Mapping Infiltration Rates in Dane County, Wisconsin

Kathleen Arrington
Steve Ventura
University of Wisconsin-Madison

ESRI Southeast Regional User Group
April 27, 2010, Charlotte NC

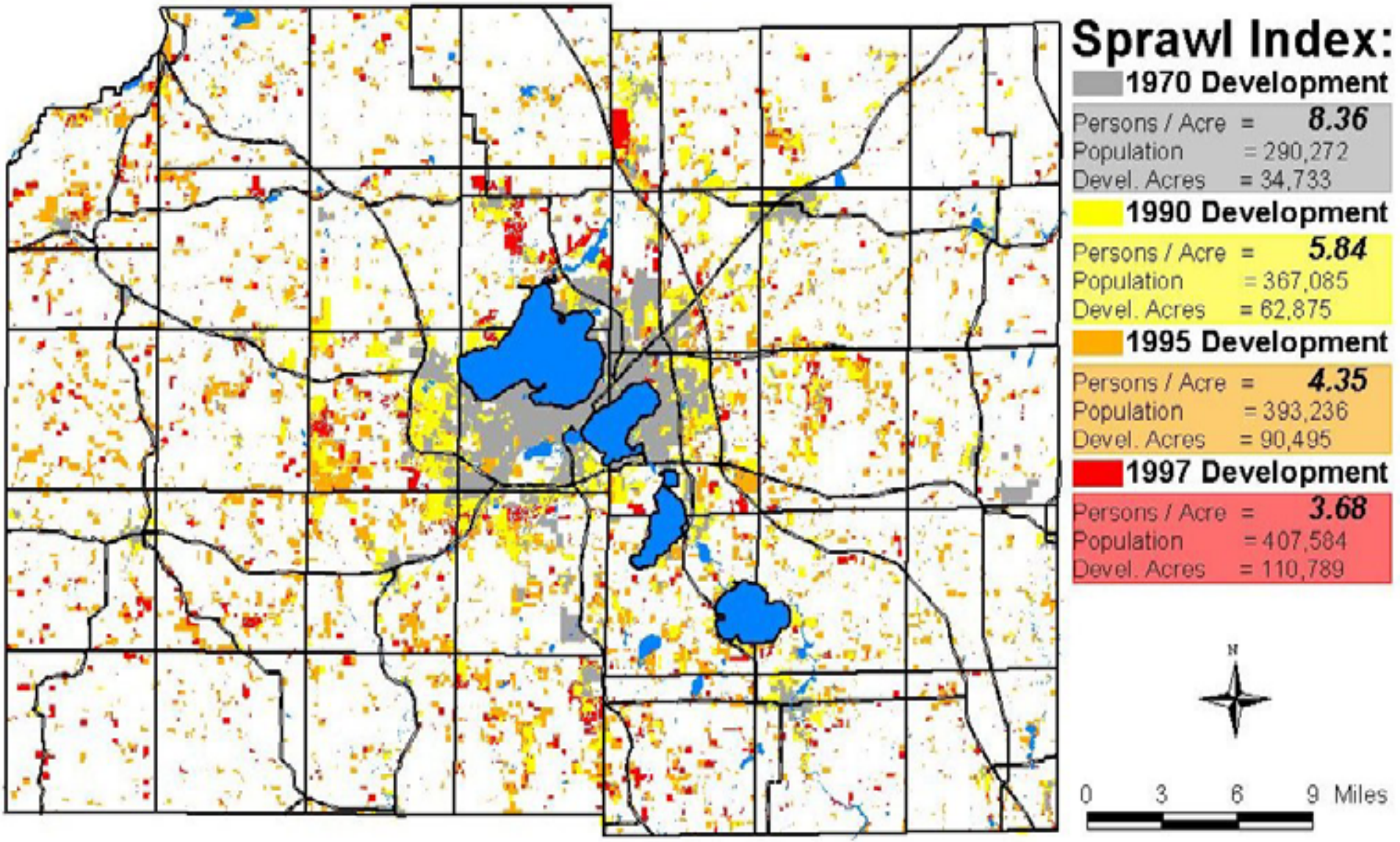
CONTENTS

- Acknowledgments:
  - United States Geological Survey
  - Dane County

- Outline
  - The issue: groundwater recharge
  - Soil infiltration
  - Our research: goals and methods
  - Results
  - Mapping

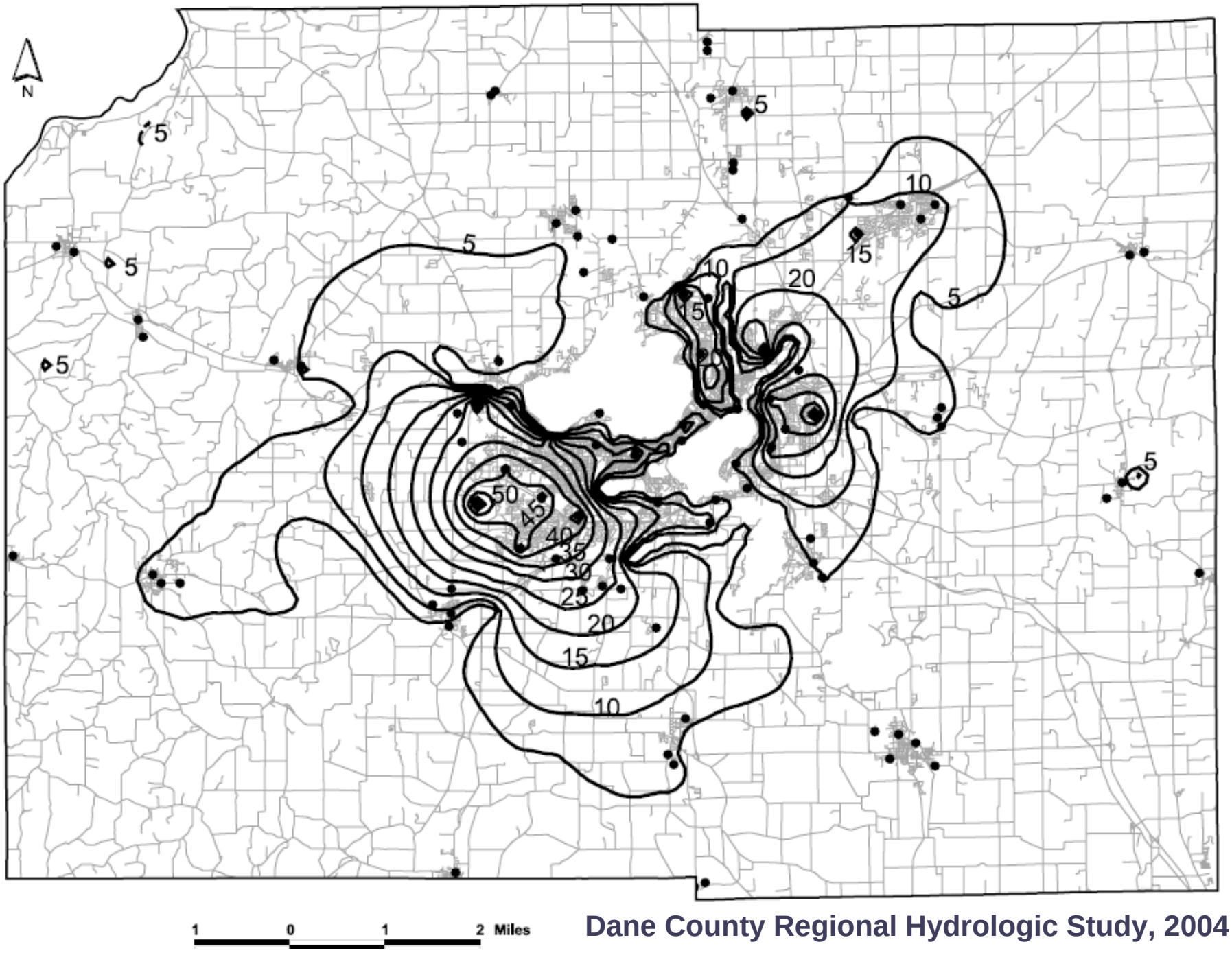
Map courtesy of Steve Ventura

Lots of people = lots of water



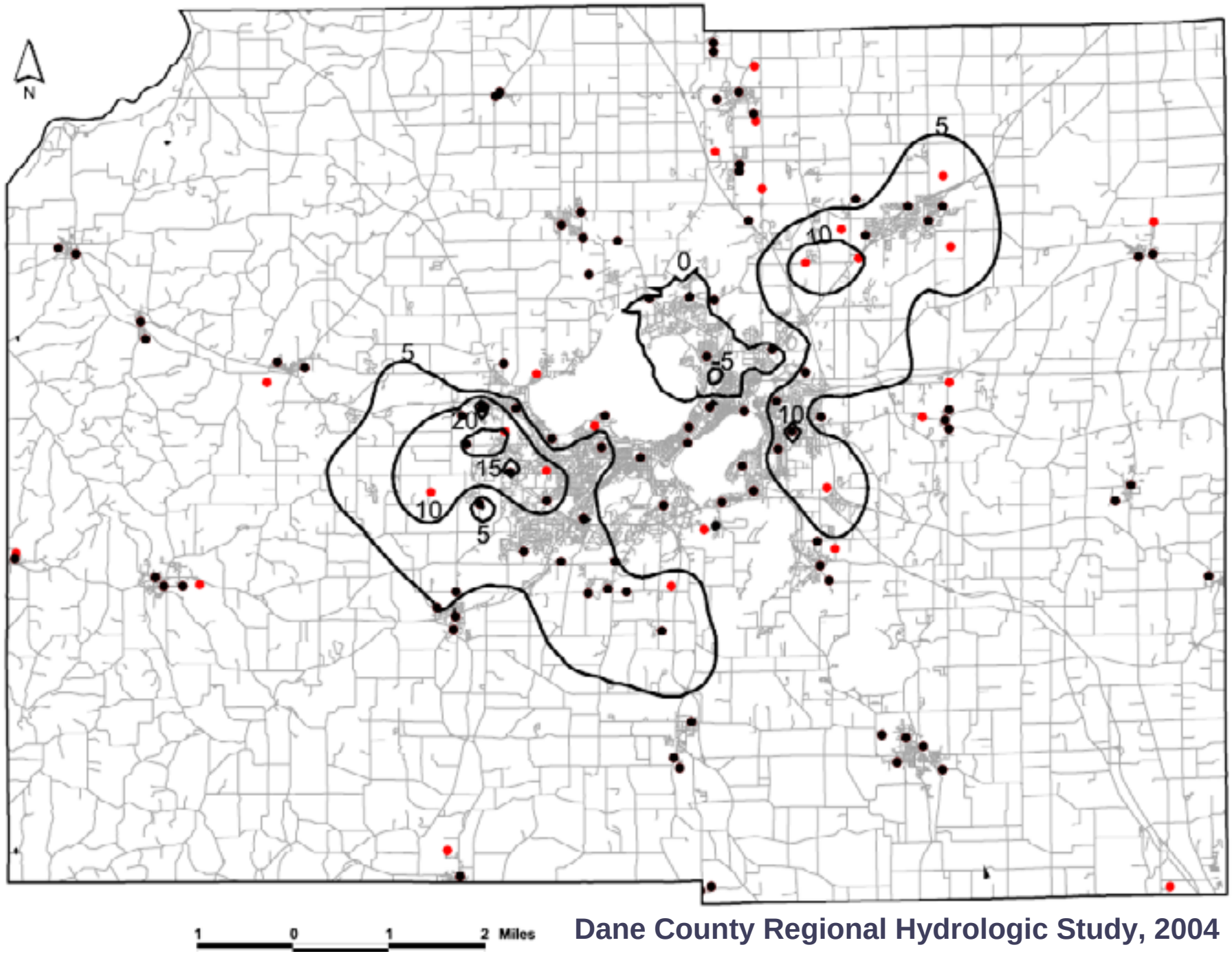
Map courtesy of Steve Ventura

Figure 7. Simulated drawdown at water table, 1900-2000. Contours represent water level declines in feet.



Dane County Regional Hydrologic Study, 2004

Figure 9. Simulated drawdown at the water table, 2000-2030. Contours represent water level declines in feet.



Dane County Regional Hydrologic Study, 2004

Causes of groundwater drawdown

- Pumping
- Loss of recharge
  - Development replaces pervious surfaces with impervious surfaces, which:
    - Reduces infiltration
    - Increases runoff

Mitigating loss of recharge

- Practices –
  - Infiltration basins
  - Rain gardens
- Maintain soil capacity

Infiltration suitability

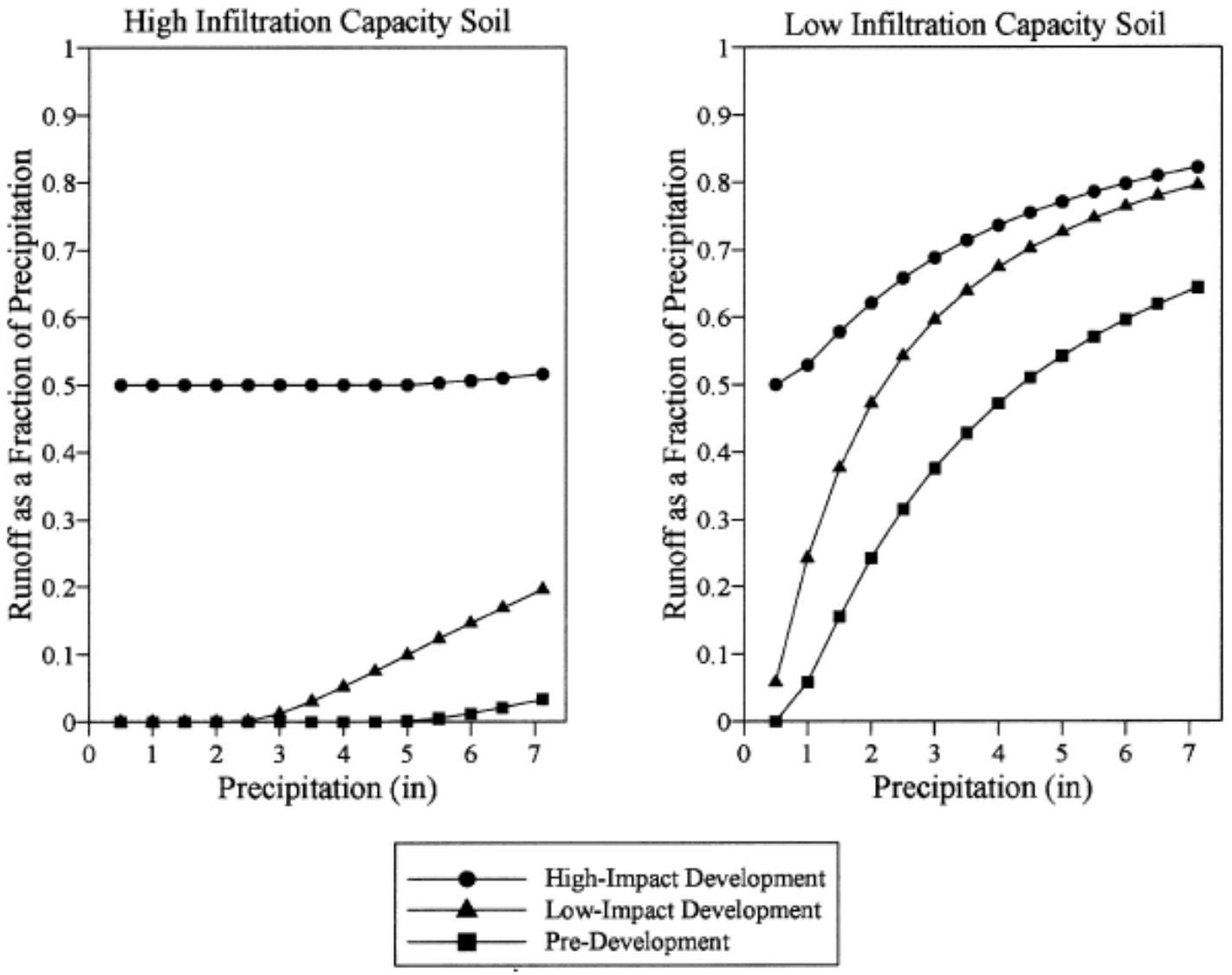


Figure 4. Runoff Fraction Under Different Development Scenarios. High infiltration capacity soil is modeled using SCS soil classification 'A' and low infiltration capacity soil is modeled using SCS soil classification 'D.'

Background – soil infiltration properties

What determines infiltration rates?

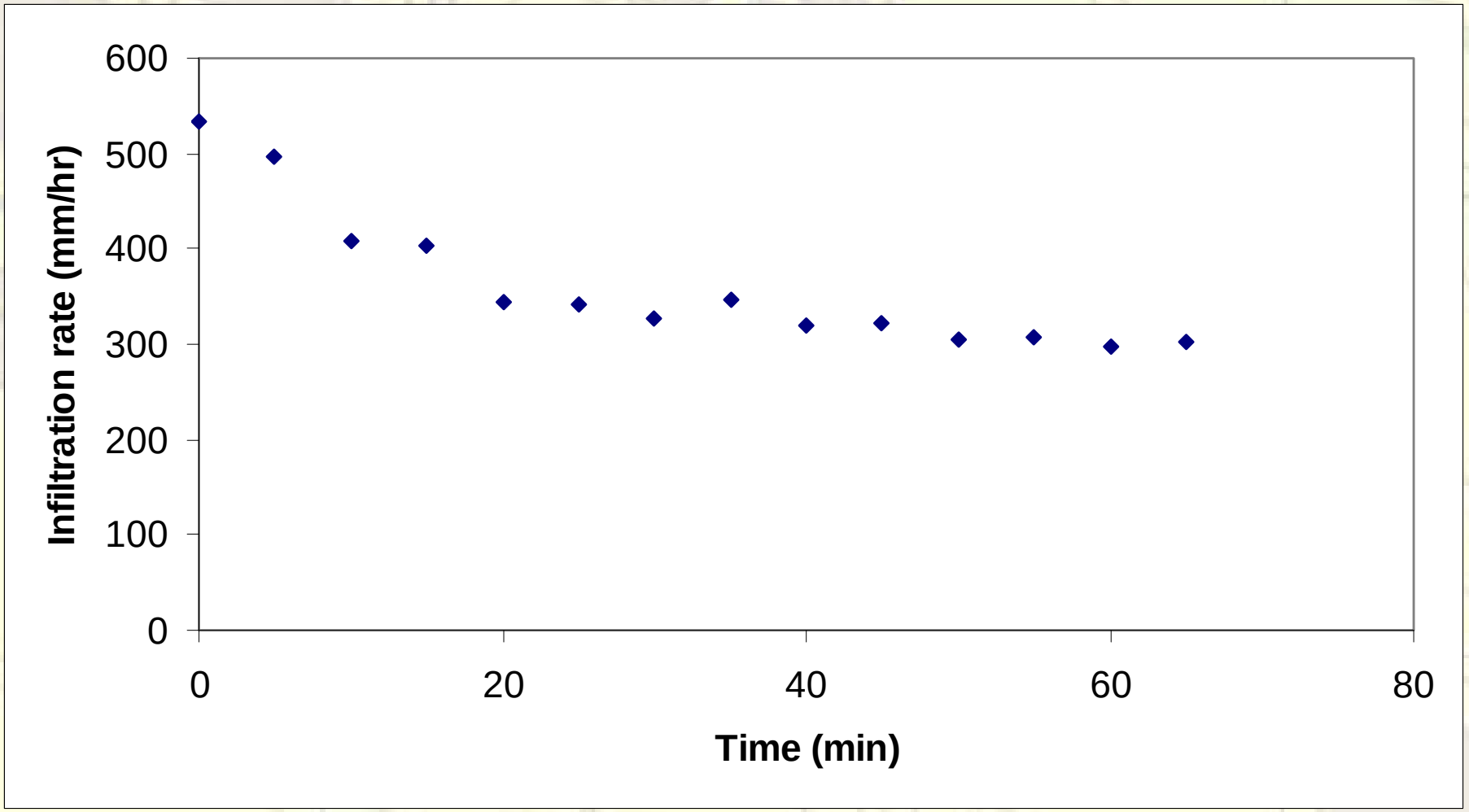
- Soil properties
  - Texture
  - Structure- macropores and micropores
- Other (?)

http://soilandwater.bee.cornell.edu/

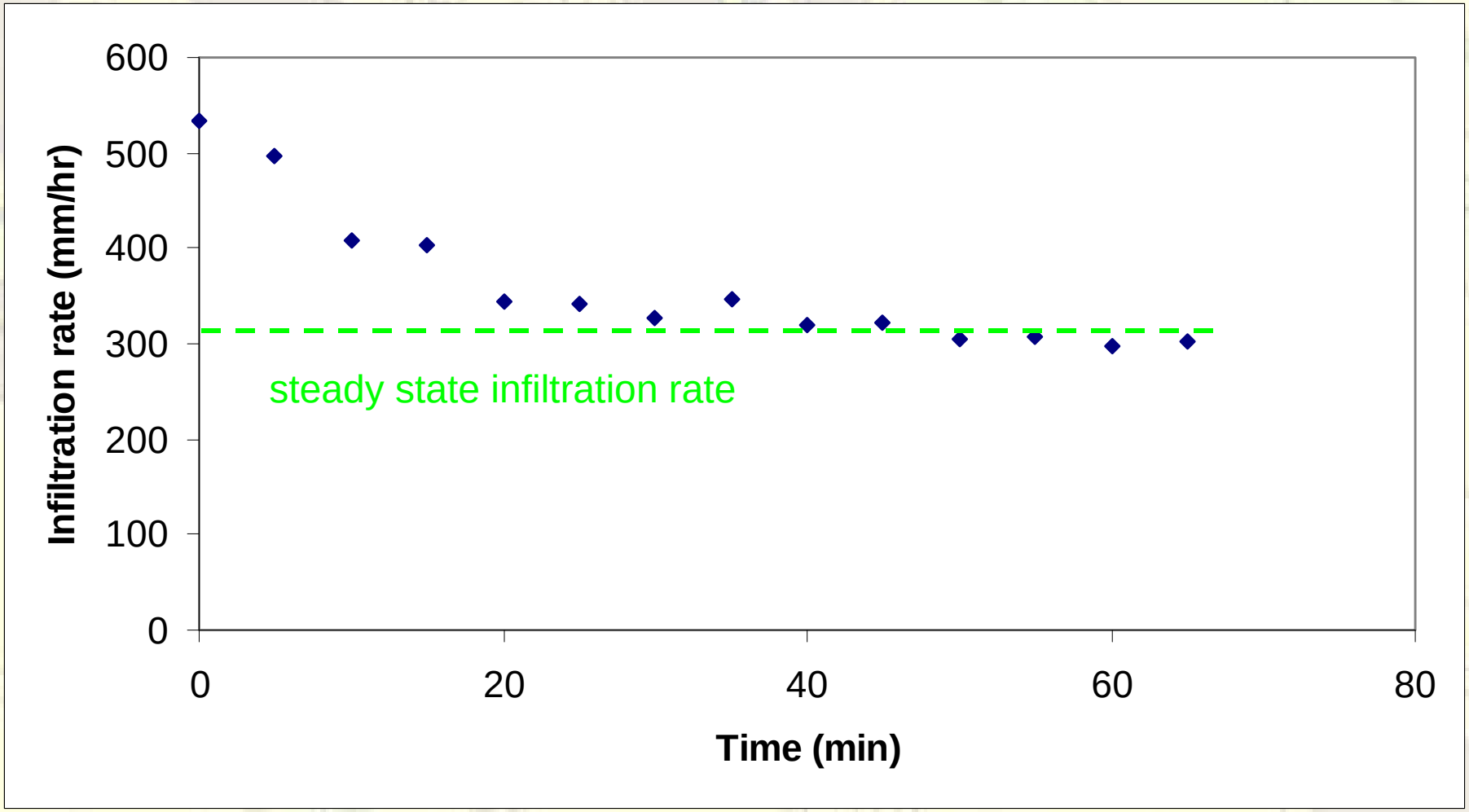
What determines infiltration rates?

- Soil properties
  - texture
  - structure- macropores and micropores
- Other
  - topography
  - land cover

Infiltration over time



Infiltration over time



Comparing infiltration rates: saturated hydraulic conductivity (K_{sat})

- Key to identifying important recharge areas
- Calculated from steady-state infiltration rate (Reynolds, 1990)
- Accounts for differences in ponding depth and lateral flow

Modeling K_{sat} – pedotransfer functions (ptfs)

- Relationships between soil hydraulic properties (such as K_{sat}) and other soil properties:
  - Texture
  - Bulk density
  - Organic matter content

PTFs with non-soil inputs

- Romano and Palladino (2002):
  - Added topographic information to existing PTFs
  - Slope and aspect showed improved some soil water retention predictions
- Sharma et al. (2006)
  - Created PTFs from local data: soils only and soils + topography, vegetation
  - Topography and vegetation generally improve soil water retention predictions
  - Improved resolution of prediction maps

PTFs with non-soil inputs

- Romano and Palladino (2002):
  - Added topographic information to existing PTFs
  - Slope and aspect showed improved some soil water retention predictions
- Sharma et al. (2006)
  - Created PTFs from local data: soils only and soils + topography, vegetation
  - Topography and vegetation generally improve soil water retention predictions
  - ***Improved resolution of prediction maps***

Project goals

- Develop a database for Dane County of field measured infiltration rates, soil properties and non-soil properties (landcover, topography)
- Establish relationships between infiltration rates and soil and non-soil properties (PTFs)
- Create a county-wide map of relative infiltration rates

Why not use an existing model?

- Usually macropore flow is not considered
- Existing K_{sat} models only use soil properties as inputs
- Spatial resolution limited to detail of soil maps

Hypotheses

- Locally-developed PTFs will have lower prediction error than the following K_{sat} estimates:
  - Soil Survey (SSURGO, NASIS database)
  - Texture/porosity table (Rawls et al., 1998)
  - Rosetta (Schaap et al., 2001)
  - Kozeny-Carman (Ahuja et al., 1984; Rawls et al., 1998)
  - PALMS (Bonilla et al., 2008)
- PTFs that include non-soil properties will have lower prediction error than those based on soil properties alone

Methods

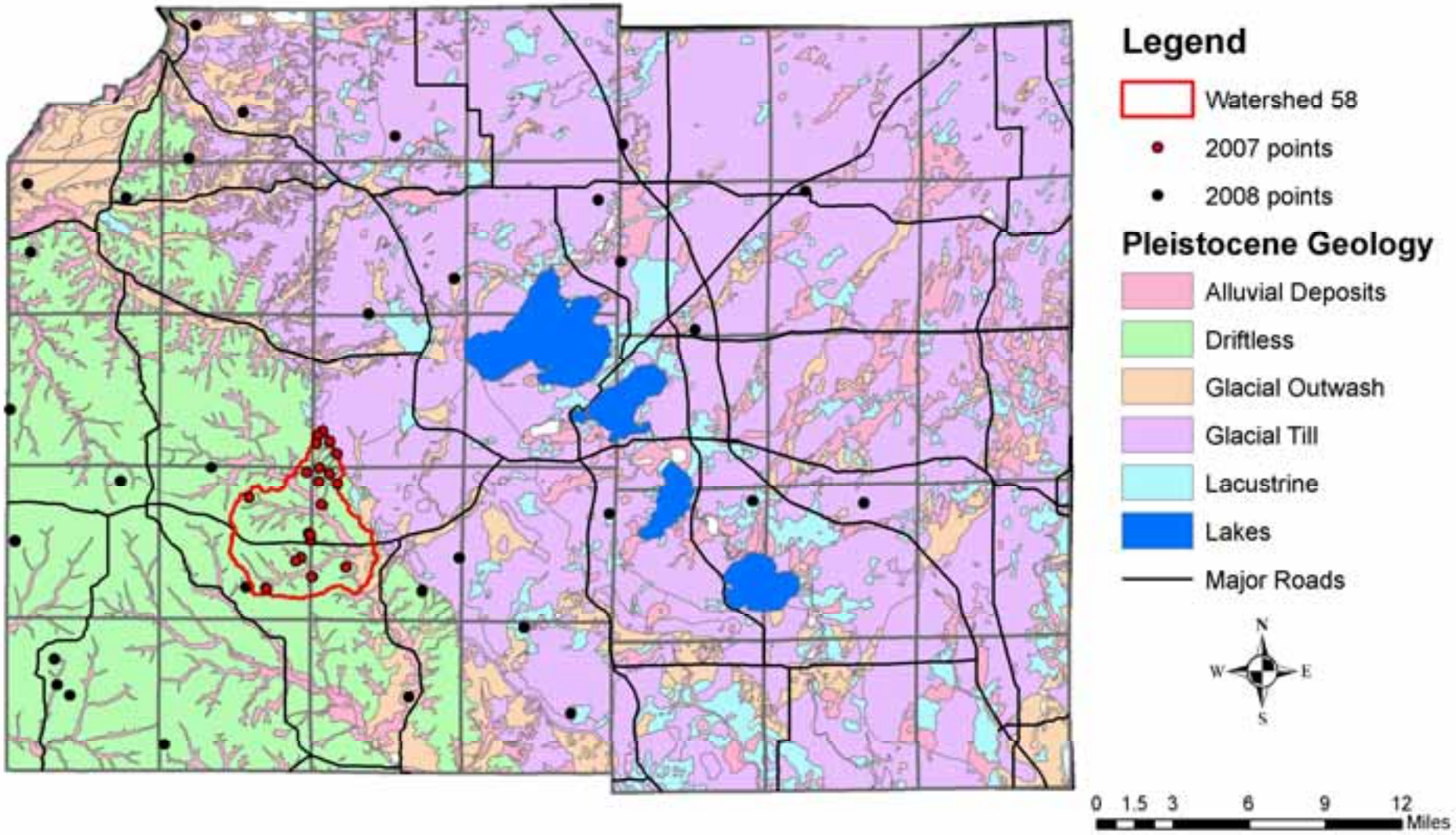
WISCO

Soil Samples

Soil samples:

- 4 depths (0, 15, 30, 45cm)
- 2-3 replicates
- Analyzed for:
  - Organic matter (LOI)
  - Bulk density
  - Particle size distribution (hydrometer method)

Infiltration sites



Geologic Regions

Geology	Percentage of sites	Percentage of county
Driftless	51	20
Glacial Till	27	49
Glacial Outwash	12	9
Alluvial Deposits	4	12
Lacustrine	6	7

Soils

- 25 different soil series
- 37 different soil map units- covering 47% of Dane County
- 11 of 12 soil textural classes

Percent of total samples/area

	Measured	NASIS	Measured	NASIS
Texture	0-30cm	Horizon 1	30-60cm	Horizon 2
Coarse	14	1	14	2
Medium	71	94	54	36
Fine	14	5	32	62

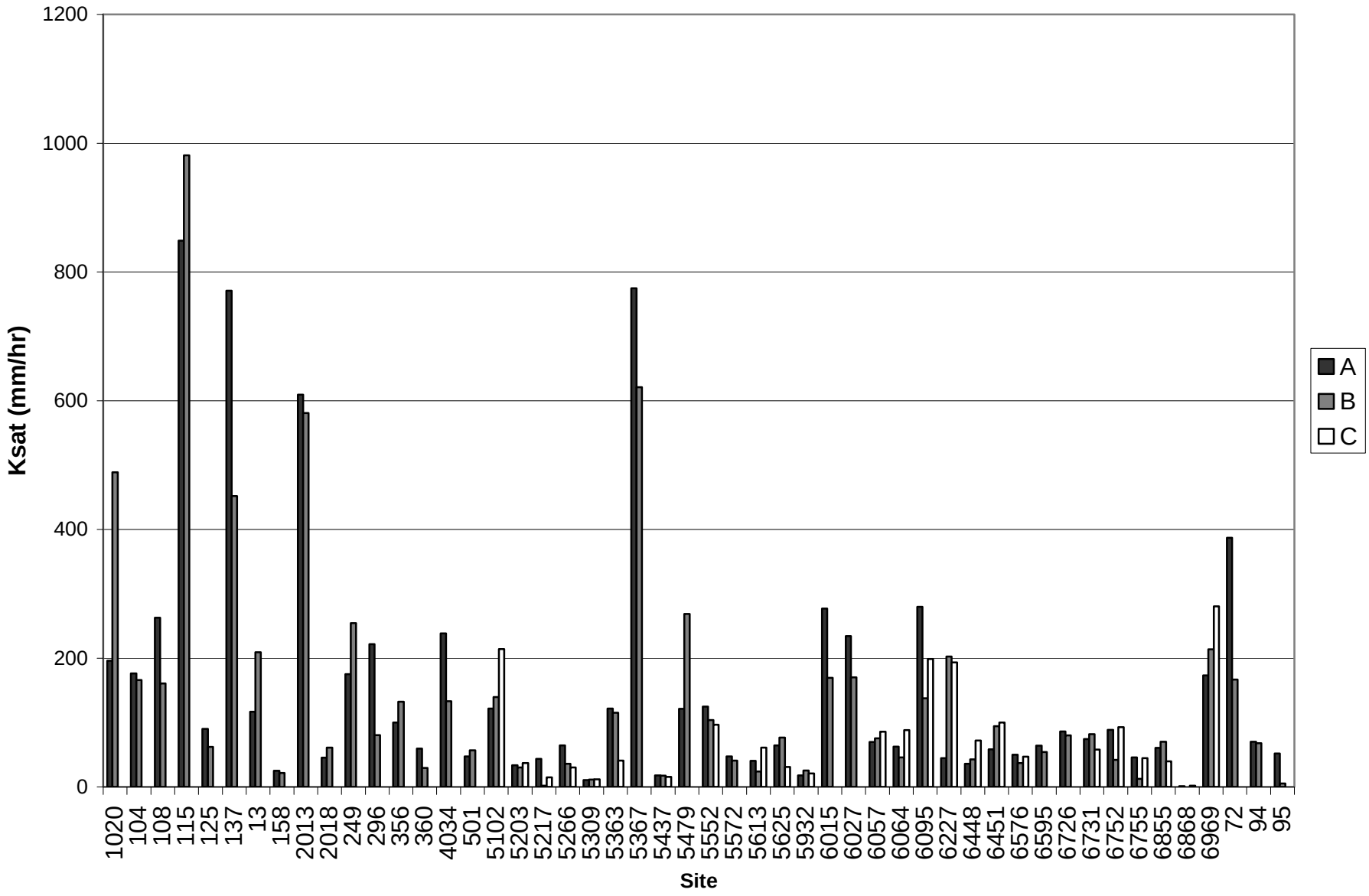
Landcover

Landcover category	Percent of sites	Percent of county area*
Forest	16	14
Grassland/shrub	22	2
Developed	22	13
Pasture/hay	14	19
Cropland	26	46
Other (water, wetlands)	0	8

*based on National Landcover Database (USGS, 2001)

Results

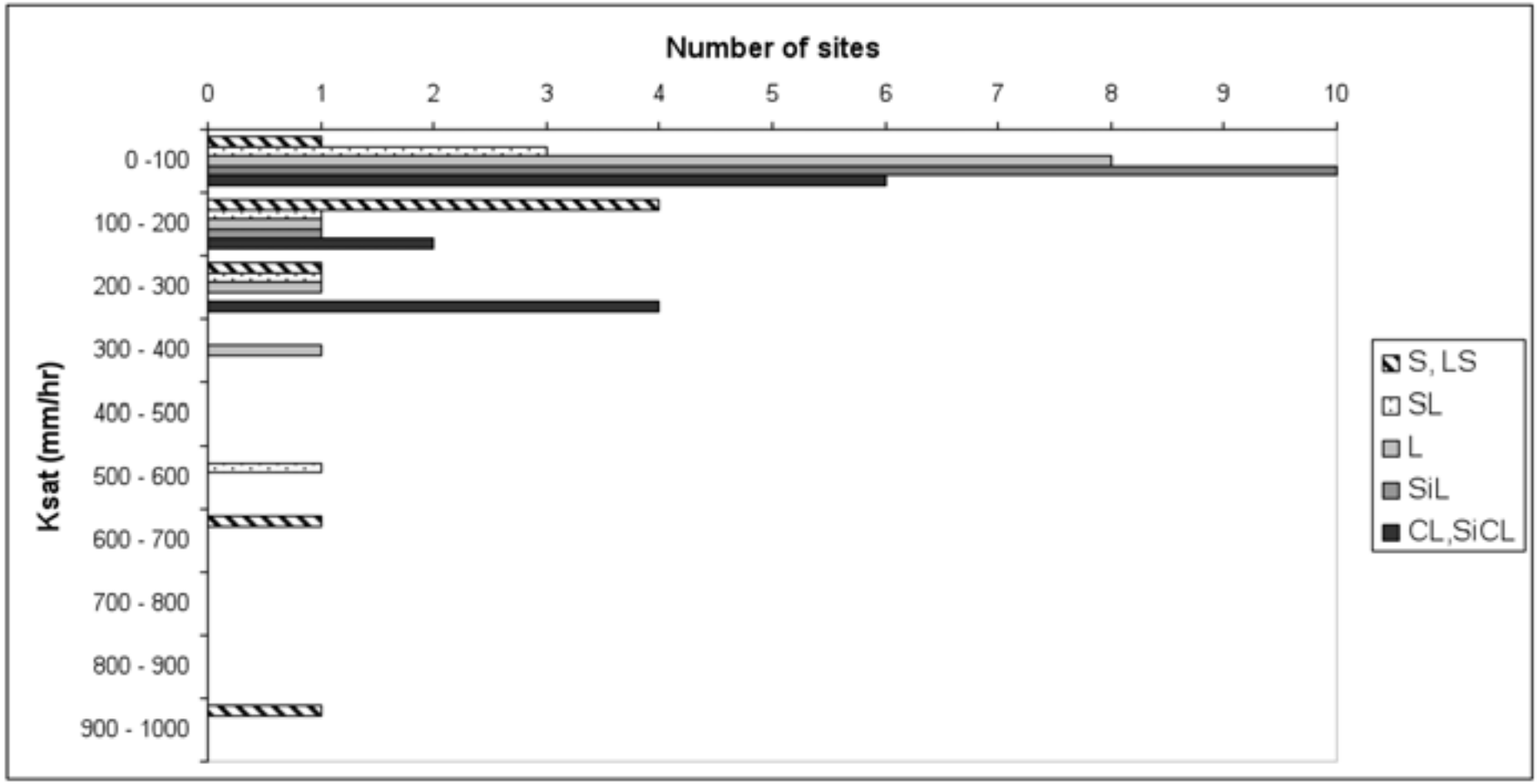
Infiltration measurements



Texture	Porosity	Ksat (mm/hr) Rawls (98)*	Ksat (mm/hr) Rawls (92)	Ksat (mm/hr) PALMS	Measured Ksat (mm/hr)*	Number of sites
Sand	-		210.0	210	360.1	2
	0.44	181.9				
	0.39	91.4				
Loamy sand	-		61.1	122.2	181.1	6
	0.49	123.0				
	0.39	41.4				
Sandy loam	-		25.9	103.6	60.9	6
	0.47	55.8				
	0.37	12.8				
Loam	-		13.2	66	73.7	11
	0.47	3.9				
	0.39	6.2				
Silt loam	-		6.8	47.6	60.0	11
	0.49	14.4				
	0.39	3.4				
Sandy clay loam	-		4.3	38.7		
	0.44	7.7				
	0.37	2.8				
Clay loam	-		2.3	32.2	49.7	6
	0.48	4.2				
	0.4	0.7				
Silty clay loam	-		1.5	25.5	108.6	6
	0.5	3.7				
	0.43	4.9				
Sandy clay	-		1.2	25.2		
	0.39	0.9				
Clay	-		0.6	24		
	0.48	2.0				
	0.4	1.8				
Silty clay	-		0.9	24.3		
	0.53	1.8				

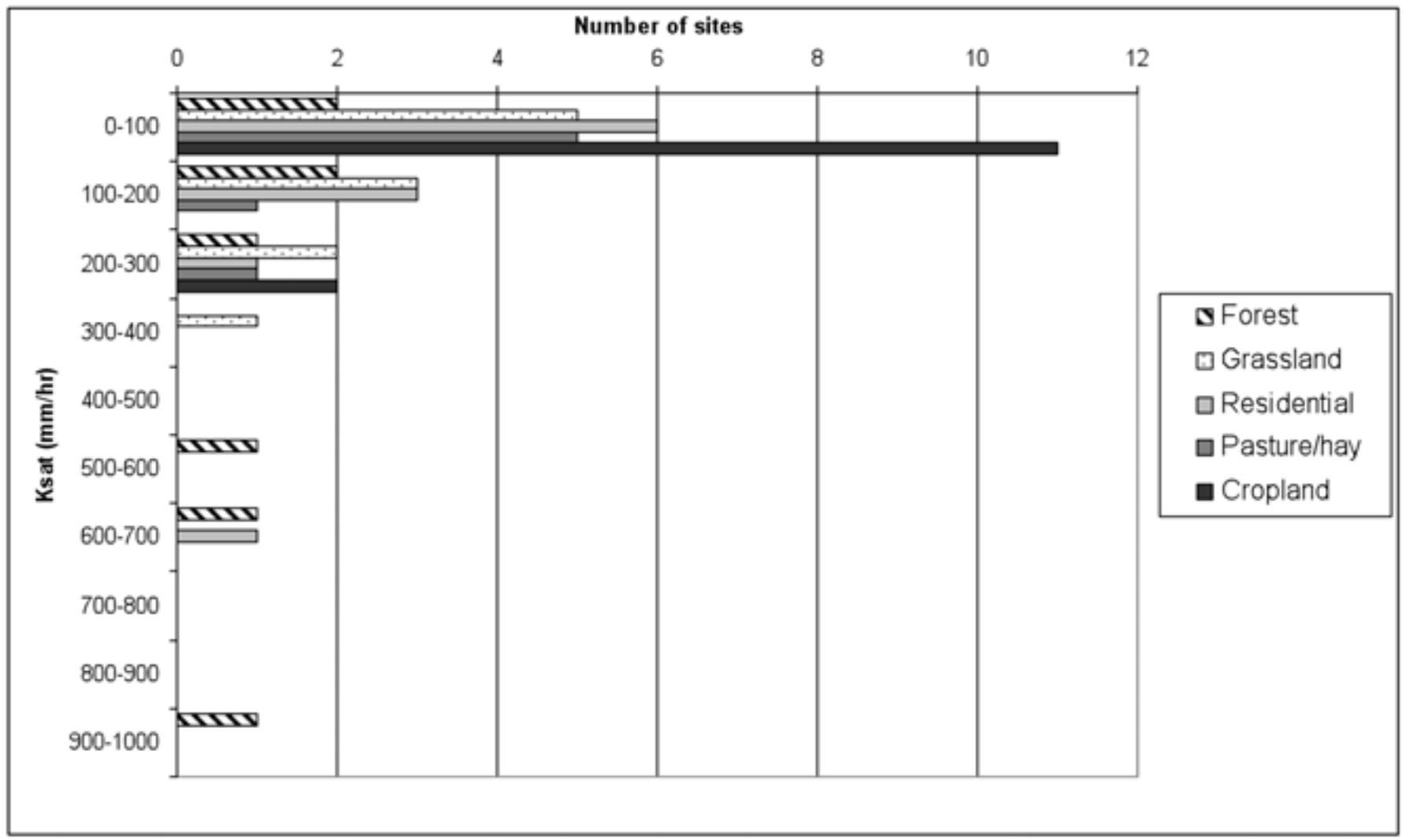
*Geometric means

K_{sat} by surface textural class



S=sand, LS=loamy sand, SL=sandy loam, L=loam, SiL=silt loam, SCL=sandy clay loam, CL=clay loam, SiCL=silty clay loam, SC=sandy clay, C=clay, and SiC=silty clay

K_{sat} by landcover



Possible models

Coefficient	Model 1b	Model 2a	Model 2b	Model 3b	Model 4b
Constant	5.55	5.87	7.4	5.5	5.74
Landcover	-0.364		-0.312	-0.351	-0.262
Ln (%sand:0-15cm)		1.19			
Bulk density: 0-15cm					
Bulk density: 15-30cm		-3.89	-1.48		-1.92
Textural class: 0-15cm				-0.276	-0.308
%Organic matter: 15-30cm				0.246	
Elevation					0.00362
R^2 adjusted	0.18	0.21	0.212	0.29	0.33
AIC_c	7.85	9.02	8.81	8.68	9.69

How well do these and other models predict K_{sat}?

- RMSE = root mean squared error
- RMSE = $\sqrt{(\Sigma(\text{Observed} - \text{predicted})^2 / \text{number of observations})}$

Cross-validation

- Used to evaluate the prediction error of a model without an independent dataset
- Procedure:
  - Remove one observation
  - Develop model
  - Evaluate prediction error of removed observation
  - Repeat for all observations

Model comparison

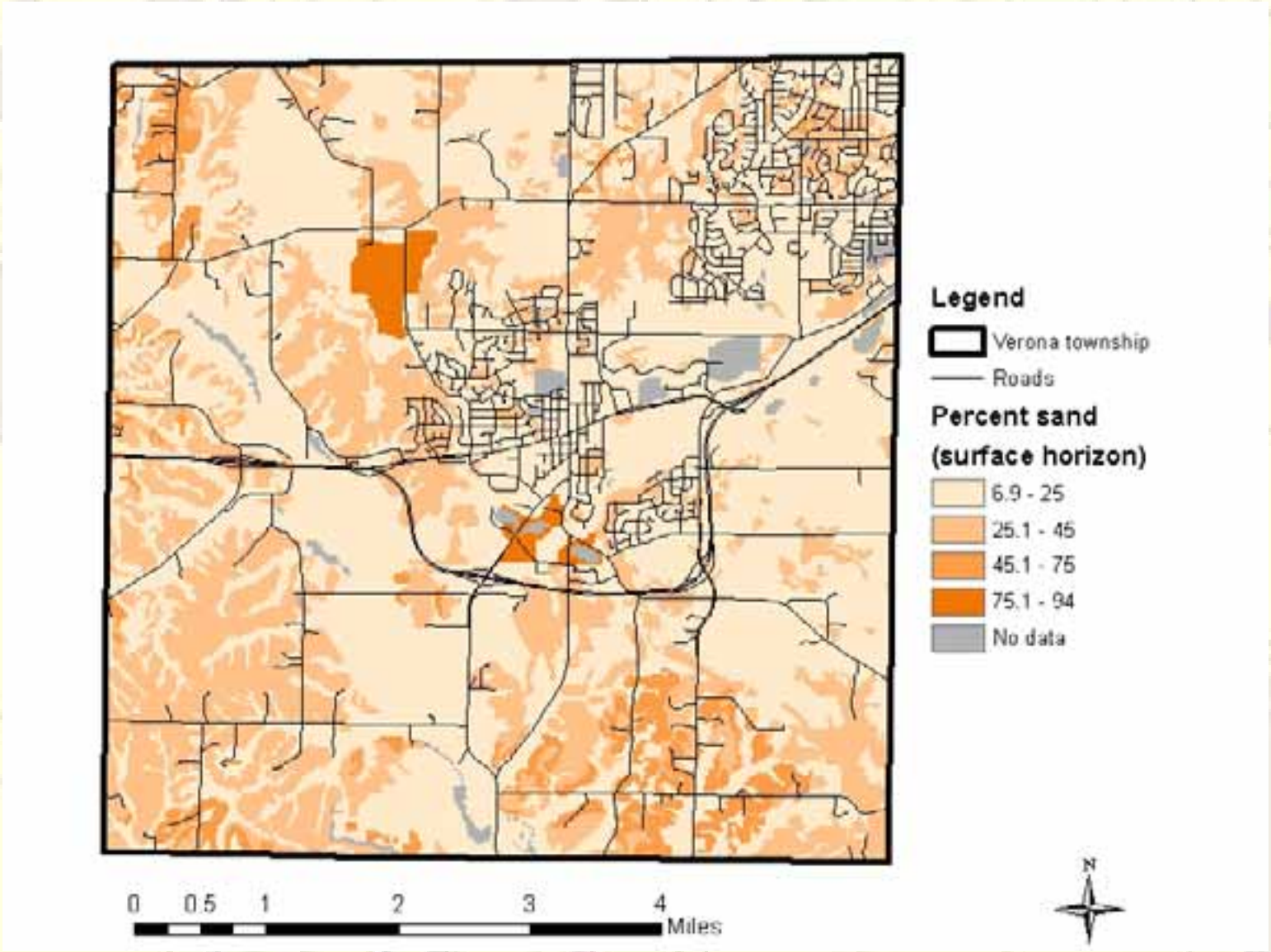
Model	RMSE
Soil Survey estimate	1.63
Texture-porosity table	2.32
Kozeny-Carman equation	2.28
Rosetta	2.15
PALMS	1.19
Model 1b(landcover)	1.17
Model 2a (Ln(%sand-0to15cm), bulk density-15to30cm)	1.06
Model 2b (landcover, bulk density- 0to15cm)	1.06
Model 3b (textural class-0-15cm, %organic matter-15-30cm, landcover)	1.06
Model 4b (textural class-0-15cm, bulk density-15-30cm, landcover, elevation)	1.02

Infiltration Maps

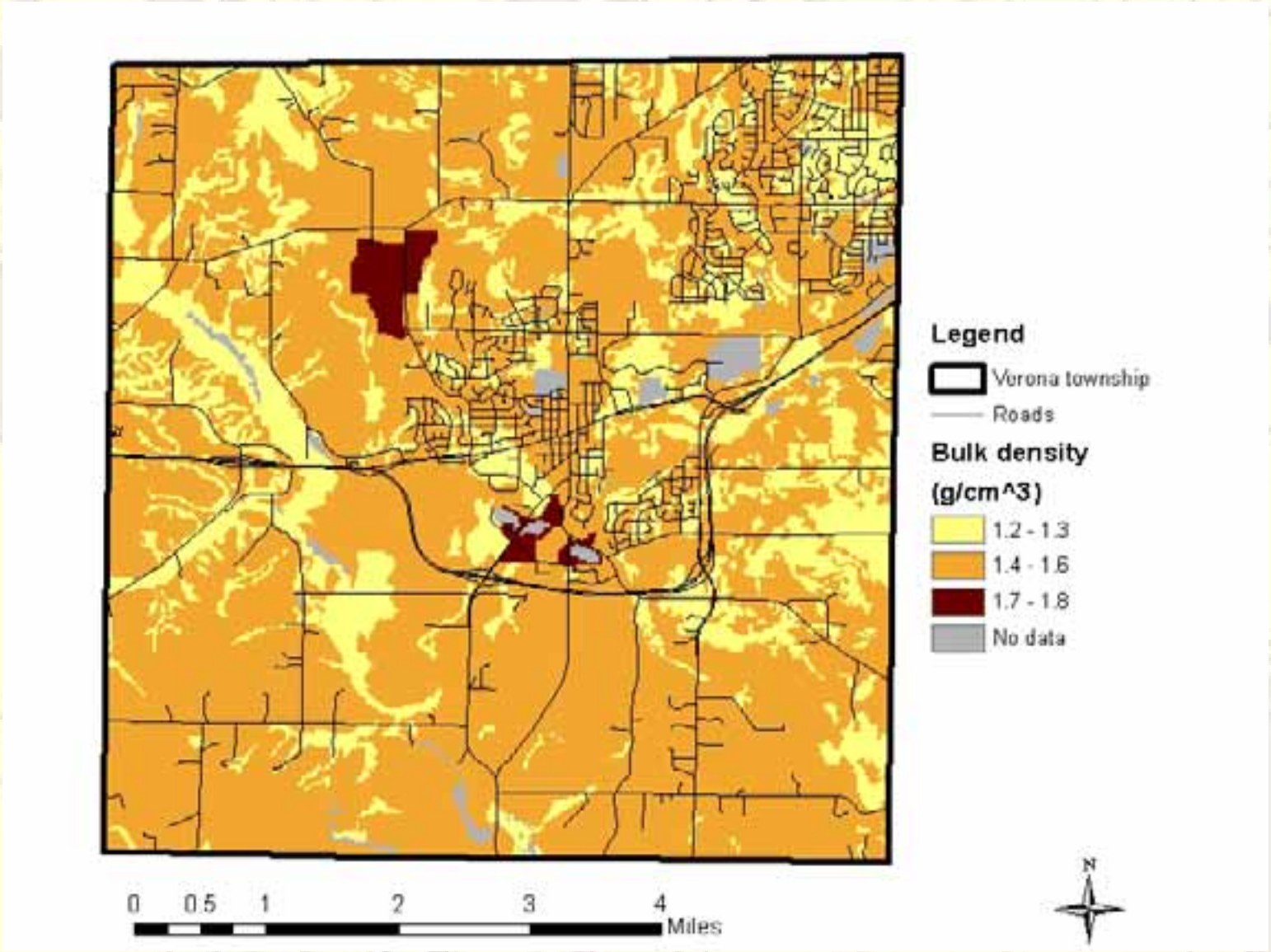
Extrapolating results

- Data Sources:
  - SSURGO map units (1:15,840) combined with representative values from NASIS database:
    - Percent sand (surface horizon)
    - Bulk density (surface horizon)
  - National Land Cover Database (NLCD) (USGS, 2001): 30m resolution

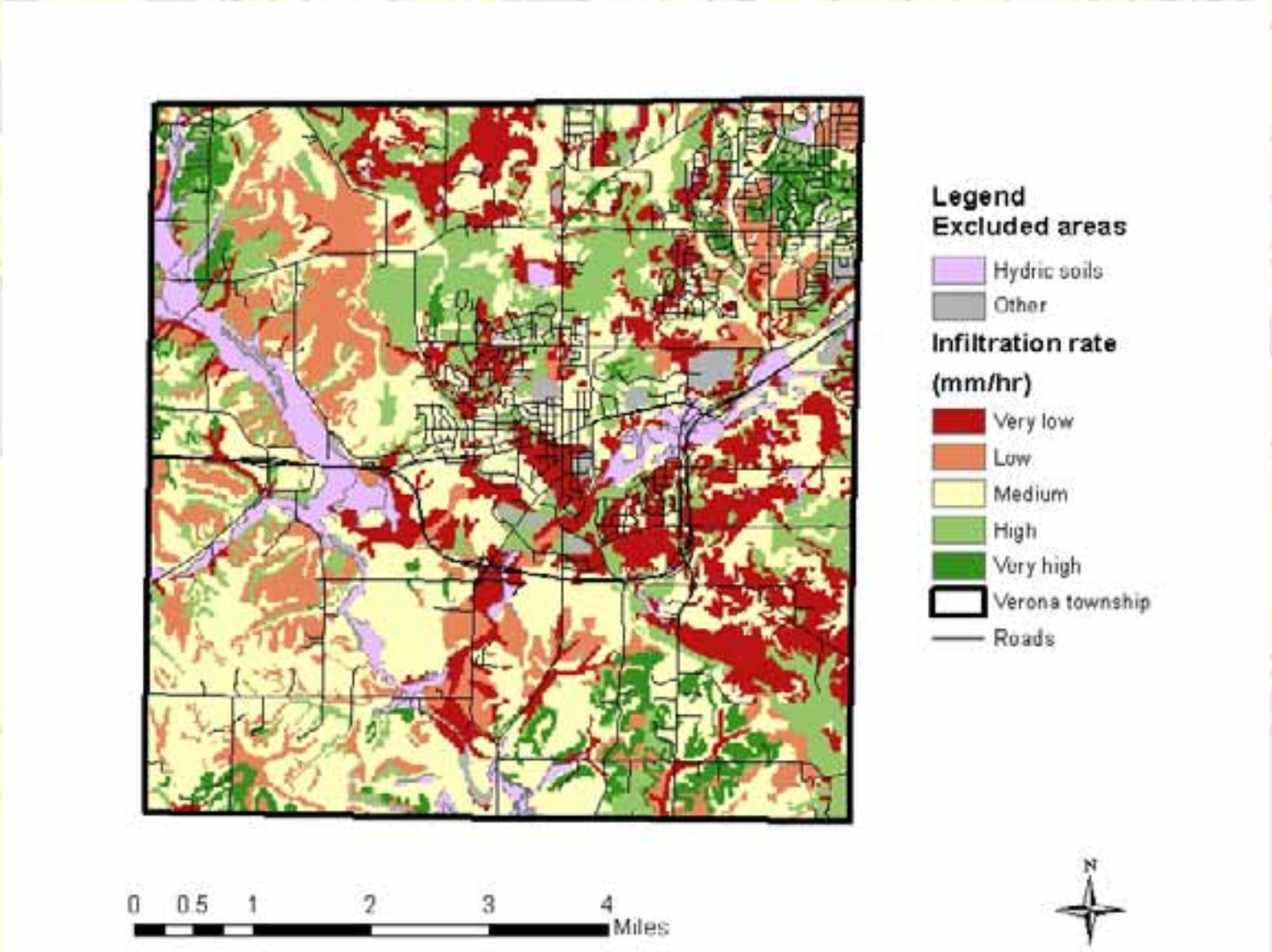
Verona: township: percent sand



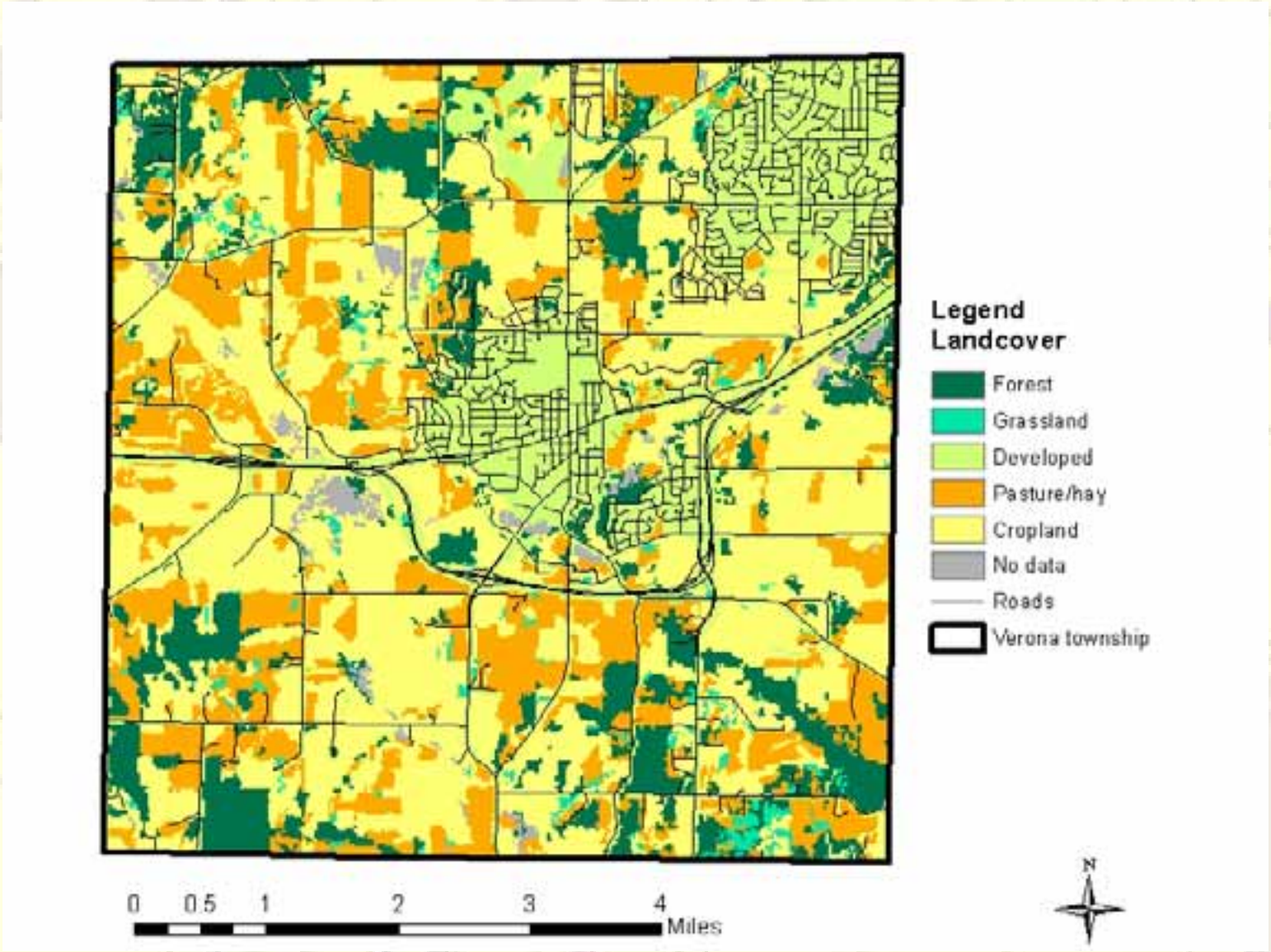
Verona township: bulk density



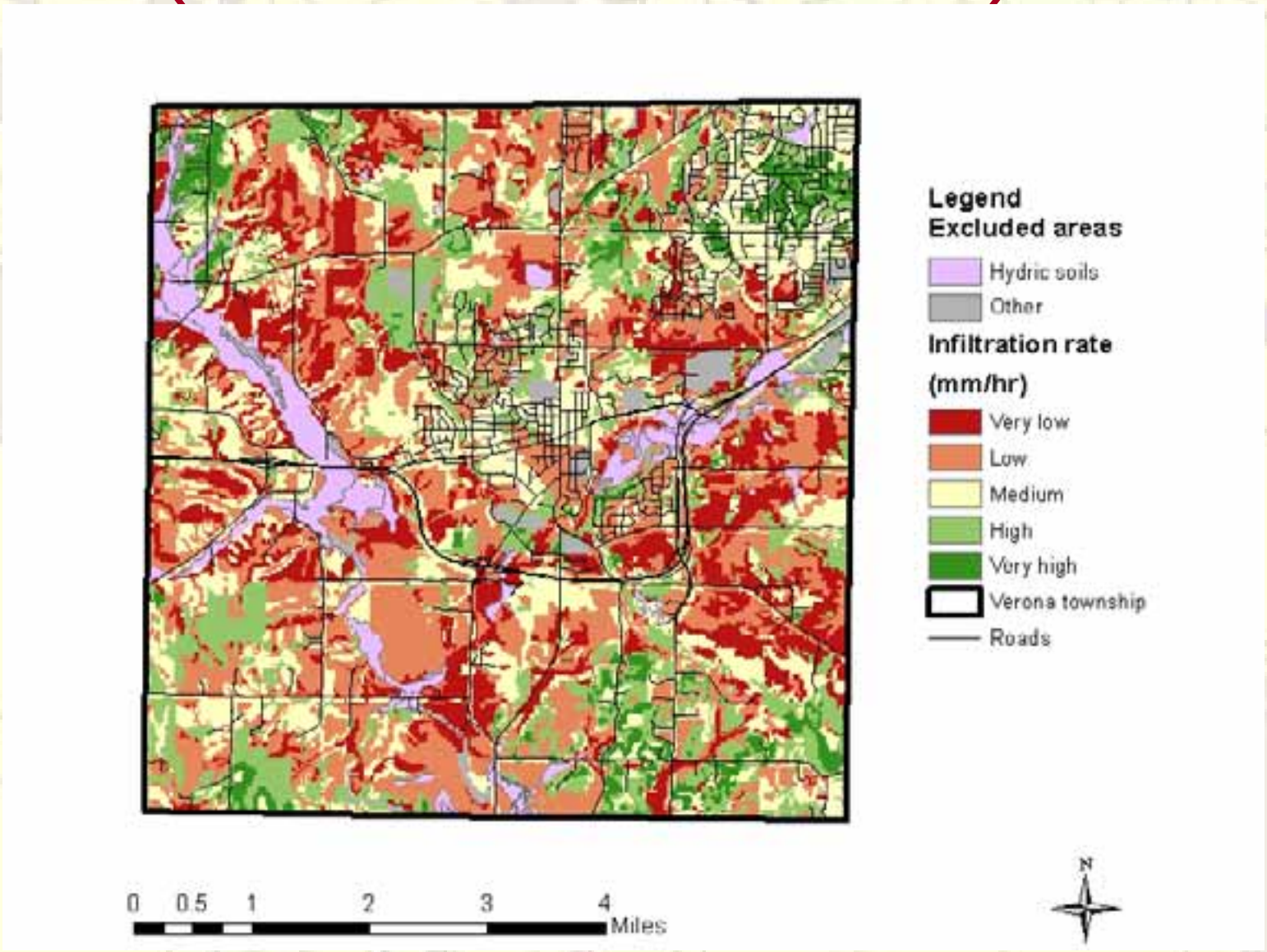
Verona township: infiltration (soil property model)



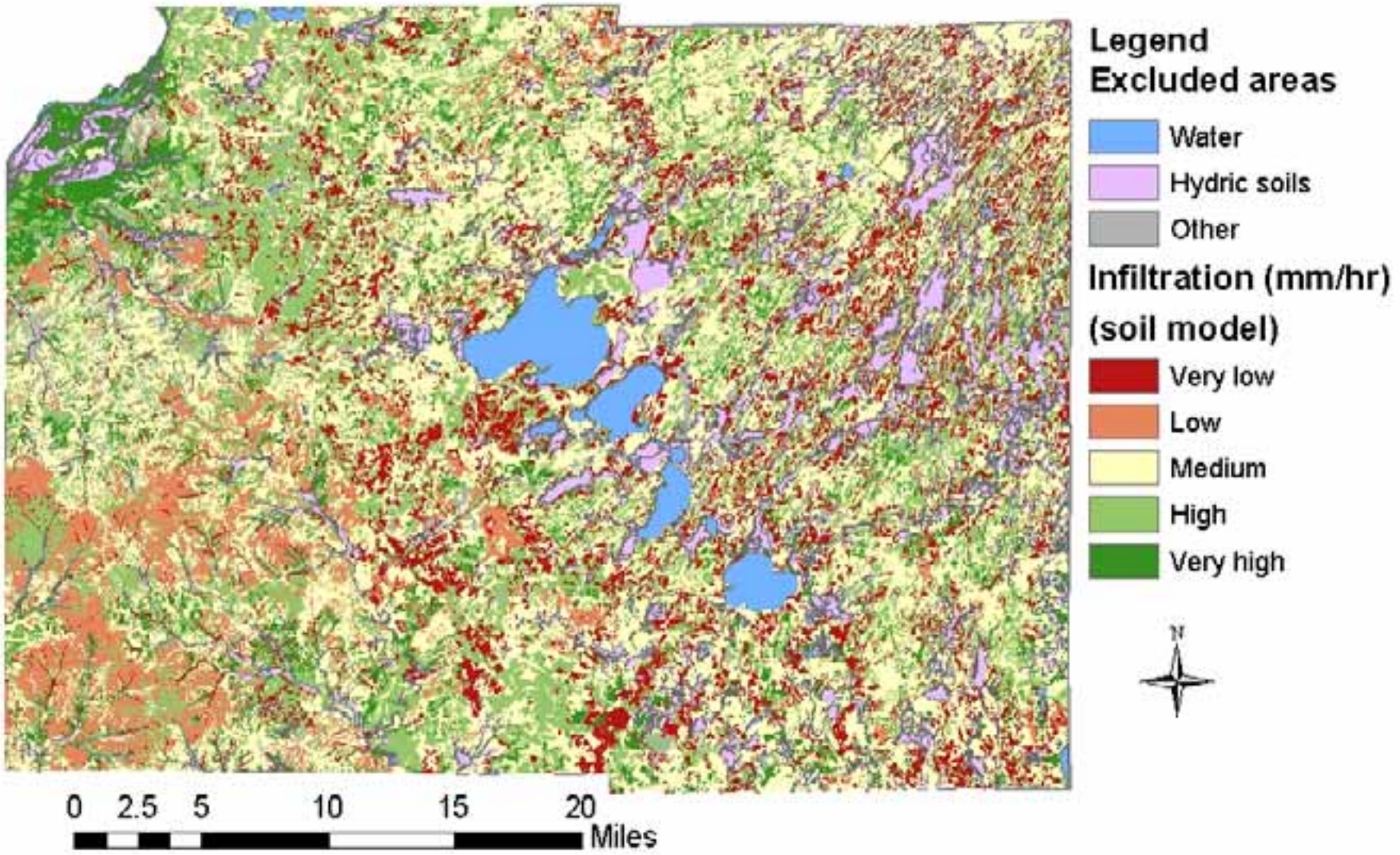
Verona township: landcover



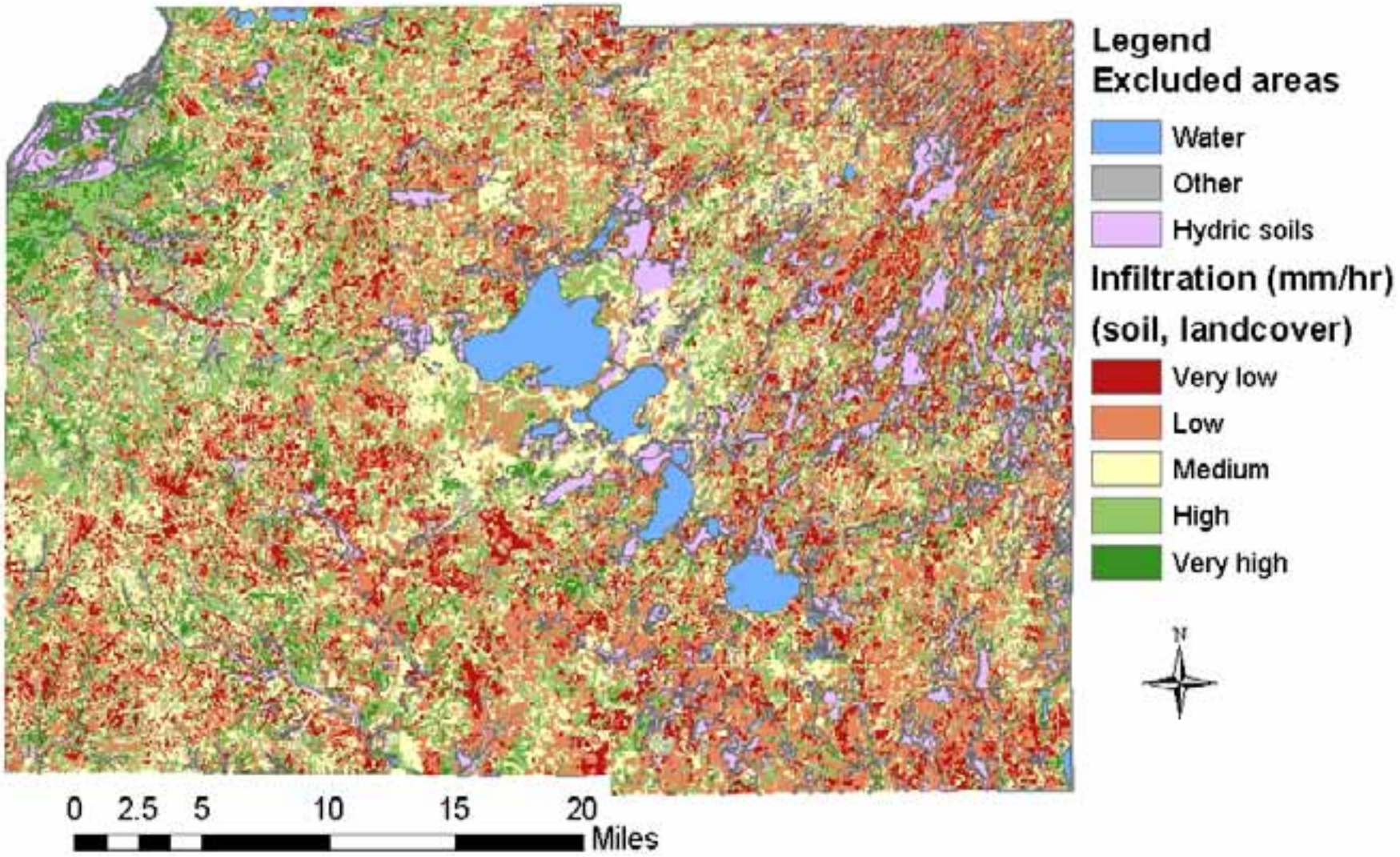
Verona township: infiltration (soil/landcover model)



Predicted infiltration: soil property model



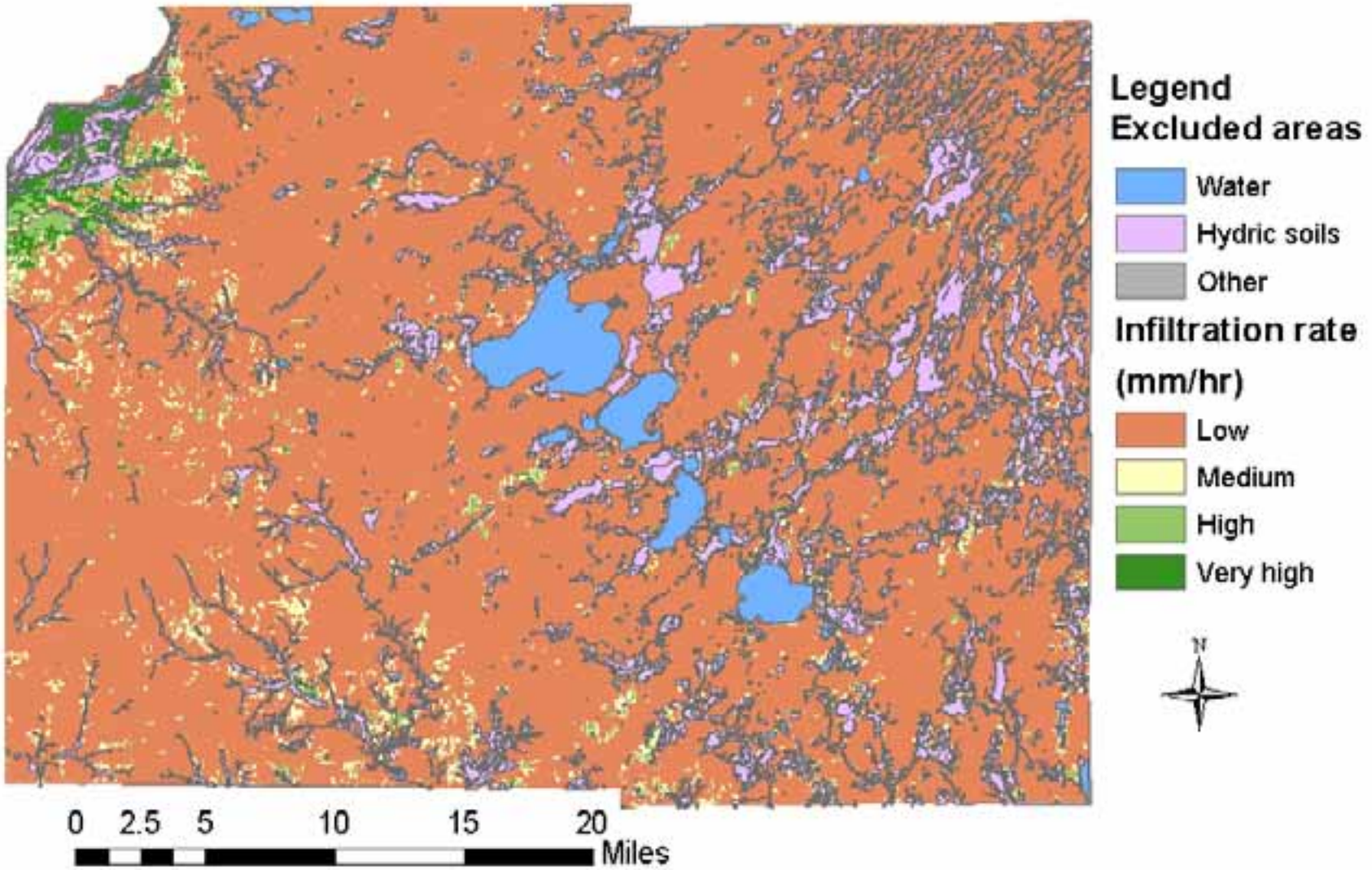
Predicted infiltration: soil and landcover model



Percent of county area

	Model	
Infiltration Category	Soils only	Soils and landcover
Very low	14	14
Low	9	32
Medium	45	24
High	27	24
Very high	7	5

Predicted infiltration: Soil Survey estimate



Map comparison

- Maps developed from PTFs have greater spatial detail and lower prediction error than Soil Survey K_{sat} estimates
- Soil/landcover map has greater spatial detail and slightly lower prediction error than soil property map

Potential uses

- Maps suitable for township or watershed-based planning – e.g., identify areas of towns important for recharge
- Limited utility at finer scales due to significant prediction error, but can raise awareness of site considerations
- Stormwater management practice siting and design still require site-specific measurements

Conclusions

- Infiltration measurements are consistent with PALMS, higher than other estimates
- Local PTFs have significant prediction error, but lower than other K_{sat} estimates
- Landcover slightly improves K_{sat} predictions and increases spatial resolution of predictive maps
- Relative infiltration maps suitable for township or watershed-scale planning

Questions?

Steve Ventura
(608)262-6416
sventura@wisc.edu

RGIS
Rural Geospatial Innovations

COLLEGE OF
AGRICULTURAL & LIFE SCIENCES
University of Wisconsin-Madison

Acknowledgements:

- Committee members: Steve Ventura, John Norman, Nick Balster, Ken Potter, Anita Thompson, and Cindy Stiles
- Field/lab assistants: Terri Emond, Sam Eldred, Samuel Freitag
- Training: Brian Lepore, Ana Wells, Marie Johnston
- Statistics consulting: Jun Zhu
- Extra field help: Nina Trautmann, Becky Carvin, Jeremiah Yahn
- Mapping feedback: Jeremy Balousek, Michelle Richardson, Kevin Connors, Josh Harder, Mike Kakuska, Dave Hart
- Child care: Tom, Tommy and Robyn Maher, Joanne Cahill, Brett Czerwonka, Page Pisapia