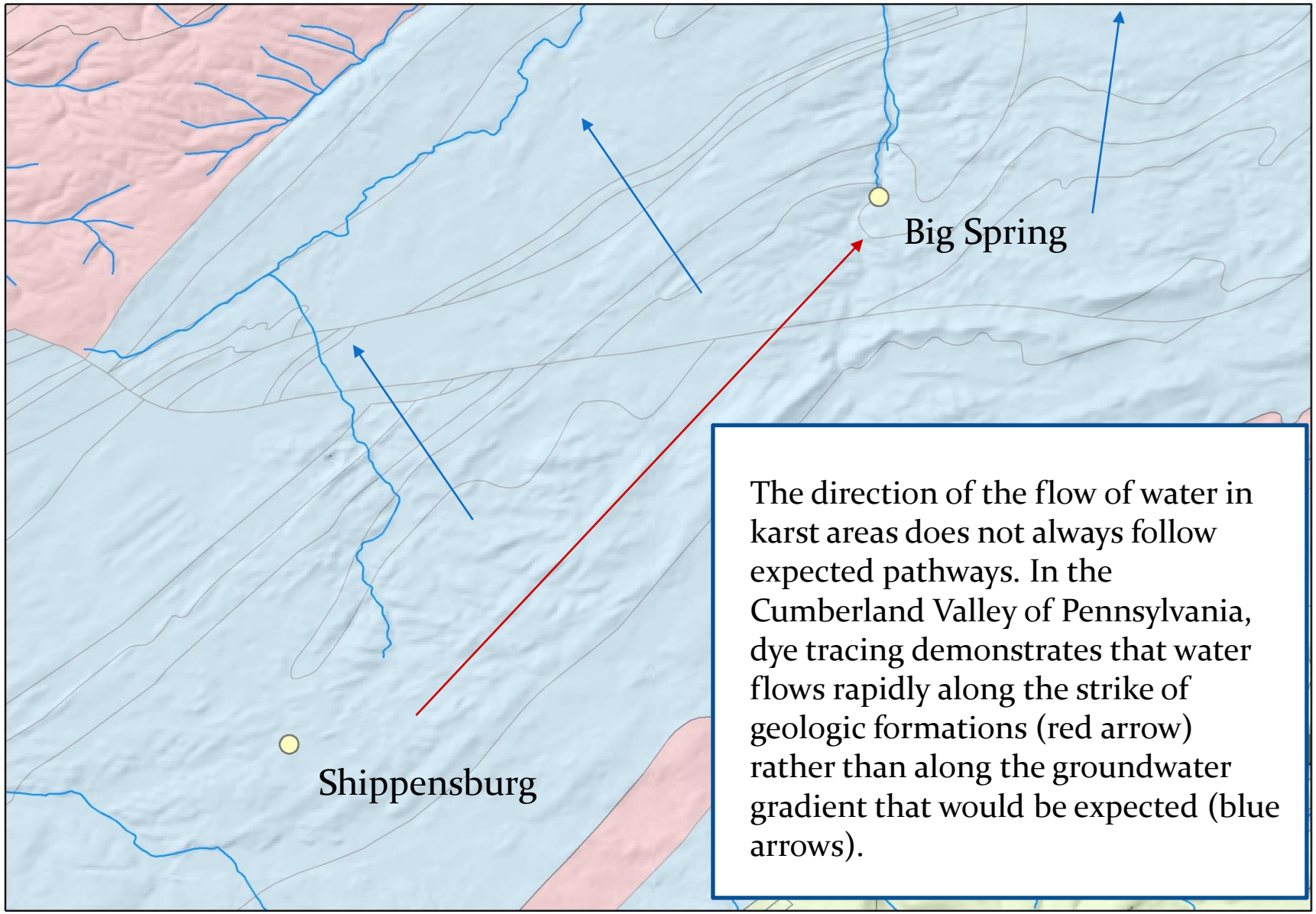
This is the same field, 6 days later. Note that the water pools in the center of a large, low depression. Because the water drains rapidly, the soils are not waterlogged, and the crop recovers quickly.

Photograph by Bruce D. Lindsey

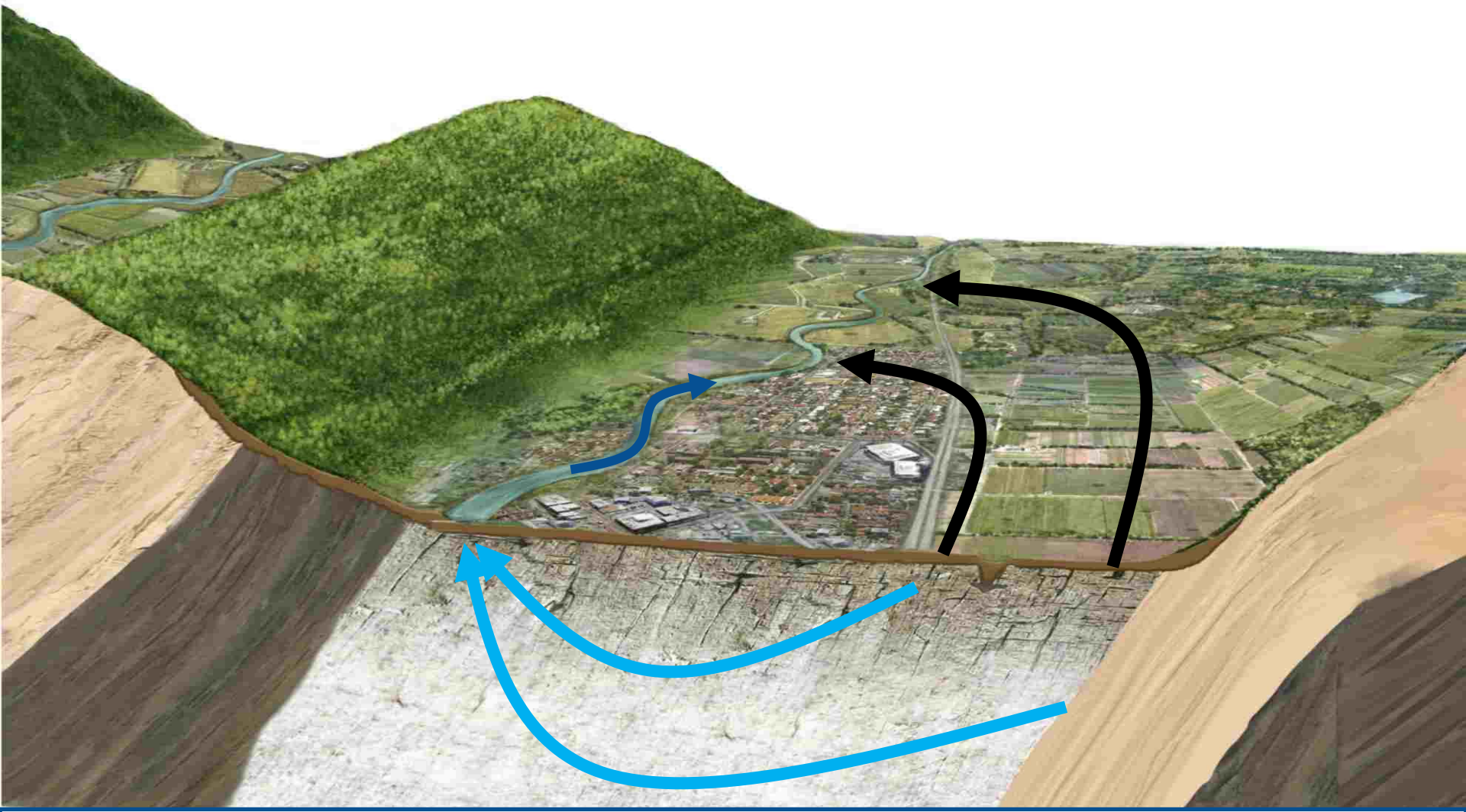


This illustration from an educational report on sinkholes illustrates a hypothetical drainage system developed in karst bedrock. The rapid infiltration illustrated on the previous slides is highly unlikely unless a subsurface drainage network like this is present to convey the water away once it infiltrates.

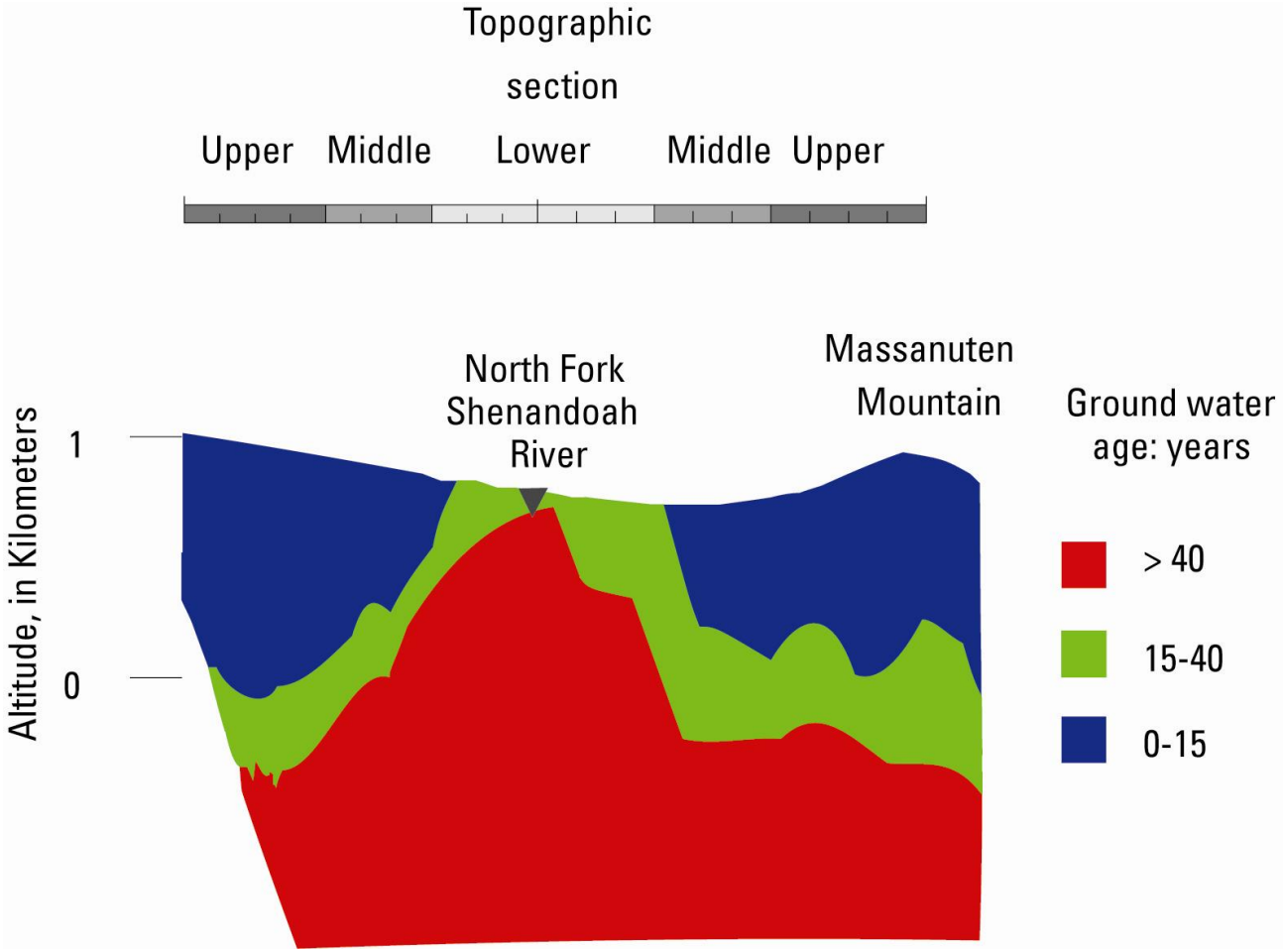
Figure 7 from Kochanov, 1999



Dye trace data from Hurd and others, in press



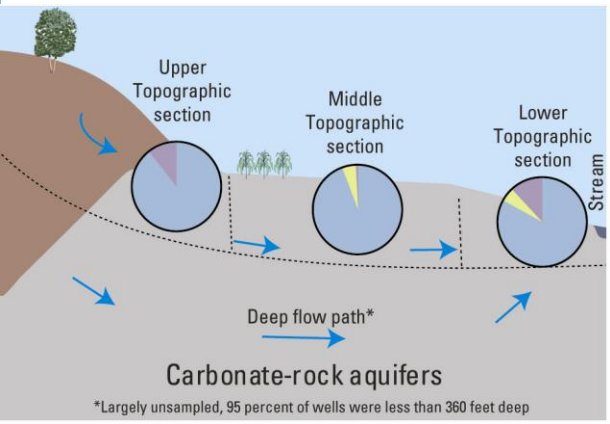
When analyzing water quality by topographic position, we are aware that water does not necessarily flow across the valley in a traditional way (light blue arrows) but has a strong component of flow down the valley (black arrows), as illustrated in the previous slide. Nonetheless, the water that is closer to the ridge is likely to have a relatively shorter residence time, and the water closer to the discharge area has a relatively longer residence time.

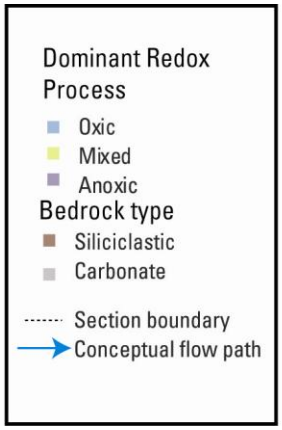


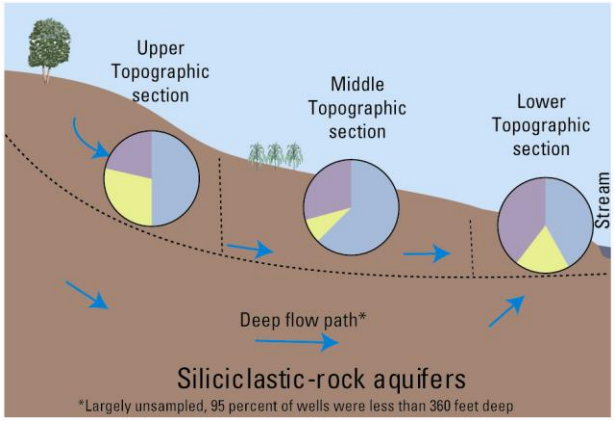
This cross section from a modeling report illustrates the concept that groundwater age is younger near the ridges and older near the discharge points. This is the conceptual model that is used for the analysis of water quality by topographic position.

Modified from Figure 13 Yager and others, 2009

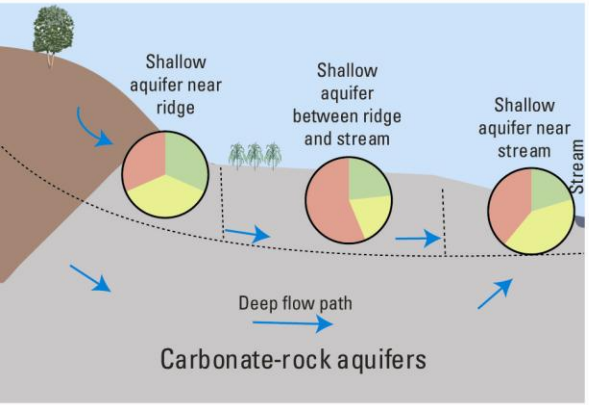
Valley and Ridge: Bedrock, redox processes, land use, and landscape position

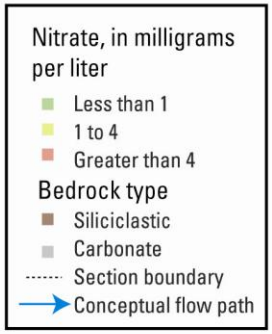


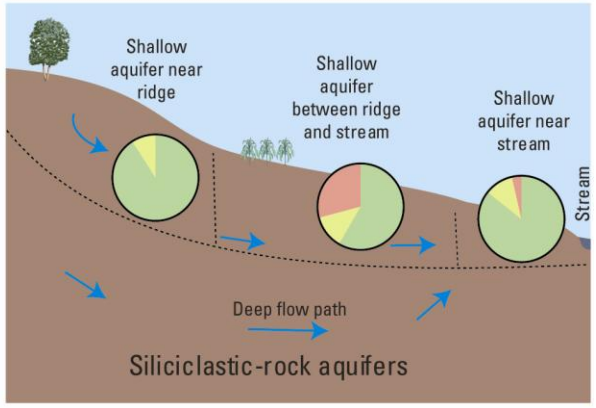




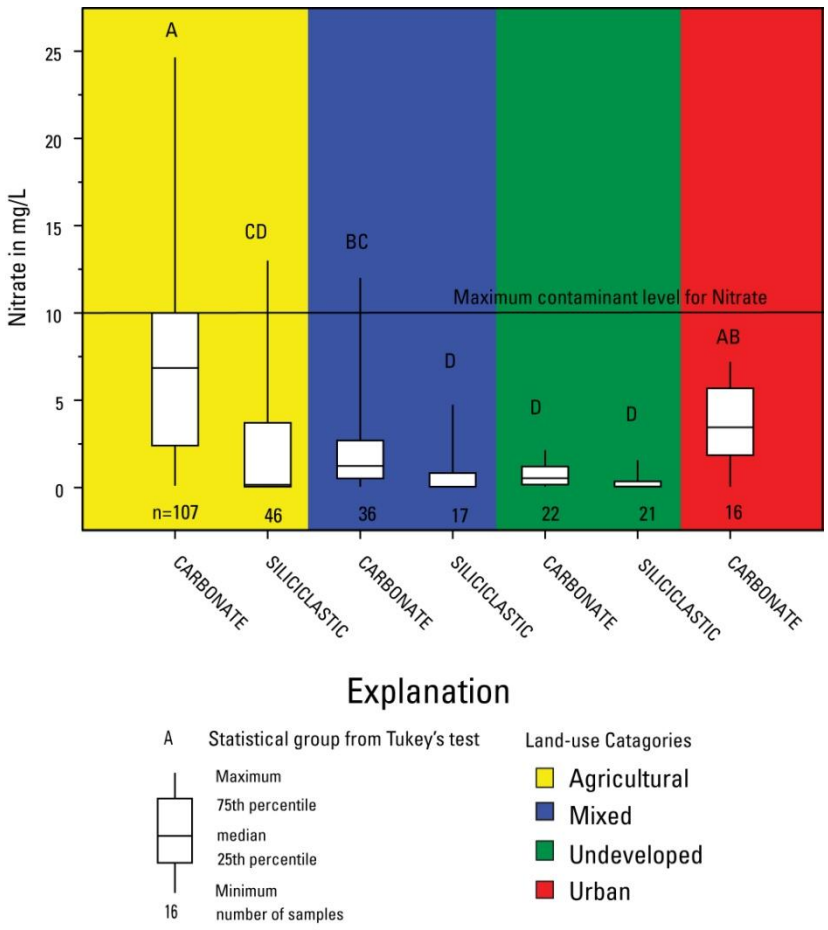
Topographic position had an effect on water chemistry as illustrated by the percentage of wells with anoxic conditions. The pattern was strong in the siliciclastic bedrock aquifers. Water closer to the discharge region may be anoxic because of age or upward migration of older water.



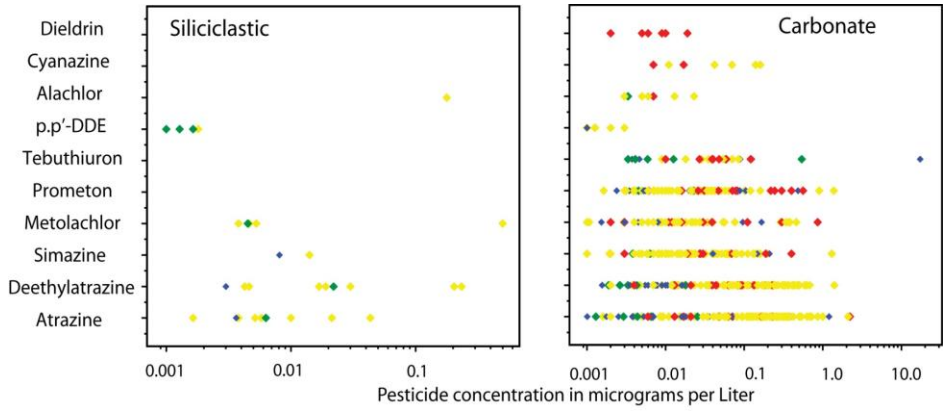




Topographic position also affected nitrate concentration. Wells closer to the ridge had fewer samples with elevated nitrate due to a lack of source, but wells closer to the stream had few samples with elevated nitrate due to groundwater age and (or) degradation of nitrate.



Nitrate concentrations were higher in carbonate-rock aquifers when compared to siliciclastic-rock aquifers, even when land use is taken into account. Agricultural and urban settings had higher nitrate concentrations as well.

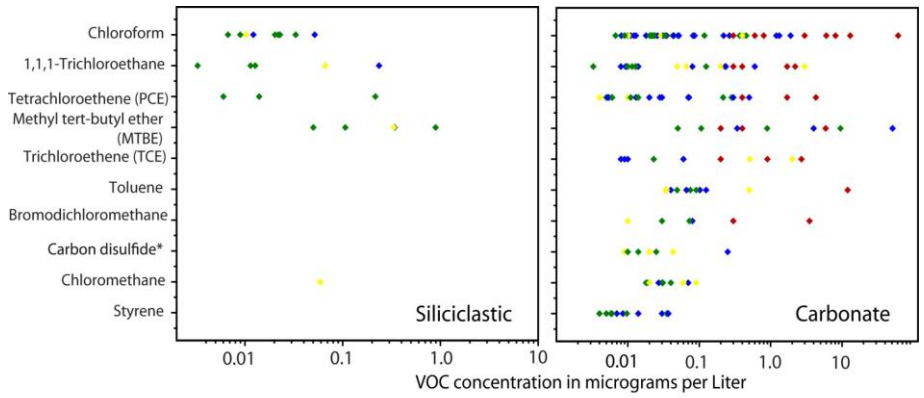


PESTICIDES

EXPLANANTION

Land Use
- Agricultural
- Mixed
- Undeveloped
- Urban

Pesticides were detected more frequently and at higher concentrations in wells from carbonate-rock aquifers when compared to siliciclastic-rock aquifers. Wells from agricultural and urban settings had higher pesticide concentrations than wells in areas with mixed or undeveloped land use.

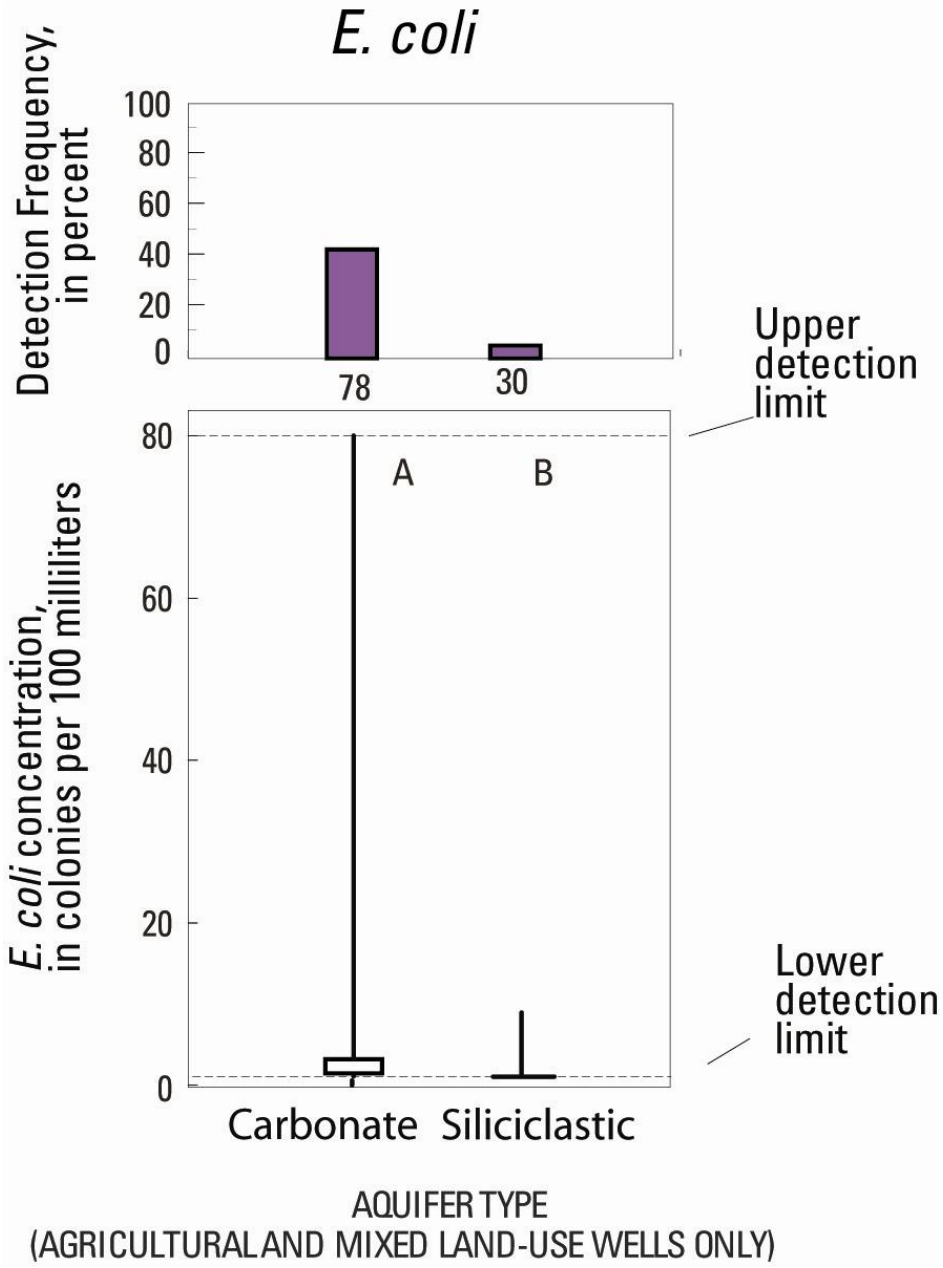


VOLATILE ORGANIC COMOUNDS

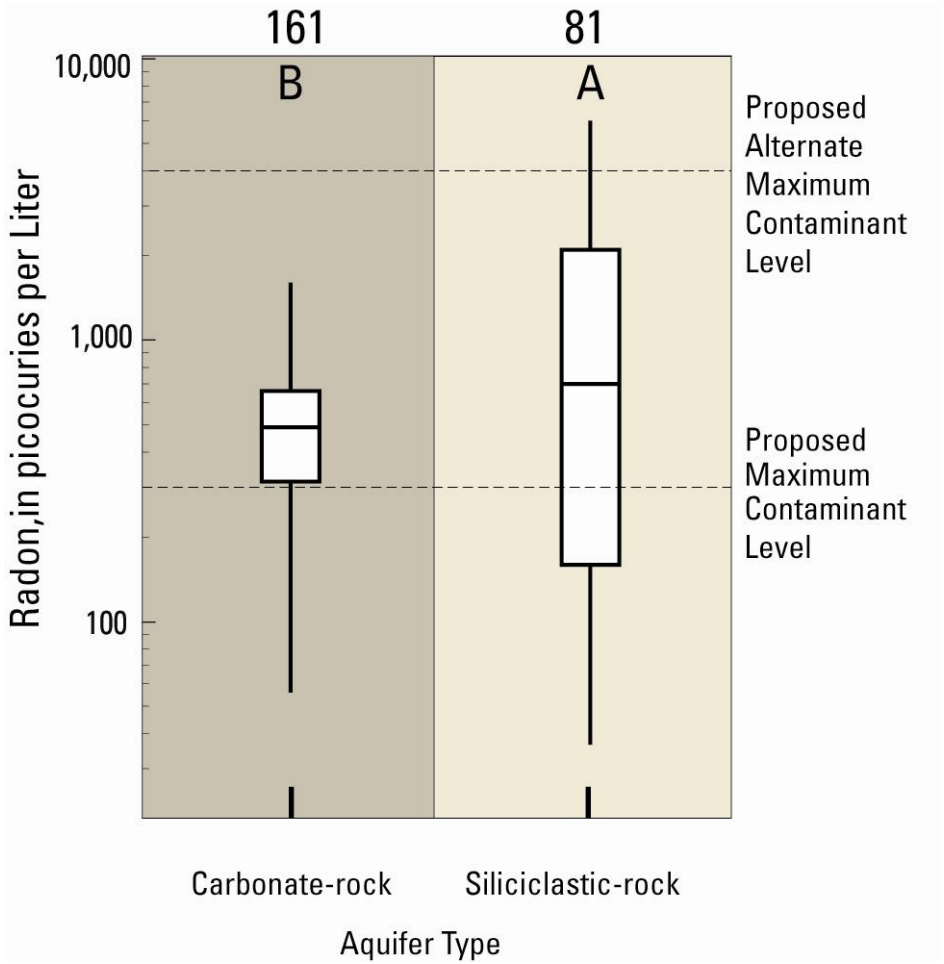
EXPLANANTION

Land Use
- Agricultural
- Mixed
- Undeveloped
- Urban

Volatile organic compounds were detected more frequently and at higher concentrations in wells from carbonate-rock aquifers when compared to siliciclastic-rock aquifers. Wells from urban or mixed land-use settings had higher concentrations than wells in areas with agricultural or undeveloped land use.



E. coli bacteria were detected more frequently and at higher concentrations in wells from carbonate-rock aquifers when compared to siliciclastic-rock aquifers.



Concentrations of radon were higher in wells from siliciclastic-rock aquifers when compared to carbonate-rock aquifers.

Good news about water quality in carbonate-rock aquifers

- Concentrations of natural contaminants such as radon and arsenic were typically lower in carbonate-rock aquifers due to lack of source or geochemical conditions not conducive to transport.
- Nuisance contaminants such as iron and manganese had lower concentrations or were non-existent due to redox conditions.
- pH in carbonate-rock aquifers was typically stable due to high alkalinity. However, calcium hardness is a trade-off for having water that is not corrosive.
- Phosphorus transport through groundwater in carbonate aquifers was highly unlikely (Denver and others, 2010).

References Cited

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Note: Please check the web site for Regional Assessment of Groundwater Quality in the Piedmont and Valley and Ridge Aquifers at: http://water.usgs.gov/nawqa/studies/praq/piedvr/index.html or contact blindsey@usgs.gov for additional information.