A Systems Approach for the Understanding of Agricultural Contaminant Source and Transport within a Karst Groundwater Basin

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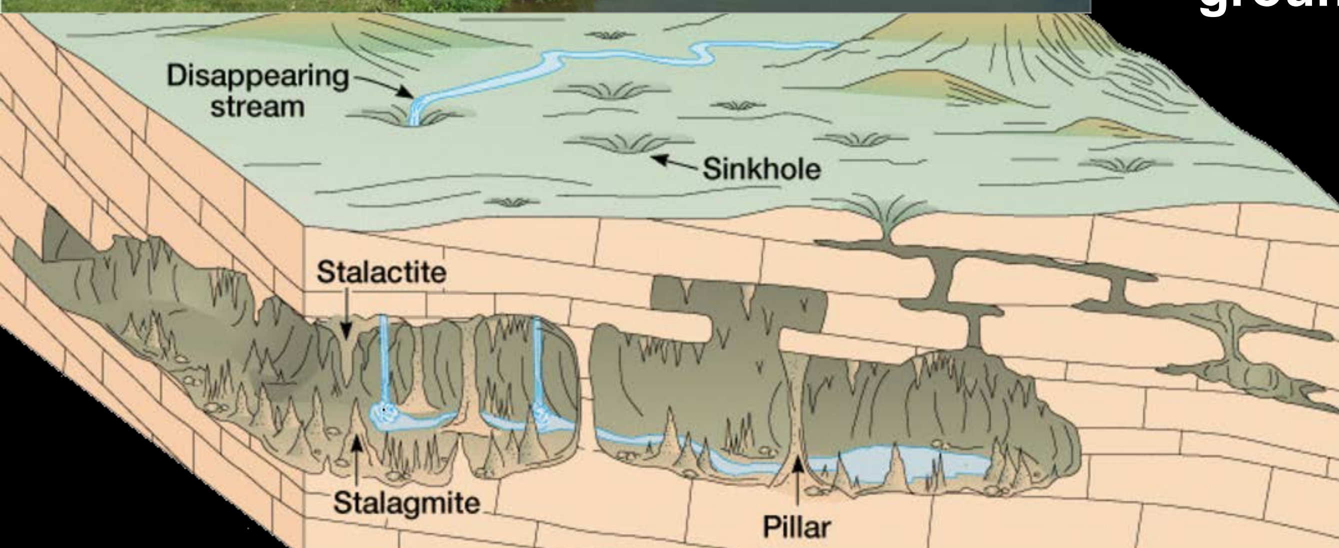
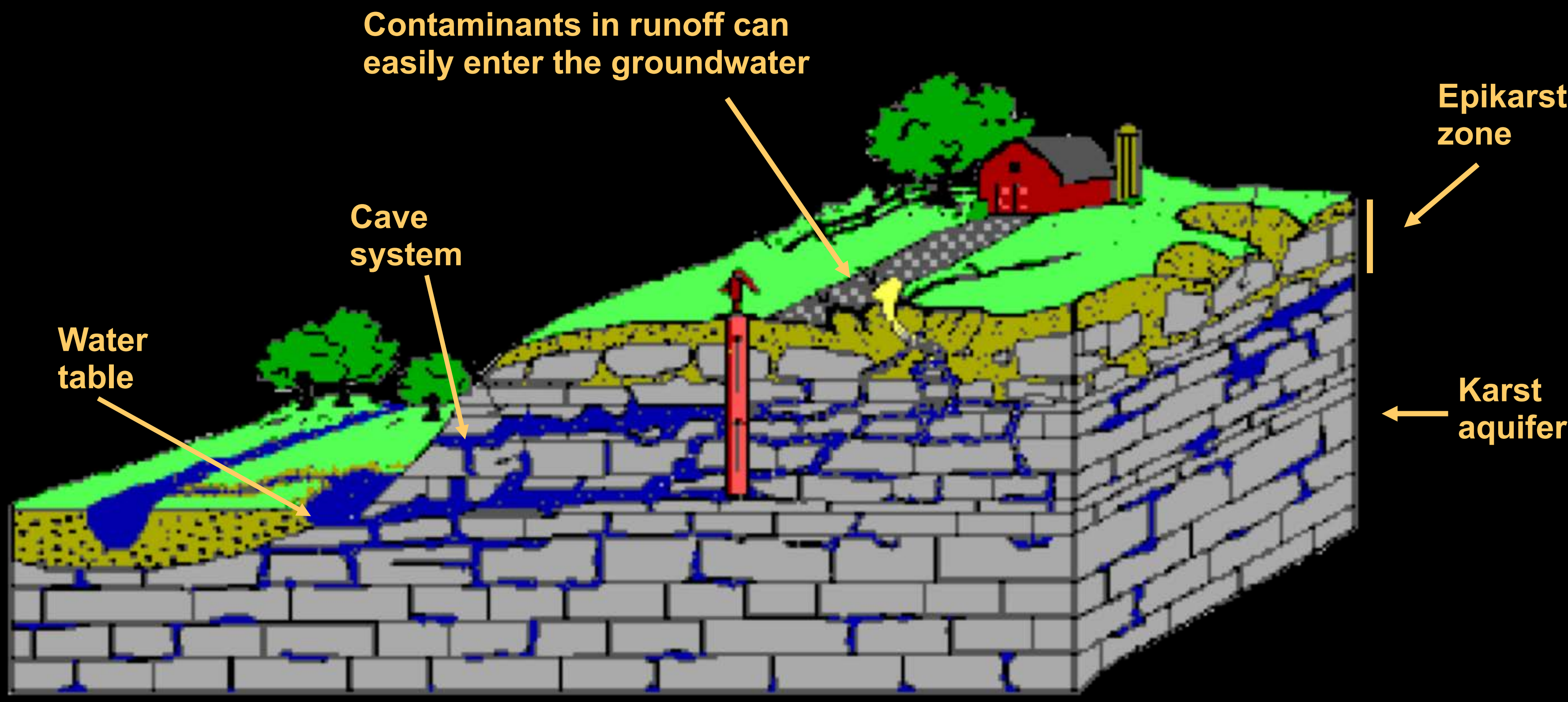


In agricultural areas underlain by karst, nitrates from livestock waste and fertilizer use, bacteria from livestock waste and faulty domestic septic systems, and the application of pesticides, cause degradation of shallow groundwater quality

Karst aquifers are more vulnerable to contamination than other types of aquifers because sinking streams, sinkholes, and open fractures in the bedrock allow little or no filtration of incoming surface water and facilitate the movement of contaminants into the groundwater system.



From Hallberg et al, 1984

The objectives of this research were to identify and delineate the linkages between contaminant sources, groundwater quality, land use, and the hydrologic character of a karst groundwater basin and its recharge area. The "Systems" approach involved:

Karst feature inventories

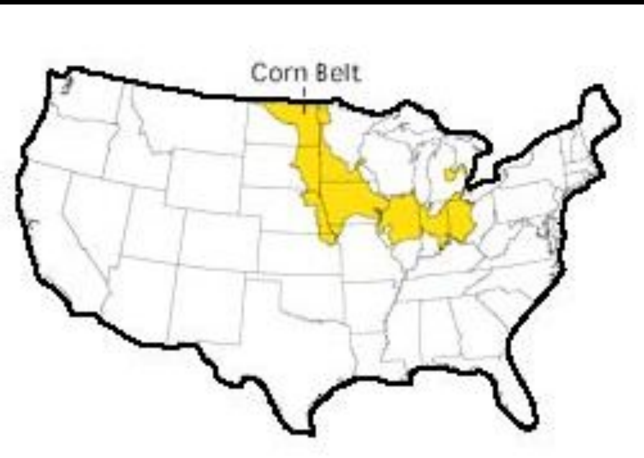
Hydrologic measurements and water chemistry

Series of dye traces

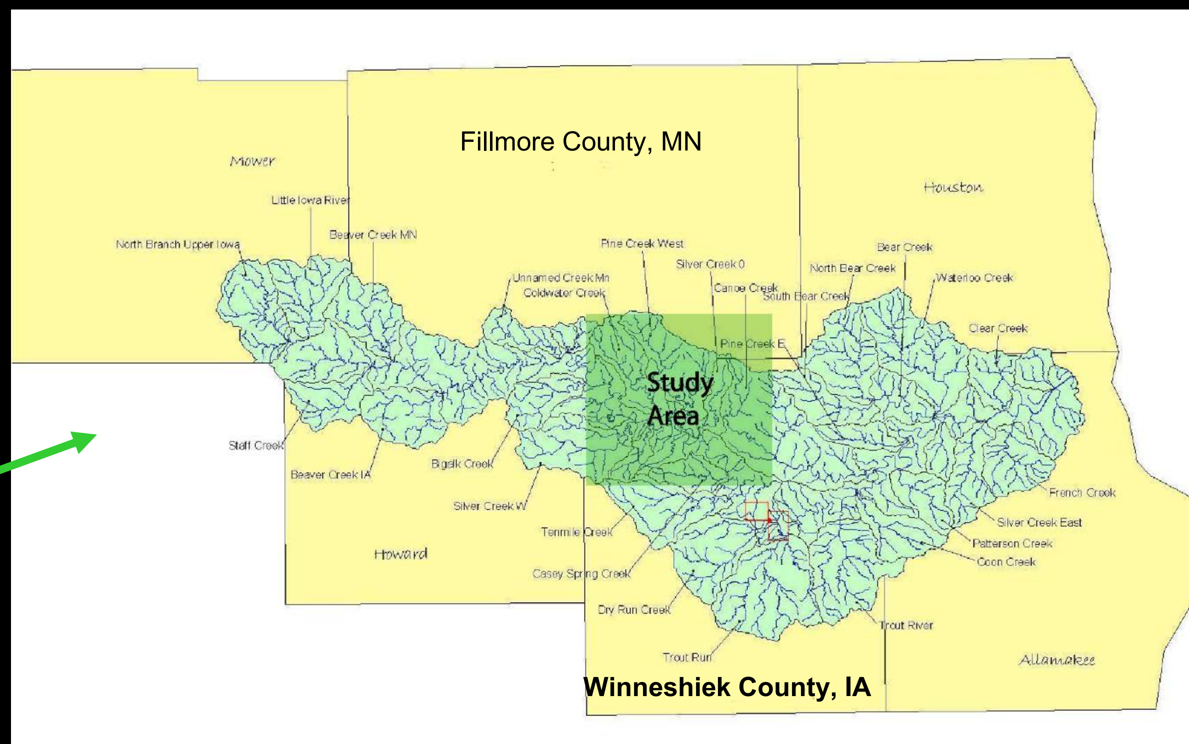
Water quality sampling

Contaminant source identification

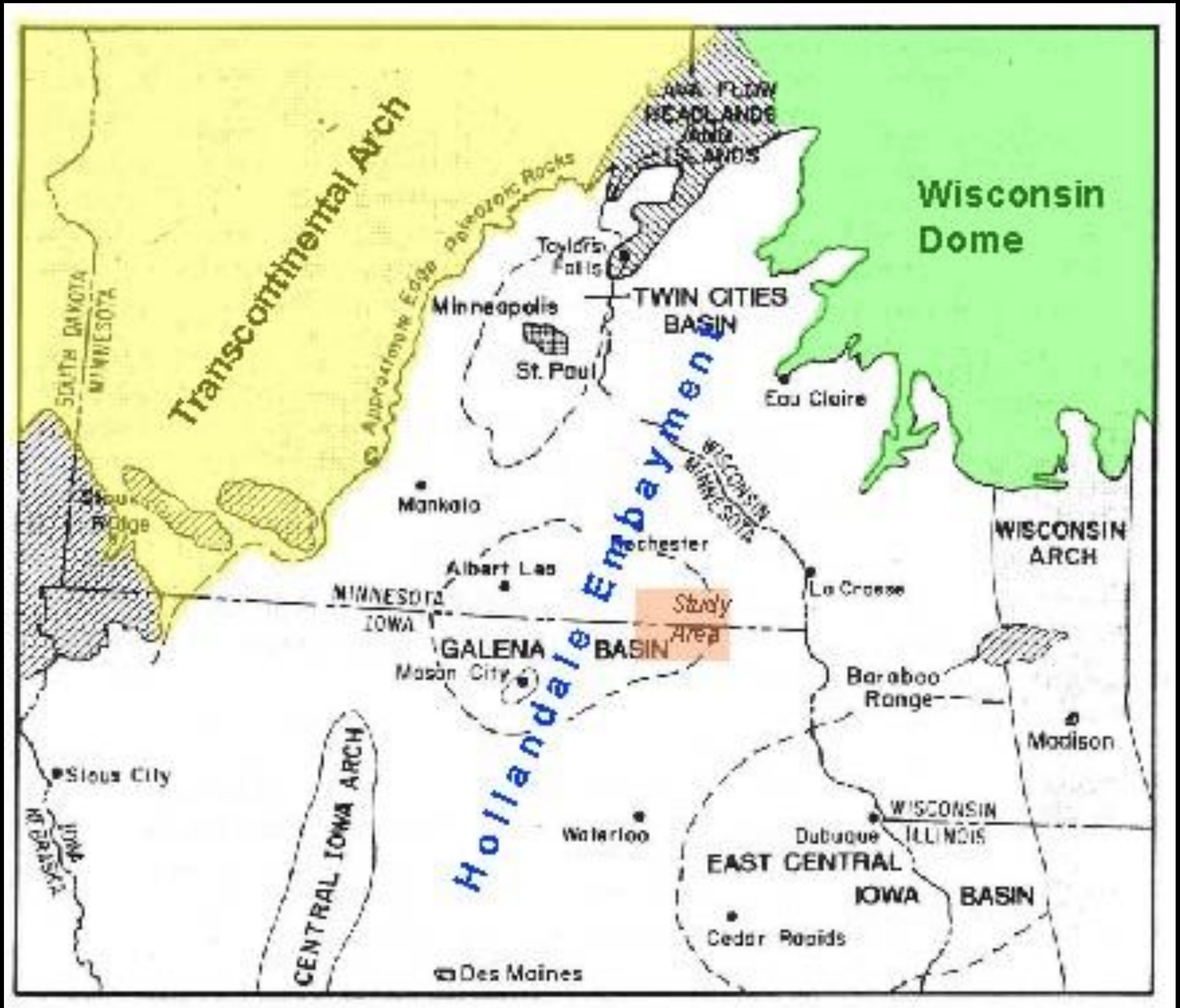
Land use analysis



The study area is within the Upper Iowa River Watershed in the corn belt region of the U.S. The Upper Iowa River flows into the Mississippi River located 60 km to the east.



Paleogeography of northeast Iowa and southeastern Minnesota



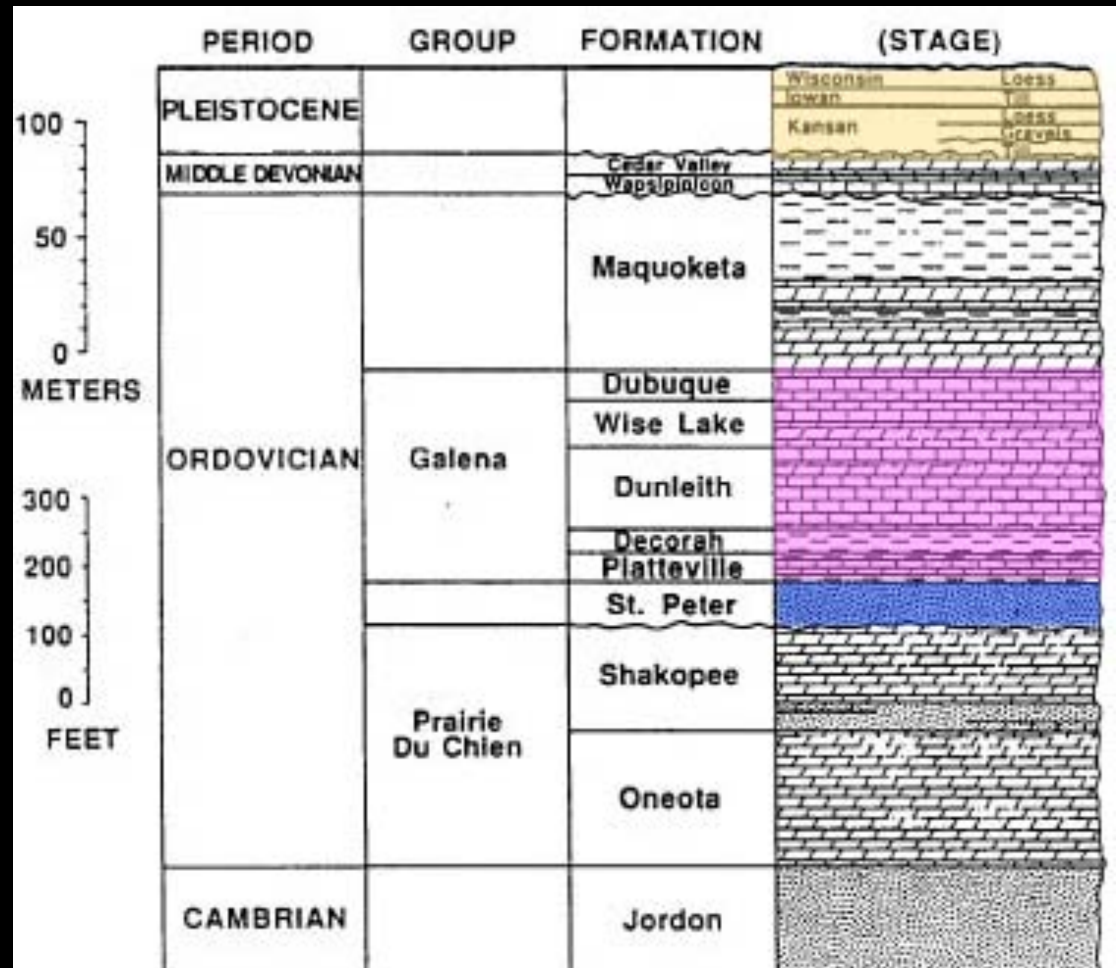
Mossler 1995

Stratigraphy of northeastern Iowa and southeastern Minnesota

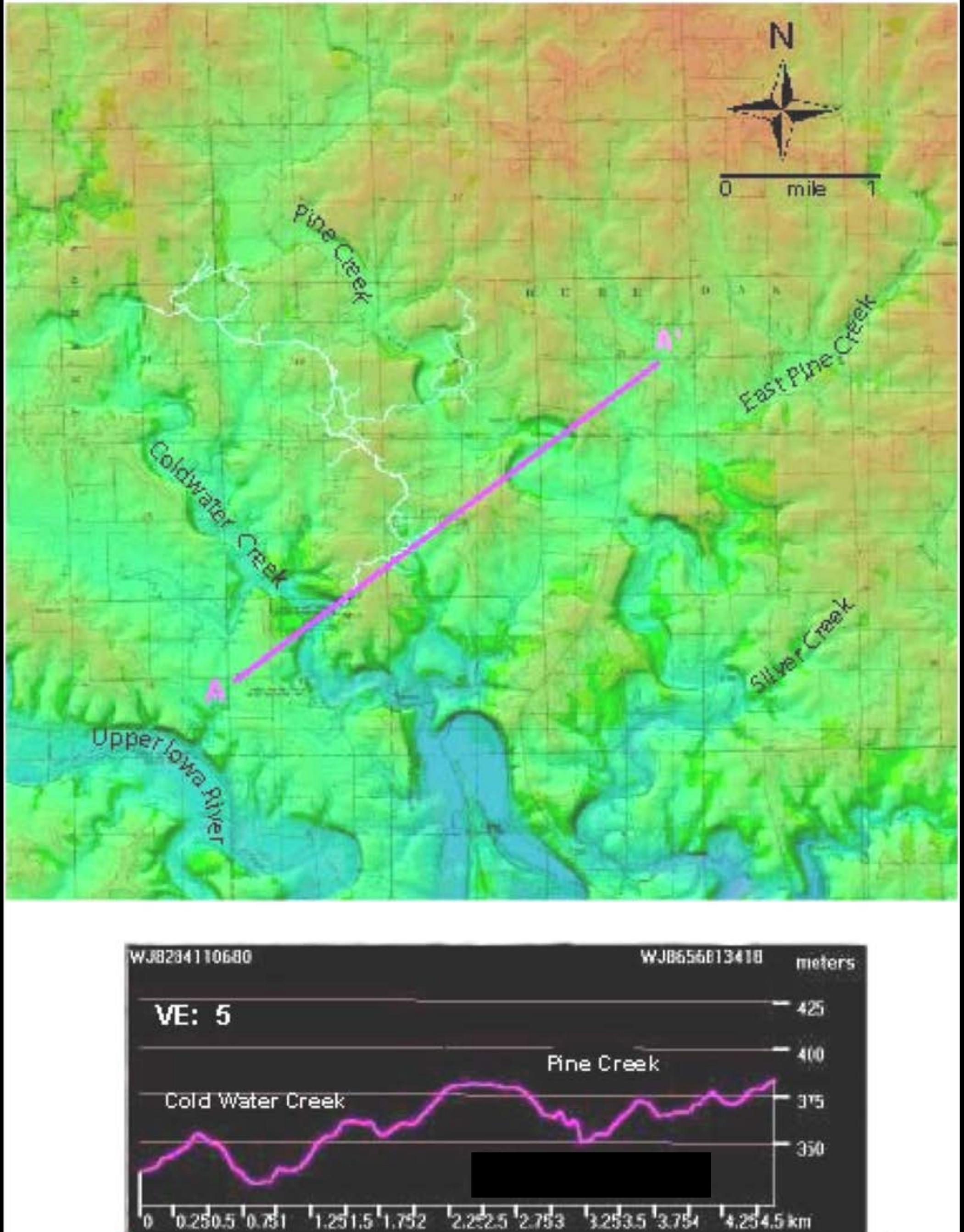
Land surface is mantled by **glacial till and loess**.

Bedrock: The Ordovician-aged Galena Group directly underlies the land surface of the study area and consists of the Dubuque, Wiselake, Dunleith, Decorah Shale and the Platteville. The Galena Group aquifer is used for agricultural water supply.

St. Peter Sandstone serves as the drinking water aquifer in the study area.

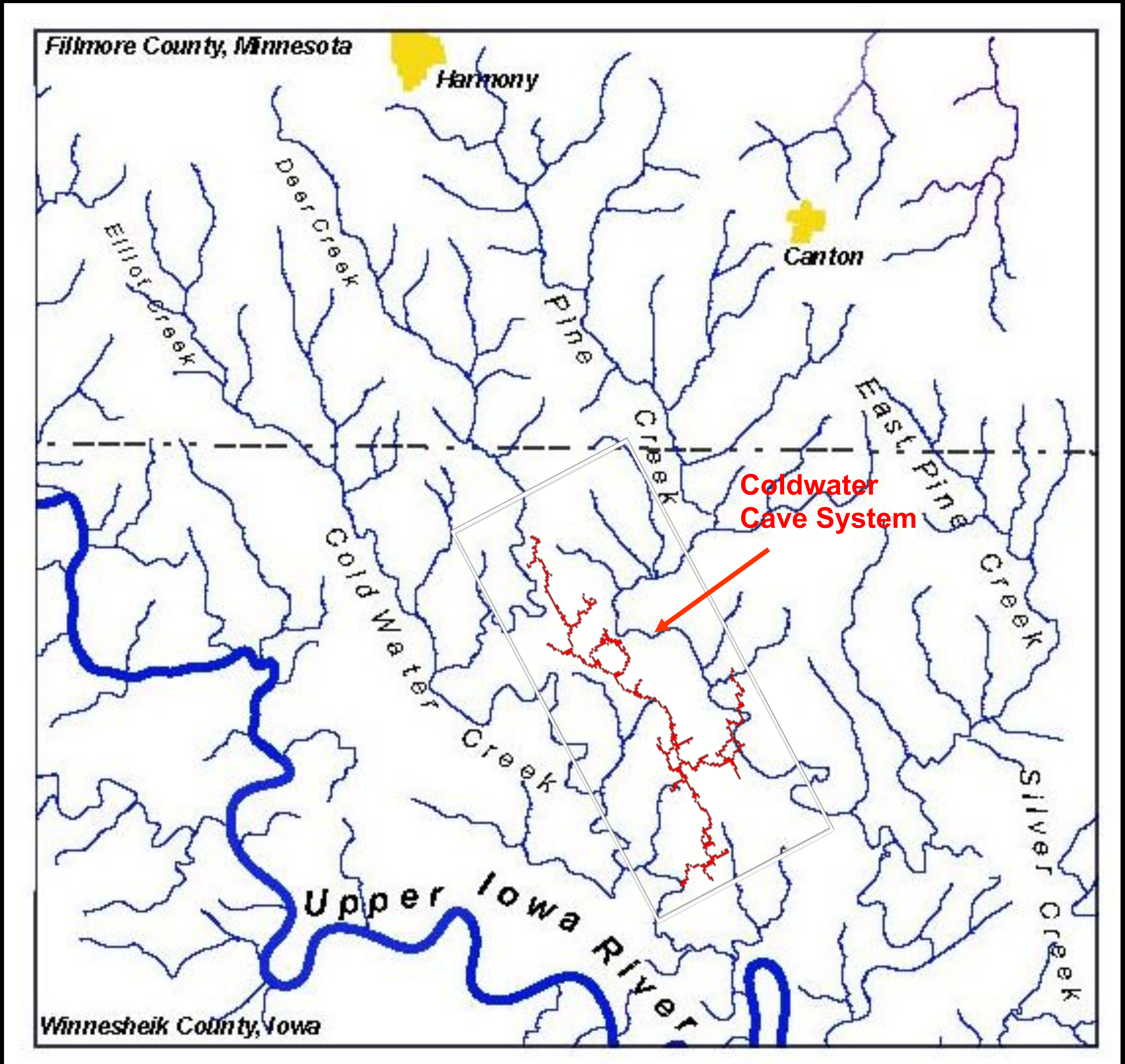


The study area displays a stepped plateau landscape which dips to the southwest at less than 1 degree. Valleys are deeply incised, and flat-lying massively bedded limestones and dolostones form successive caprock layers which reflect the plateau morphology.

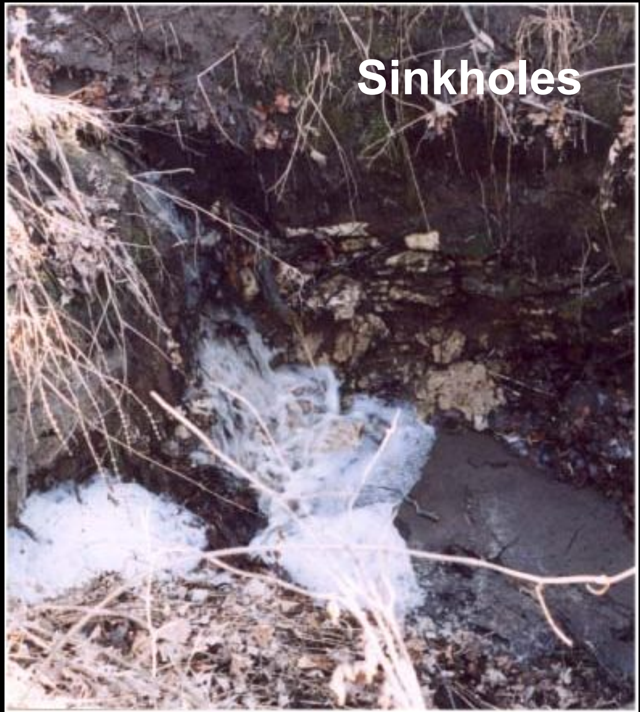


Stepped plateau profile

The area is highly karstified and is drained by surface streams and by a the Coldwater Cave System which is a significant subterranean conduit. All surface springs and streams flow into the Upper Iowa River



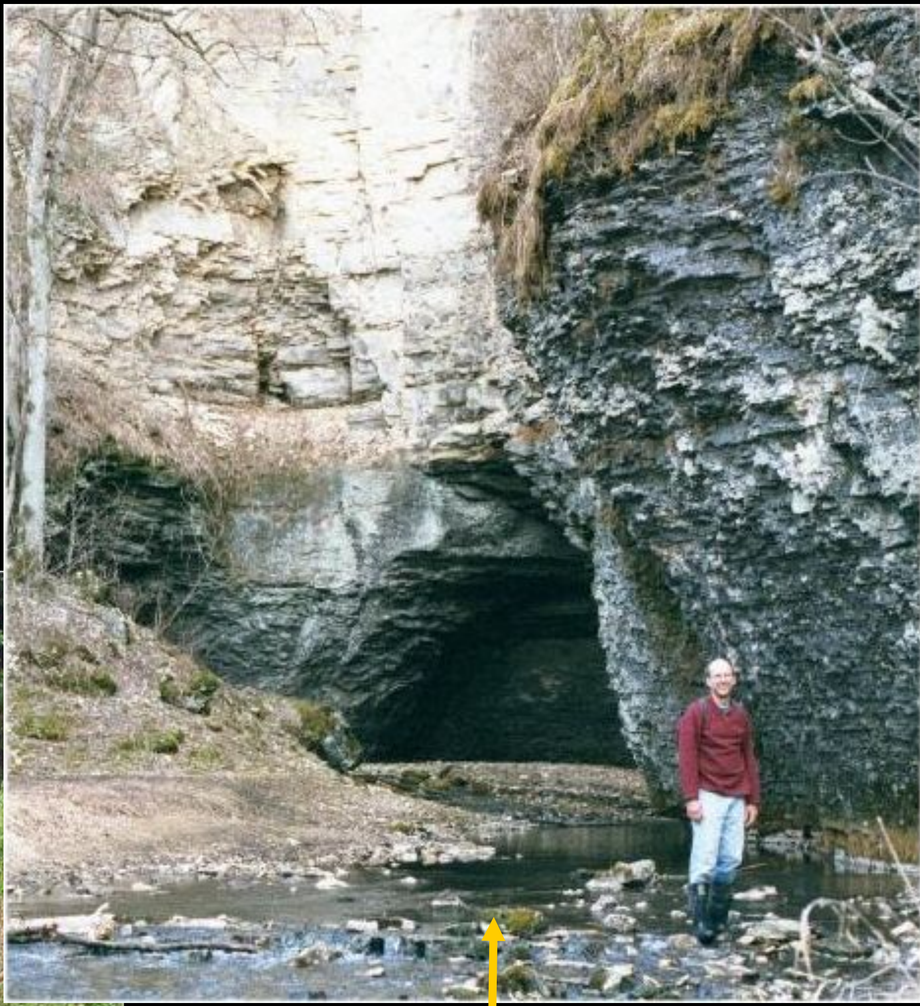
A detailed **karst feature inventory** was done to locate where surface water was entering the groundwater system



Water is also getting underground through many fissures and fractures in the bedrock which will eventually transport it to the karst aquifer

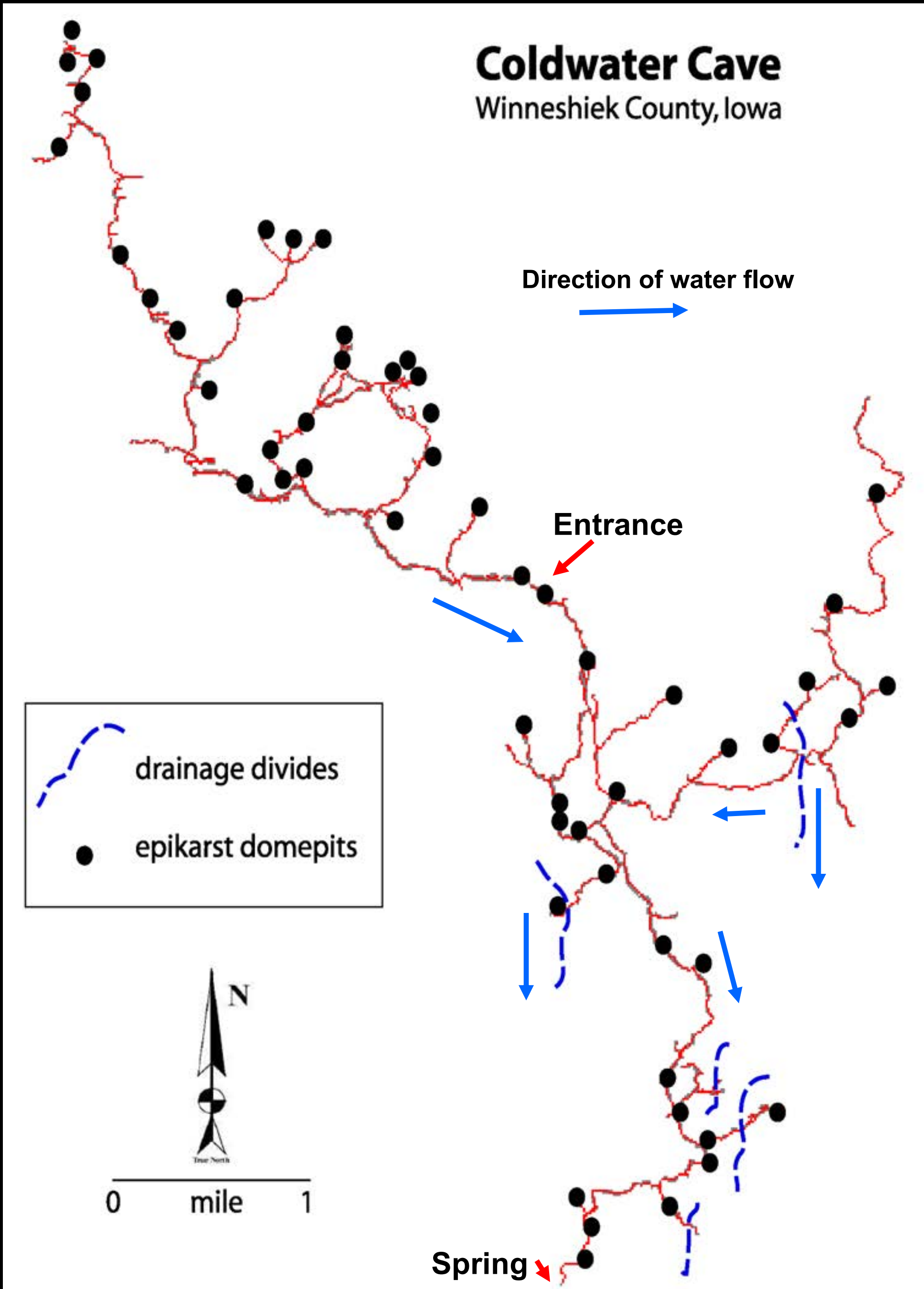
Locate discharge points where groundwater was coming back to the surface.

The study area has 6 karst springs which bring groundwater to the surface at the downstream end of the basin.

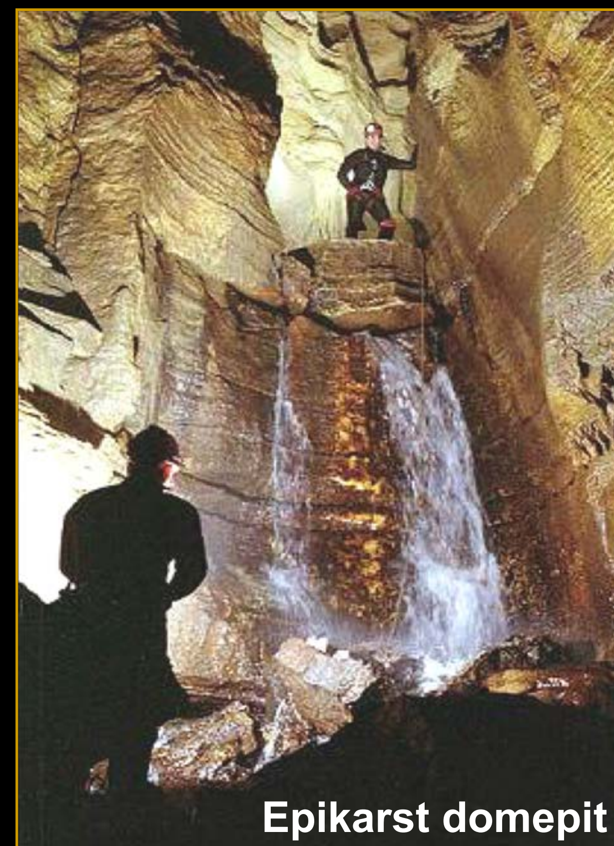


Coldwater Spring discharge: 8700 gpm

Carolan Spring discharge: 2500 gpm

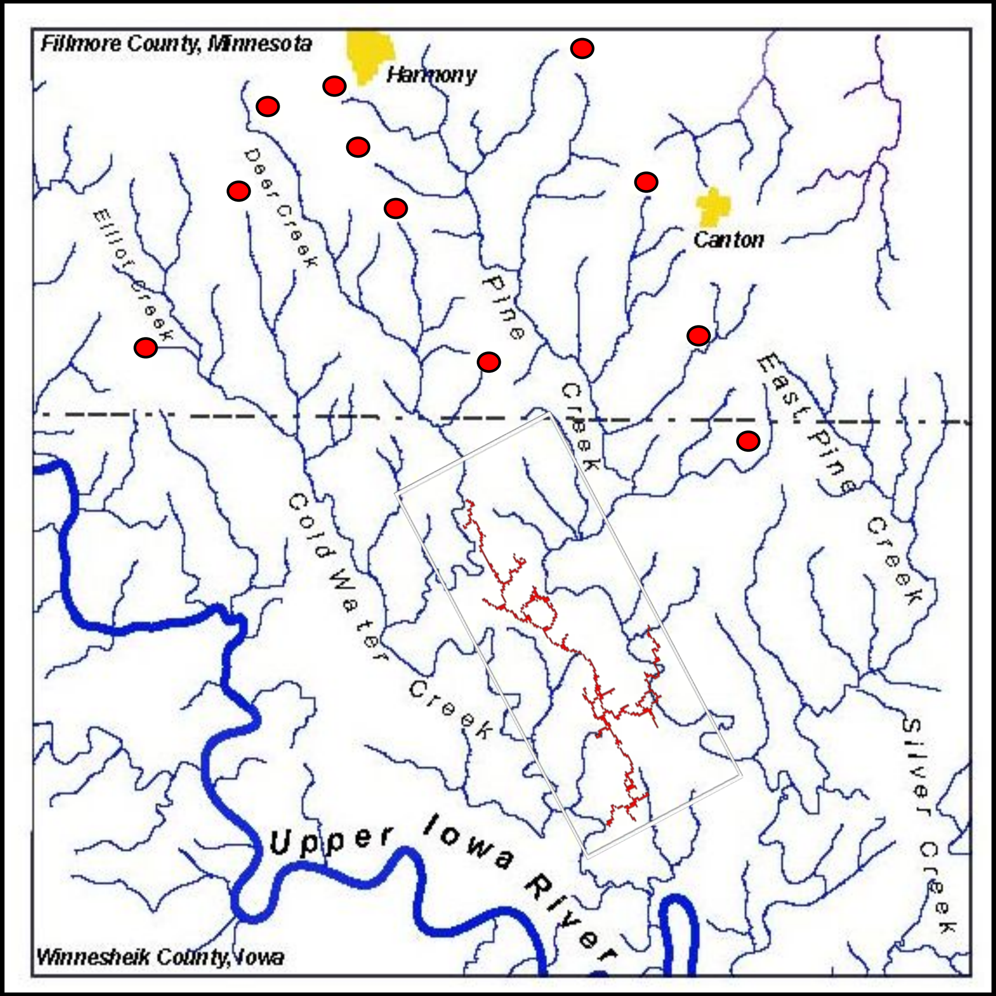


Inventory of cave and karst features was also conducted inside the Coldwater Cave System. Among the features documented where epikarst domepits and underground drainage divides.

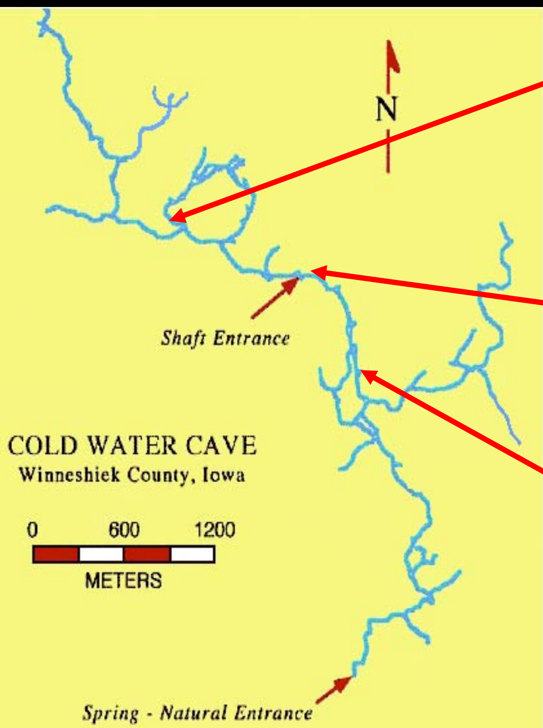


Epikarst domepit

Small springs flow from a local non-karst aquifer which Is perched on the Galena Group Karst aquifer. These springs are the headwaters for all of the surface creeks in the area.



• Non-karst springs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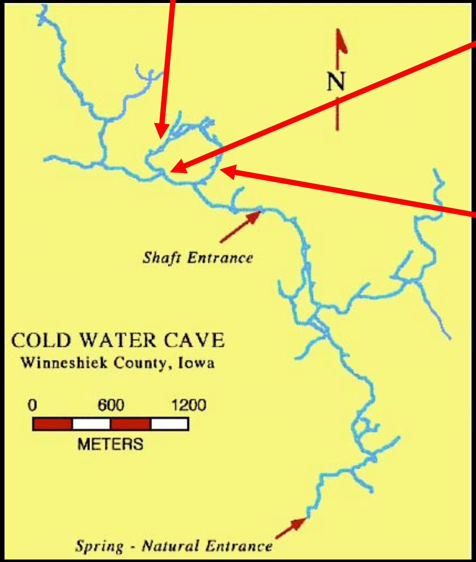
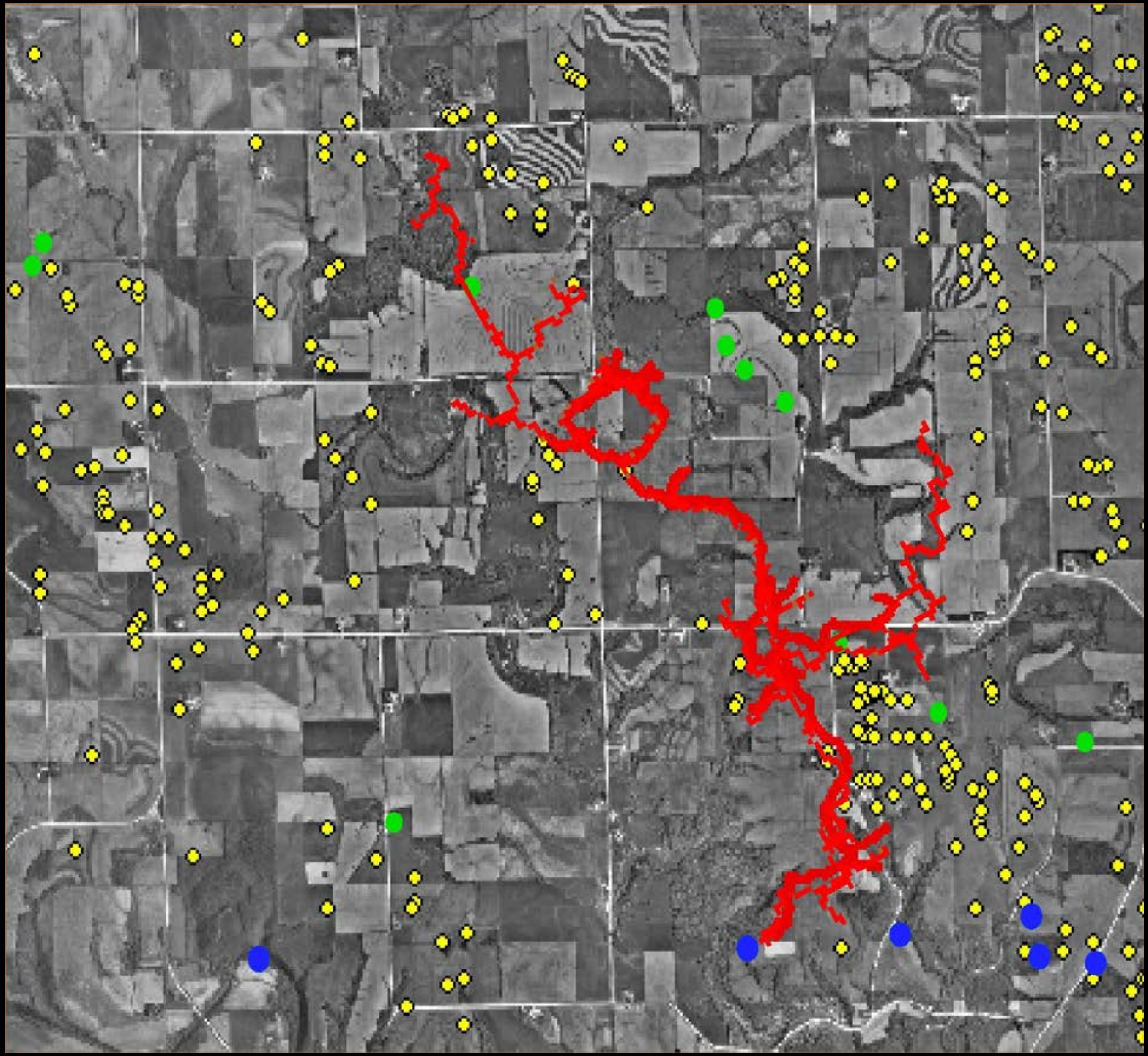
Shaft Entrance
COLD WATER CAVE
Winneshiek County, Iowa
0
600
1200
METERS
Spring - Natural Entrance


N
Shaft Entrance
COLD WATER CAVE
Winneshiek County, Iowa
0
600
1200
METERS
Spring - Natural Entrance

Karst Feature Inventory



● Swallets & loosing streams ● Sinkholes ● Karst springs — Coldwater Cave

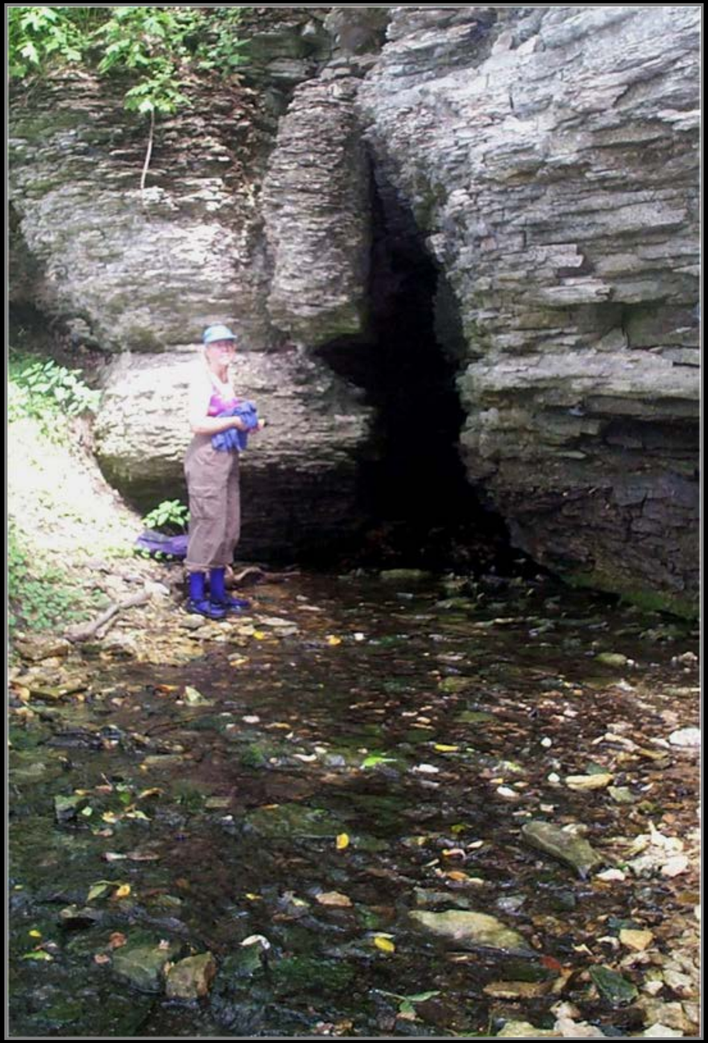
Dye Traces:

Delineate the boundaries and extent of the groundwater basin

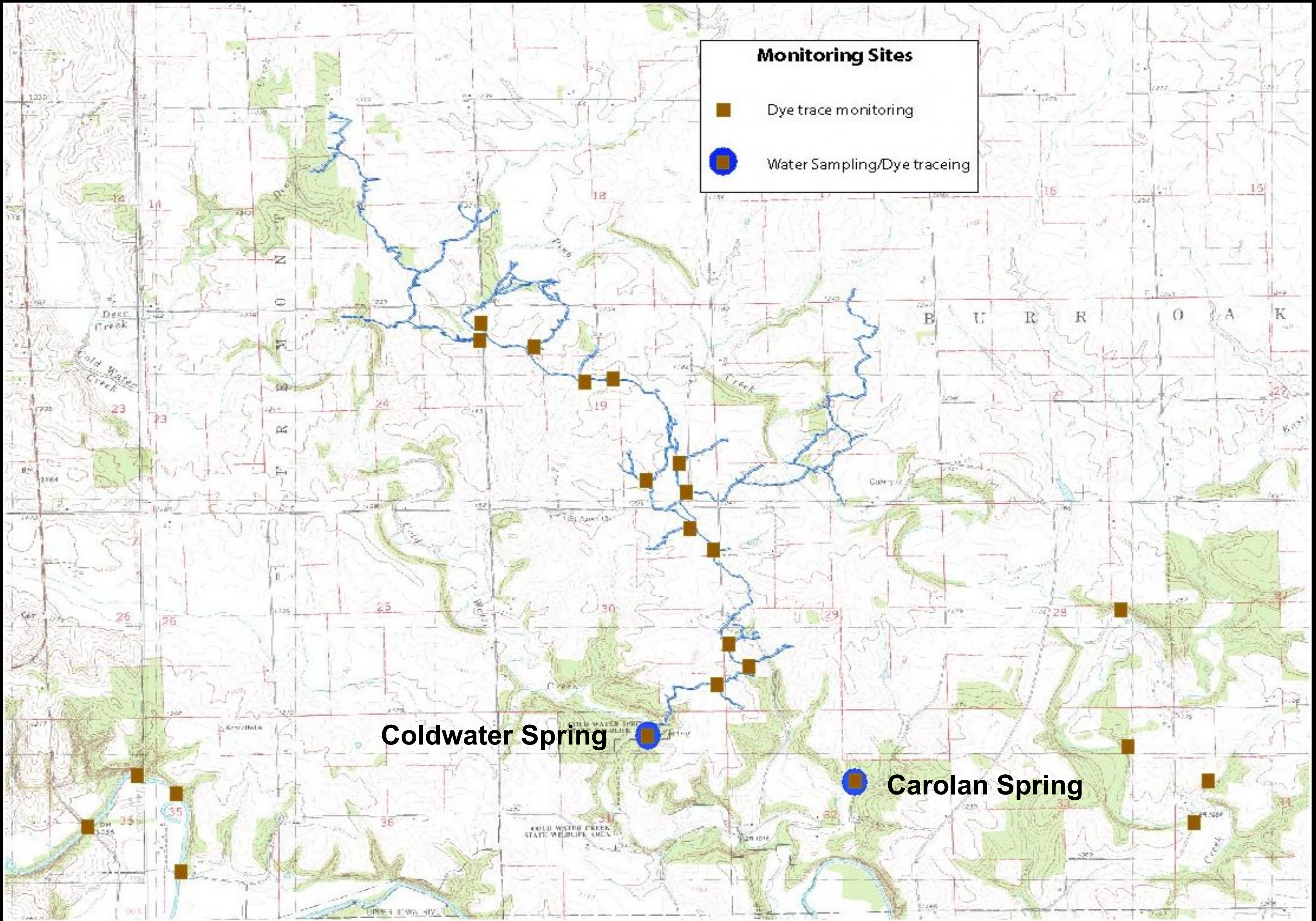
Identify underground flow paths

Establish travel time of fluorescent dyes through the basin since they emulate the movement of soluble contaminants in surface and subsurface streams.

The karst feature inventory provided dye injection locations and identification of potential monitoring sites for water quality sampling and for dye receptors.



A total of 23 monitoring sites were chosen for dye tracing including two for water quality sampling.

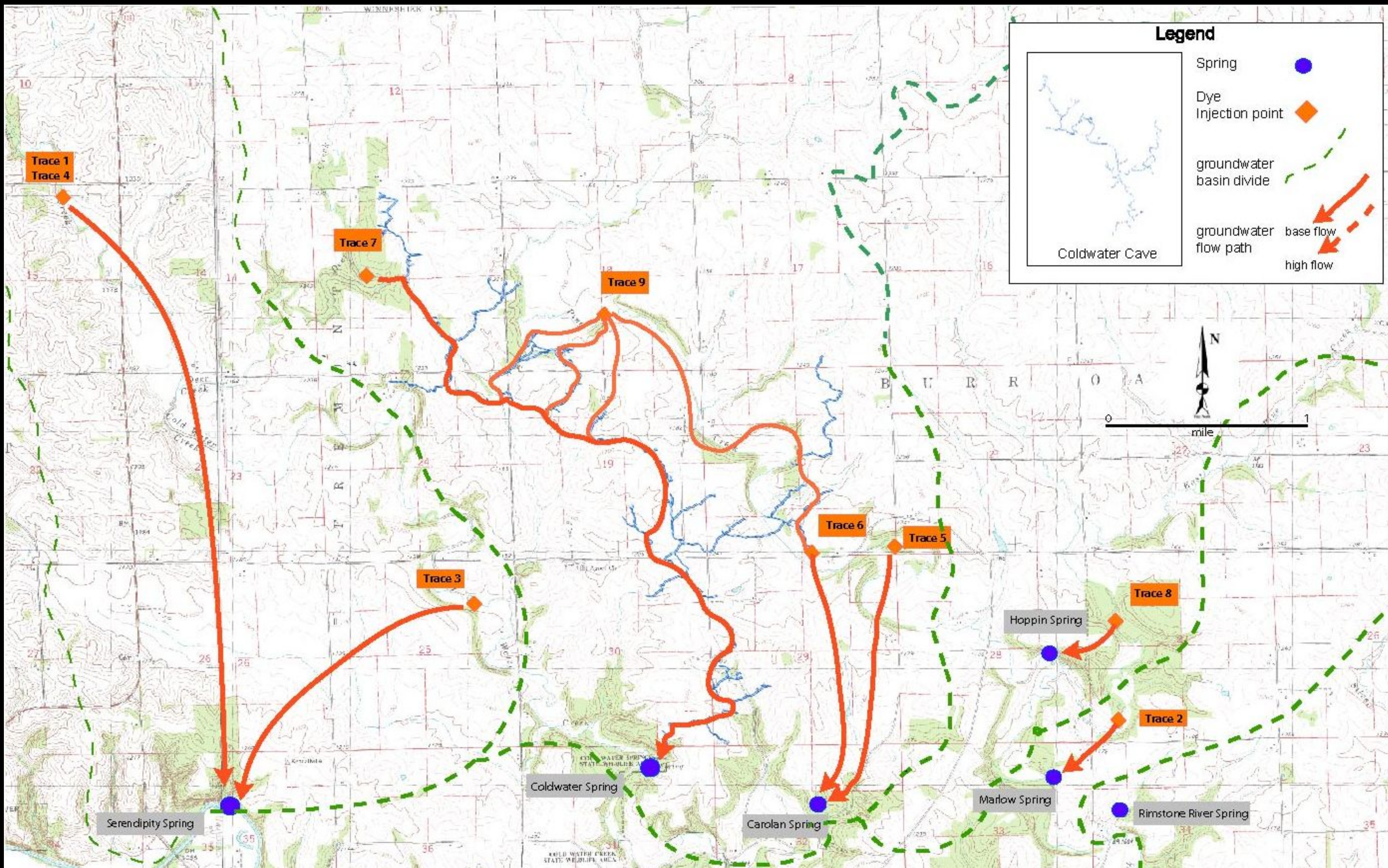


A series of 9 qualitative traces and one quantitative trace was conducted in the area, using using Rhodamine WT, Eosine and Fluorescein dyes

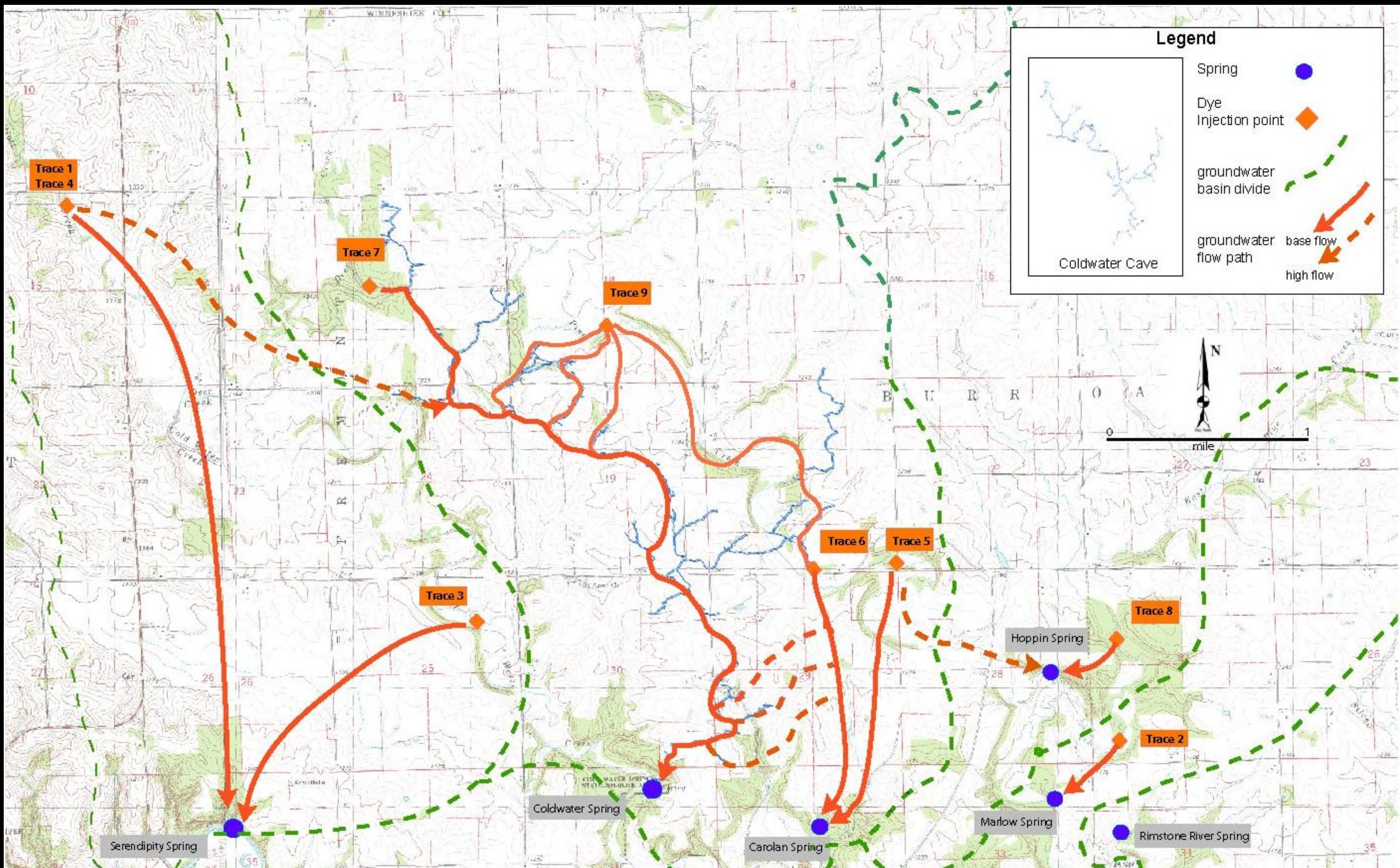
Fluorescein at a swallet

Rhodamine at a loosing stream

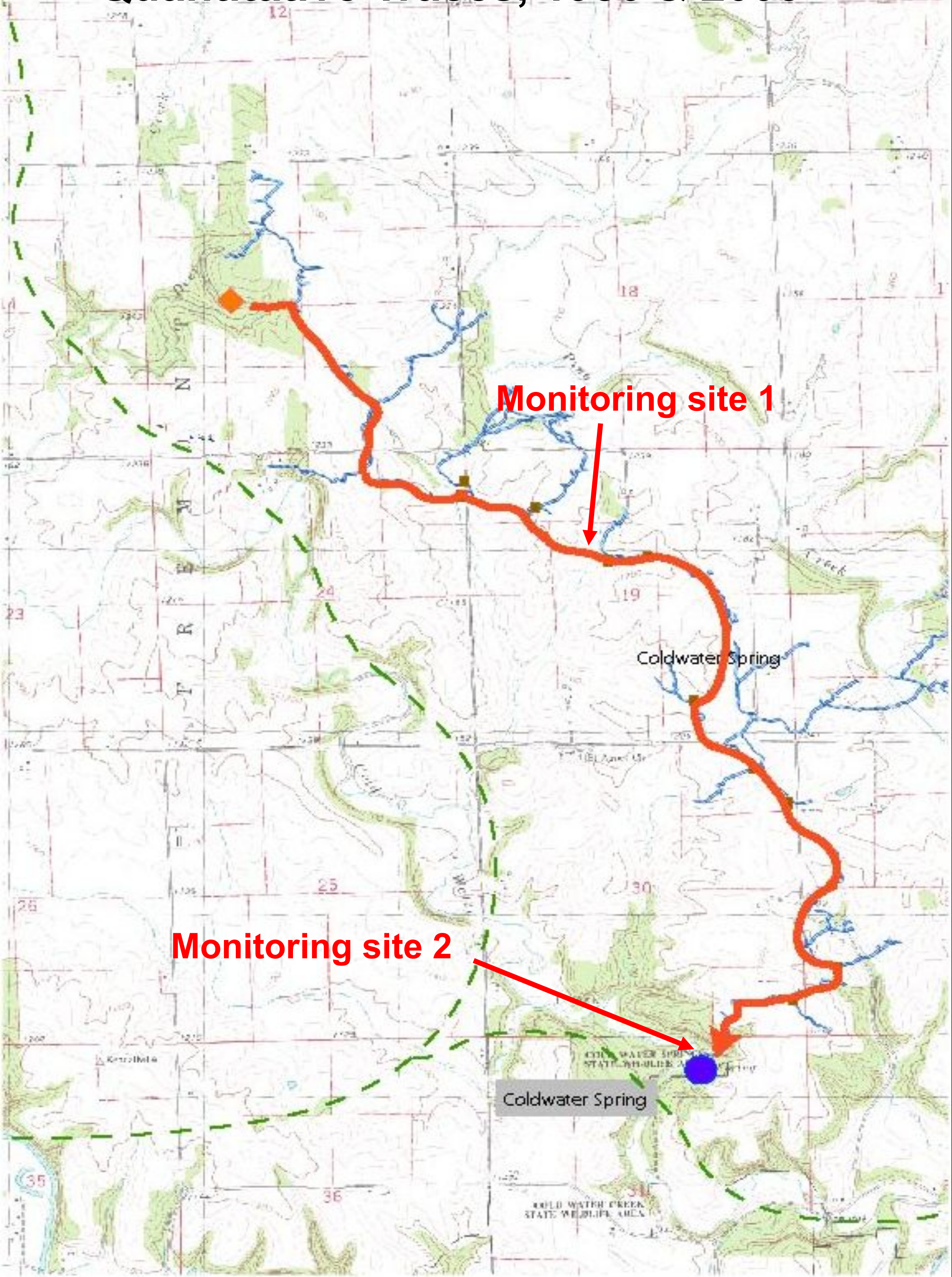
Drainage basin boundaries and groundwater flow paths during base level flow

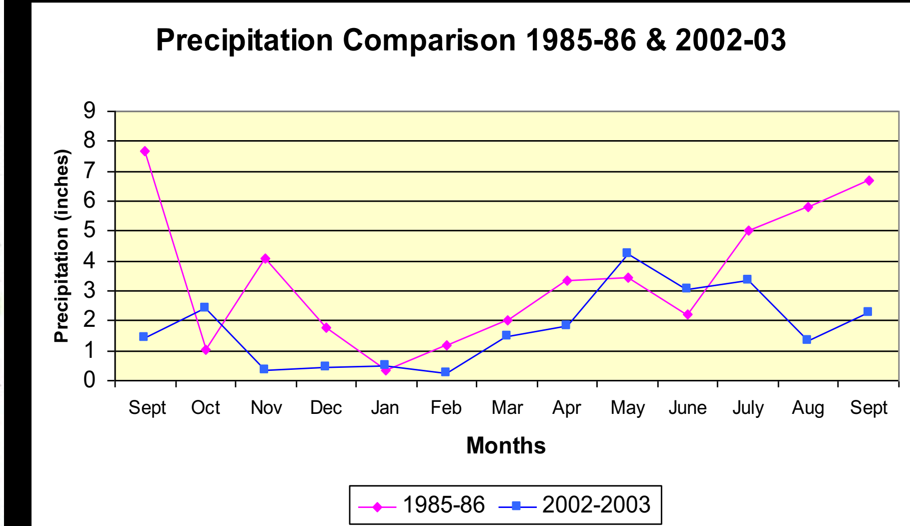


Groundwater flow paths (dashed lines) during high water conditions



Quantitative Traces, 1986 & 2003



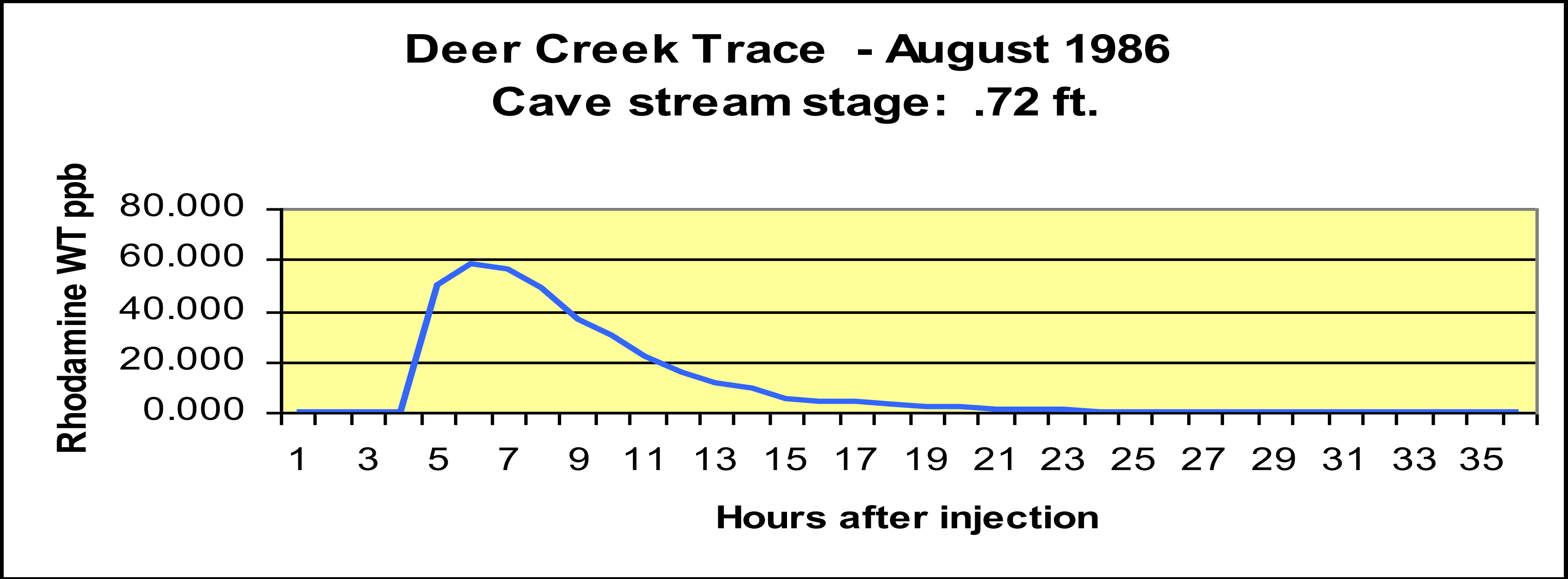


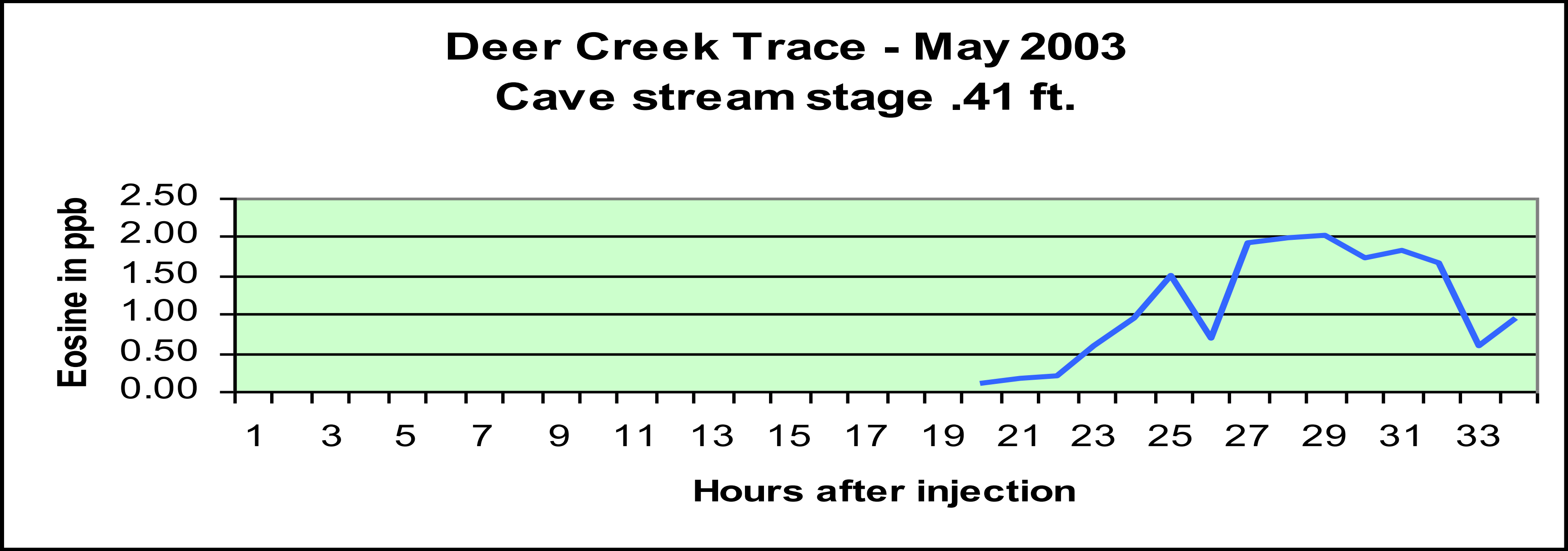
Travel time of dye through the system:

In a 1986 trace, it took 5 hours for the dye to reach the first monitoring point and an additional 11 hours to be detected at Coldwater Spring (450 m/hour). This was during high water conditions.

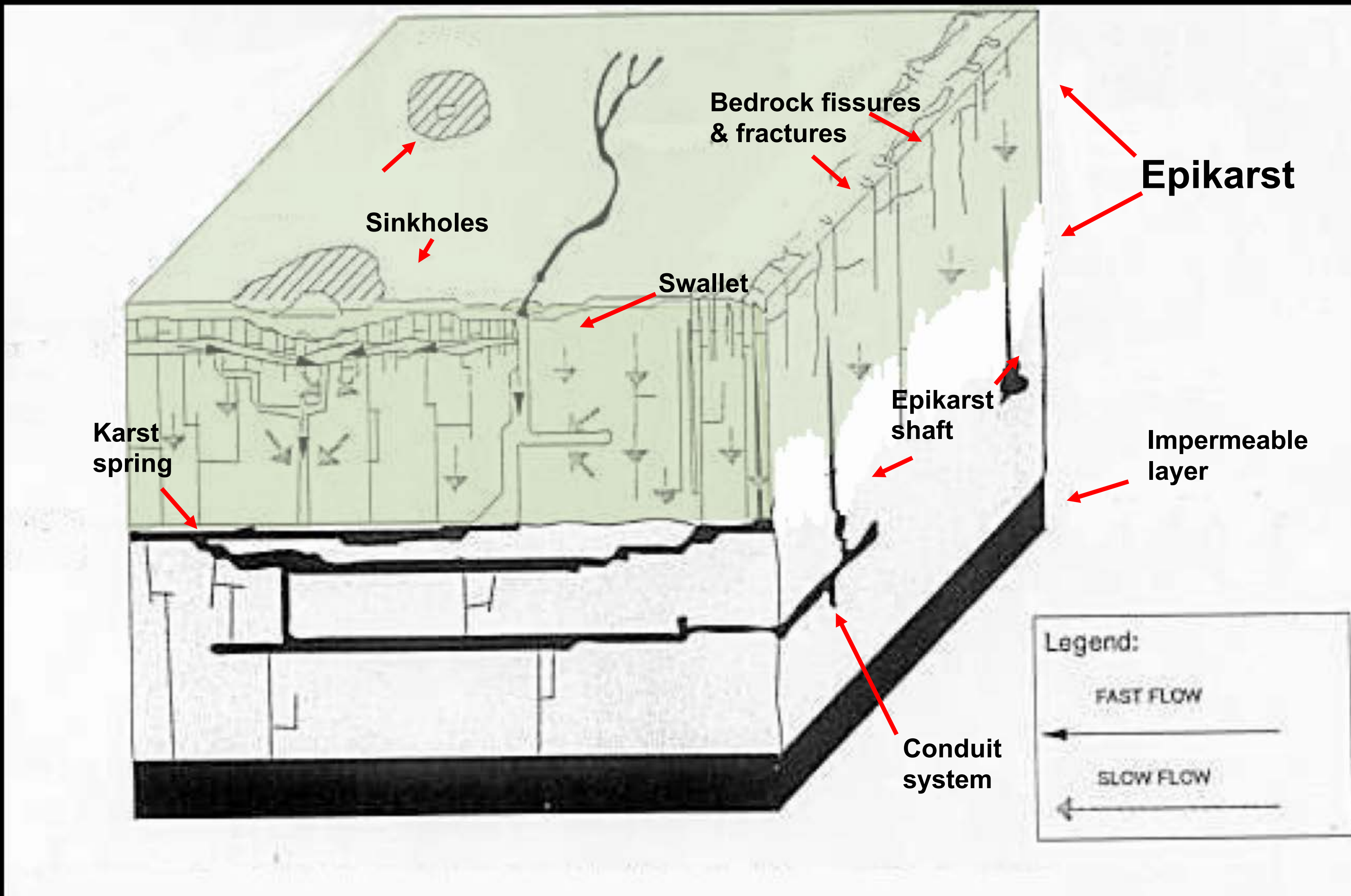
In 2003, in a similar trace, it took 19 hours for the dye to reach the first monitoring point and 27 hours for it reach the spring (126m/hour). This was during drought conditions.

Breakthrough Curves for quantitative dye traces on Deer Creek, Winneshiek County, IA





The network of swallets, loosing streams, sinkholes and fractured bedrock bring water into the epikarst which is the upper layer of the aquifer..



Groundwater basin study results:

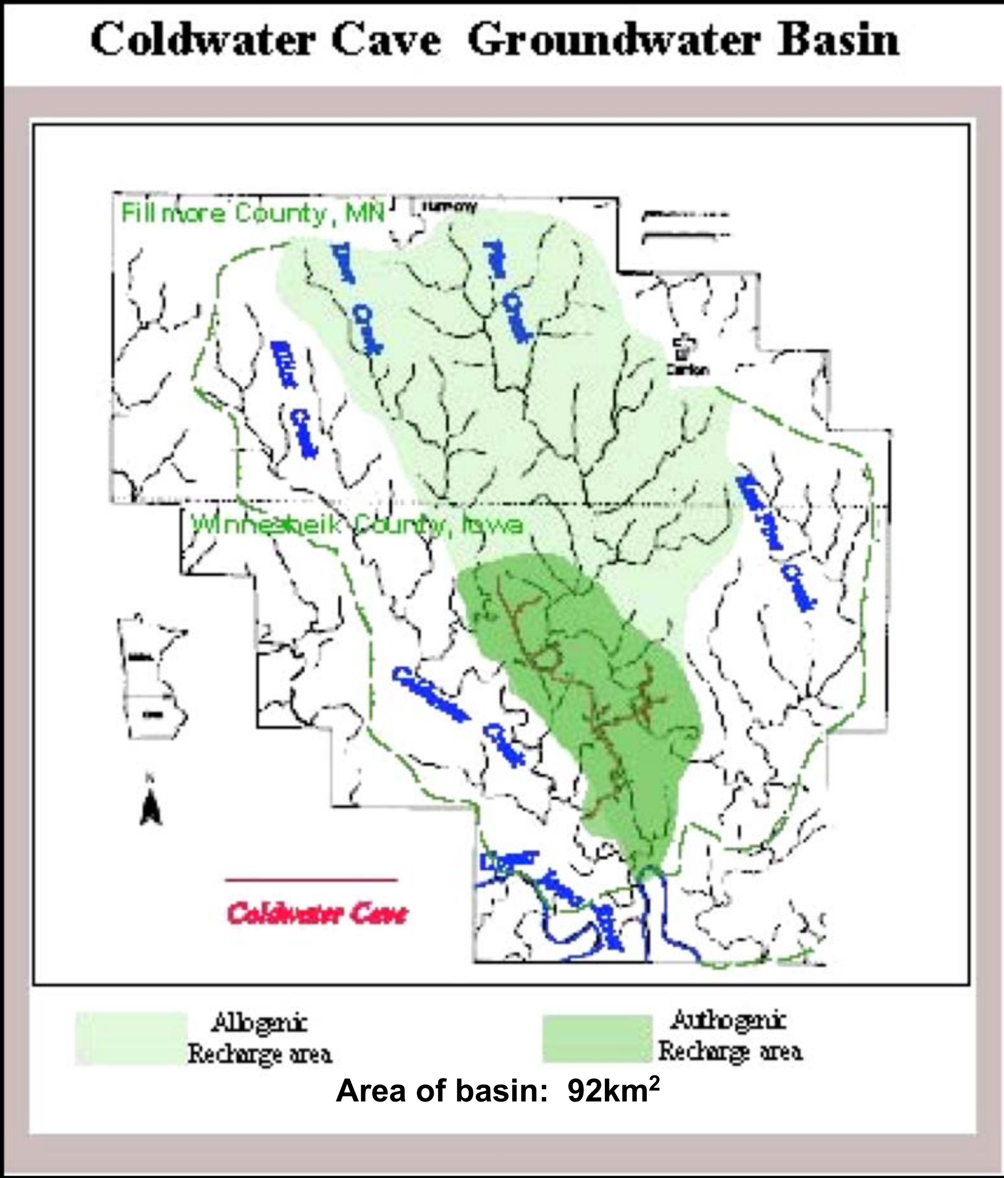
Spring-fed surface streams drain the allogenic part of the basin.

Once the streams cut down into the Galena carbonate unit, the surface streams sink as swallets or they loose water to the groundwater basin (autogenic).

Dye tracing defined 5 drainage basins.

During rain events, the basin divides can shift and water from adjacent basins can mix.

Surface and ground water are intimately connected . The karst landscape allows surface water to get into and move very quickly through the groundwater system.



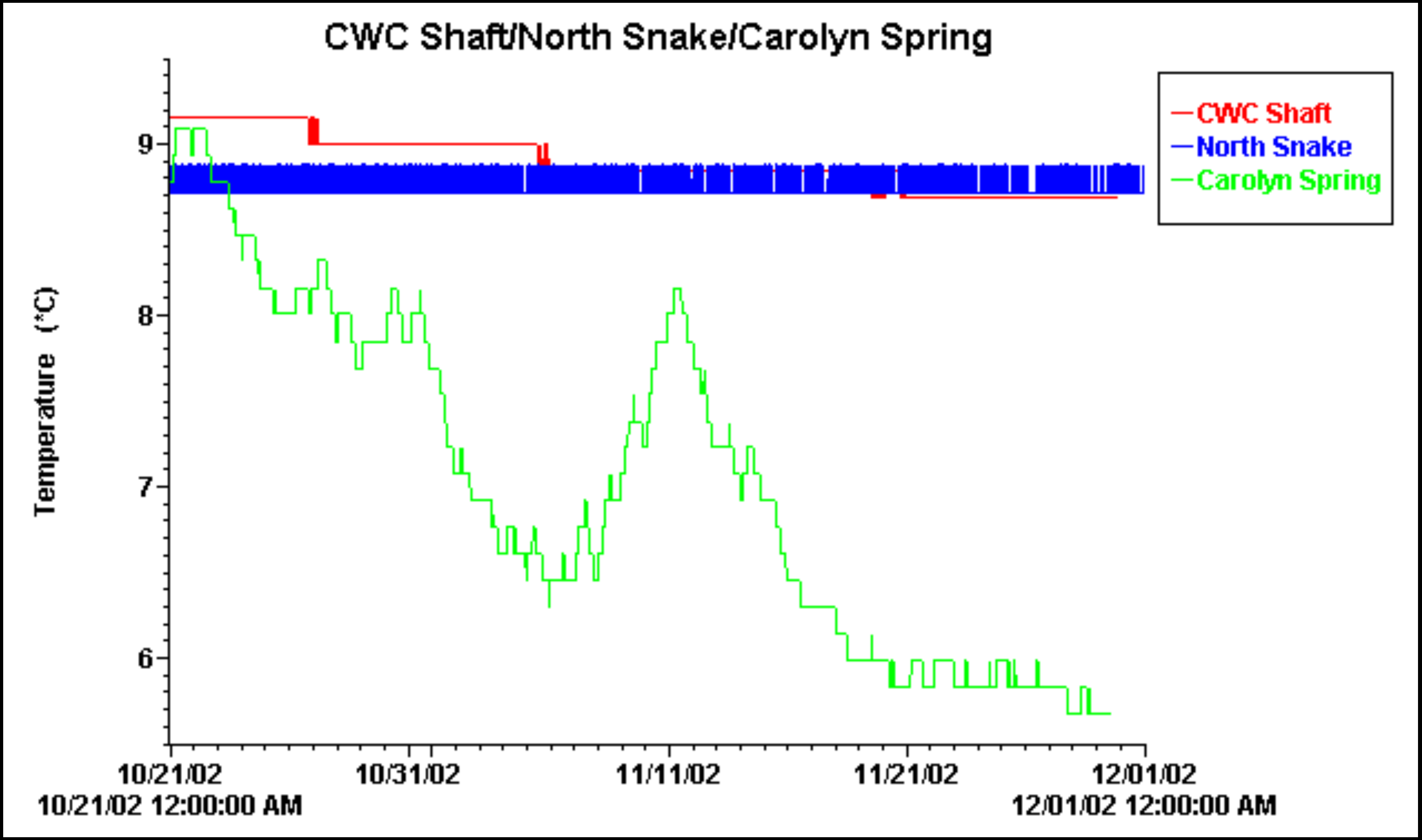
Water sampling was conducted to determine water quality within the Coldwater Cave groundwater basin. Coldwater Spring and Carolan Spring both drain the groundwater basin and they served as water sampling sites for this study

Water was analyzed for cations, anions, pesticides, and fecal coliform levels

In conjunction with water sampling, the study also tracked pH, conductivity, temperature and discharge at both of the springs.

Additional sampling was done for contaminant source analysis.

Comparison of Temperature data
October – December 2003



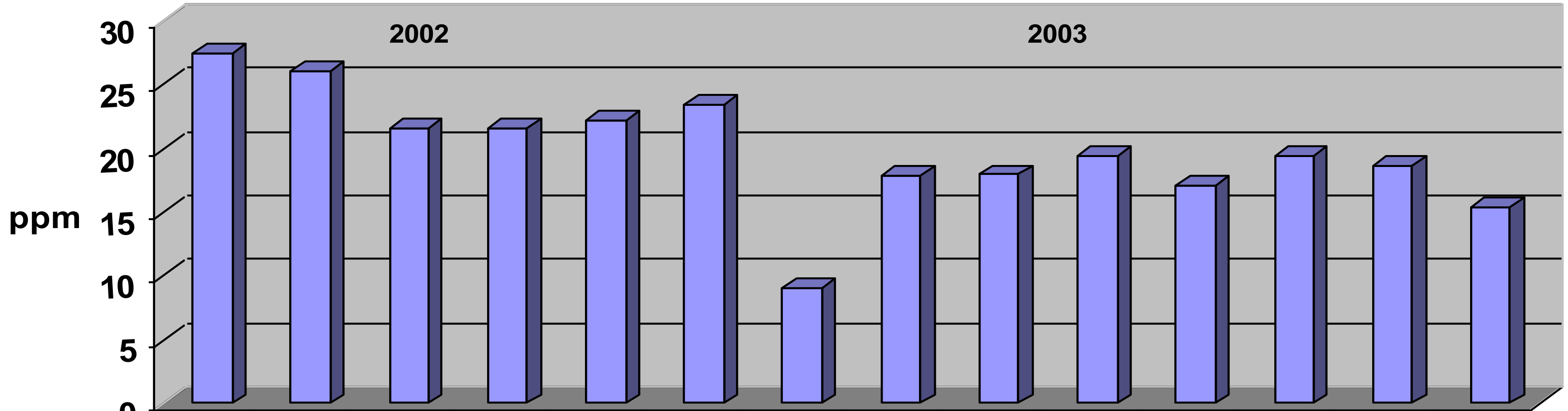
Agricultural Pollutants in the Coldwater Cave Karst Drainage Basin

Atrazine	**Runoff from use as herbicide on corn** natural background levels: 0
Nitrate/Nitrite	**Animal waste, fertilizer, septic tanks, sewage** natural background levels: 1.9-2.0 mg/l
Fecal Coliform	**Animal fecal waste, septic tanks** F/C ranges for some nationa parks less than 1 to 600 c/100ml For Class A rivers EPA standard 100c/100ml

Chlorides, ammonium, fluoride, bromide, sodium & phosphate were not found in significant concentrations

Nitrate levels at Coldwater Spring

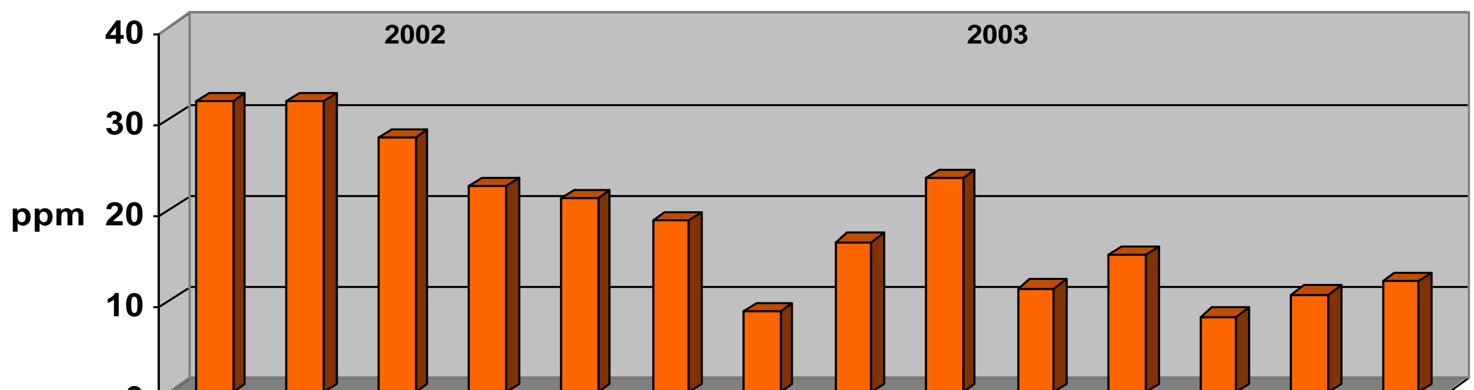
Mean: 20.1



	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.
Nitrates	27.44	26.06	21.52	21.56	22.18	23.42	9.00	17.84	17.94	19.45	17.04	19.39	18.60	15.43

Nitrate Levels at Carolan Spring

Mean: 18.7



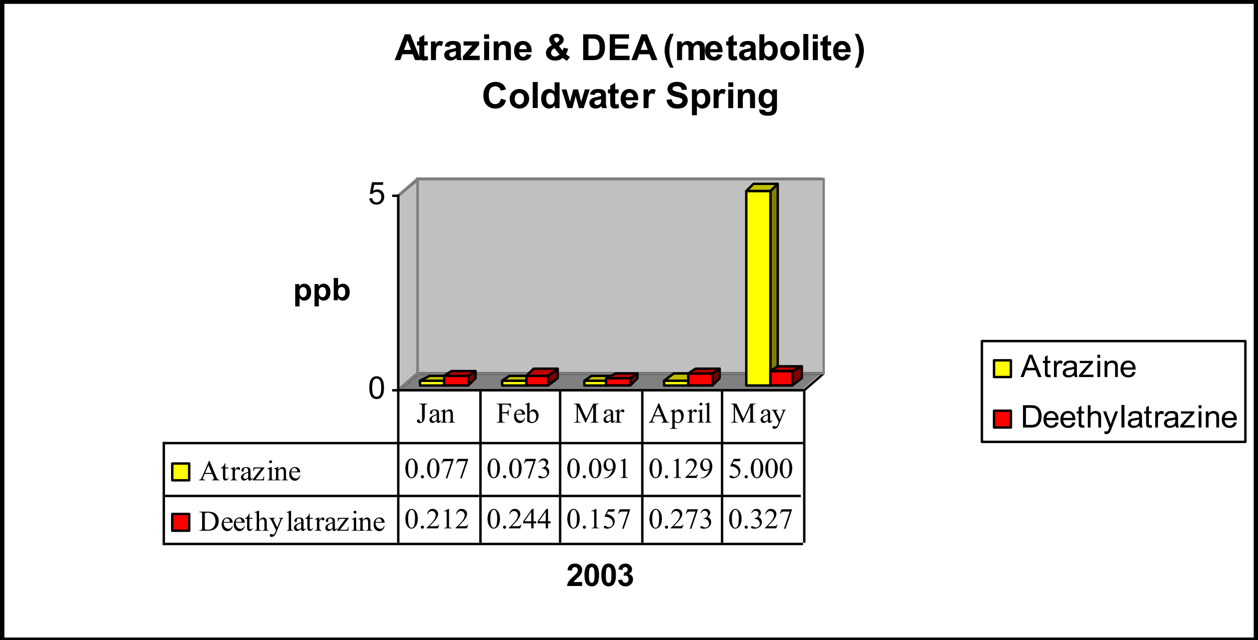
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.
Nitrates	31.97	31.93	27.98	22.69	21.41	18.93	8.94	16.54	23.48	11.45	15.18	8.37	10.79	12.28

EPA Standard: 10 ppm

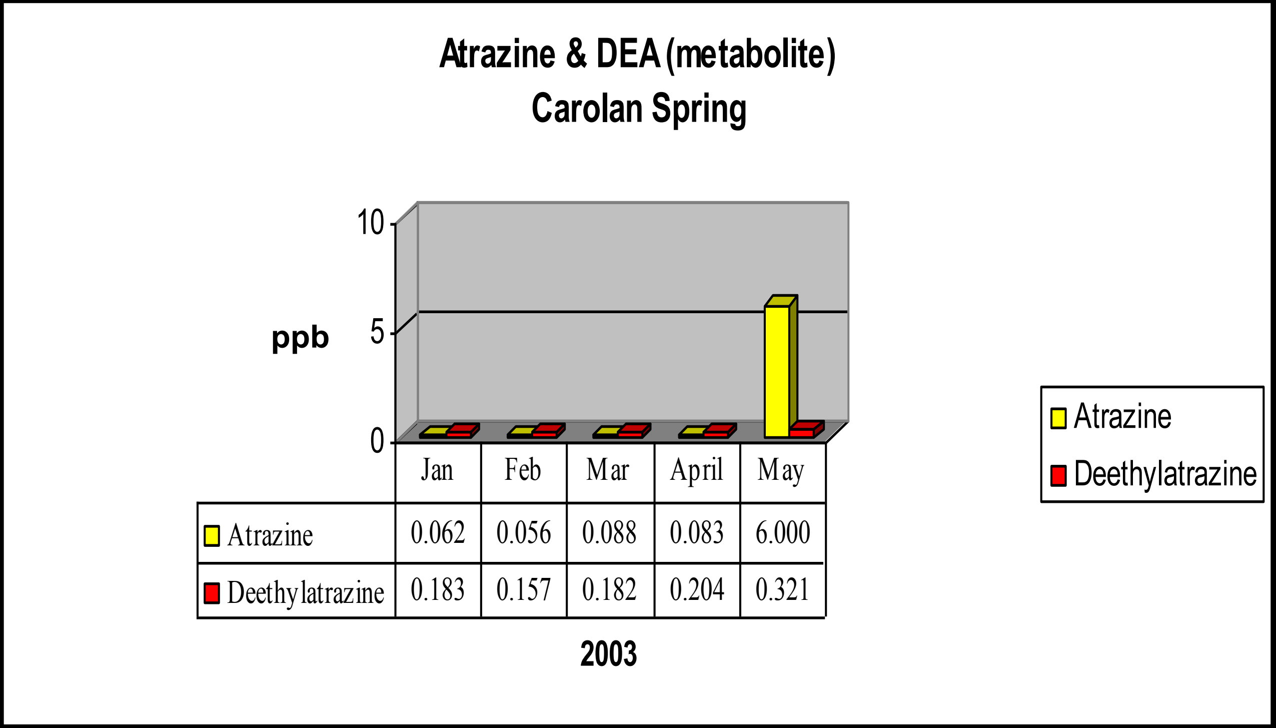
Atrazine levels varied seasonally.

Atrazine and its metabolite DEA persisted in all of the samples during the sampling period.

EPA Standard: 3 ppb



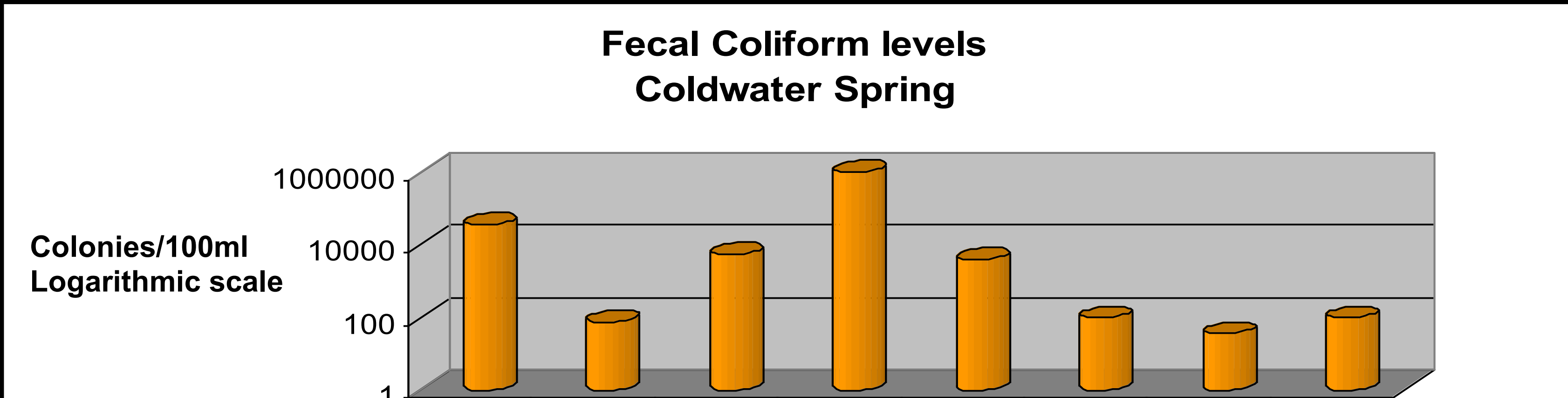
	Jan	Feb	Mar	April	May
Atrazine	0.077	0.073	0.091	0.129	5.000
Deethylatrazine	0.212	0.244	0.157	0.273	0.327



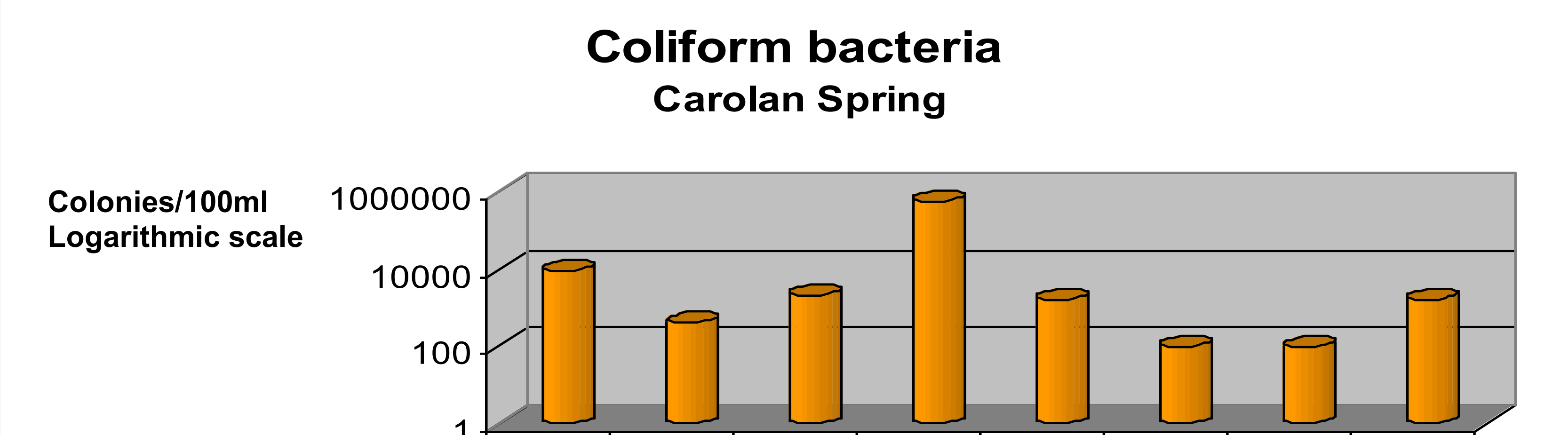
	Jan	Feb	Mar	April	May
Atrazine	0.062	0.056	0.088	0.083	6.000
Deethylatrazine	0.183	0.157	0.182	0.204	0.321

Fecal Coliform Levels

EPA standard for Class A rivers: 100colonies/100ml



	July 99	Oct. 99	Feb 00	May 00	July 00	Jan 00	Oct 00	Oct 03
Fecal Coliform	36000	76	5500	100000	3900	100	36	100



	July	Oct. 99	Feb 00	May 00	July 00	Jan 00	Oct 00	Oct 03
Coliform bacteria	9400	410	2100	600000	1600	100	91	1600

Contaminant Sources :

Atrazine	Runoff from use as herbicide on corn
Nitrate/Nitrite	Animal waste, fertilizer, septic tanks, sewage
Fecal Coliform	Animal fecal waste, septic tanks

Nitrogen Isotope Analysis

Purpose: To identify source of nitrogen

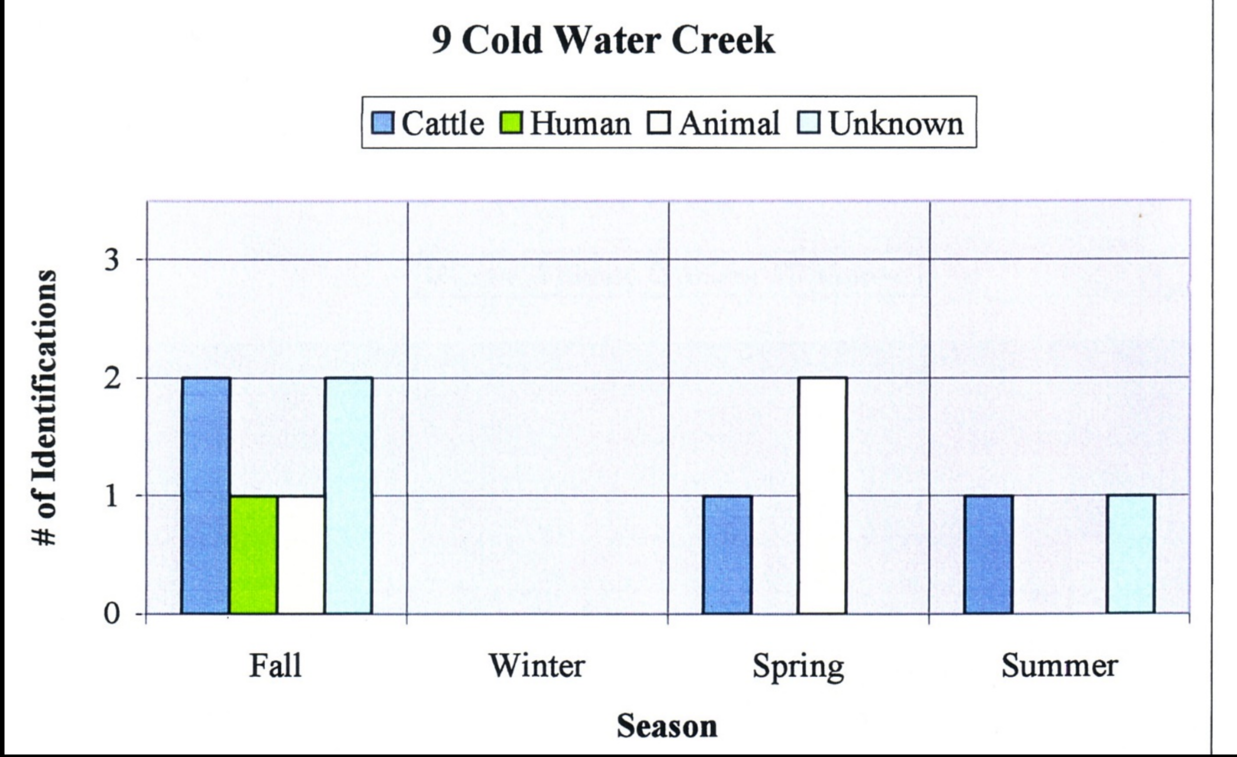
Each type of nitrogen source (wastewater or septic discharge, crop field runoff, animal production facilities) has a narrow range of isotopic ratios (14 and 15) that can be used to identify the process that created it.

Preliminary Results:

Nitrogen isotope ratios for samples collected in the study area indicate that the source of some of the nitrogen is related to livestock operations.

Ribotyping

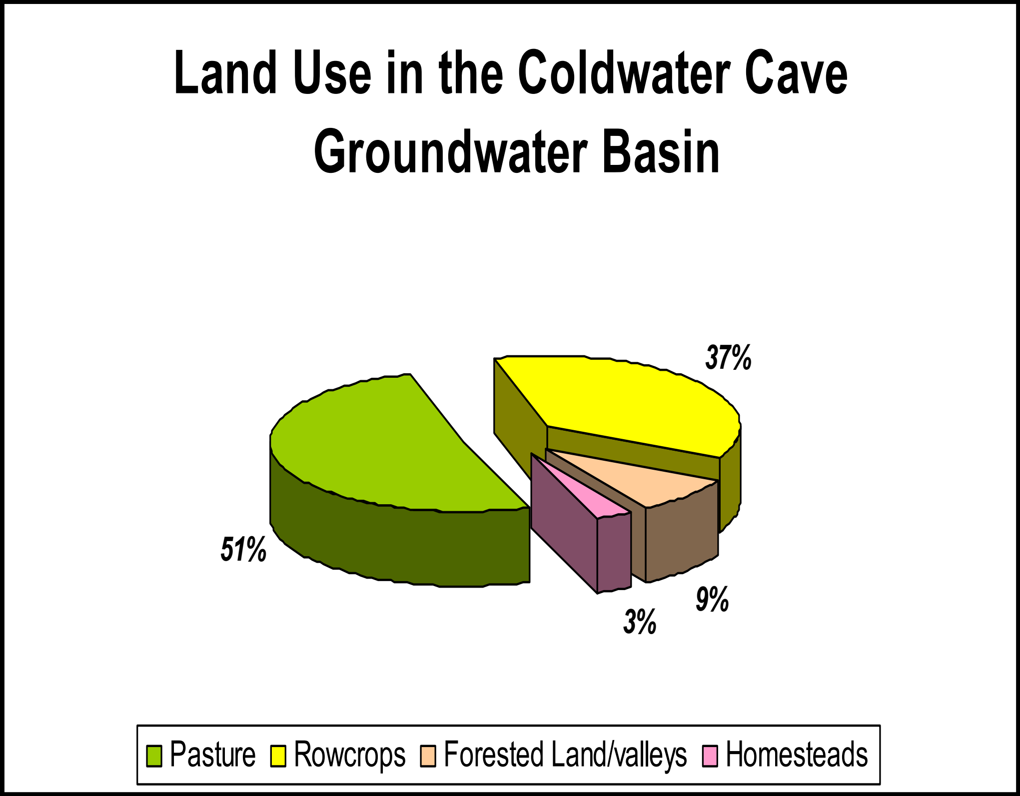
One of the sampling sites in this study was chosen to participate in a ribotyping project that was conducted by the University of Iowa Hygienic Lab.

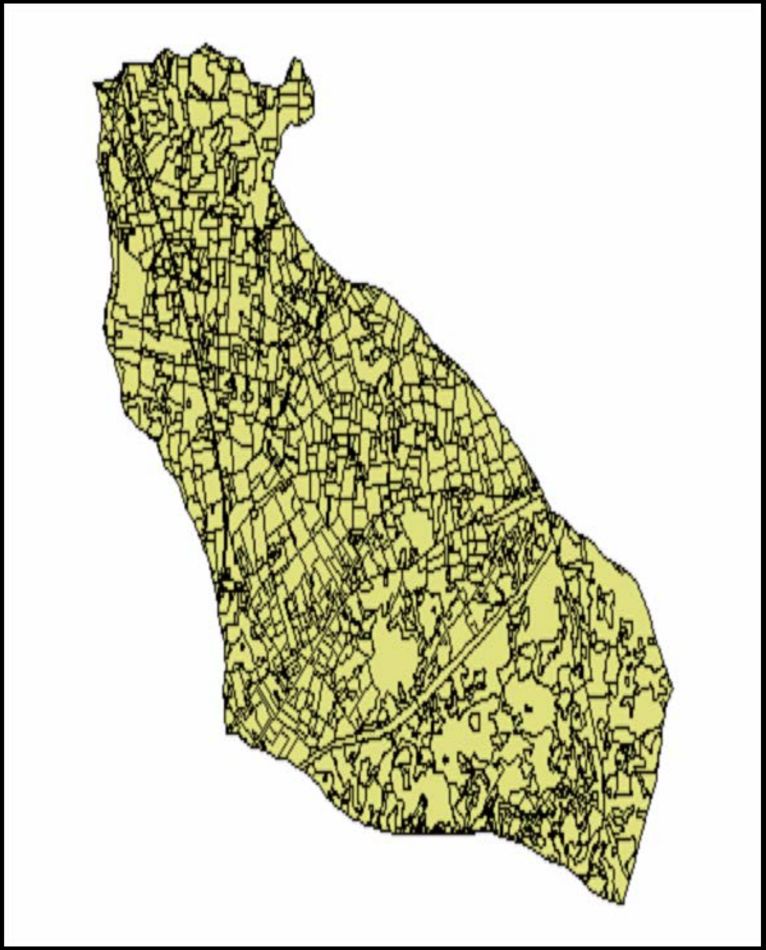


Purpose of the project was to determine the sources of bacteria in the Upper Iowa River basin using ribotyping analysis.

The results of the project are very preliminary but they suggest that potential sources of bacteria in the Coldwater Creek basin may come from livestock and from humans.

Land use in the Coldwater Cave groundwater basin





There are 120 homesteads which use private onsite wastewater systems. Approximately 30% are not effective in treating water.

Source: Winneshiek County sanitarian - 2003

The total number of livestock producers in the basin is 42 (4003 heads of beef, 860 hogs, 599 dairy, 299 sheep). These operations generate 19,000 tons of waste products per year. Most operations do not have waste storage and common practice is to scrape and haul manure to the field, throughout the year.

Source: Upper Iowa River Alliance 2003

Contaminant Source and Land Use

Preliminary results of the Nitrate isotope analysis and from ribotyping indicate that dairy and livestock operations are a source of nitrates and bacteria

Sampling shows that Atrazine levels vary seasonally. Atrazine and its metabolite still persists in the basin throughout the year..

Ribotyping results (preliminary) suggest that the second major source of bacteria may be human – this may be a reflection of inadequate septic systems in the area.

Conclusions:

The karst terrain that characterizes the Coldwater Cave groundwater basin provides multiple direct hydrologic connections from the surface into the groundwater aquifer.

The surface-groundwater connections and the rapid velocities associated with groundwater flow in the Coldwater Cave karst aquifer allows for contaminants to move quickly into and through the groundwater system.

When karst groundwater returns to the surface via springs, any contaminants within the water become part of the surface streams and rivers.

Water quality in the Coldwater Cave groundwater basin is a function of land use conditions and practices.

Question:

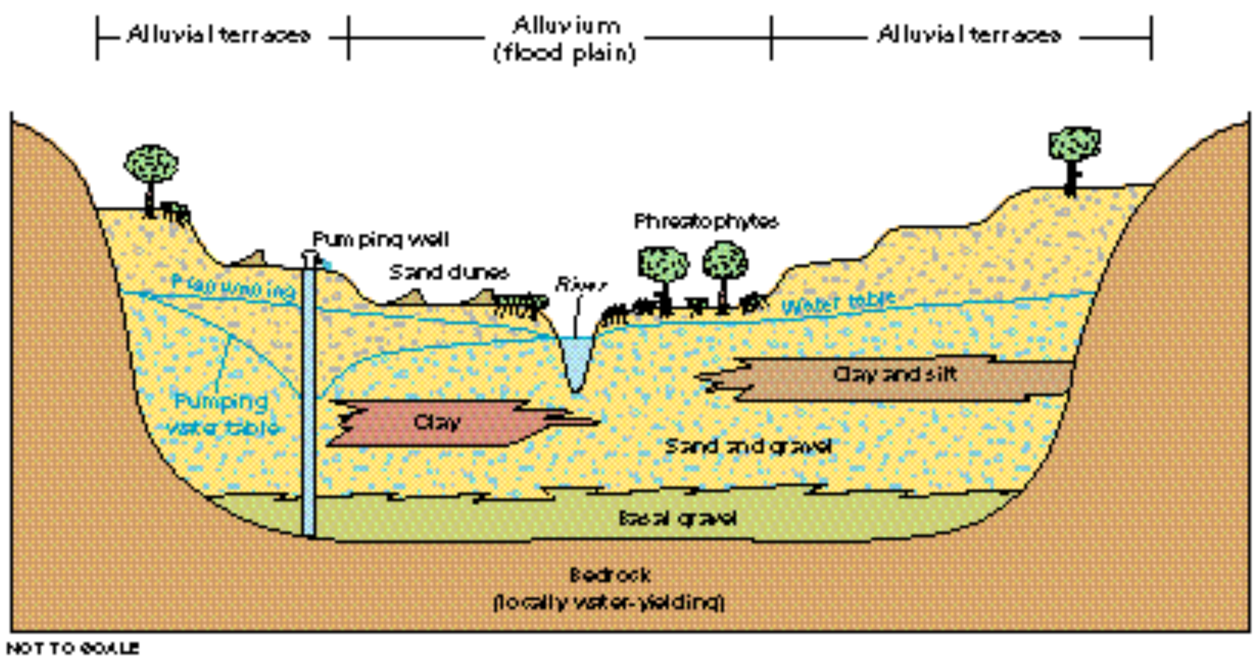
If the shallow karst aquifer doesn't serve as the local drinking water source, then why is it important?

Answer:

The karst aquifer is one of many similar aquifers that discharges directly in the Upper Iowa River.

So What?

The city of Decorah is located 10 miles downstream of the study area and gets its drinking water from shallow wells in unconsolidated sands and gravels located next to the river. The well capture zone of these aquifers extends into the Upper Iowa River. The city has documented elevated levels of nitrates in their wells.



Idealized hydrogeologic section of a typical stream valley alluvial aquifer shows that the natural slope of the water table gradient is toward the river. The gradient is reversed near the pumping well. This reversal may induce movement of water from the stream toward the well

The Upper Iowa River is one of the most heavily utilized in-state rivers for swimming, fishing, tubing, and canoeing. The river supports a significant recreational industry that brings in close to $35M to the area annually. The study area contributes significantly high fecal coliform concentrations to the river.

In the Gulf of Mexico, a large zone of hypoxia off the coast of the Mississippi River Delta, known as the "dead zone," is an example of a problem that results from intensive agricultural practice in the basins upstream, especially in the upper Mississippi region. Hypoxia, defined as water that does not have enough dissolved oxygen to support life, results in loss of diversity in the Gulf.

Acknowledgements

Hoffman Environmental Research Institute
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