

Groundwater flow and residence time – Twin Cities metropolitan area

Estimating vertical travel times to upper bedrock aquifers

Bob Tipping – MGWA Spring Conference, April 19, 2012



Questions asked by resource managers

- “What’s the quality of water in my area?”
- “Is it getting worse or better?”
- “If we change our use patterns, what are the consequences?”

What is the problem?

- The spatial and temporal variability in groundwater composition and flow is largely unrecognized and undocumented
- These problems are compounded in urban areas, where the effects of pumping, natural and human induced changes in recharge and a wide variety of pollution impacts make things more complicated

- what is the composition, spatial distribution and hydraulic characteristics of unconsolidated materials overlying bedrock aquifers?
- what is the spatial distribution of vertical gradient that drives the downward movement of groundwater through these deposits?

Not a new approach: Larson-Higdem and others, 1975; incorporated into Ruhl and others, 2002; MN Department of Natural Resources, 1991

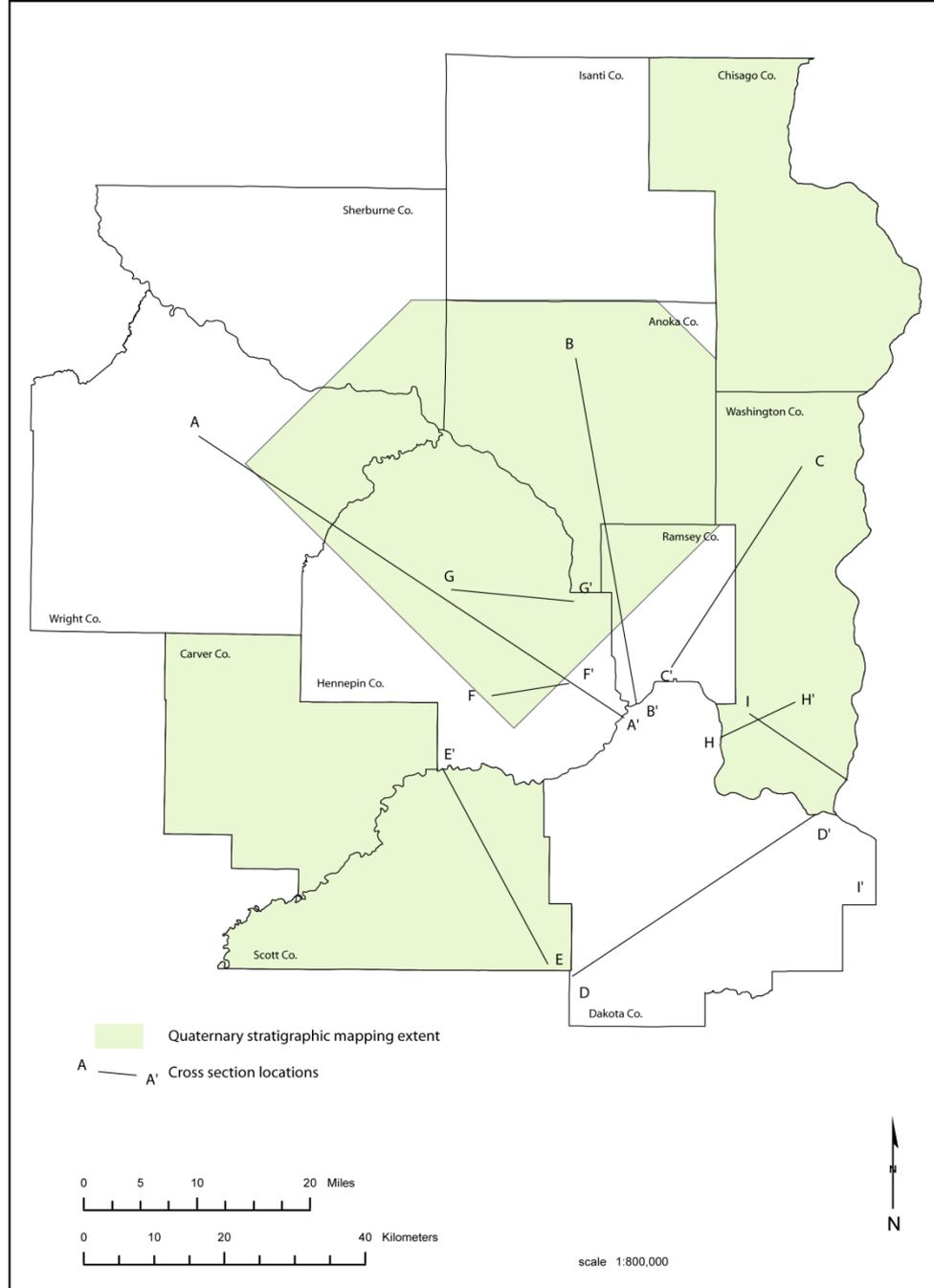


Fig. ___ Regional Map

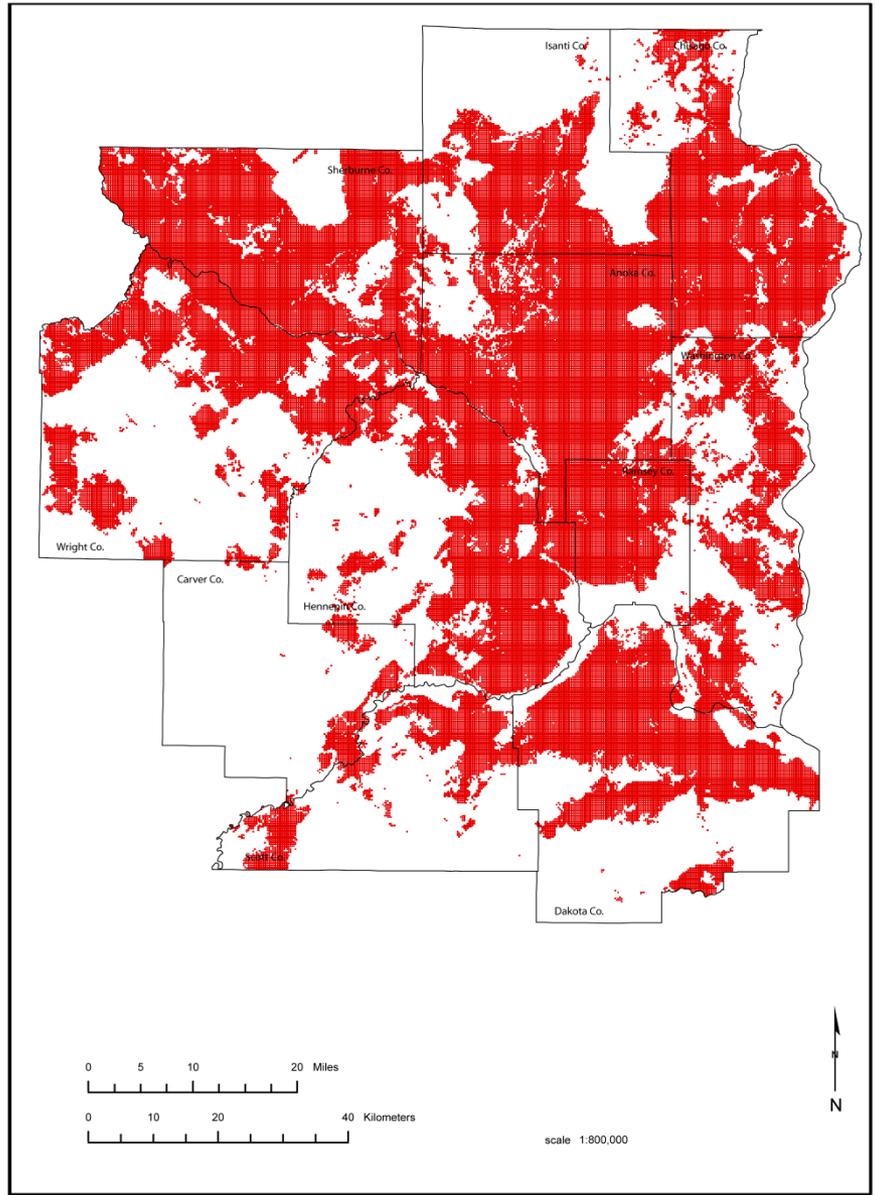


Fig ___ Subsurface Interpolation - sand

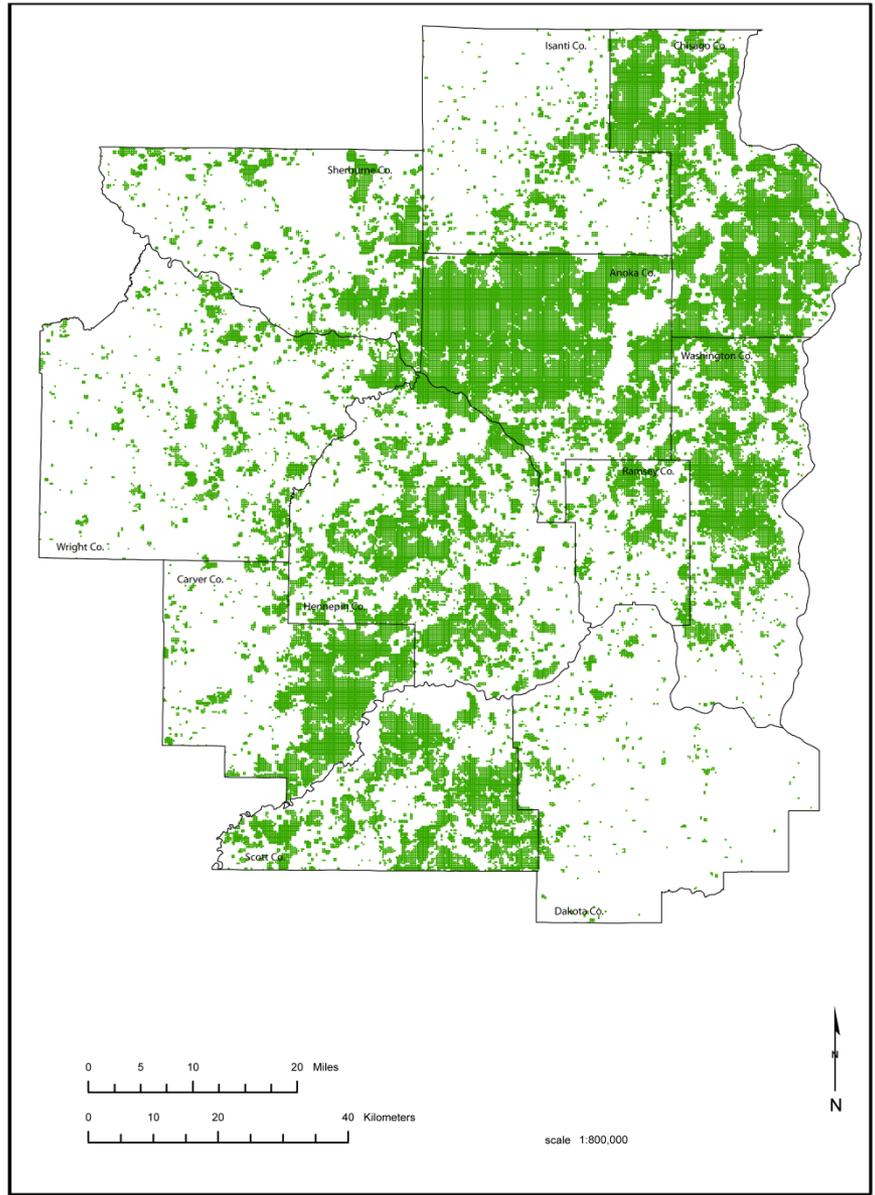


Fig ___ Subsurface Interpolation - mix sand and clay

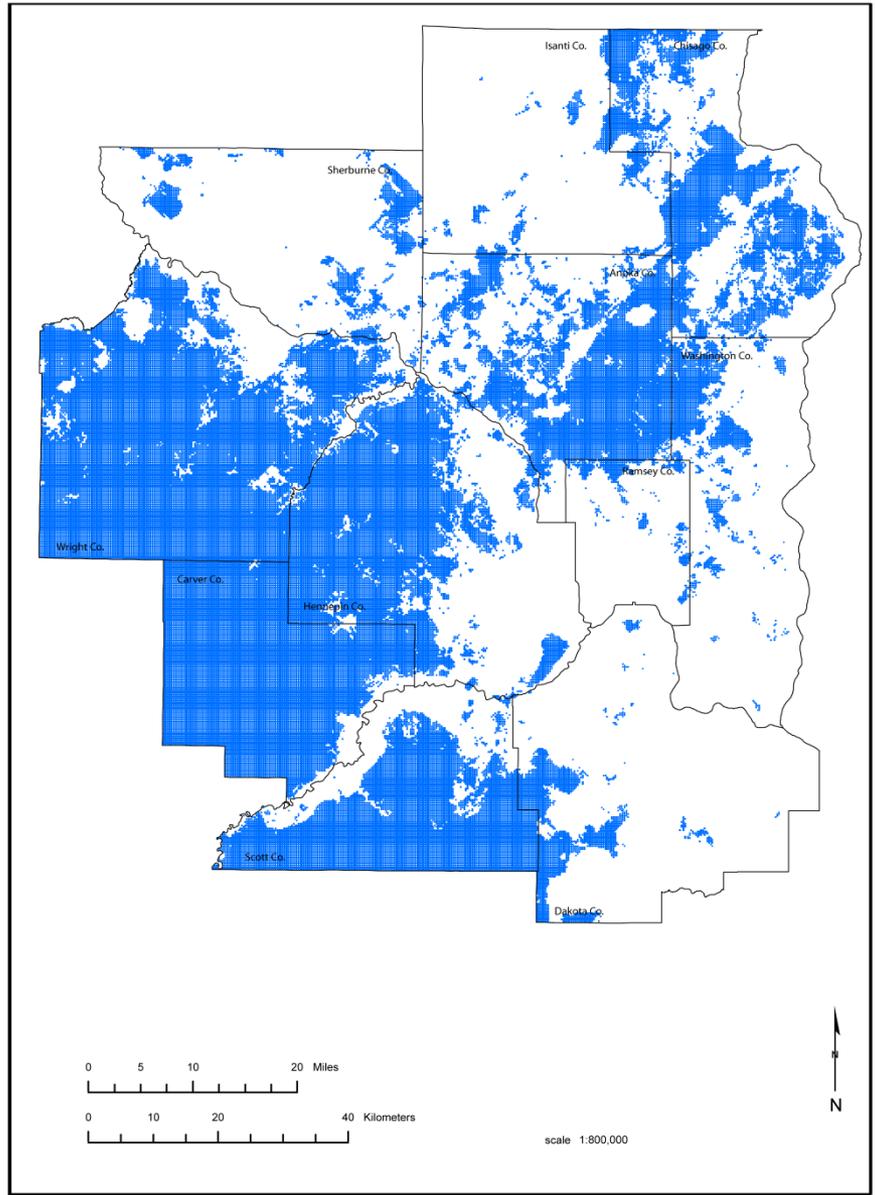
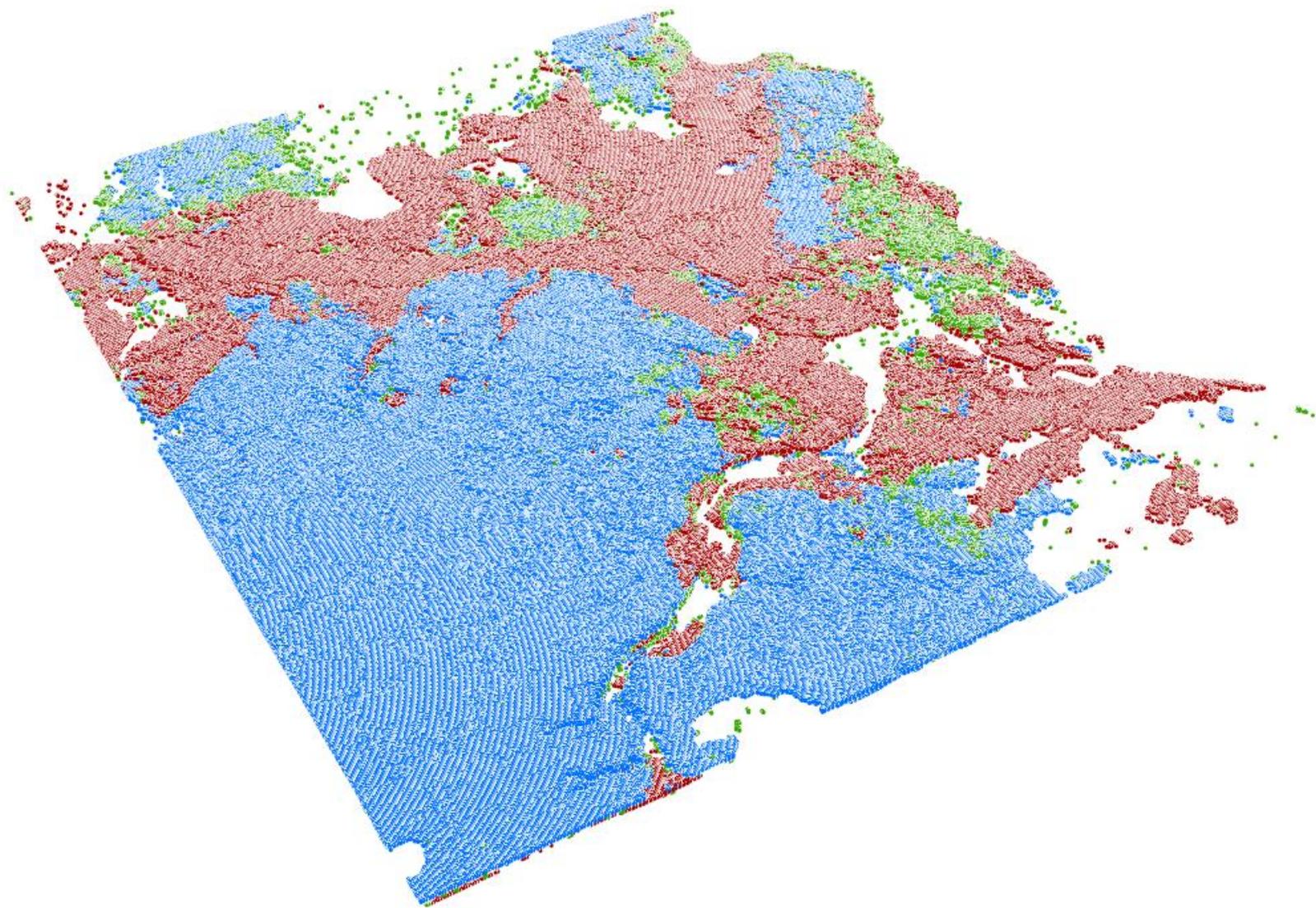
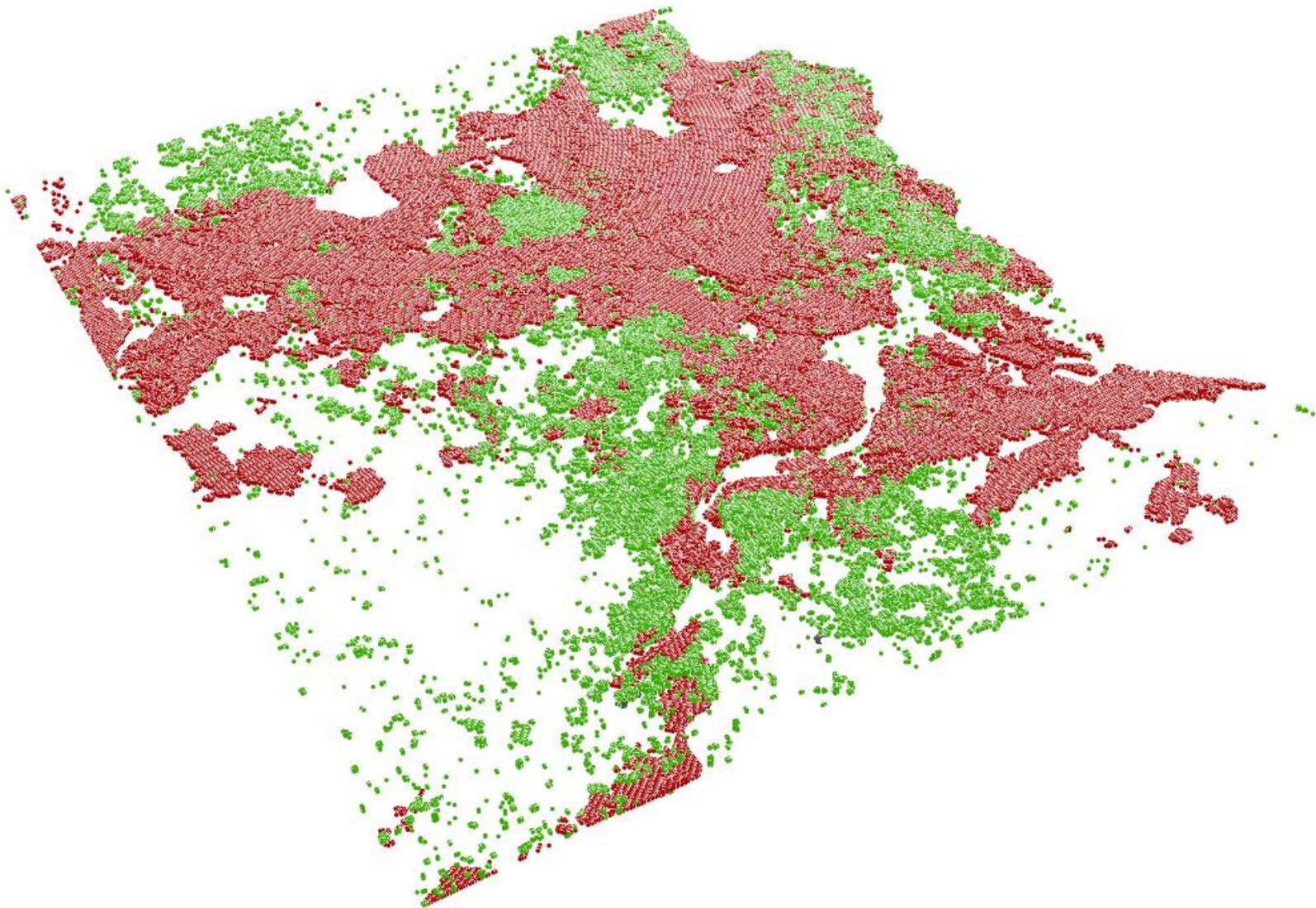
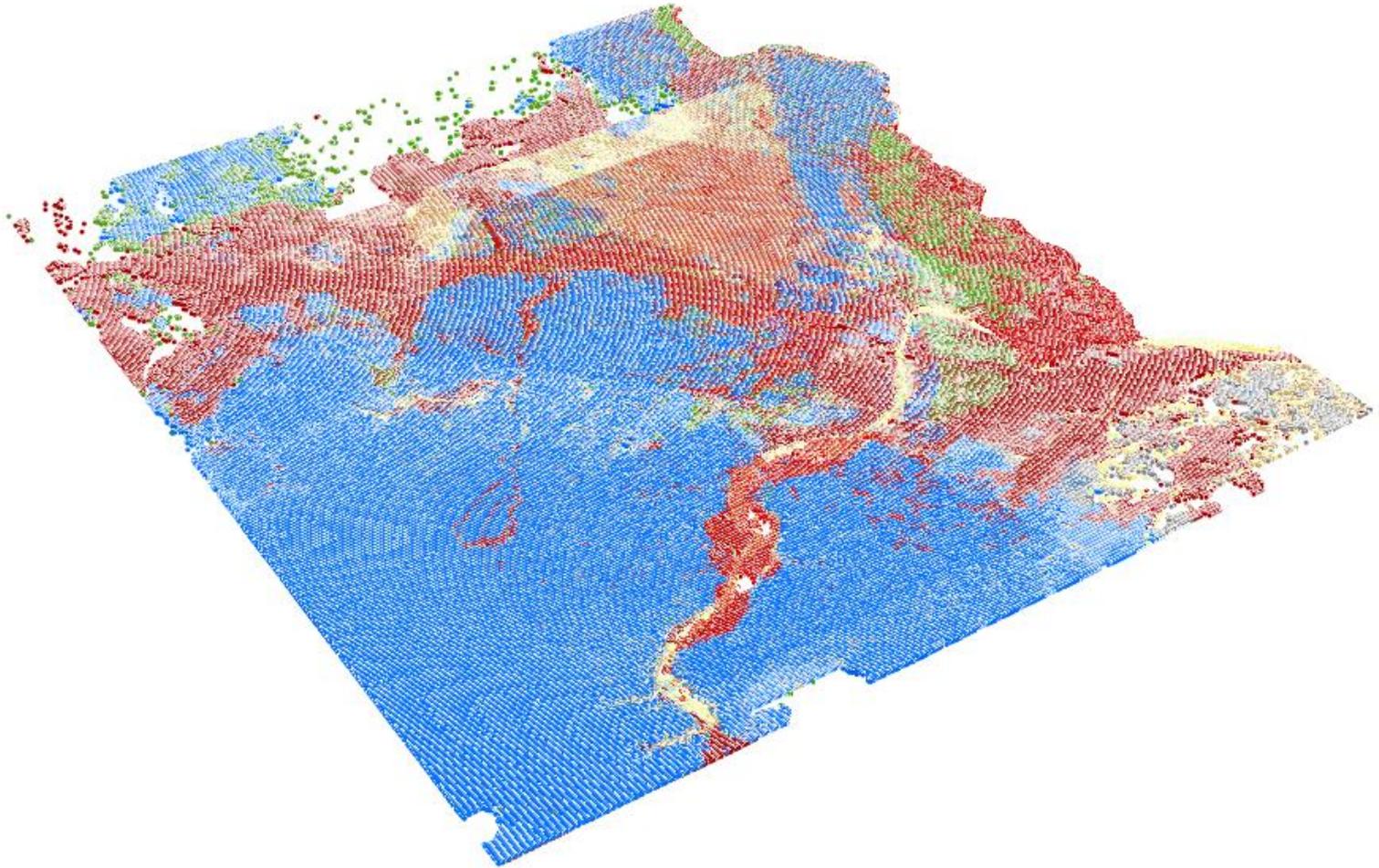


Fig ___ Subsurface Interpolation - clay



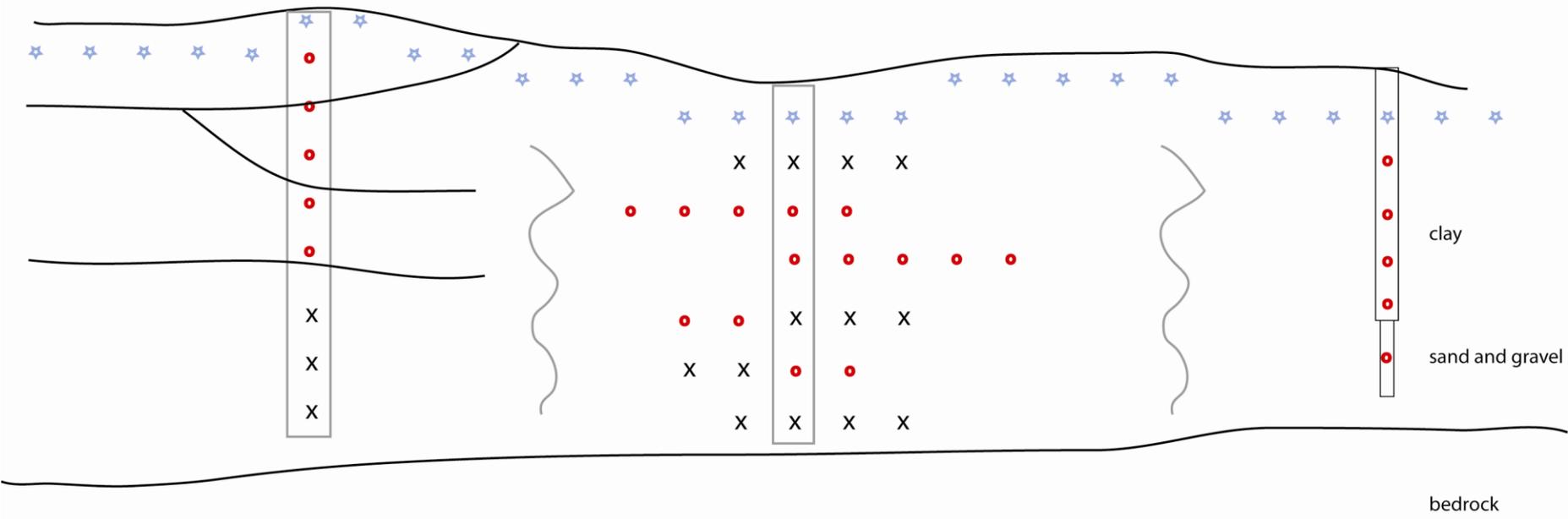




QSTRAT

MODEL

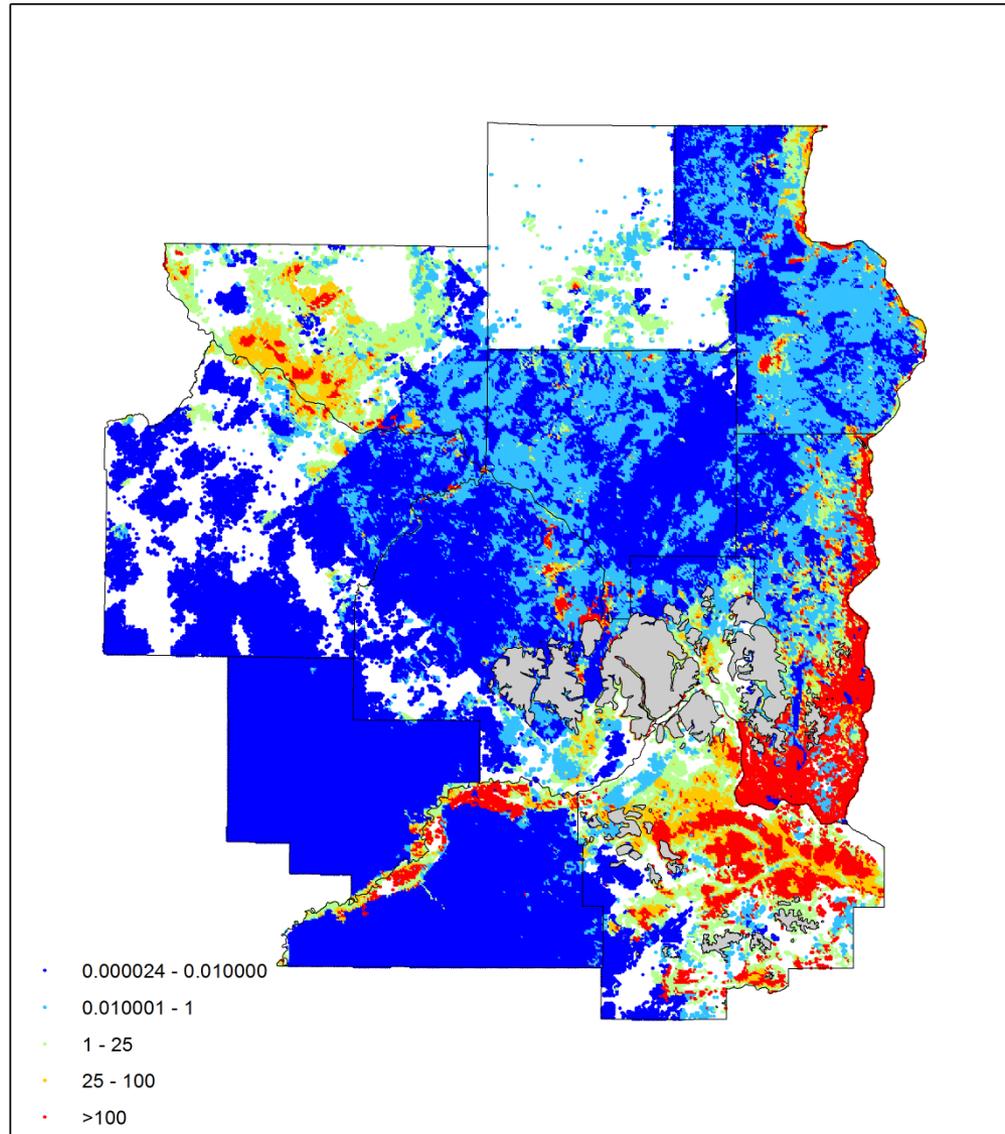
WELLS



- ★ K value assigned from surficial map
- K value assigned
- X unassigned

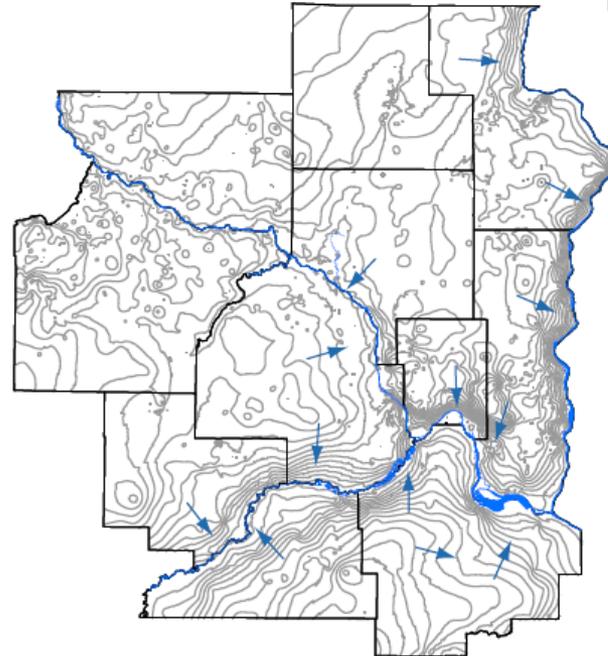
xK_CLASS Corresponds to fields "K_class," and "K_class_sgpg," code specifies range of expected hydraulic conductivity in feet/day. Reference to "deep" in codes 8-11 are for point depths greater than 60 feet from land surface, estimated to be 2 orders of magnitude lower hydraulic conductivity than equivalent textures in shallow settings:

<i>code</i>	<i>Texture Description</i>	<i>Kmax (ft/day)</i>	<i>Kmin (ft/day)</i>
1	loam to clay loam	3.0E-3	1.0E-3
2	loam to sandy loam	2.0E+1	1.0E-1
3	loam, silt rich; silt and clay	2.0E-2	3.0E-4
4	loam to sandy clay loam	2.0E+1	1.0E-1
5	sand and gravel	5000	100
6	fine sand	30	0.3
7	sandy silt	3	0.1
8	loam to clay loam - deep	3.0E-5	1.0E-5
9	loam to sandy loam - deep	2.0E-1	1.0E-3
10	loam, silt rich; silt and clay - deep	2.0E-4	3.0E-6
11	loam to sandy clay loam - deep	2.0E-1	1.0E-3



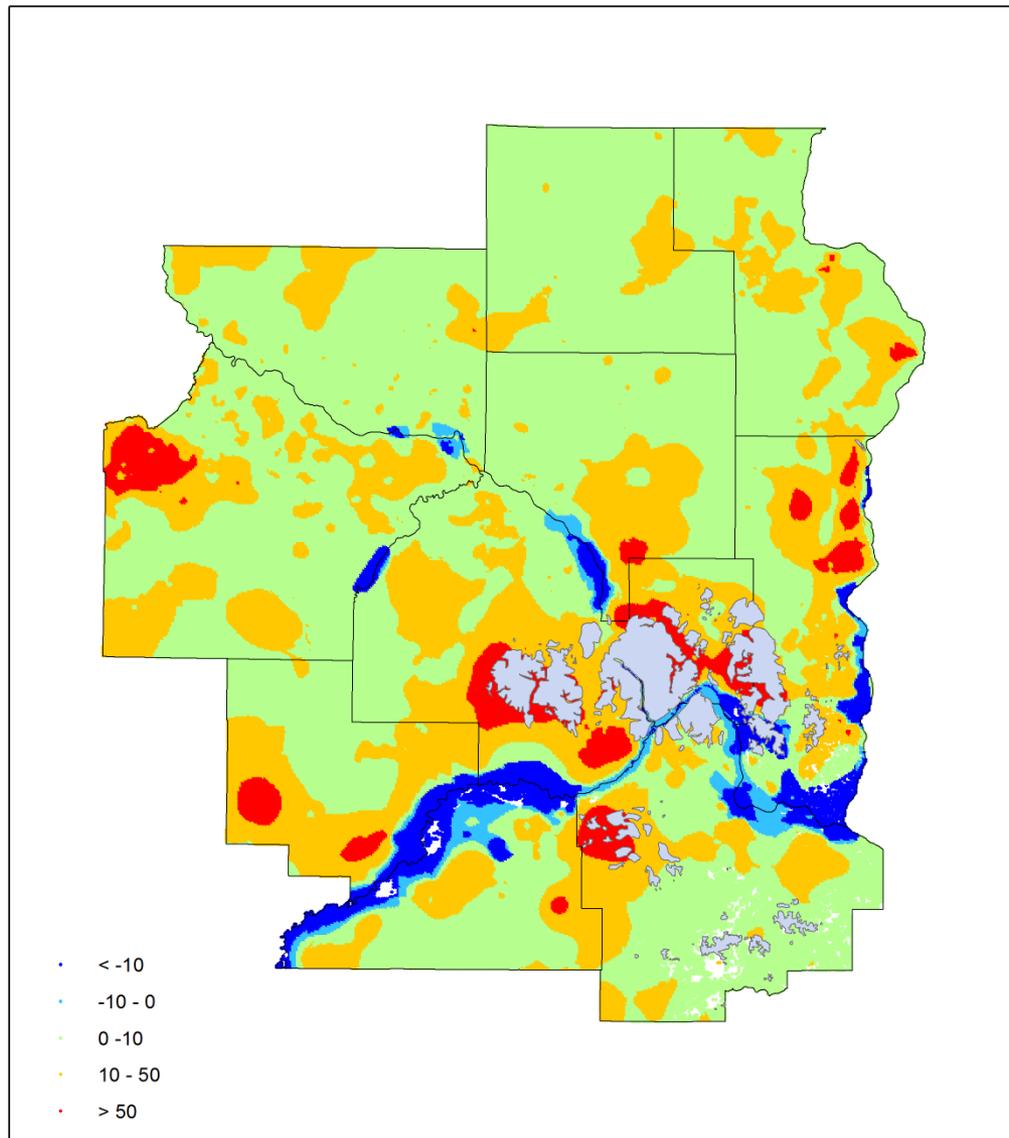
Harmonic mean of vertical hydraulic conductivity from the regional water table to the bedrock surface

March 2008 Prairie du Chien-Jordan Potentiometric surface (Sanocki et al., 2009)

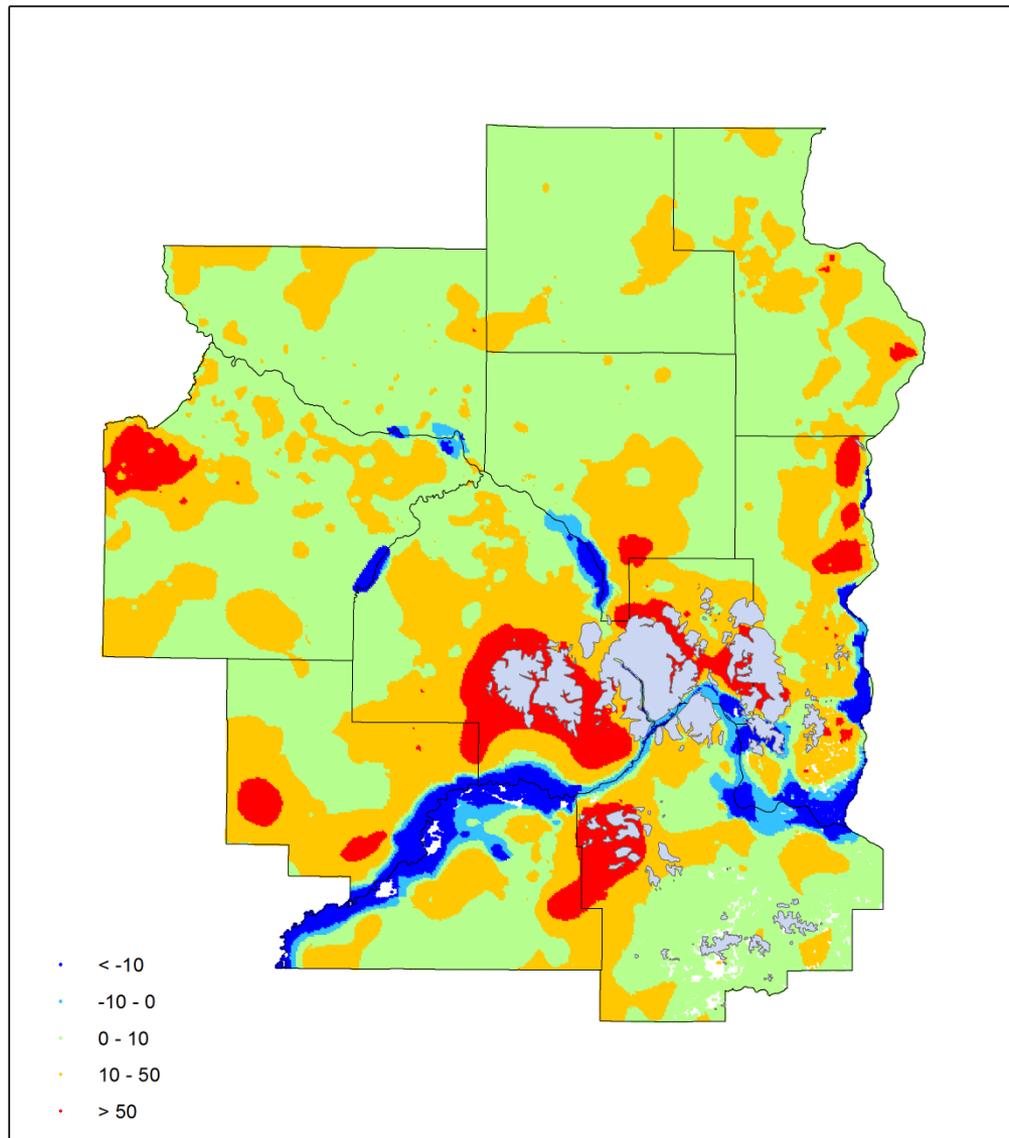


Regional water table surface (Barr, 2010)

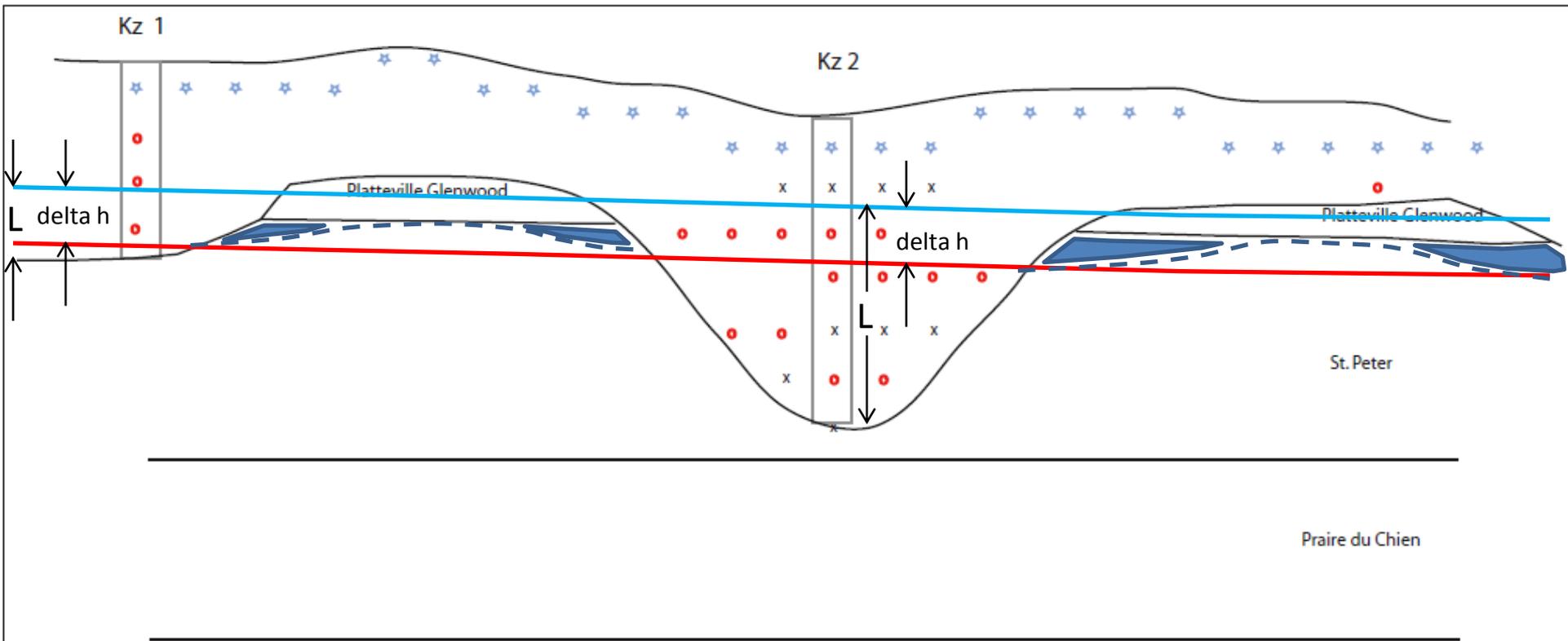
groundwater flow direction



Regional water table – modified OPCJ March
2008 synoptic surface



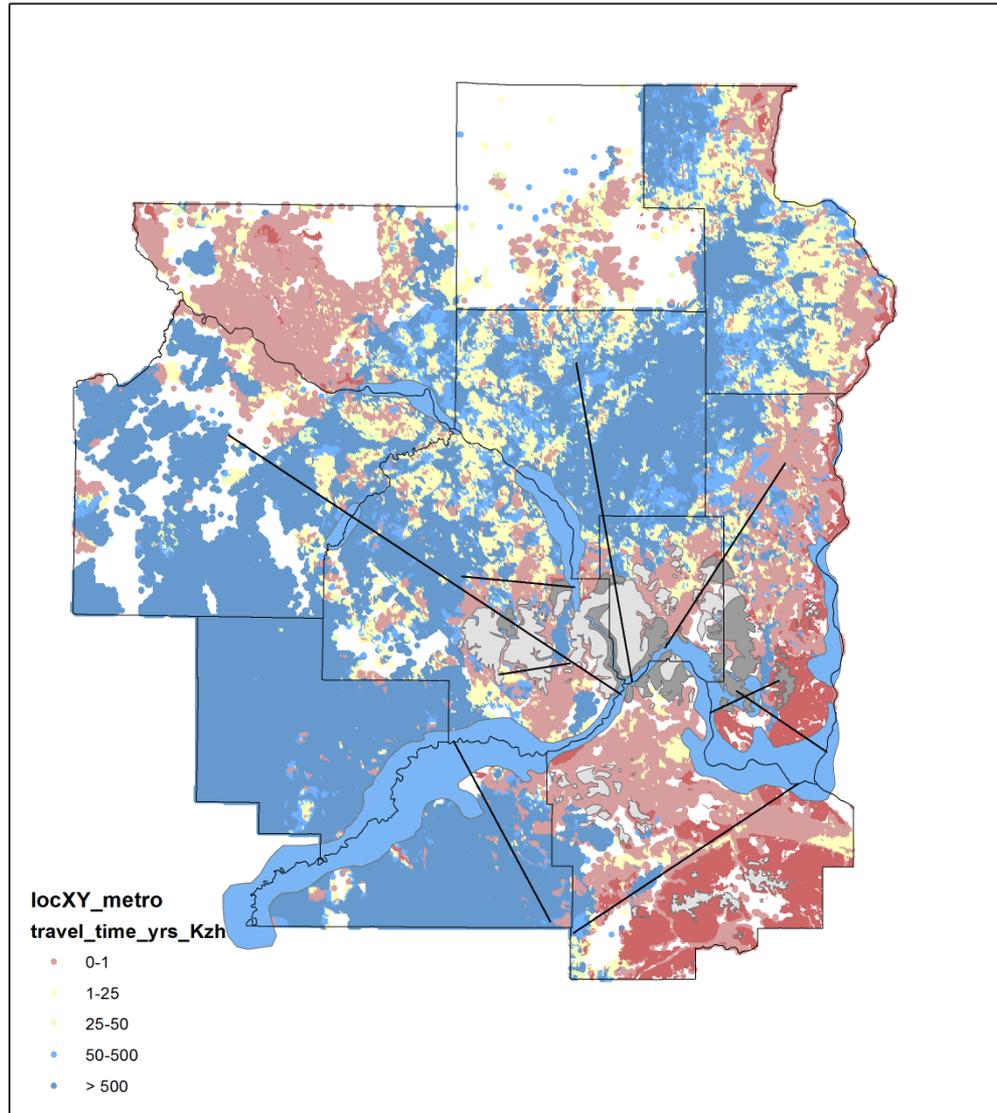
Regional water table – modified OPCJ August
2008 synoptic surface



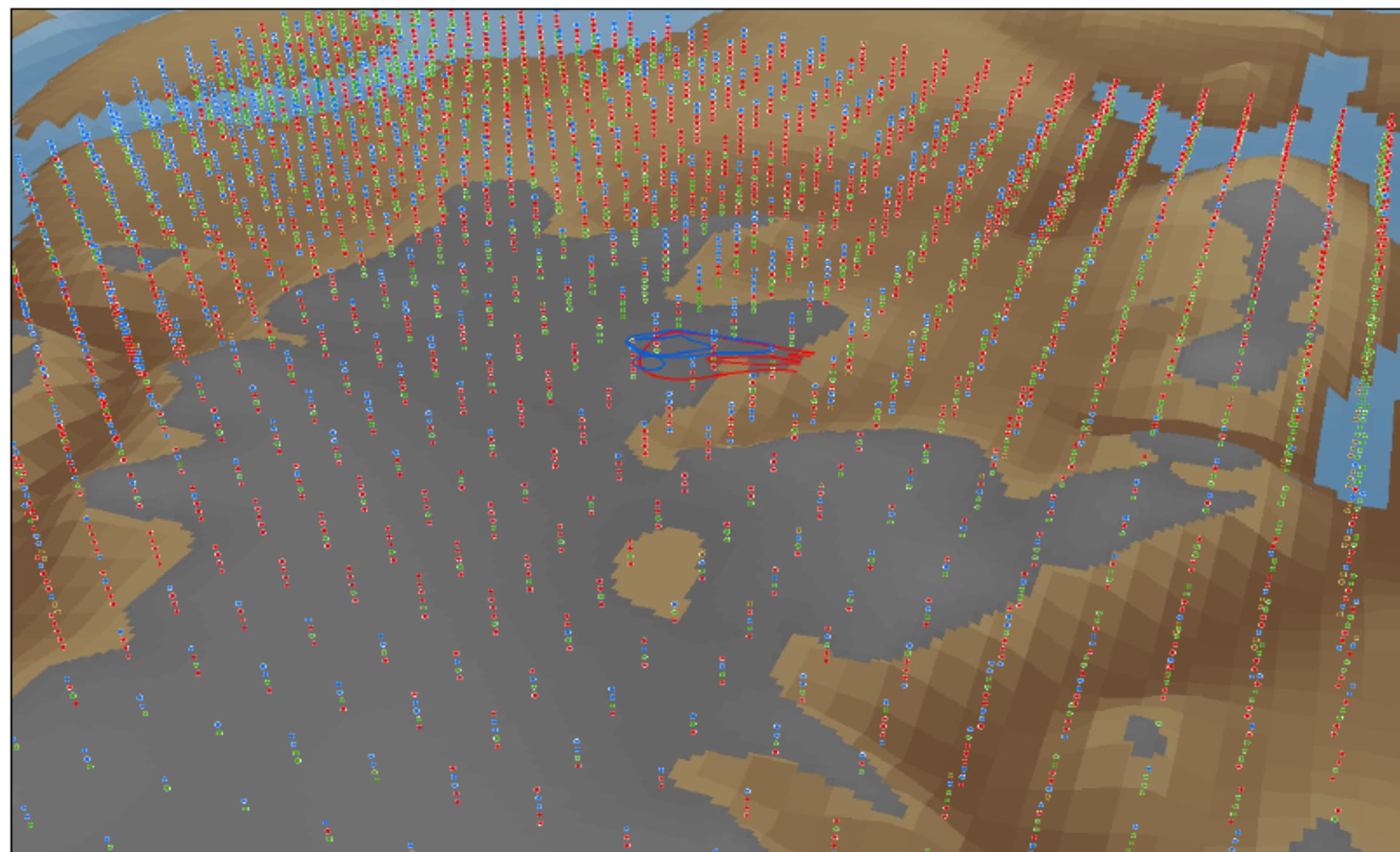
- ☆ K value assigned from surficial map
- K value assigned
- x unassigned

- Barr water table
- USGS March '08 synoptic
- - - St. Peter static water elevation

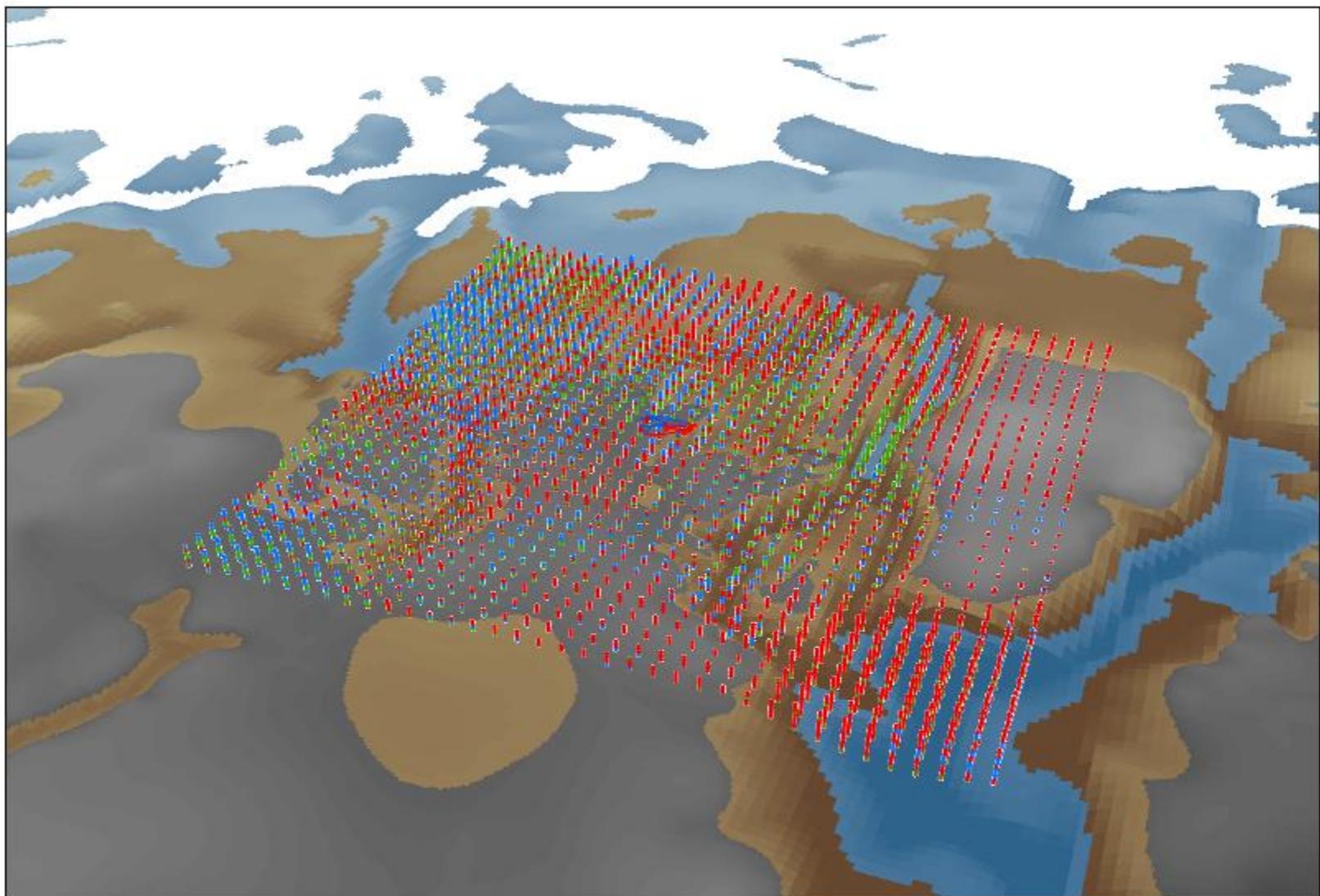
$$\text{gradient} = \frac{\text{delta } h}{L}$$
 Kz saturated mean calculated only over distance L



Calculated time of travel from water table to the bedrock surface, in years.



A



B.

Generalized unconsolidated sediment textures.
grid spacing 250 meters in horizontal, 20 feet
in vertical

- coarse-grained
- coarse- to fine-grained
- fine-grained

Bedrock

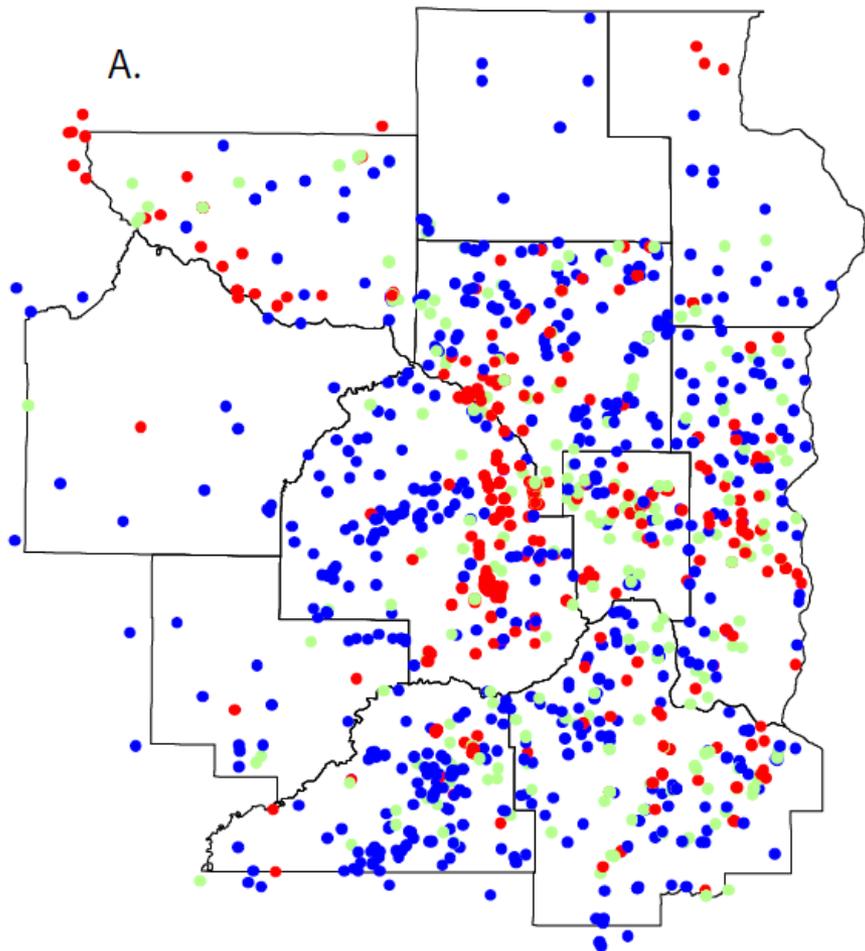
- Platteville Formation
- St. Peter Sandstone
- Prairie du Chien Group
- bedrock stratigraphically lower than the Prairie du Chien Group



1990 plume

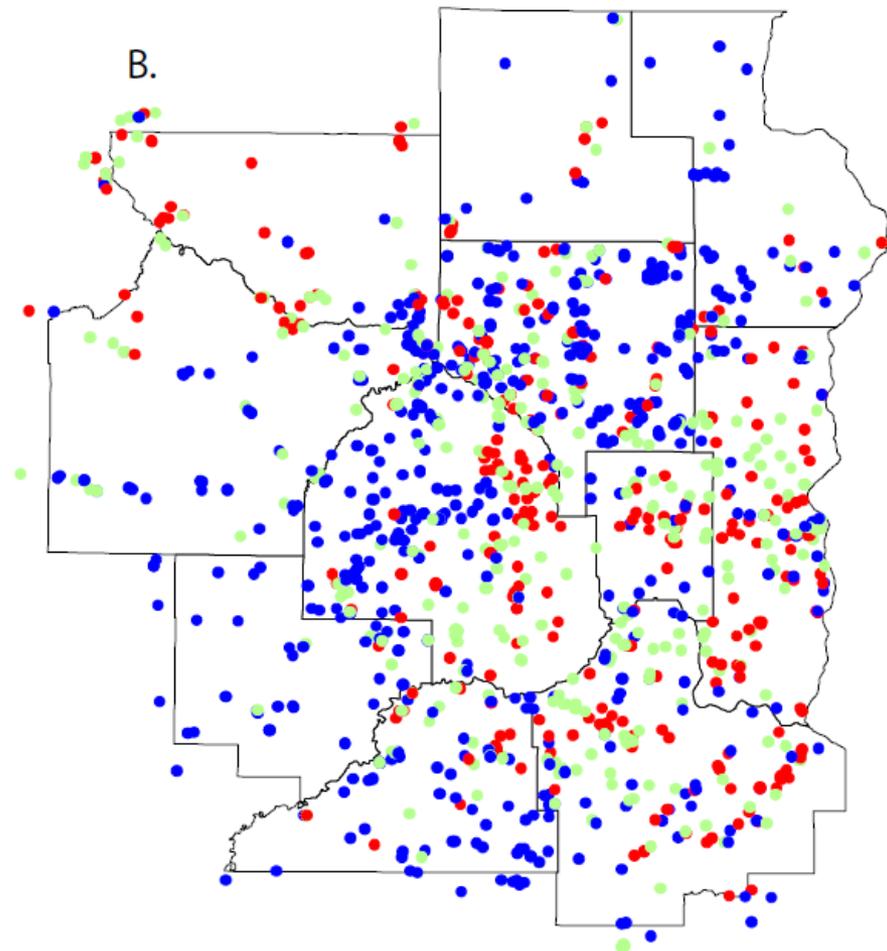


2009 plume



chloride concentration (mg/l)

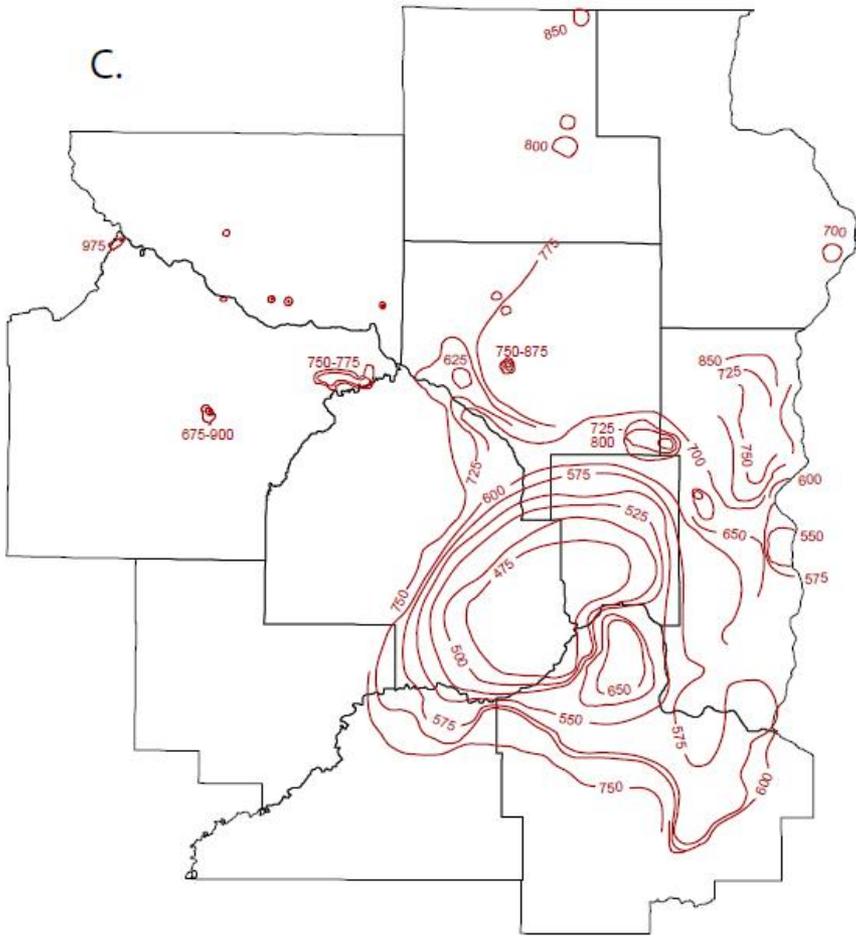
- 15 to 4000
- 5 to 15
- 0 to 5



tritium concentration (TU)

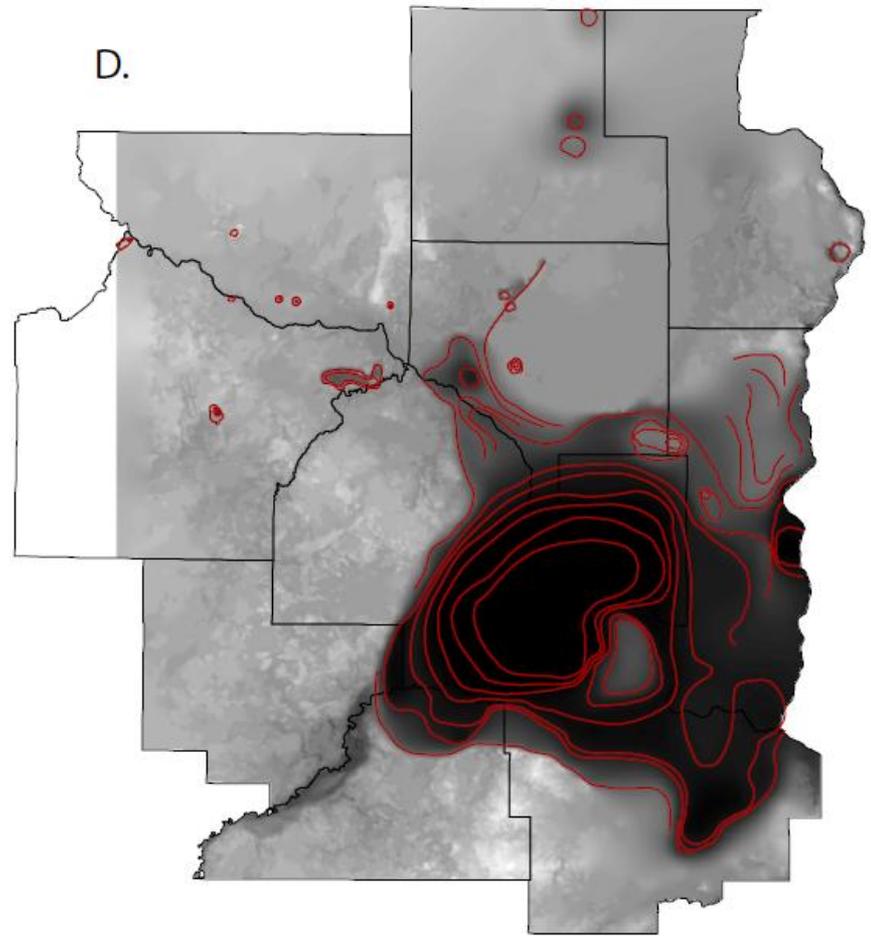
- greater than 10
- 1 to 10
- less than 1

C.

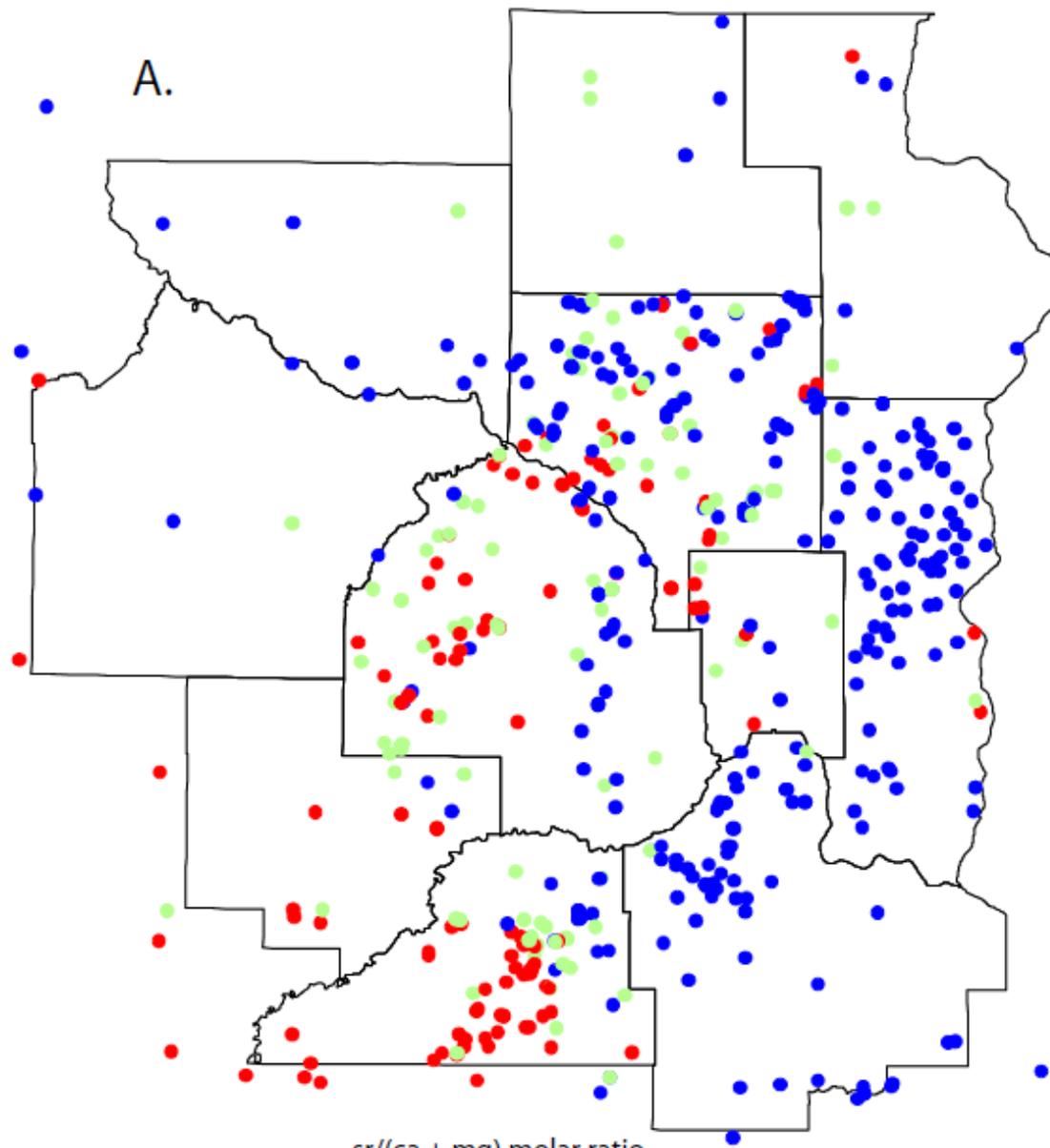


elevation of open-hole top
bedrock wells with detectable tritium

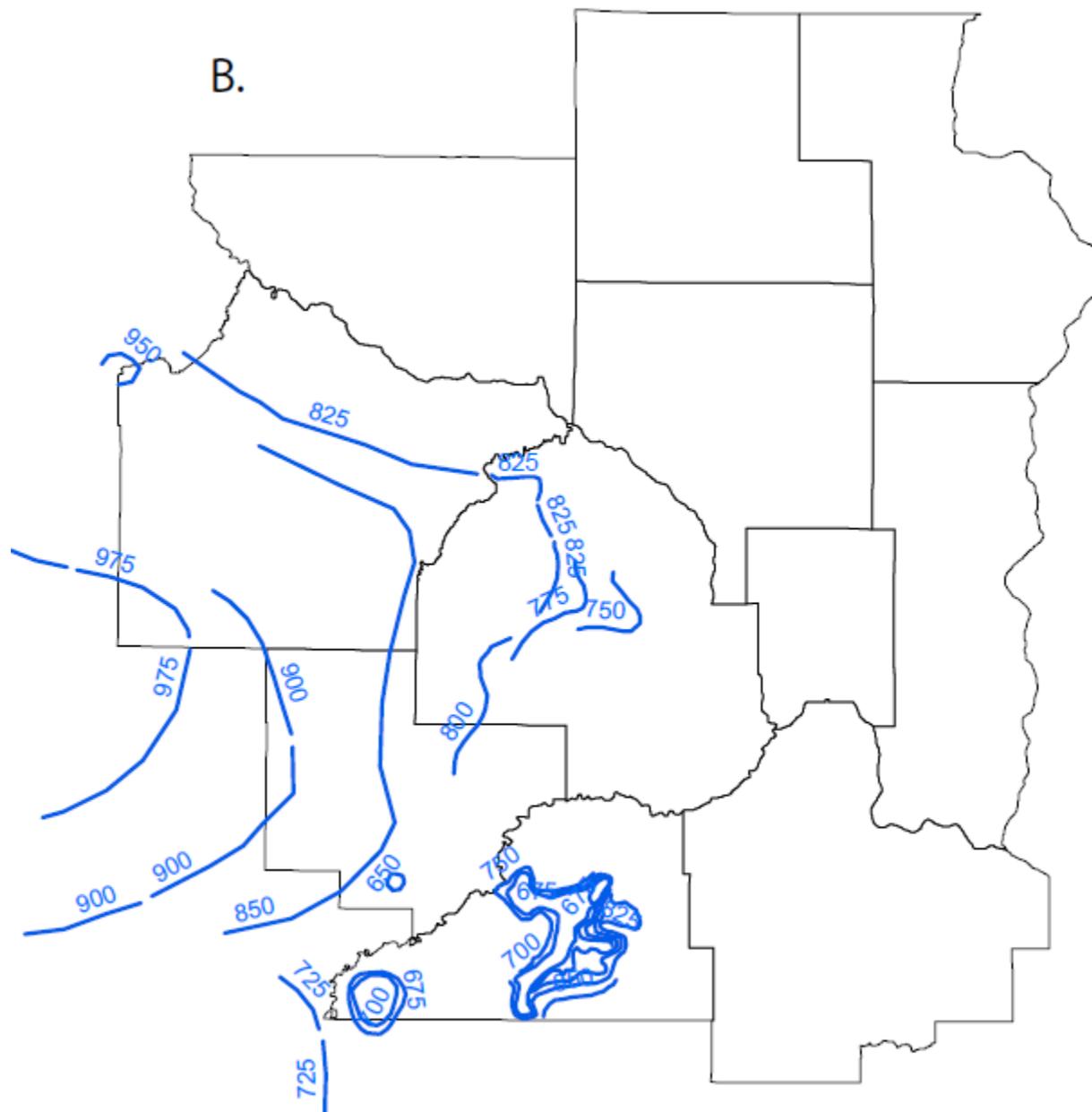
D.



digital elevation model for marking base
elevation for recent waters

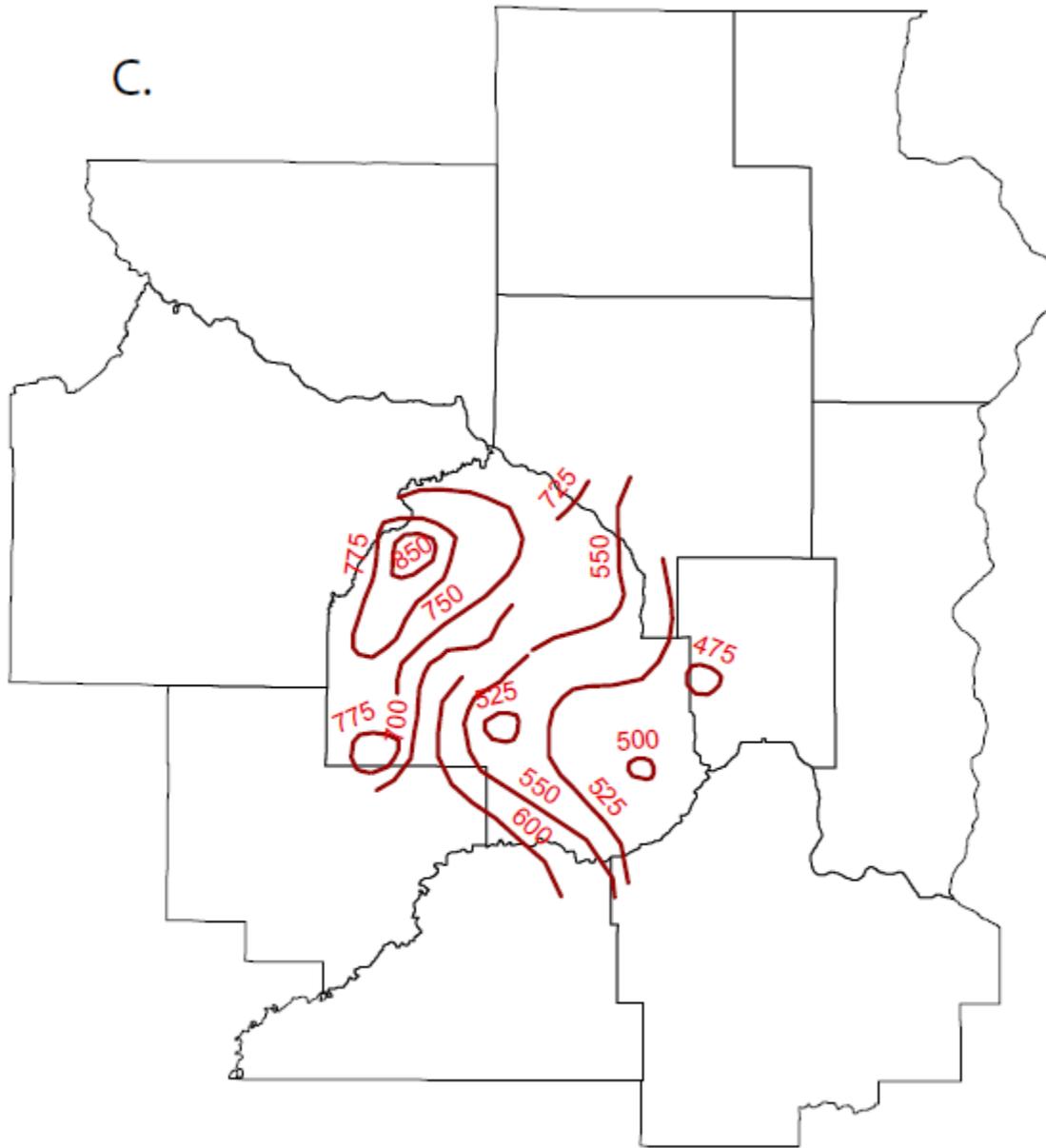


B.



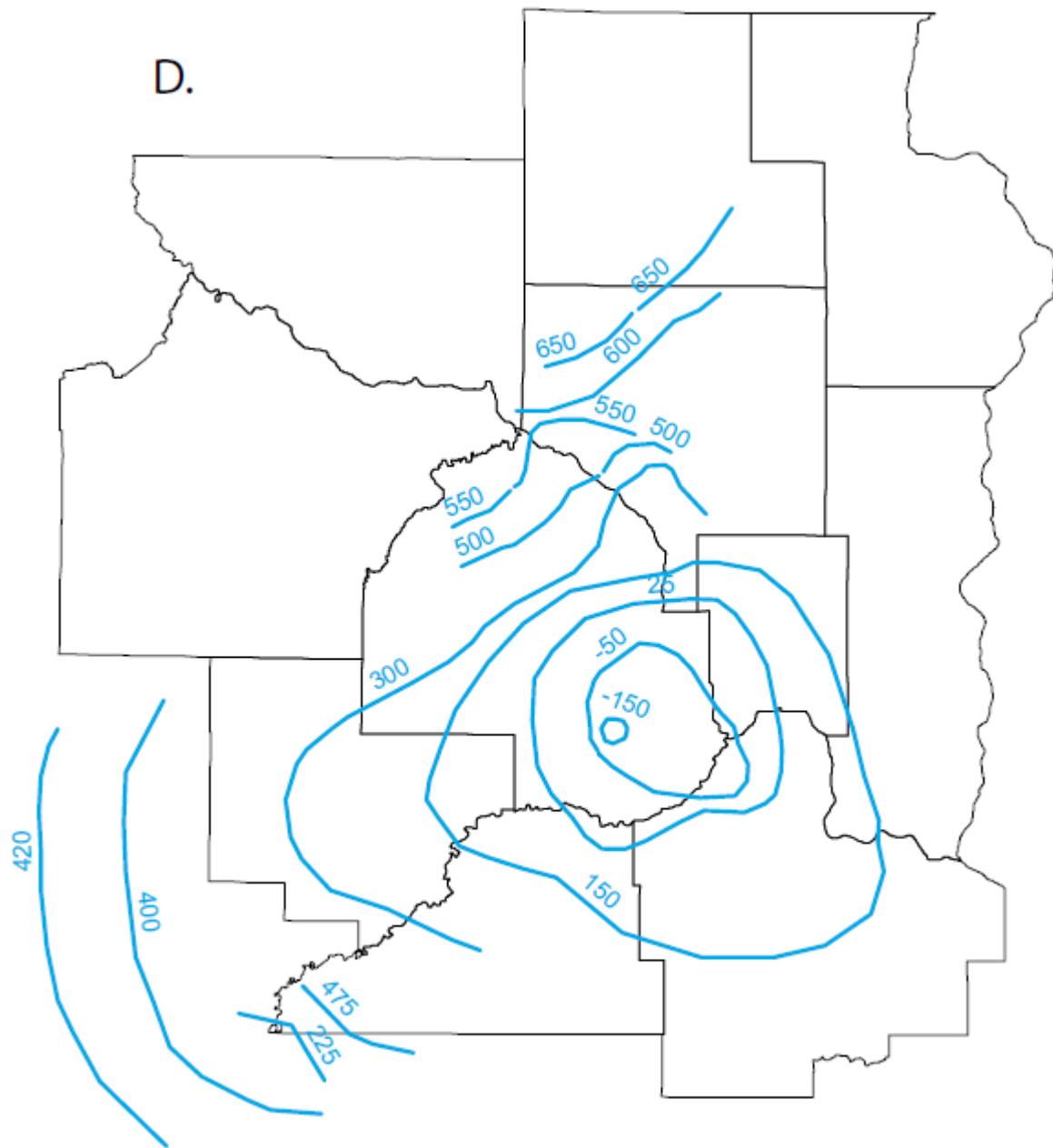
elevation of open-hole top
Quaternary wells with $sr/(ca+mg)$ ratios
greater than 0.001

C.



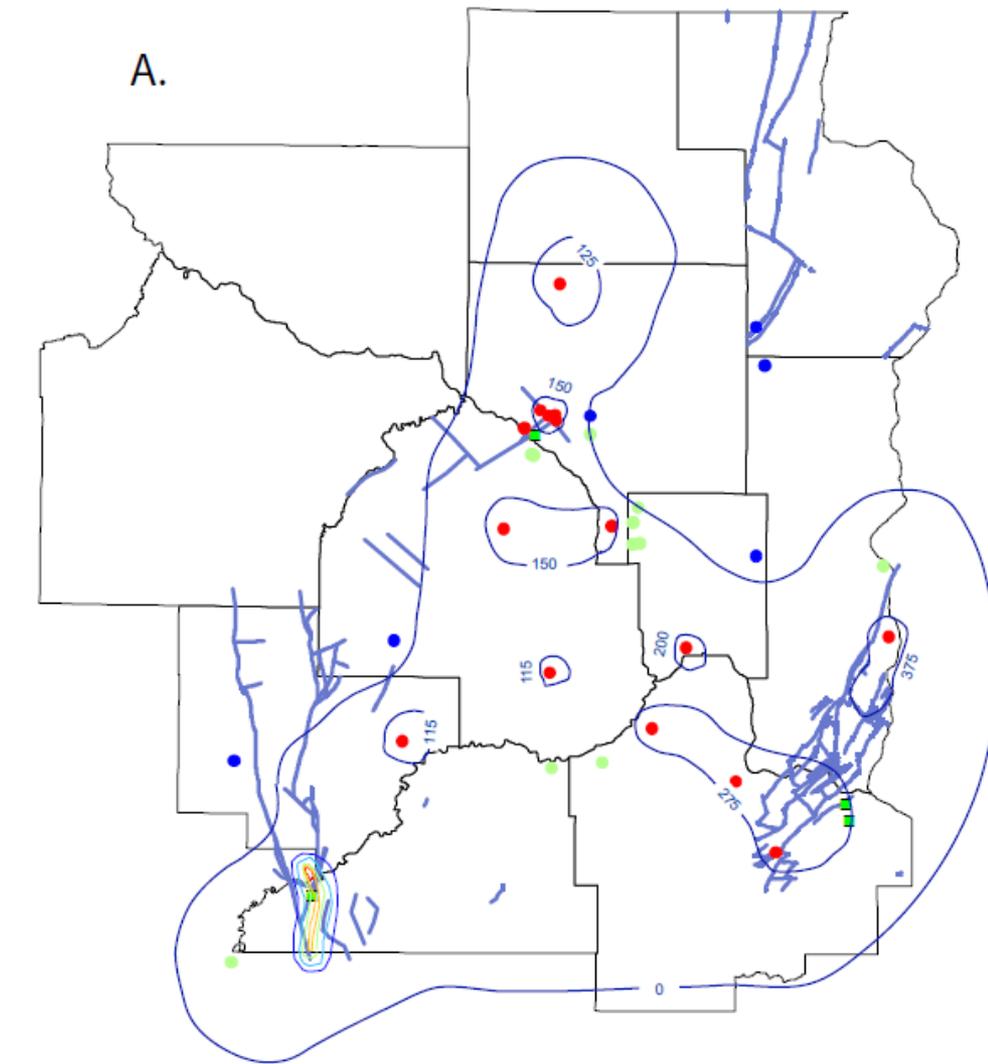
elevation of open-hole top
Jordan wells with $sr/(ca+mg)$ ratios
greater than 0.001

D.



elevation of open-hole top
Mt. Simon wells with $sr/(ca+mg)$ ratios
greater than 0.001

A.



cl concentrations from samples
with c14 ages greater than 1200 years

- 15 to 4000
- 3 to 15
- 0.1 to 3

height above preCambrian surface (ft)

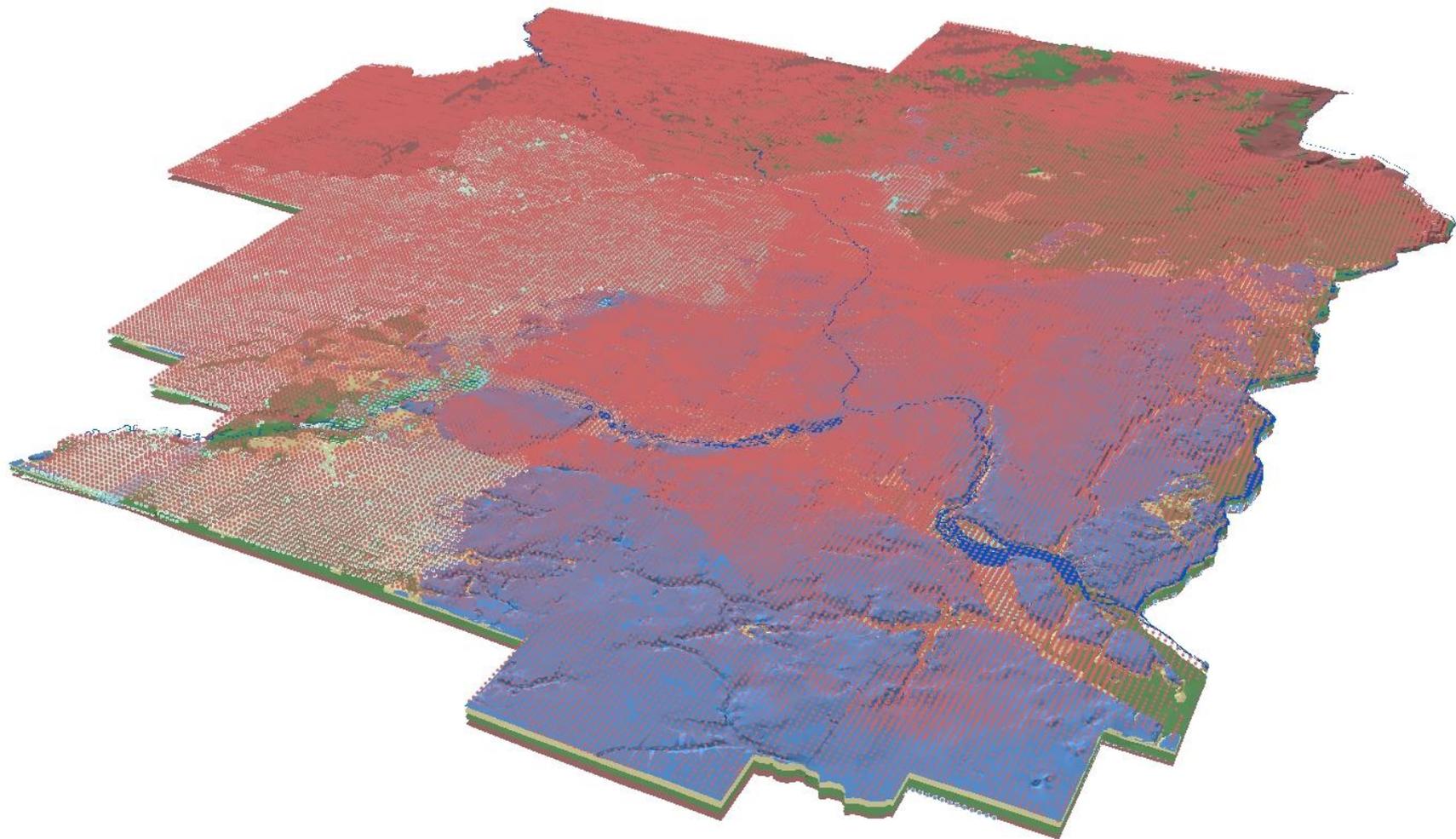
faults

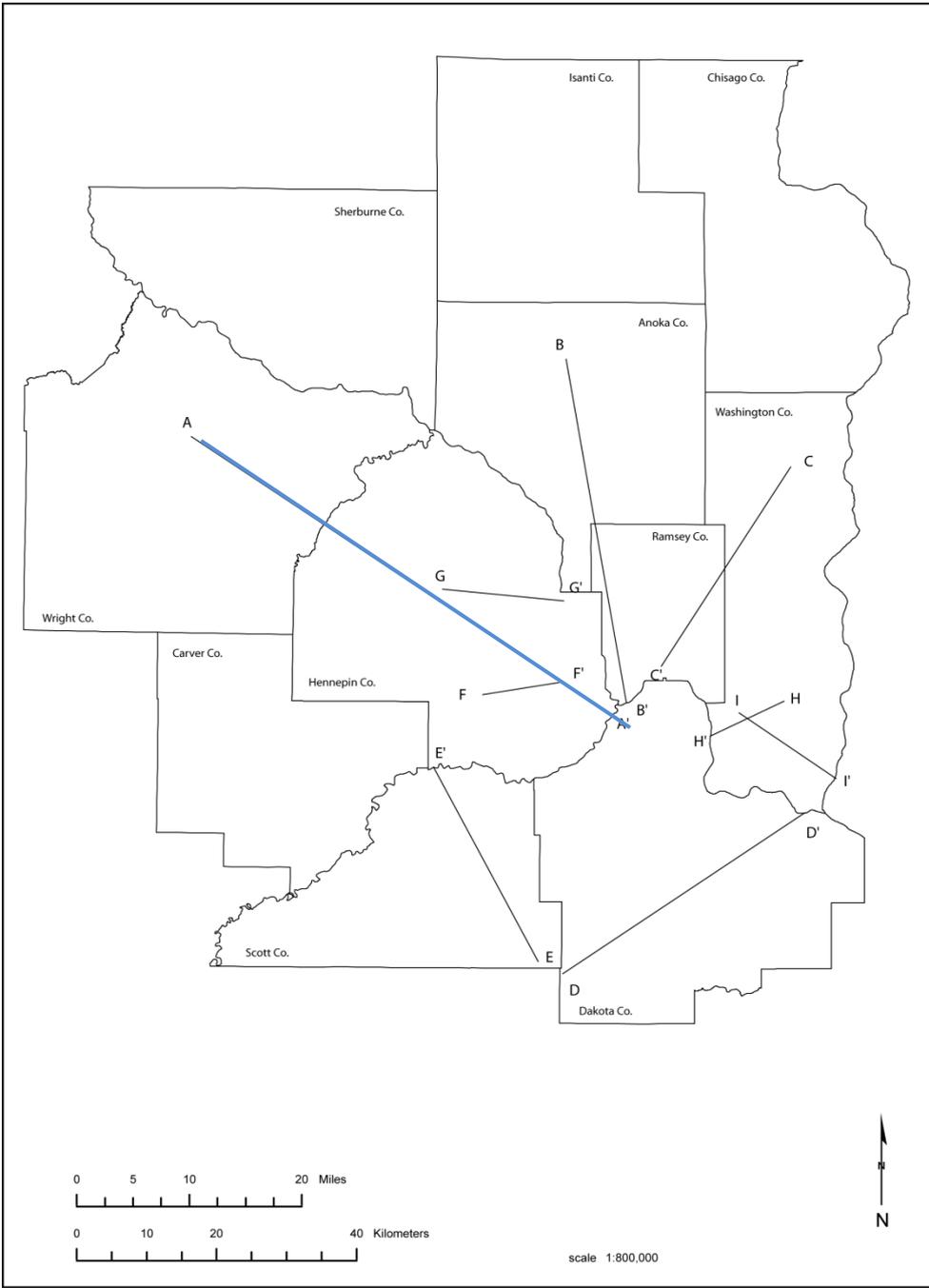
Hall and others, 1911

■ cl greater than 40 mg/l

elevation of elevated cl in
unconsolidated desposits, Belle Plaine area

- 531 -575
- 526 - 530
- 301 -525
- 201 - 300
- 200





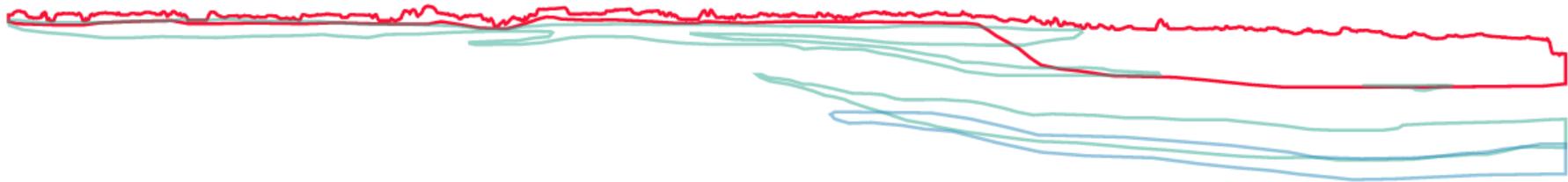
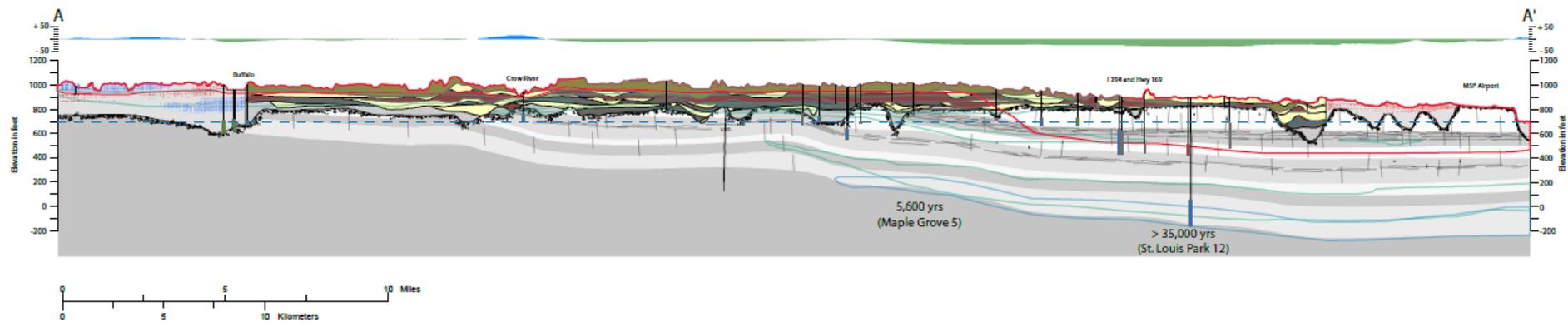
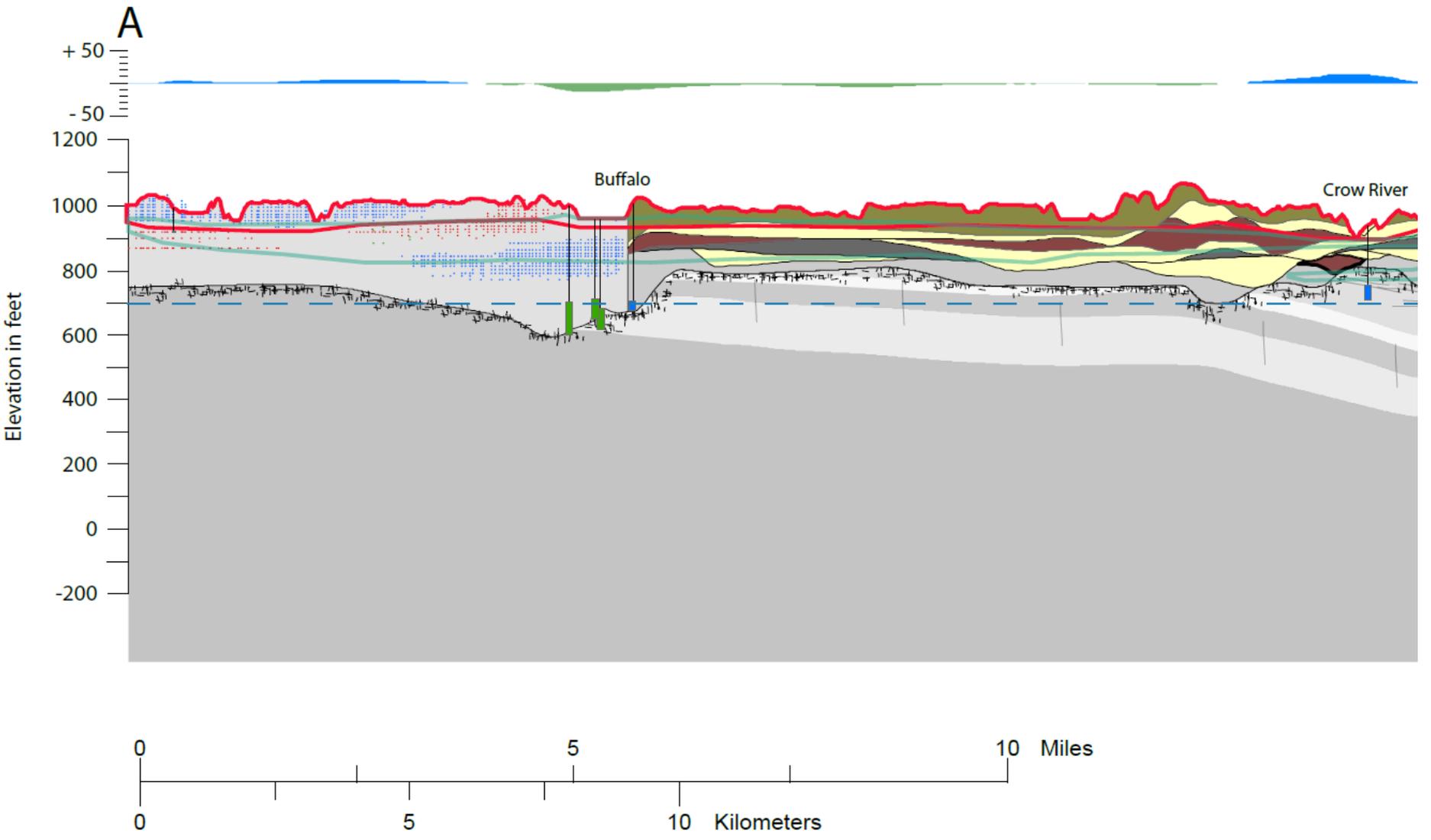
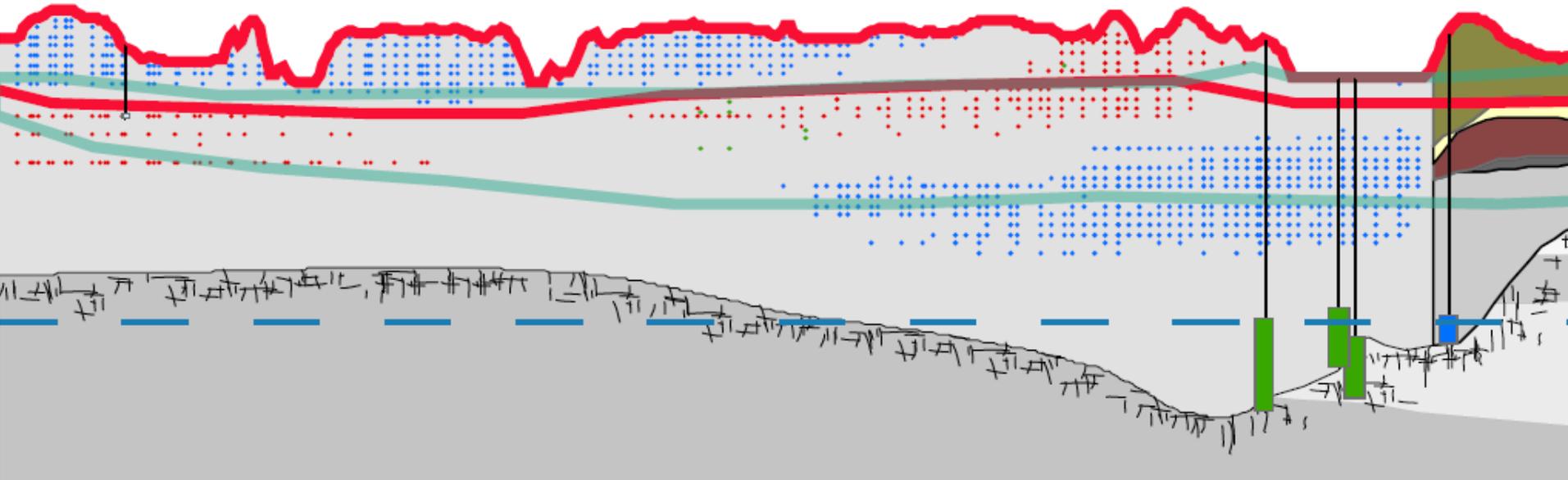


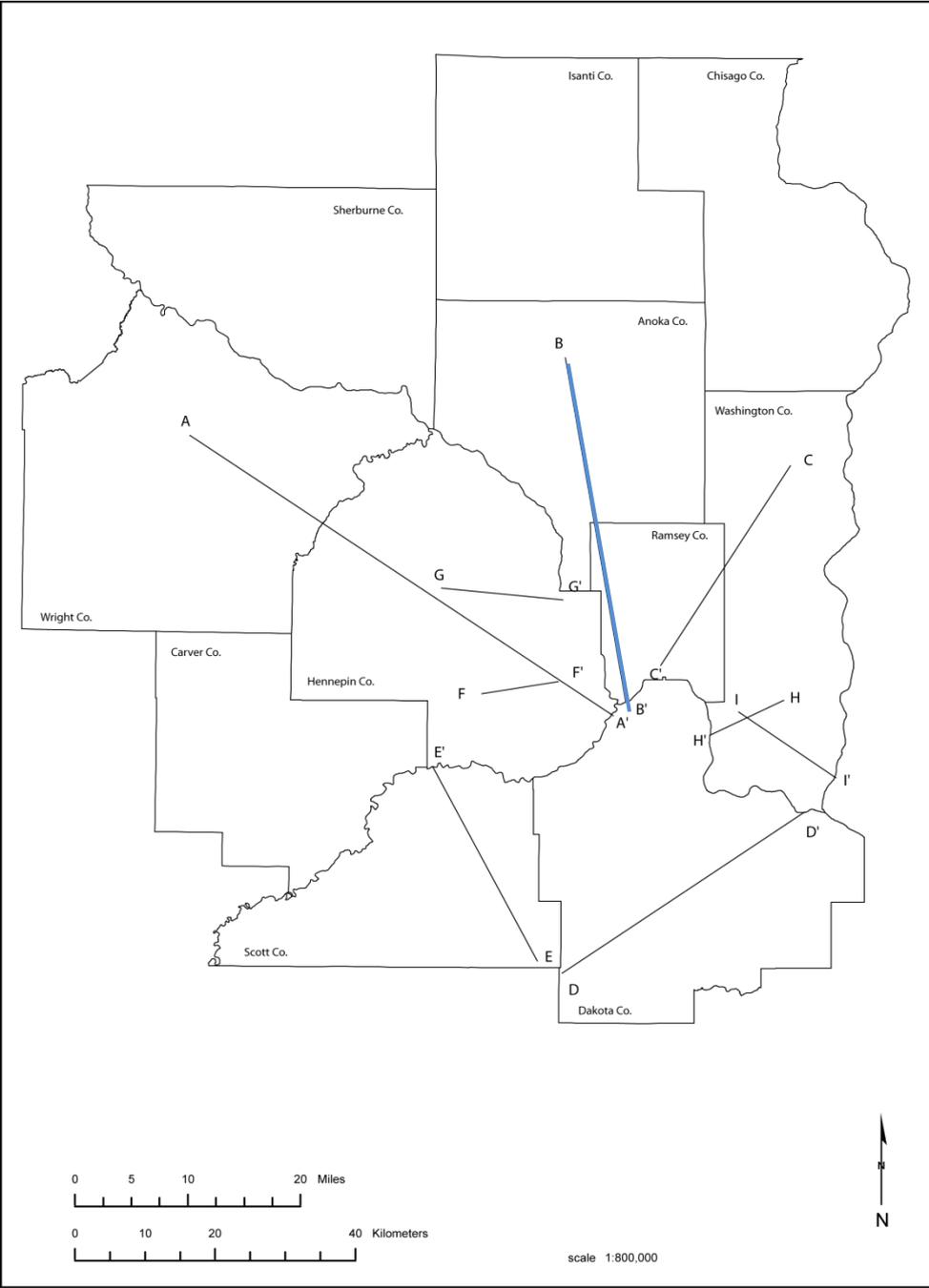
Figure 16

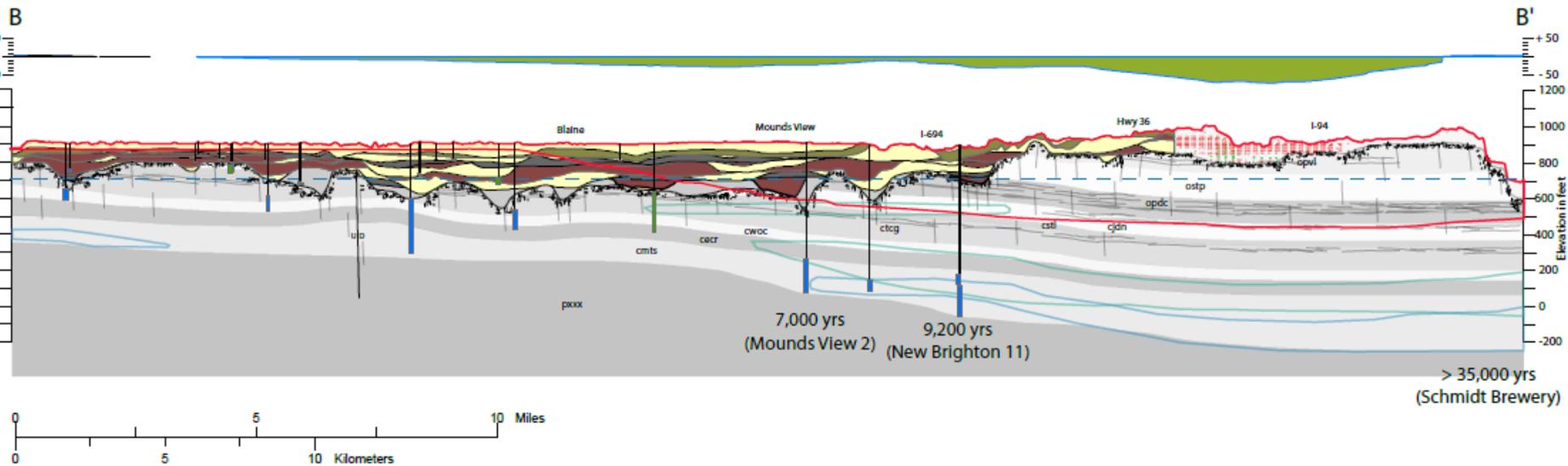
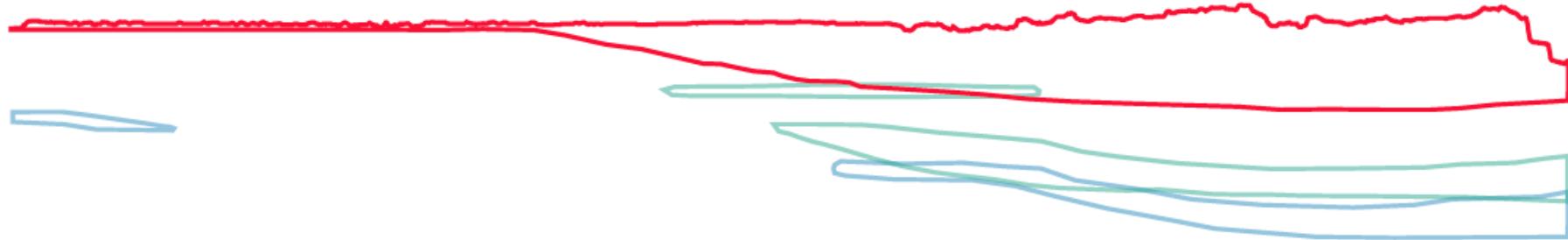


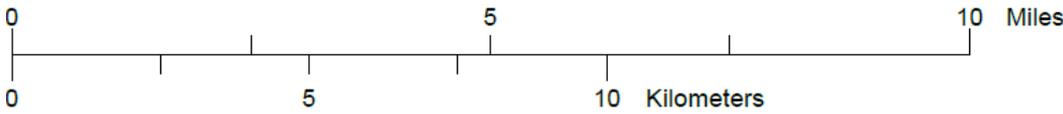
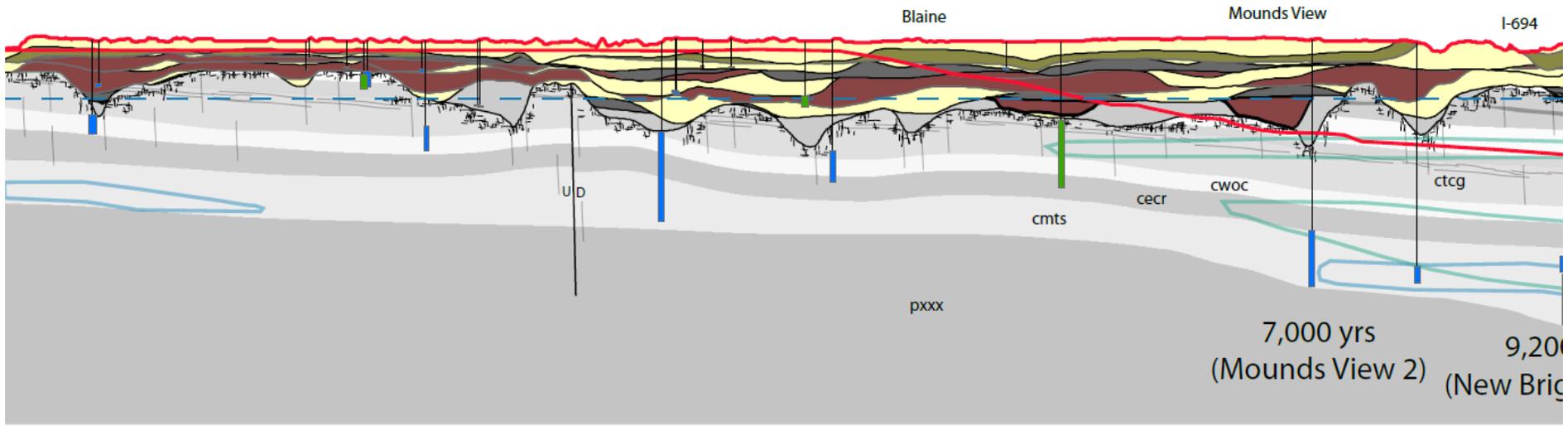


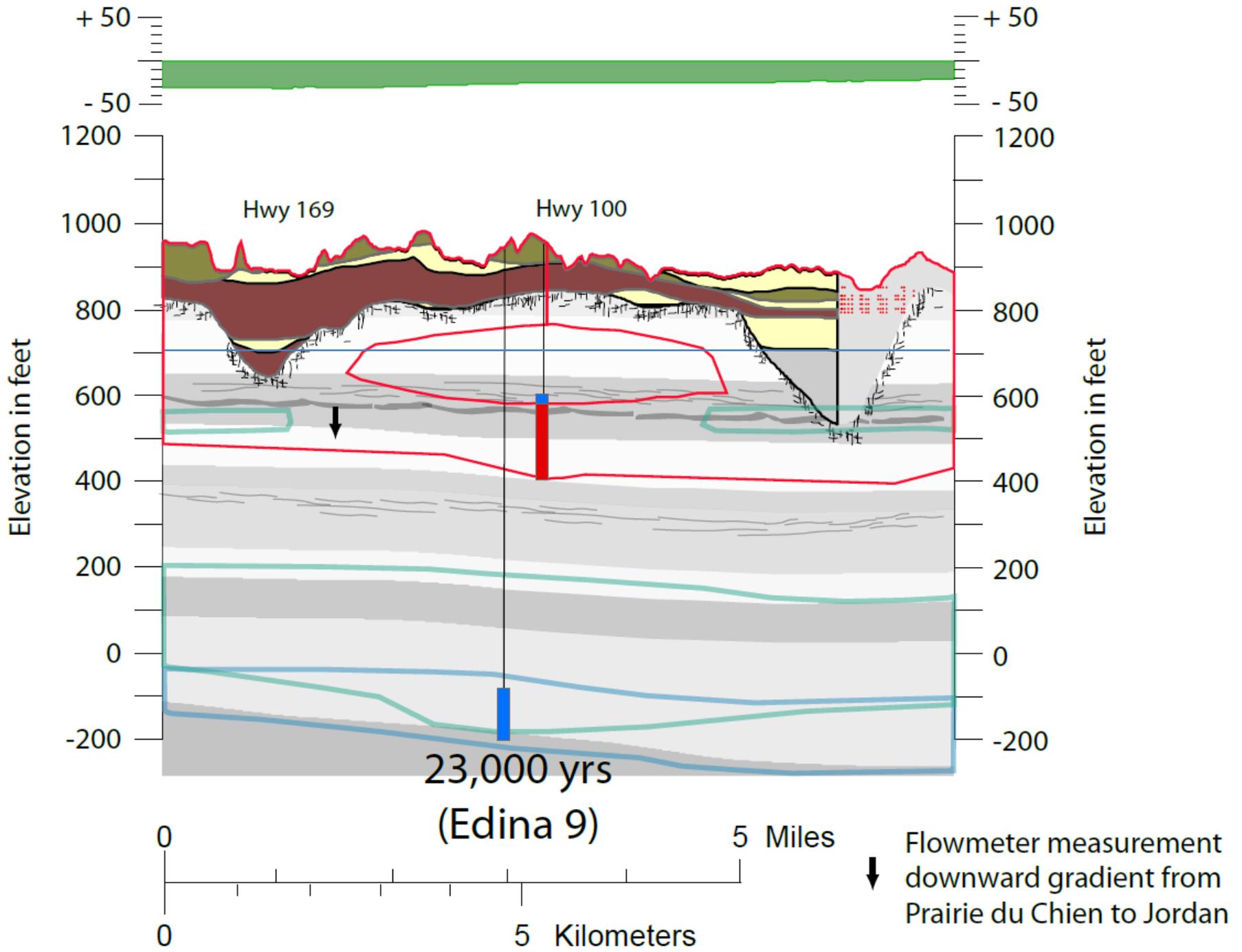
Buffalo



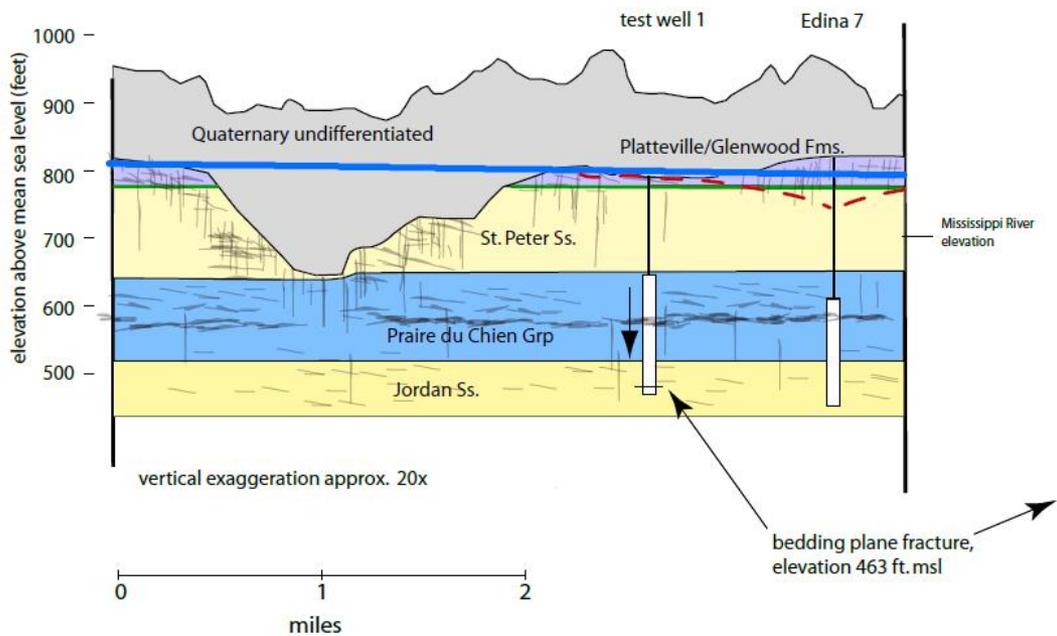




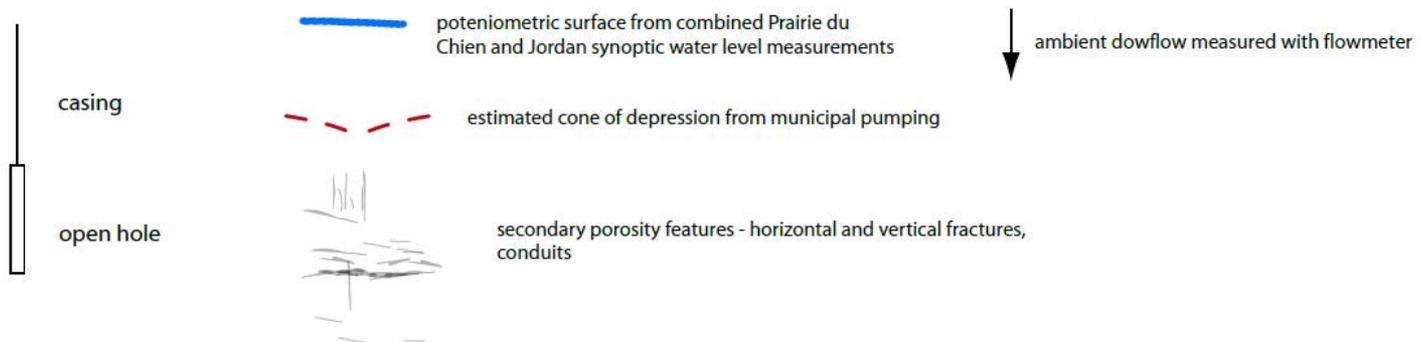


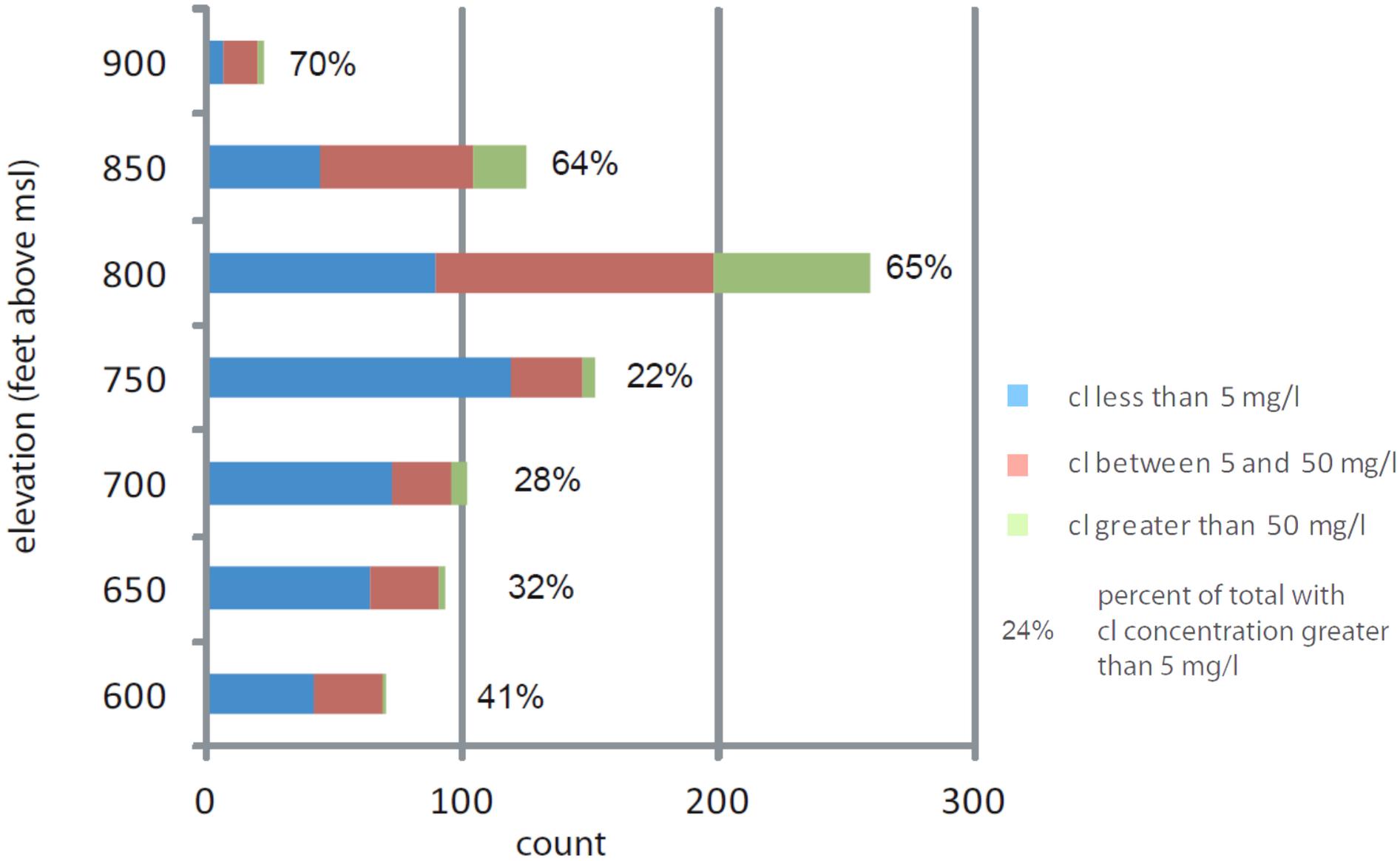


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suspended sand grains entering bedding plane fracture under turbulent flow conditions





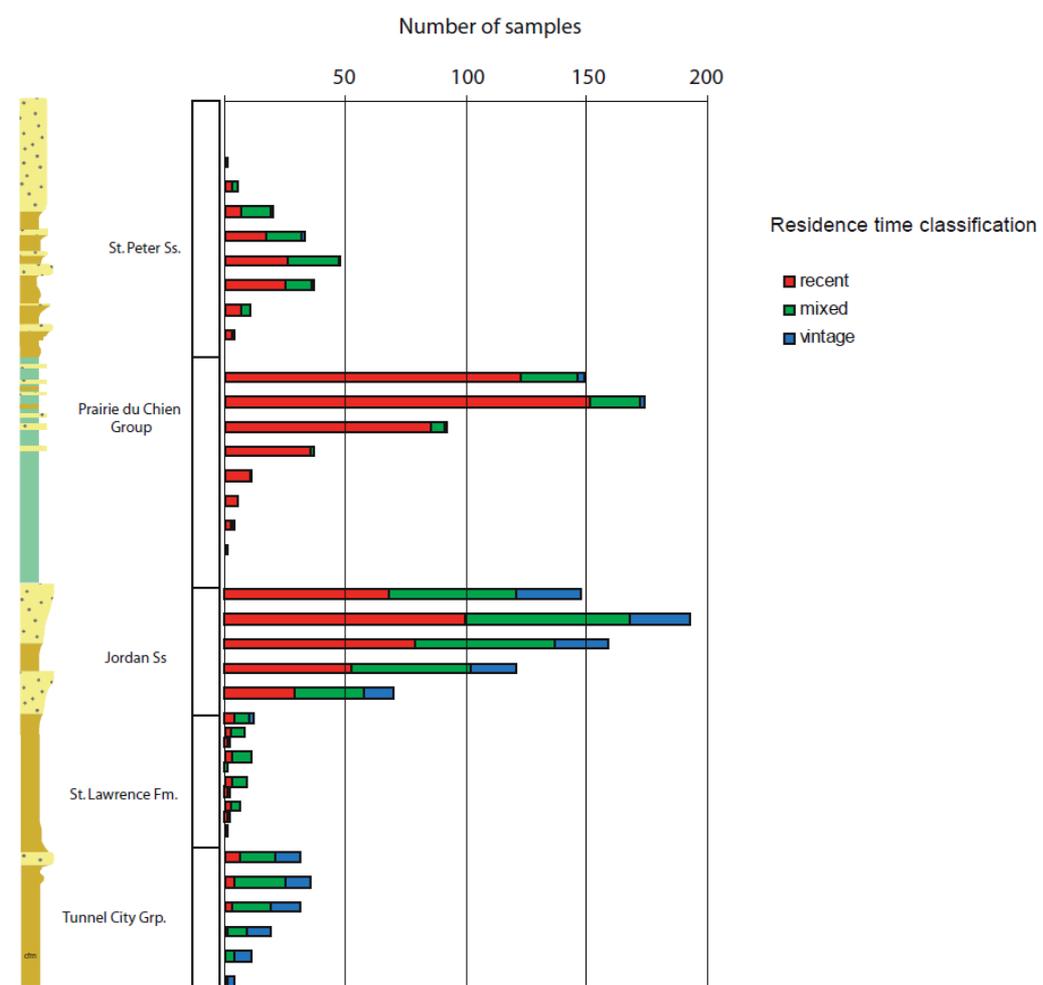
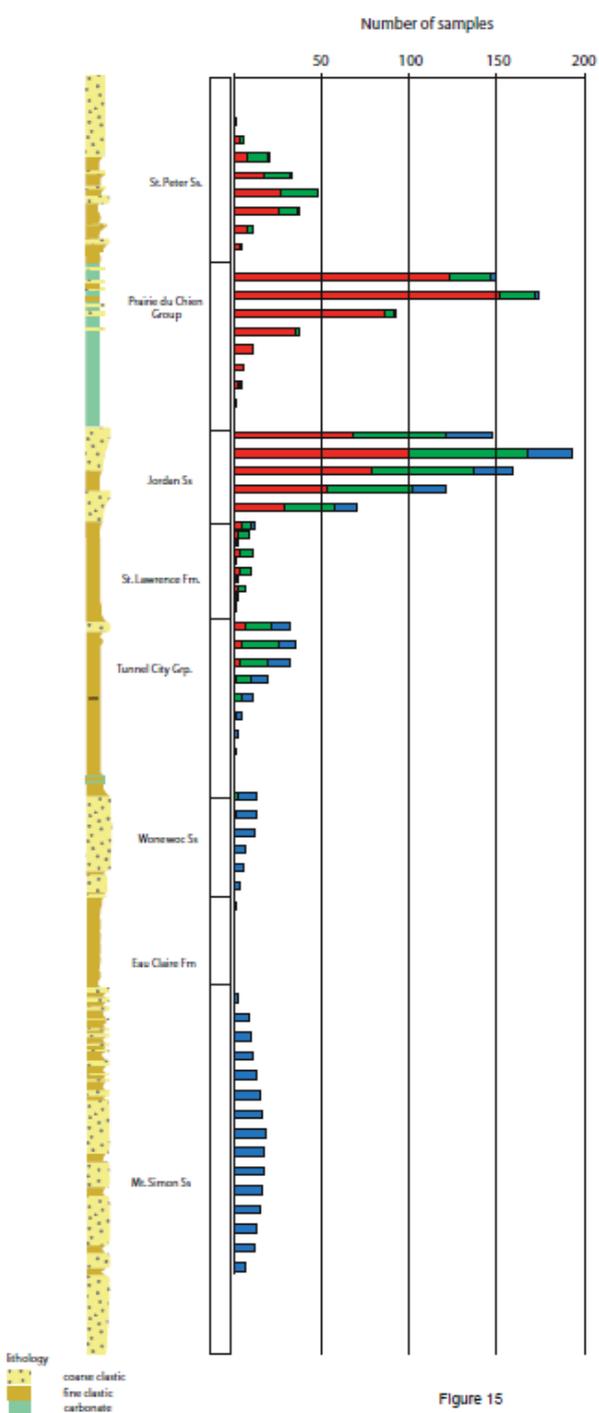


Figure 15

Conclusions

- Gradient matters!
- Distribution of geologic materials in unconsolidated material is complex, but not without regional patterns.
- Chemical and isotopic data help refine conceptual models of groundwater flow by providing information on residence time and groundwater pathways