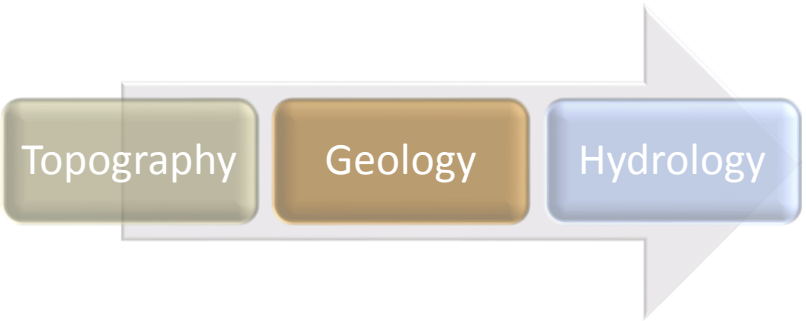

Using groundwater-flow model results to evaluate a useful 3-D GFM mapping scale

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Indiana Geological Survey

CENTER FOR GEOSPATIAL DATA ANALYSIS
INDIANA UNIVERSITY

Background

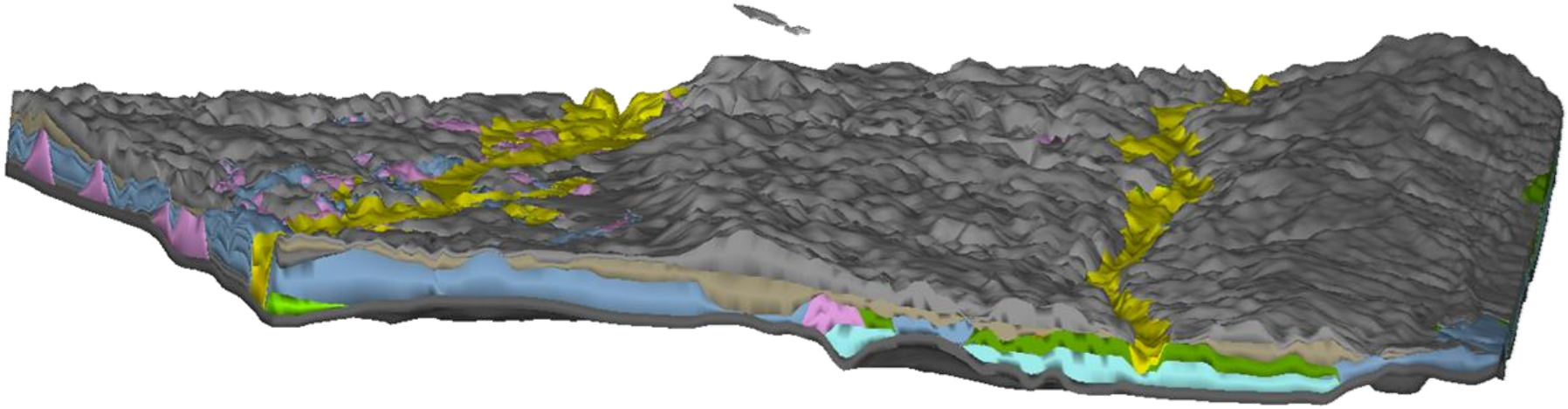
- Three-dimensional geologic framework modeling (GFM)
  - Focus has been on regional scale

    (e.g., US county-scale)
  - Used as input to groundwater modeling
  - Intended to investigate the influence of glacial geology on groundwater flow, recharge, aquifer sensitivity

Where?

- We have worked in two primary geologic settings:
  - Berrien County, Michigan – glaciolacustrine, deltaic, and near-shore environment; primarily unconfined hydrogeologic settings
    - 3-D geologic framework model, 200-meter horizontal scale
    - Steady-state and time-dependent groundwater flow models
  - (Northern) Allen County, Indiana – interlobate glacial environment; both confined and unconfined hydrogeologic systems
    - 3-D geologic framework model, 50-meter horizontal scale
      - Two versions: Simplified (undifferentiated Lagro Fm) and complex
    - Steady-state and time-dependent groundwater flow models

Huntertown (northern Allen County), Indiana



And so?

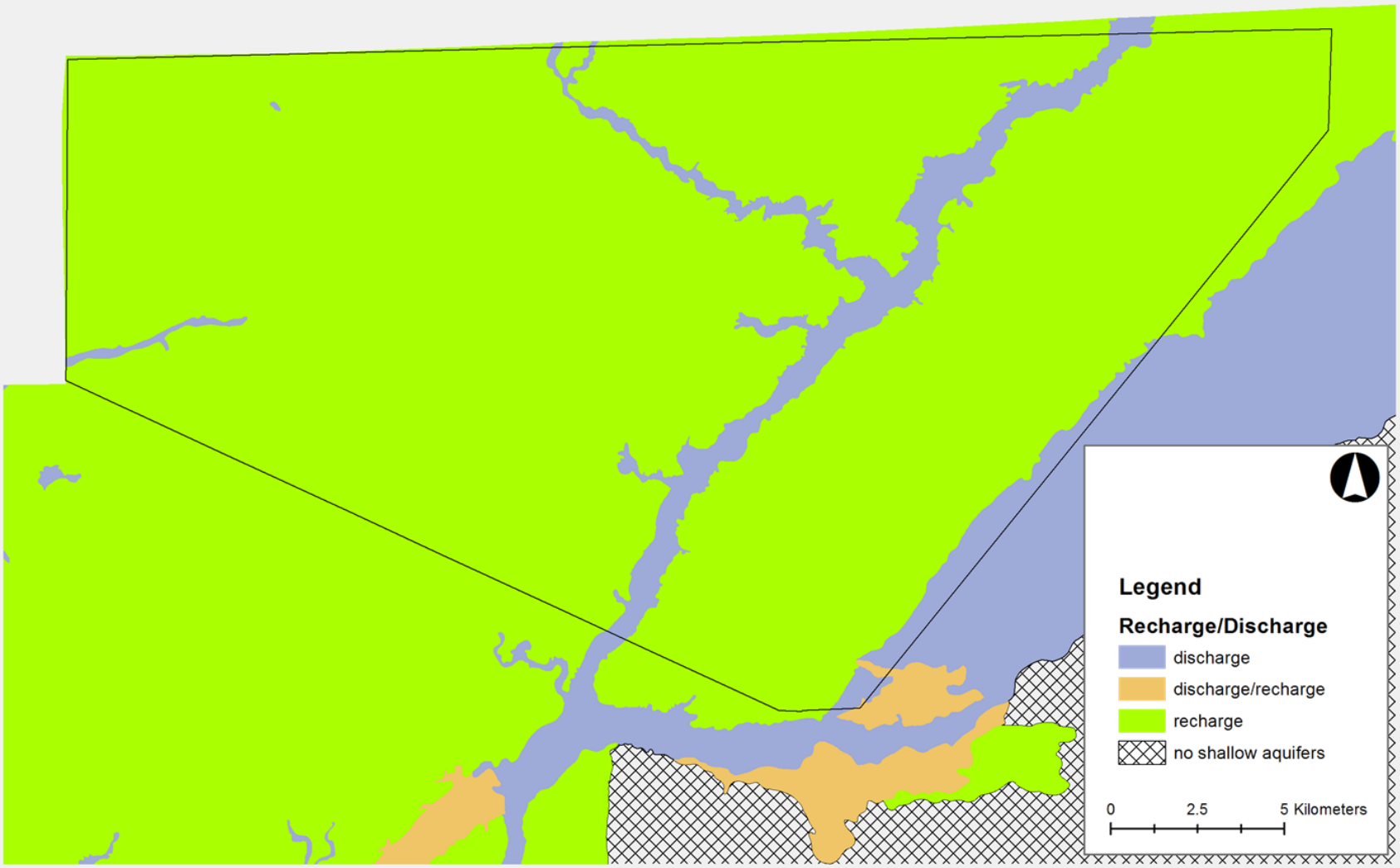
- Groundwater-flow modeling has yielded information on local versus regional flow paths and caused us to question assumptions about groundwater travel times through thick sequences
  - Shorter than we assumed
  - In unconfined settings, flow paths are controlled by topography and flow paths circumvented by stream incision
- Extracting model results for interpretation at the regional scale has prompted inquiry into questions of scale
  - What are useful GFM model dimensions that will answer hydrogeologic questions at a regional scale?
  - What model outputs will inform our understanding of the controls of geology on aquifer recharge and aquifer sensitivity?

What model results did you extract?

- Flow paths in the Berrien County, Michigan model
- Recharge vectors in both models
  - Extract flow vectors at every cell near the simulated water table
  - Examine the magnitude and direction of the z-direction (vertical) vector
  - We can map these values over the landscape to visualize the spatial distribution of recharge

Why Groundwater Recharge?

- Integrated result of near-surface processes and earth-surface and earth-material characteristics
- A dominant control on aquifer sensitivity (Robins 1998; Foster, 1998; Nolan et al., 2007)
- Poorly constrained (in Indiana)

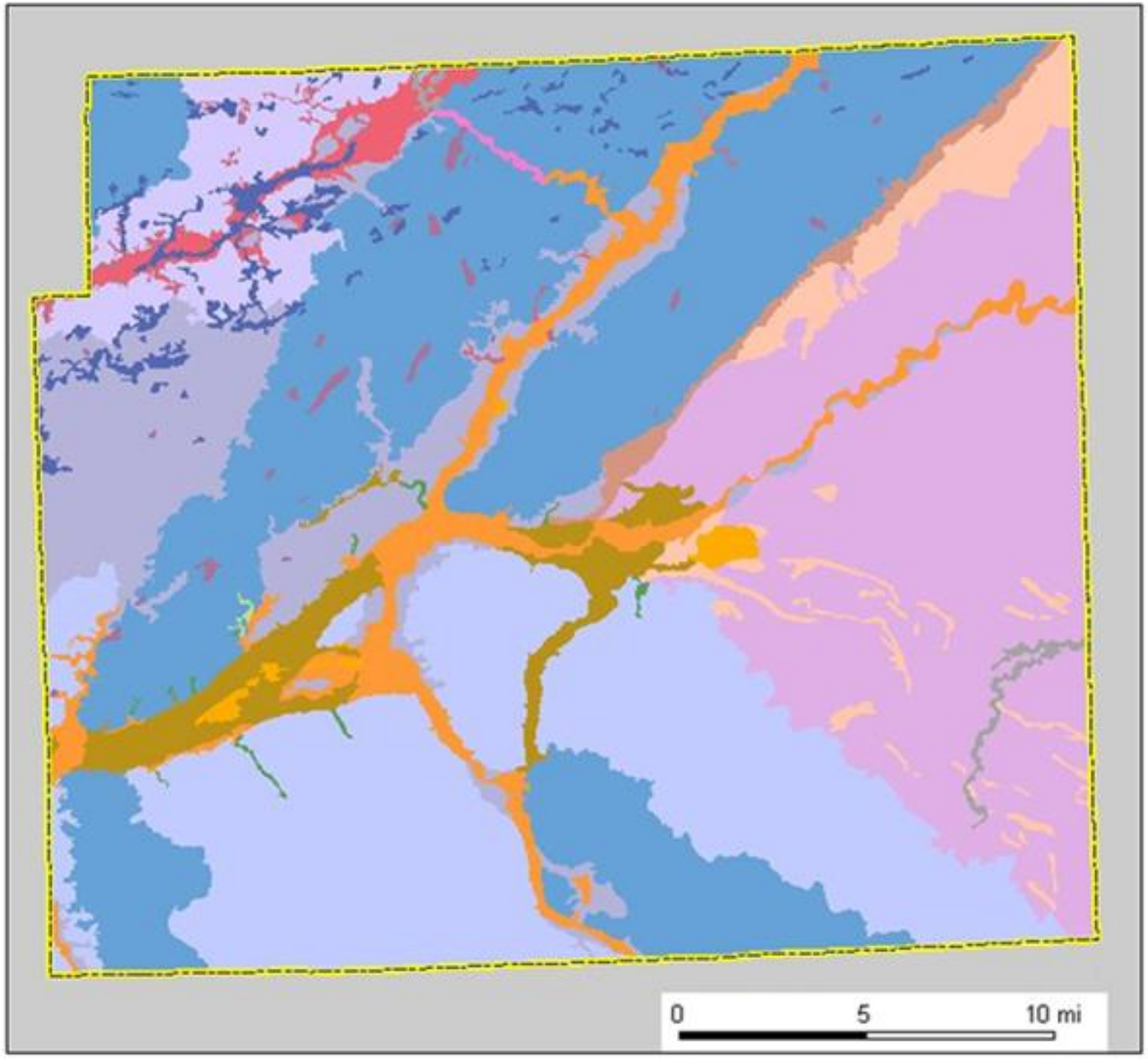


Fleming, 1994

Groundwater Recharge – Model Results

The mapped distributions of recharge in both Berrien County, Michigan, and Allen County, Indiana, were intuitively correct

- Independent of scale
- Dependent on the mapped geology; different results with different geologic mapping
- Promising for understanding aquifer sensitivity



Surficial Geology

Post Glacial Sediments
- a - alluvial channel
- p - peat depressions
- d - sand dunes
- m - ancestral channel
- s - spits and beach ridges
- b - beach ridges

Outwash Associations
- O - outwash valley and terraces
- OH - outwash valley
- Otc - outwash channel

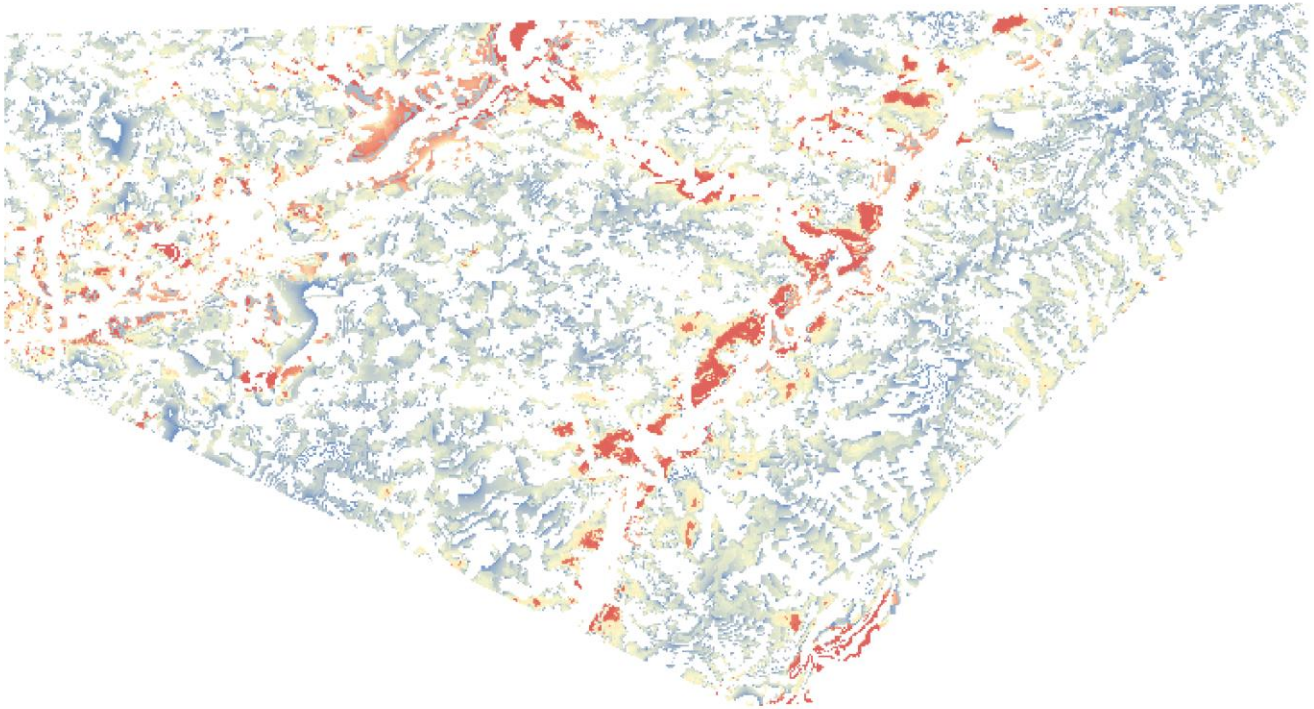
Lagro Formation
- Lc - eskers and channels
- Lt - till plain
- Lte - end moraine
- Lts - water-washed till plain
- Ltl - lacustrine plain
- Lt/H - interlobate landscape

Huntertown Formation
- H - undifferentiated

Trafalgar Formation
- Tc - meltwater channel
- T - till plain

Index map of Allen County, Indiana

Index map of Indiana highlighting the area of the main map



0 2 Miles

0 1 2 4 Kilometers

Recharge rates (log m/day) - simplified GFM

Value

High : 1.1

Low : -8

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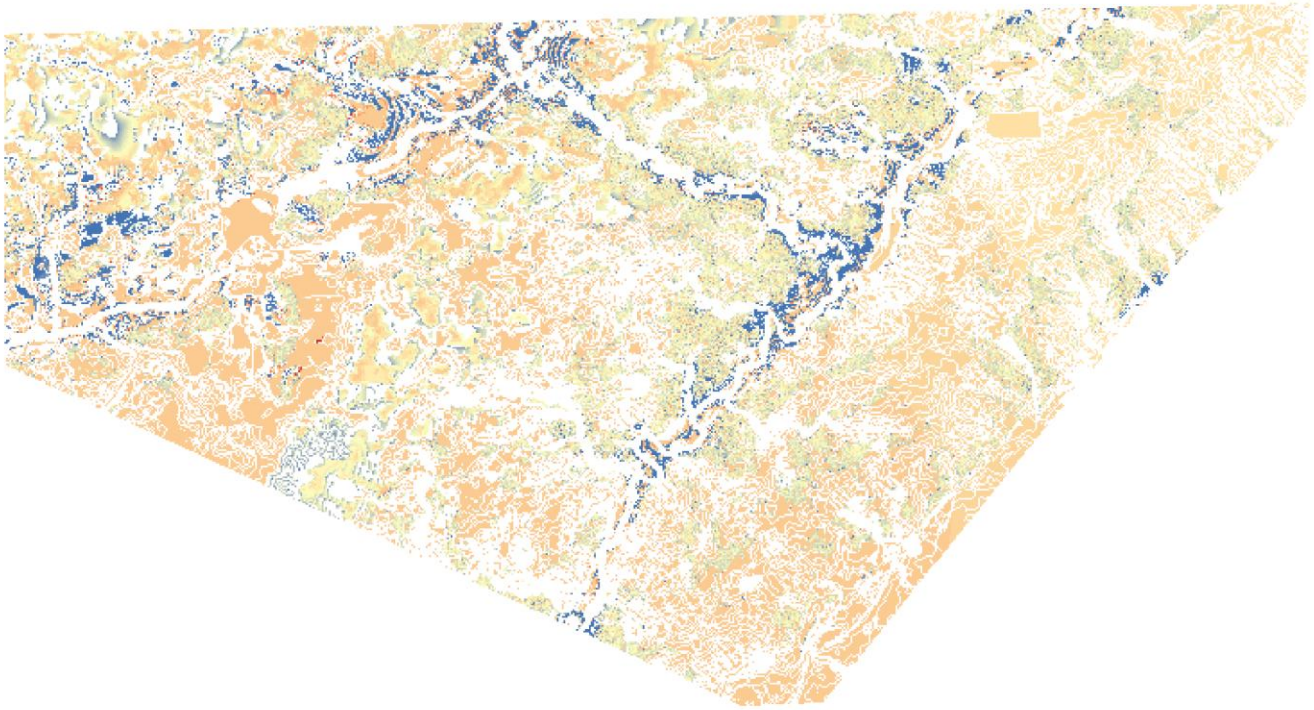
Index map of Indiana highlighting the area of the main map



0 2 Miles

0 1 2 4 Kilometers

Recharge rates (log m/day) - complex GFM

Value

High : 1.1

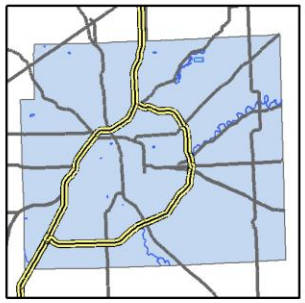
Low : -8

So, about this scale thing…

- Scale has been investigated with respect to understanding groundwater recharge
  - To yield an understanding of the controls on groundwater recharge and to be able to extrapolate the model results to a larger geographic area, we undertook multiple regression analysis
    - Recharge > Response variable
    - Multiple terrain, geology, soils layers > Predictor variables

Elevation	Soils: hydrologic group
Slope	Soils: saturated hydraulic conductivity
Compound topographic index	Depth to water table
Flow direction	Unconsolidated thickness
Distance downstream to nearest stream	Surficial clay thickness
Height above local base level	Surface flux
Upstream contributing area	Aquifer distribution
Near-surface geology	Estimated aquifer conductivity

Multiple Regression Results from Groundwater Model Recharge Output
Allen County, Indiana



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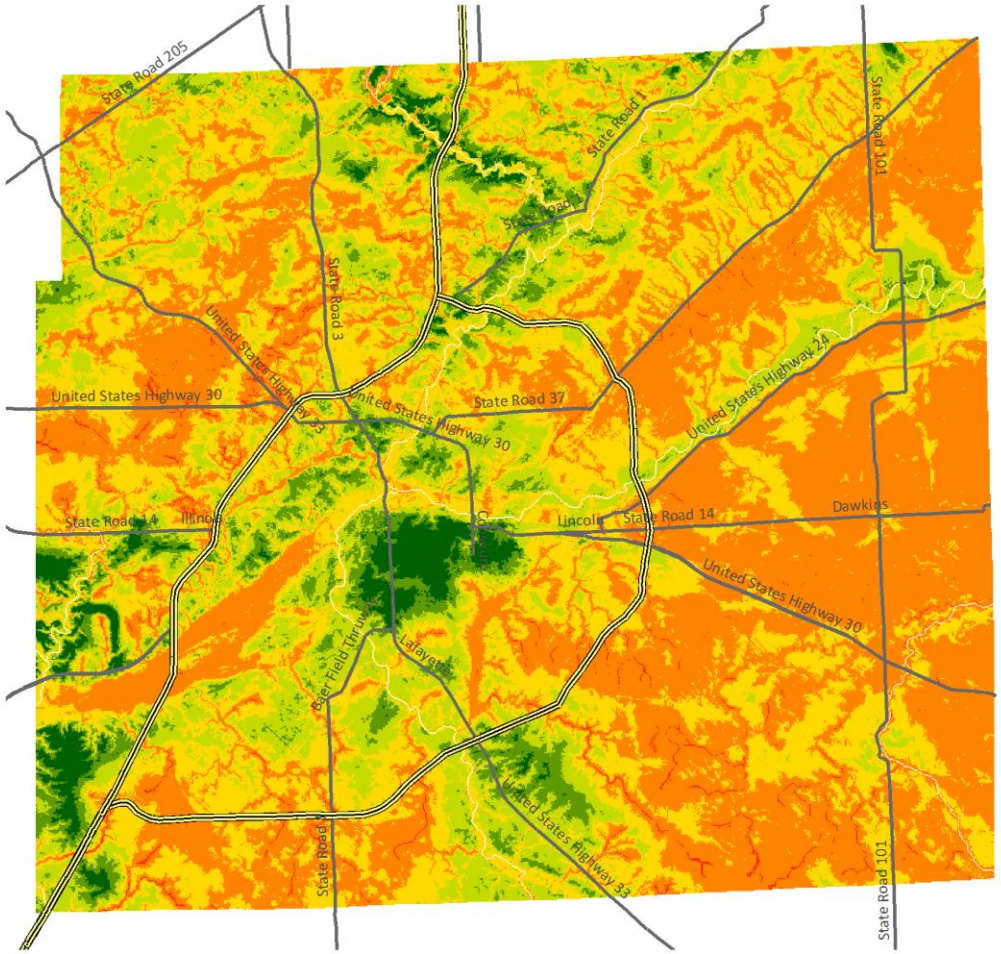
Index map of Indiana highlighting the area of the main map



Legend

Relative recharge

(OLS, 500m mapped to 50m)

High recharge

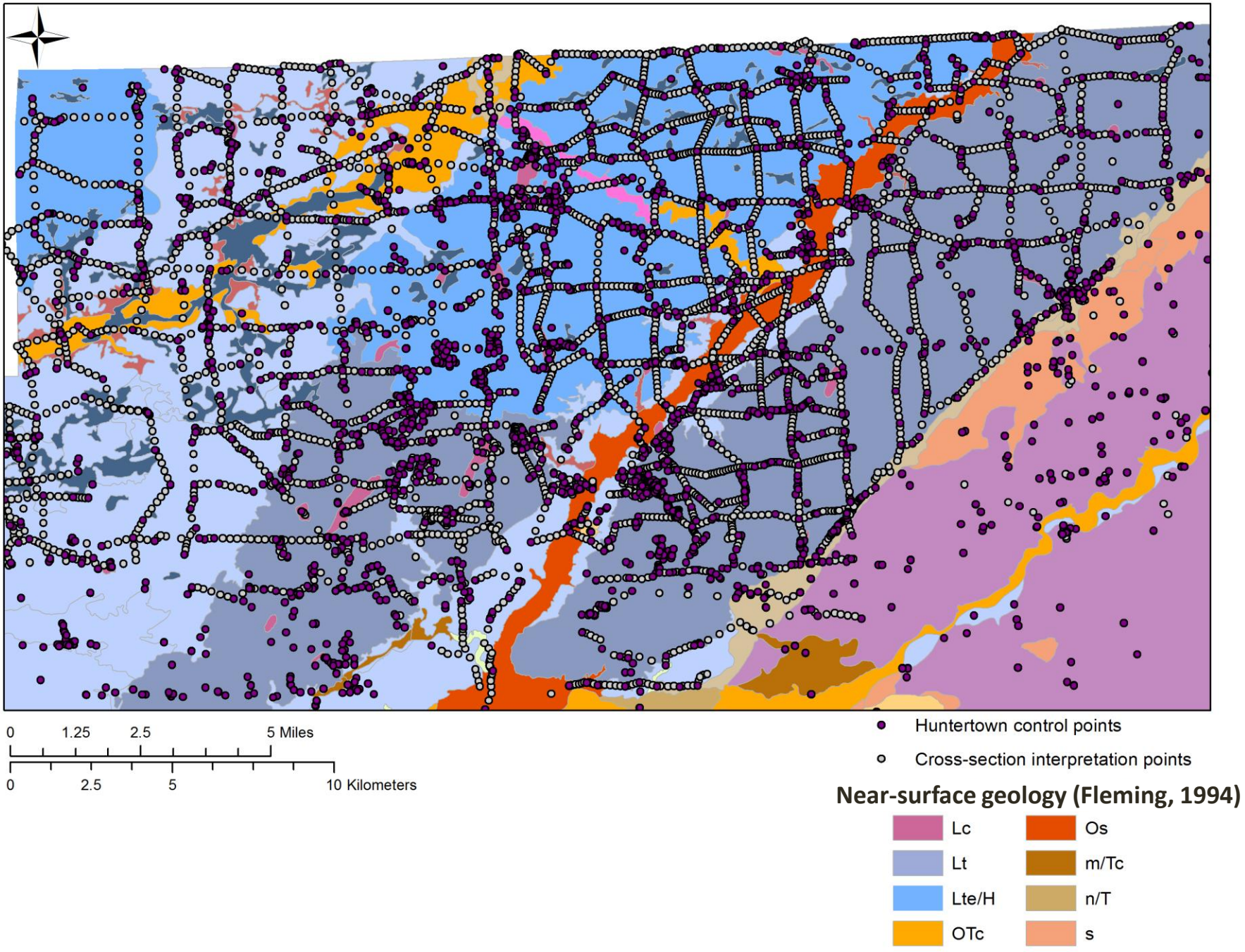
Low recharge

0 2 Miles

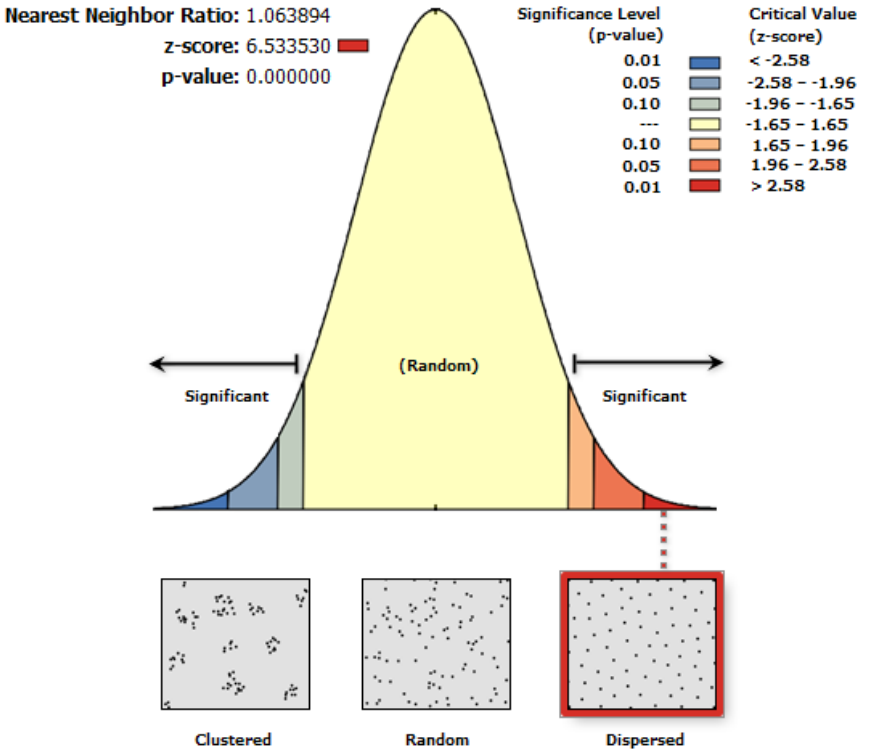
0 1 2 4 Kilometers

Scale experiments

- The 50-m Allen County interlobate recharge regression model was upscaled (horizontal scale) to:
  - 200-m
  - 500-m
  - 1000-m
- The terrain, geology, and soils data were used as predictor variables in all regression models
  - Each upscaled suite of response and predictor variables in the regression models improved the R^2 value
  - Important landscape features, such as continuous outwash valleys began to disappear beyond 500-m scale


0 1.25 2.5 5 Miles
0 2.5 5 10 Kilometers
Huntertown control points
Cross-section interpretation points
Near-surface geology (Fleming, 1994)
Lc
Lt
Lte/H
OTc
Os
m/Tc
n/T
s

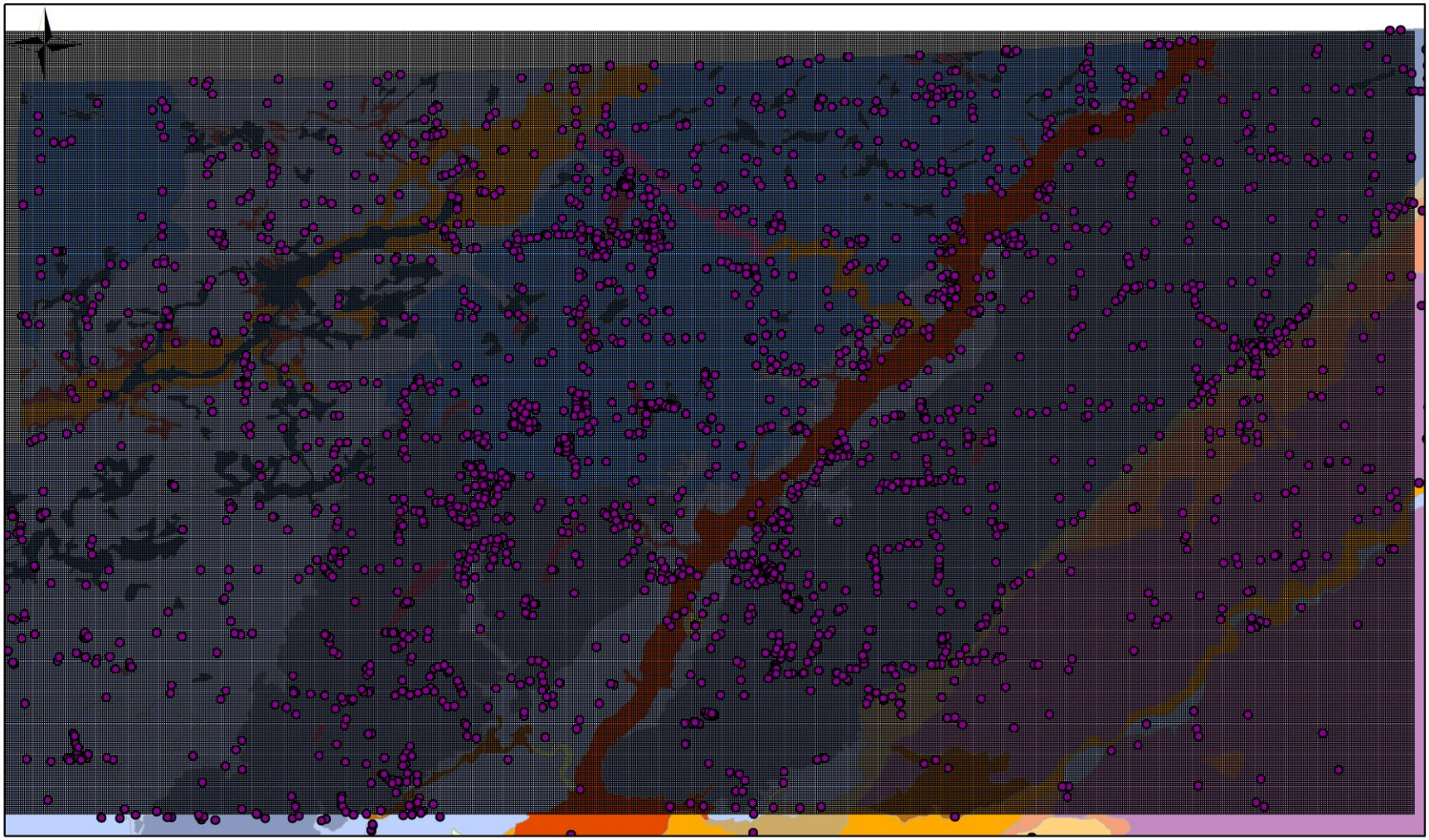
Average Nearest Neighbor Summary



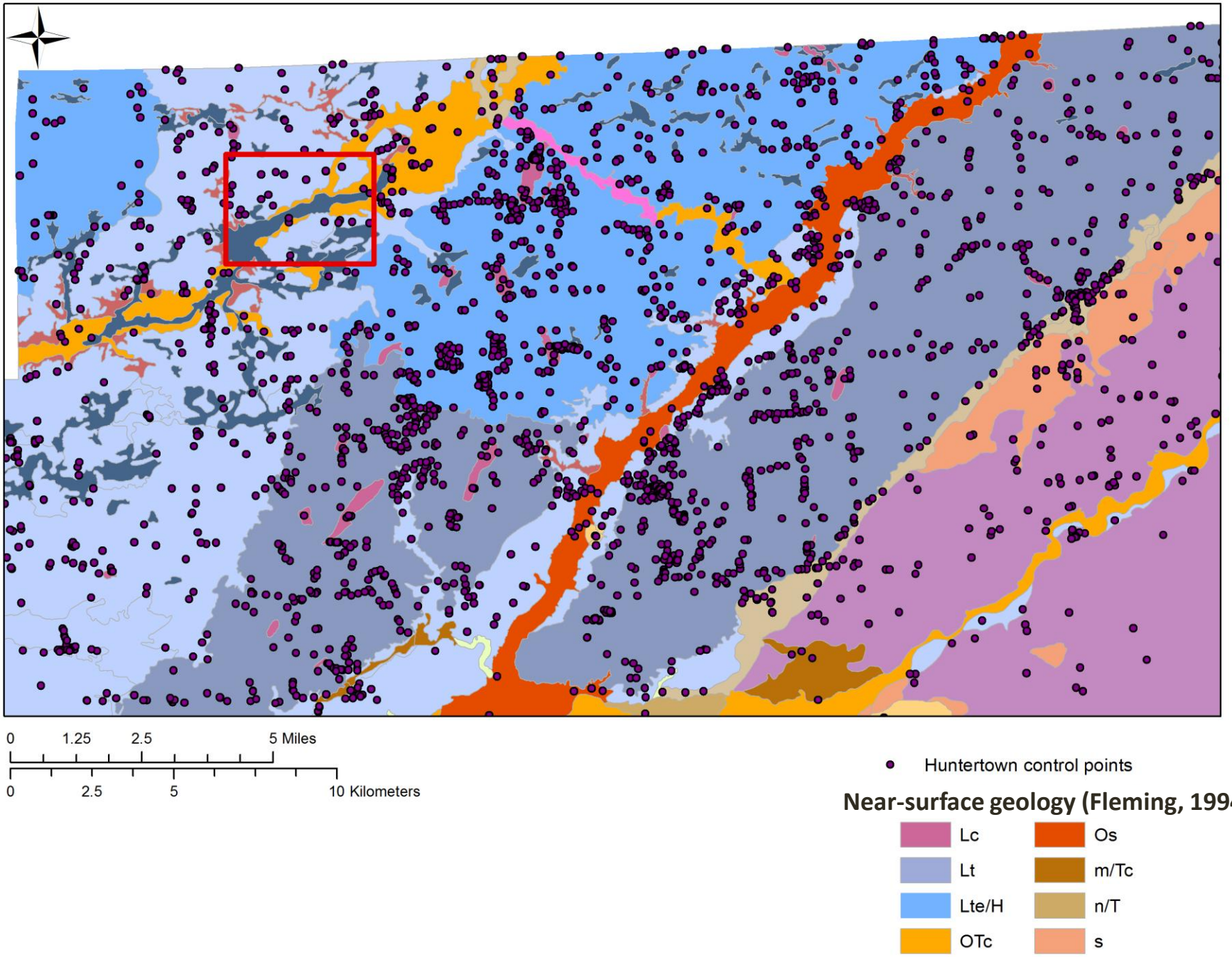
Given the z-score of 6.53, there is a less than 1% likelihood that this dispersed pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance:	220.015248 Meters
Expected Mean Distance:	206.801799 Meters
Nearest Neighbor Ratio:	1.063894
z-score:	6.533530
p-value:	0.000000



Horizontal (XY) spacing = 50m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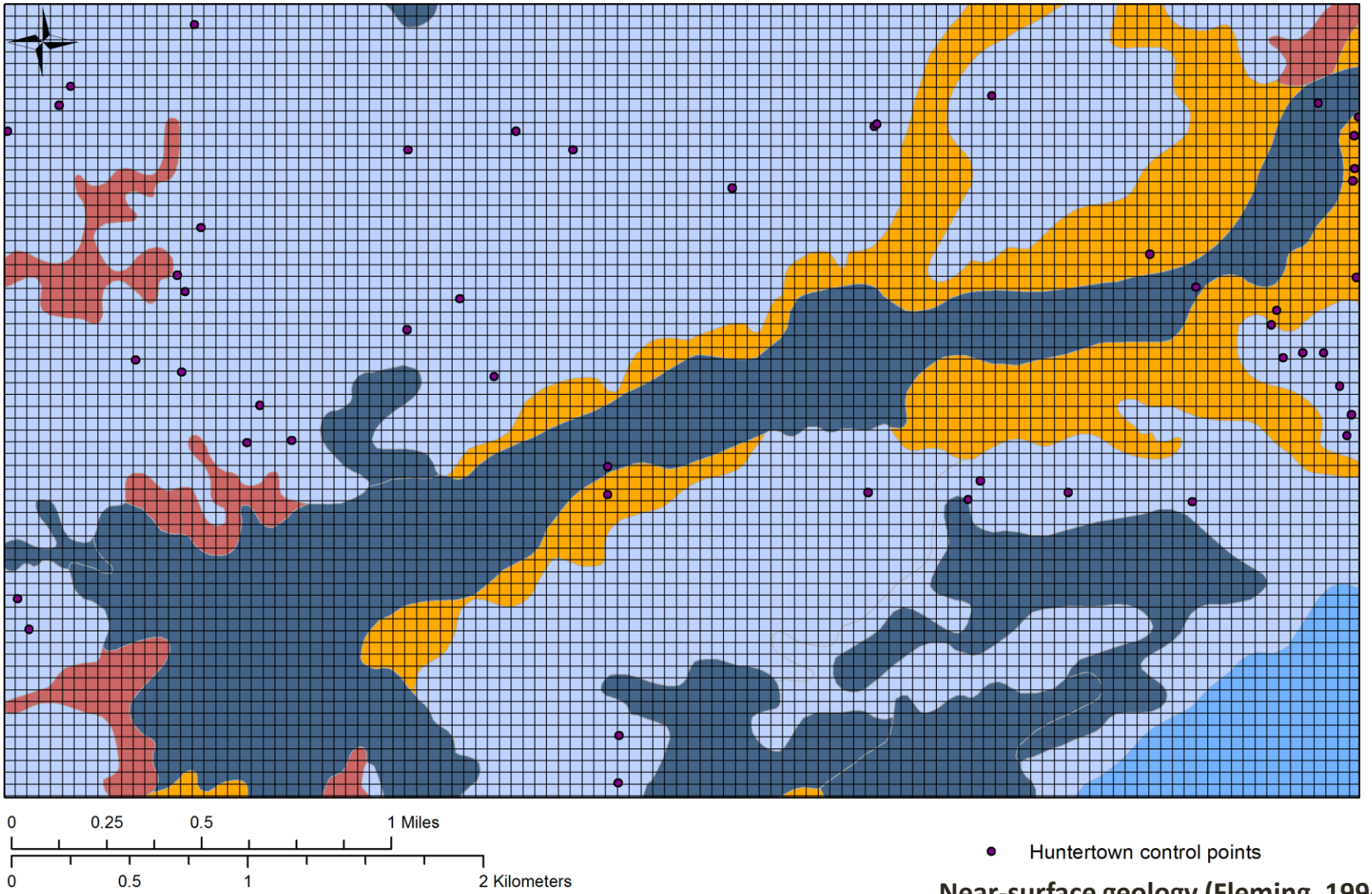
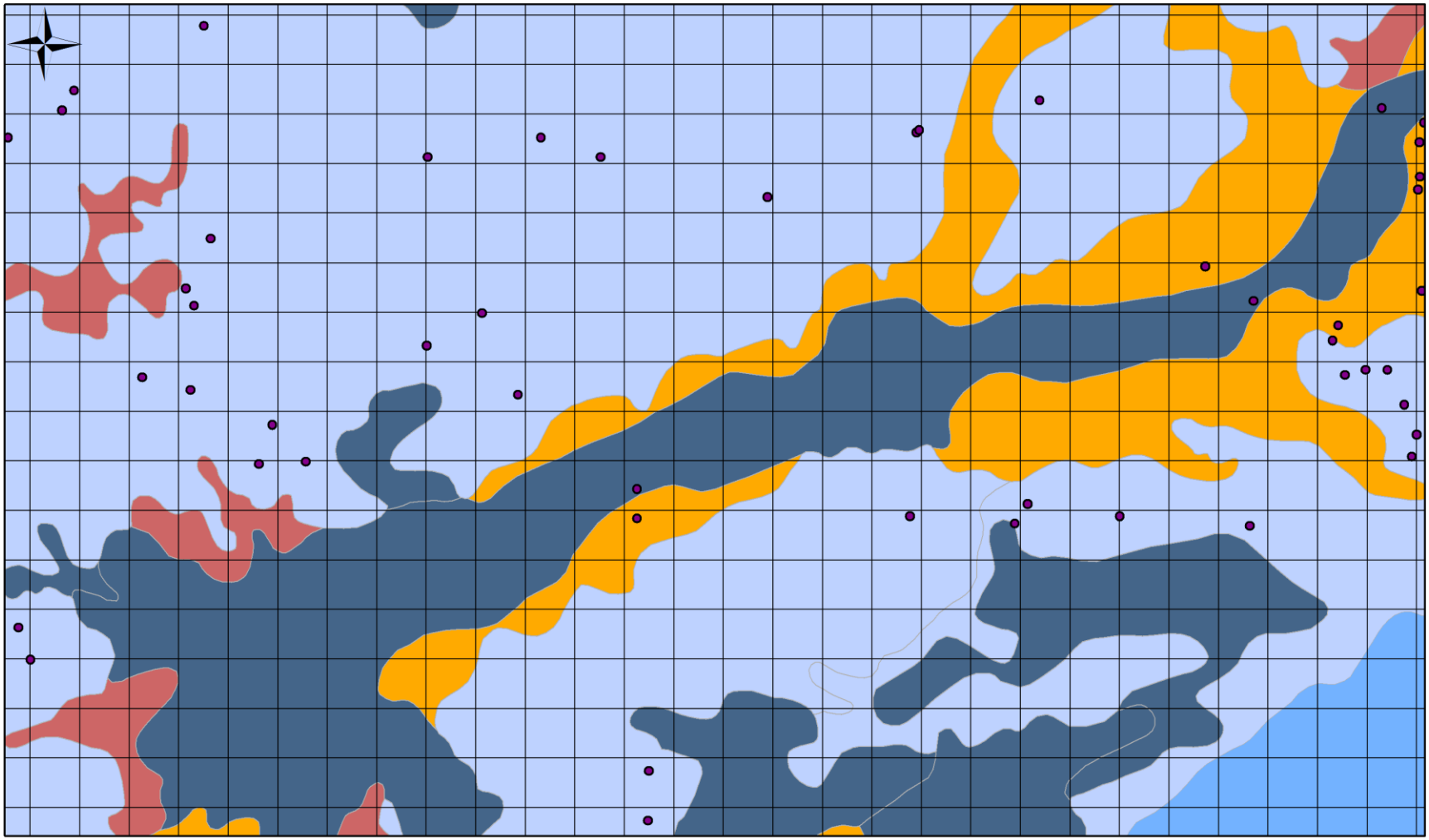
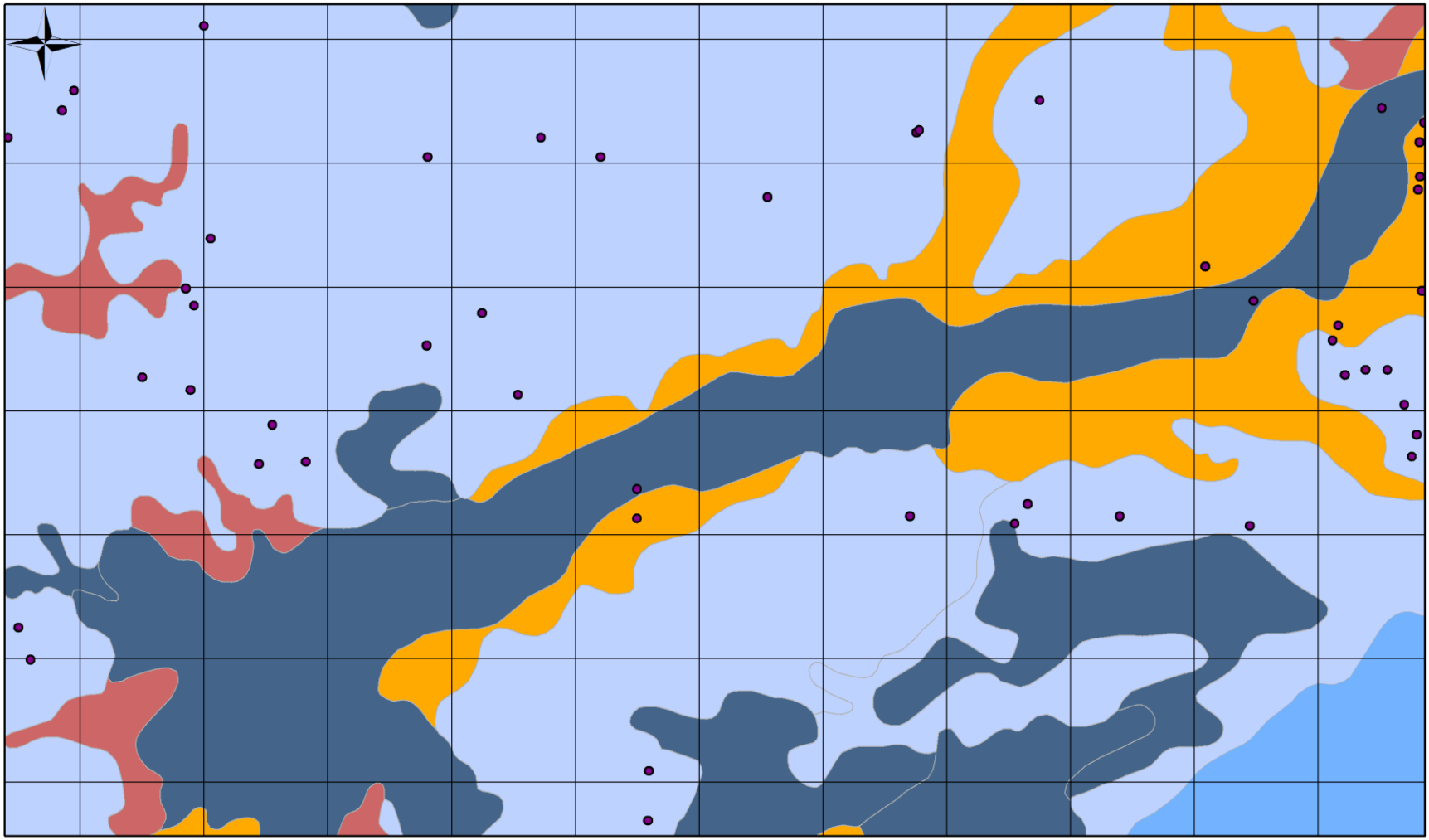


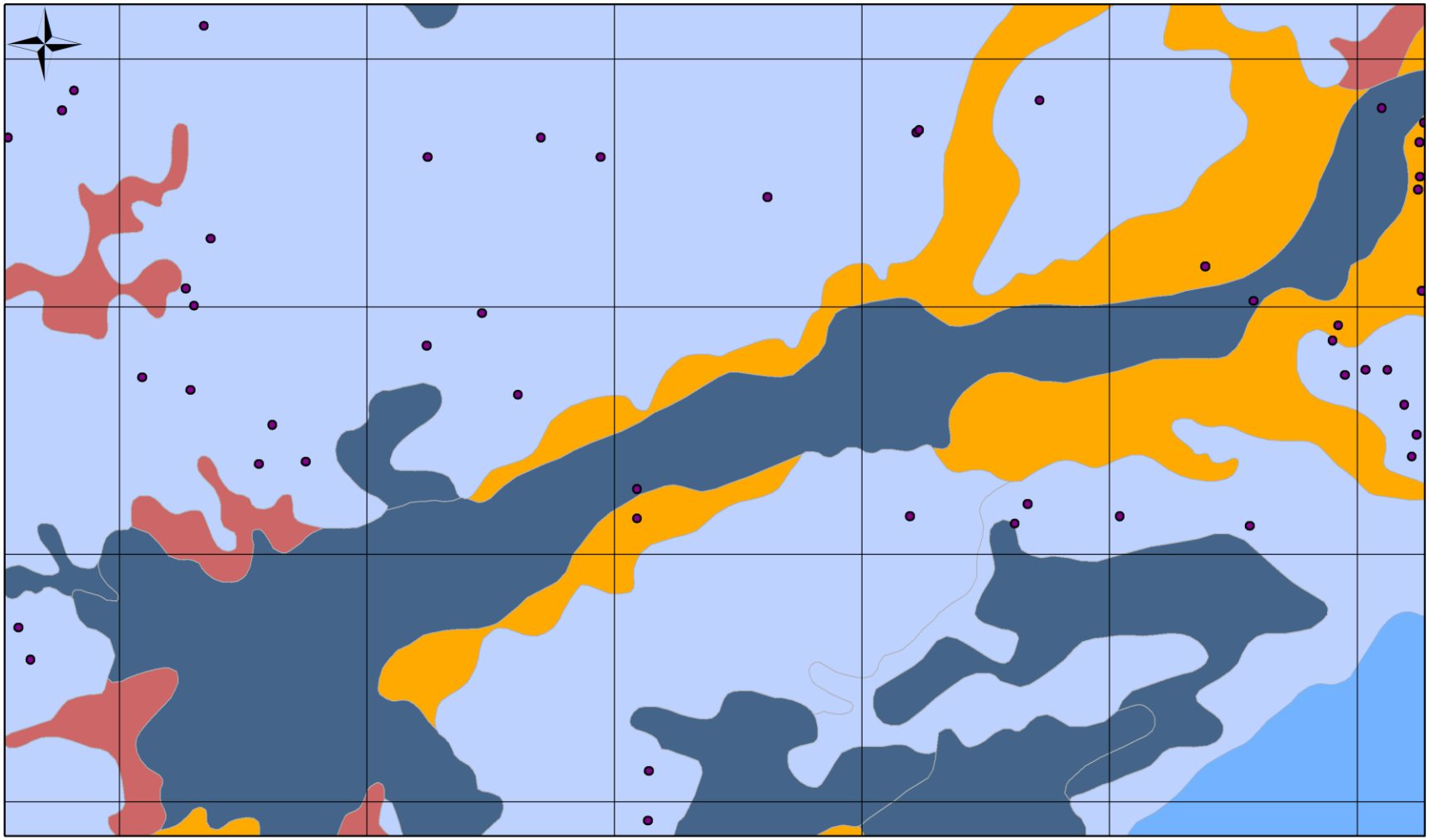
Horizontal (XY) spacing = 50m



Horizontal (XY) spacing = 200m



Horizontal (XY) spacing = 500m



Horizontal (XY) spacing = 1000m

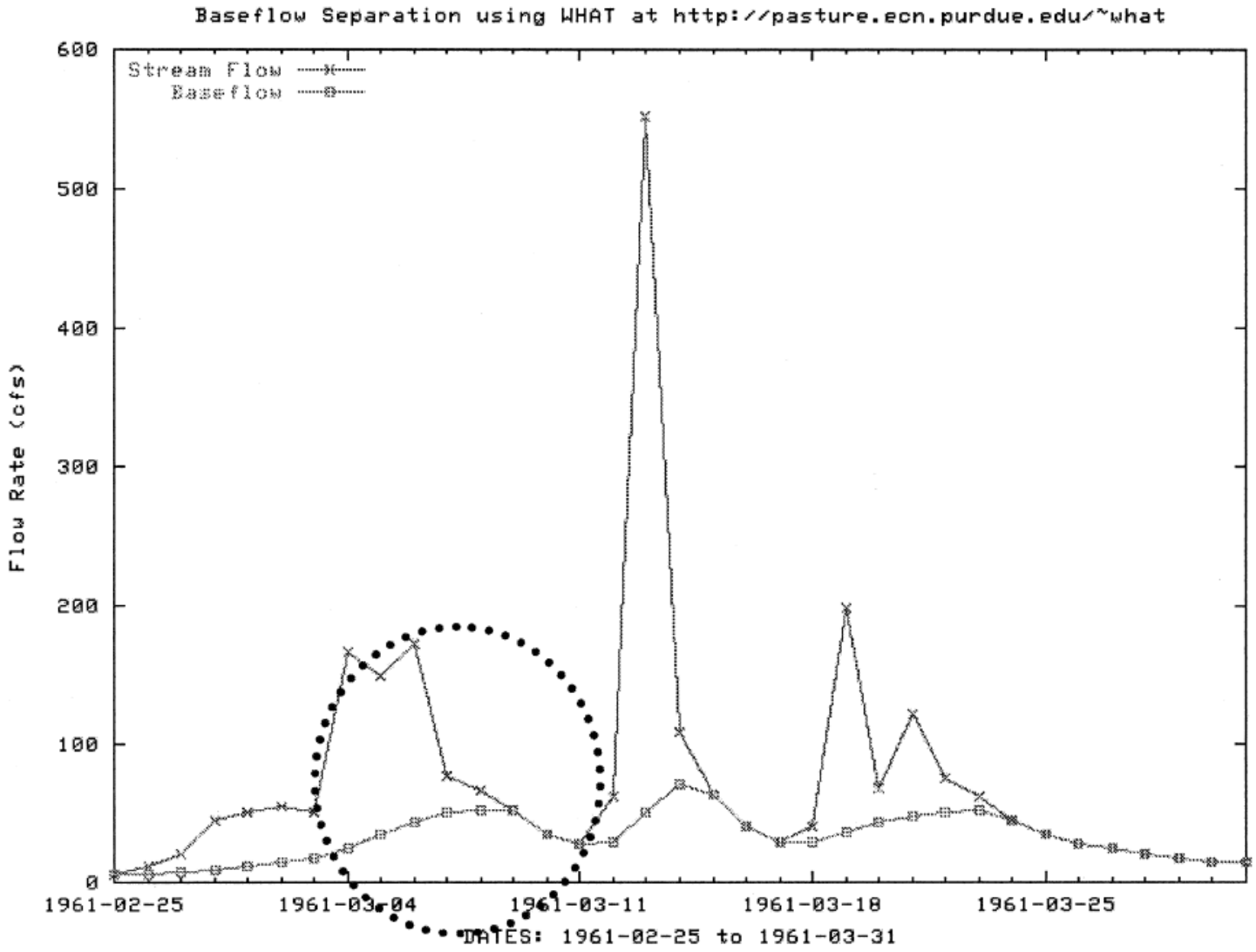
Scale experiments

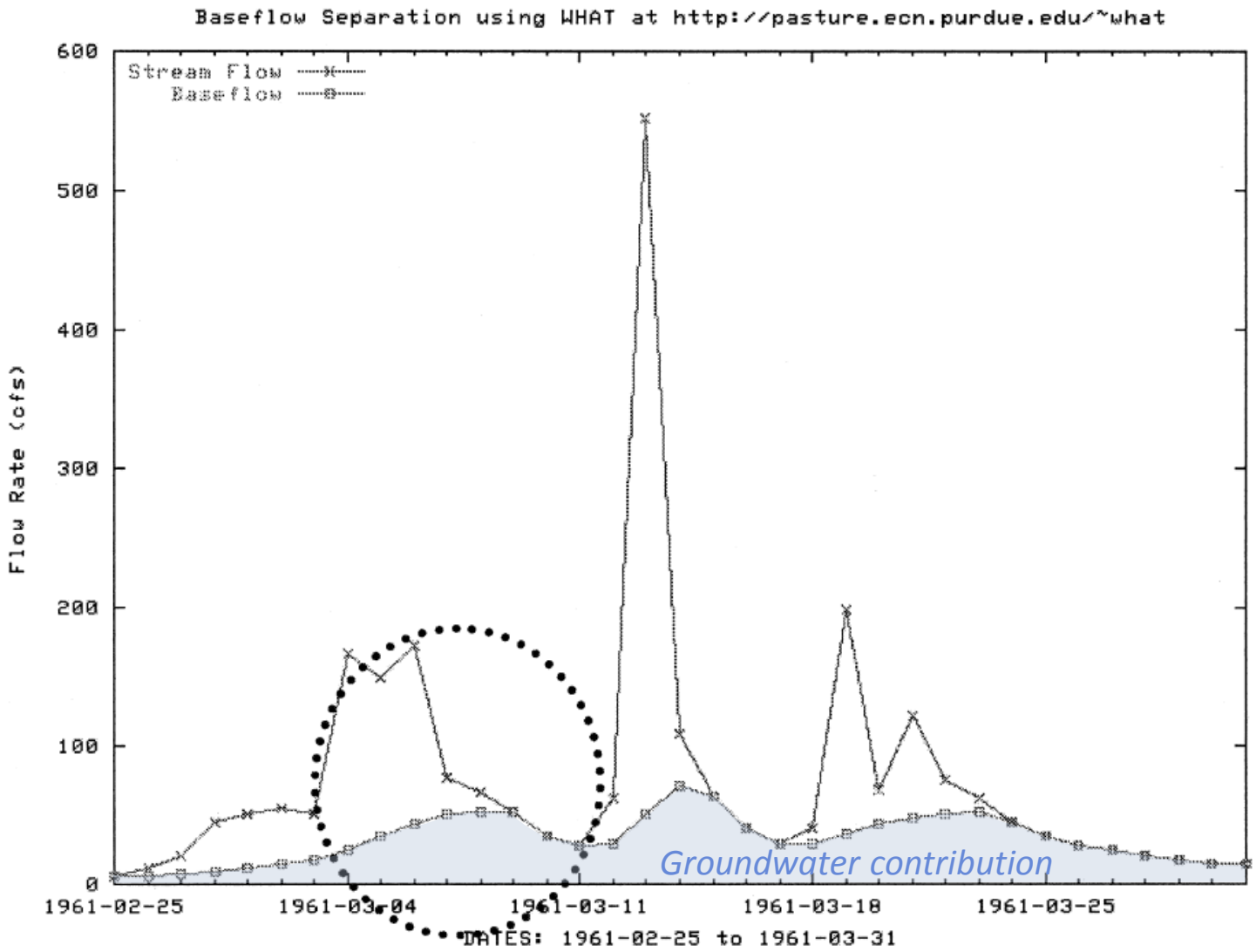
So far, here is what I have found:

- The 200-m (Berrien County) horizontal scale model (GFM and flow) produces a regression model that explains much more (R^2=0.6) of the variability than does the 50-m (Allen County) GFM and flow models (using the same predictor variables).
- The 50-m GFM model has the same (lousy, R^2=0.3) recharge regression results whether it uses the simple or complex version of the geology
- Upscaling the 50-m model results to smooth out the noisy high-resolution recharge values improves the regression model results
- Smoothing the recharge values by interpolating to a trend surface also improves the regression model results

Did you compare the modeled results to other recharge data?

- Well, yes I did; thanks for asking.
  - Hydrograph separations to determine long-term baseflows were conducted using two techniques (following USGS methods used to produce national baseflow and recharge data layers)
    - BFI
    - WHAT
  - Point data were interpolated, and recharge estimates were subjected to the regression modeling process
  - Regardless of scale (200m, 500m), the predictor variables could explain 80 to 90% of the variability in the recharge values.
  - This technique uses long-term estimates of recharge, which represents an equilibrium condition across the landscape, and the groundwater model equivalent would be to use flow vectors from a steady-state model solution.


Baseflow Separation using WHAT at http://pasture.ecn.purdue.edu/~what
Stream Flow
Baseflow
Flow Rate (cfs)
600
500
400
300
200
100
0
1961-02-25
1961-03-04
1961-03-11
1961-03-18
1961-03-25
DATES: 1961-02-25 to 1961-03-31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0
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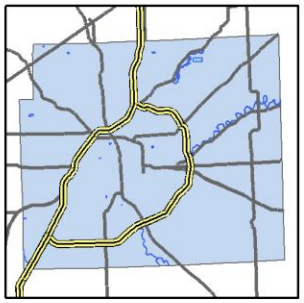
1961-03-04
1961-03-11
1961-03-18
1961-03-25
DATES: 1961-02-25 to 1961-03-31
Groundwater contribution

Baseflow Estimates in and around Allen County, Indiana



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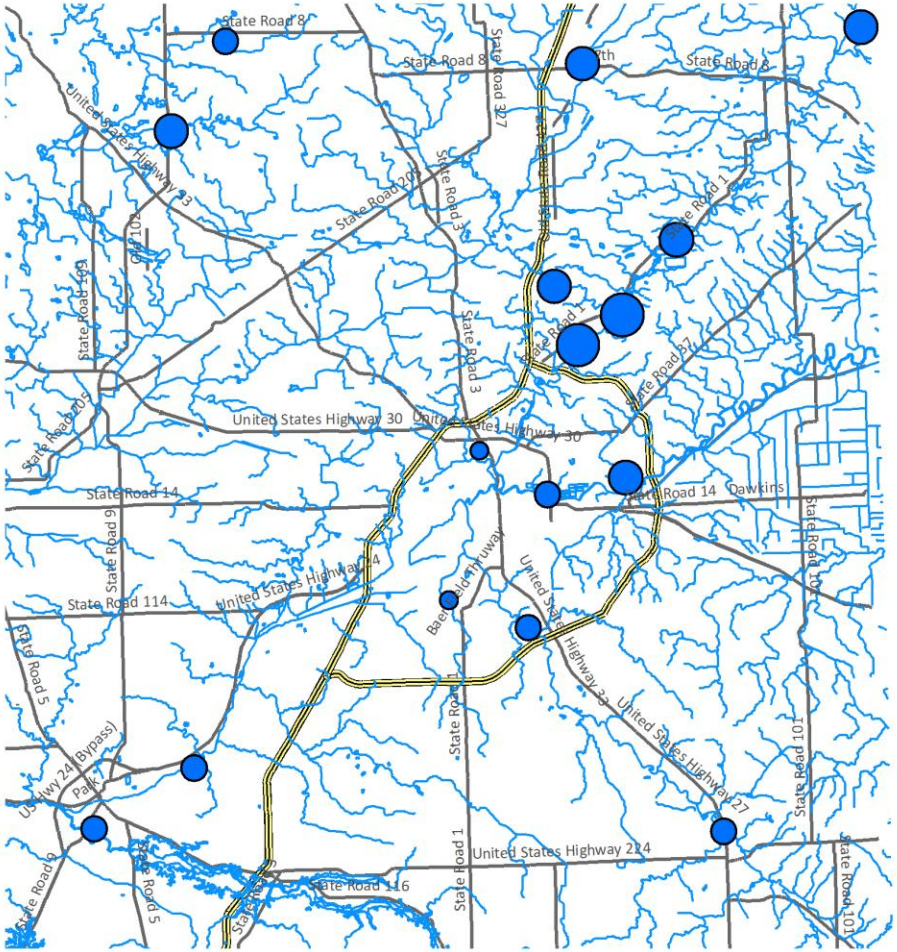
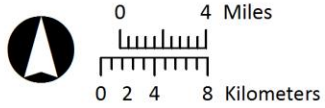
Index map of Indiana highlighting the area of the main map





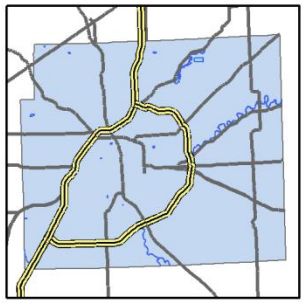
WHAT Baseflow Calculations

Base Flow Index

- 0.00 - 0.26
- 0.27 - 0.45
- 0.46 - 0.56
- 0.57 - 0.68
- 0.69 - 0.80

Provisional
2012

Predicted Groundwater Recharge Rates (Provisional)
Allen County, Indiana



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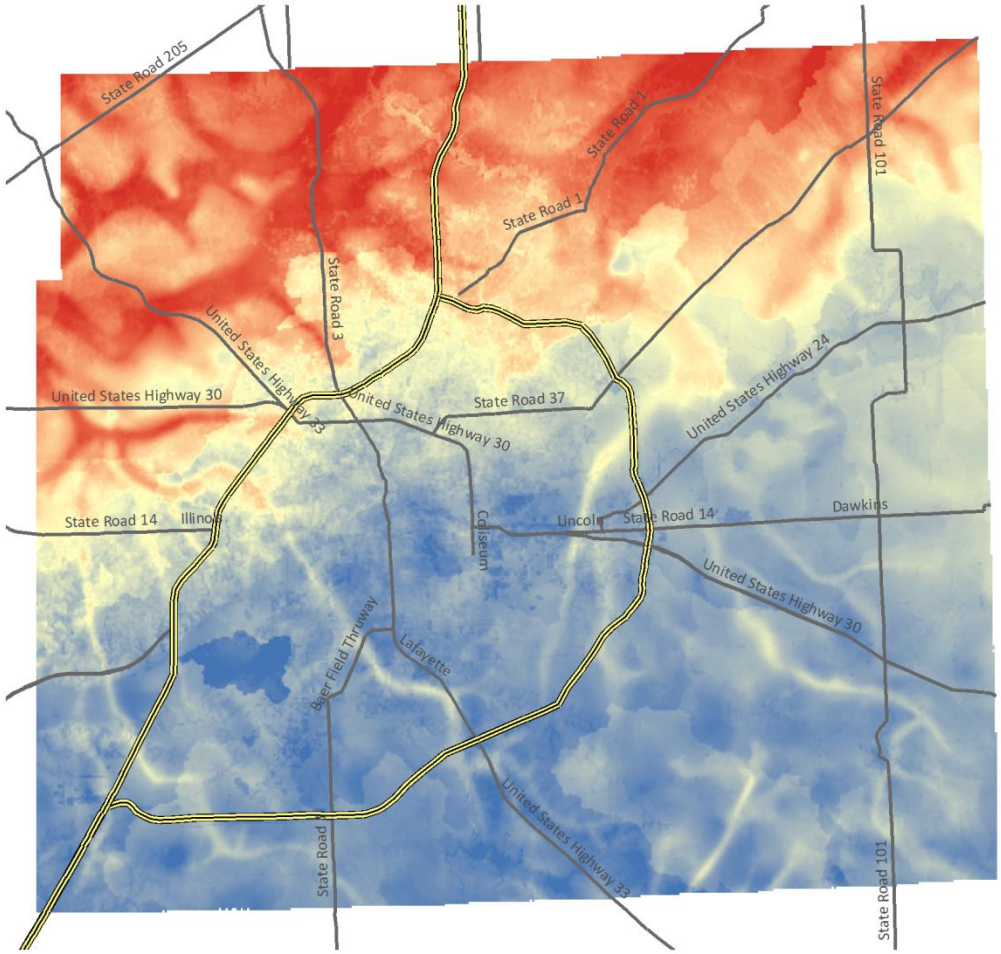

Predicted Groundwater Recharge

(mm/year)

High : 166

Low : 133

0 2 Miles

0 1 2 4 Kilometers

Provisional
2012

Resultant recommendations for appropriate mapping scales

- For the purpose of understanding the dynamics of **regional** groundwater flow, aim for 1:250K to 1:500K
  - This scale range seems to:
    - Capture primary terrain and geological features at the regional scale
    - Enhance the signal over the noise of uncertainties in the response variable (recharge)

Now what?

- This is an ongoing area of inquiry. The work to date has largely been driven by hypotheses crashing and burning.
- The completed work has defined the boundaries of the problem.
- Additional GFM scaling, and additional groundwater modeling (for the Allen County model) will be conducted in a methodical way to document the results
- A simplified 4-layer GFM model of the Erie Lobe basin will be subjected to steady-state groundwater-flow modeling at the recommended discretization (~200-m), and the results will be evaluated with respect to groundwater recharge.

Conclusions

- Geologic framework modeling using irregularly spaced borehole data and conceptual models should aim for a mapping resolution that is on par with the certainty of the data
- Geostatistics or standard spatial analysis tools (nearest neighbor analysis) might be a useful tool for quantifying this value
- In Allen County, Indiana, the GFM produced for the purpose of understanding regional groundwater flow appears to have been modeled at a resolution that exceeds the certainty of the input data
- For the two areas I have studied, a scale of 1:250K to 1:500K appears to capture the limits of the data certainty without filtering out known features