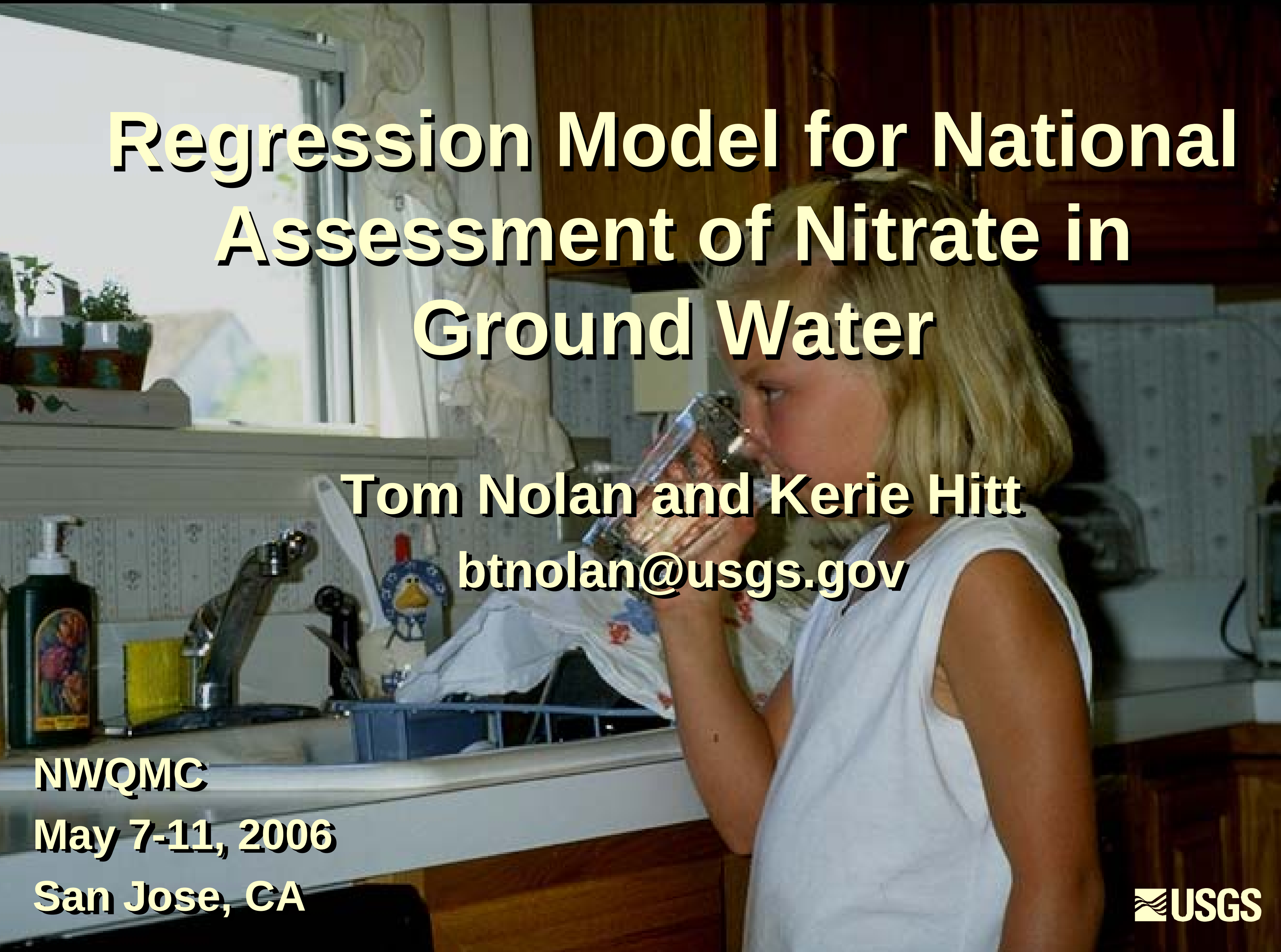
Assessing Ground Water Vulnerability through Statistical Methods I

NWQMC

May 7-11, 2006

San Jose, CA



Regression Model for National Assessment of Nitrate in Ground Water

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Road Map

- Societal implications of aquifer vulnerability
- Monitoring and prediction
- National examples for nitrate:
  - (1) shallow ground water
  - (2) drinking-water wells

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Ground-Water Vulnerability

"The tendency or likelihood for [nonpoint-source] contaminants to reach a specified position in the GW system after introduction at some location above the uppermost aquifer."

-National Research Council, 1993

Focazio, M.J., and others (2002), Assessing ground-water vulnerability to contamination — providing scientifically defensible information for decision makers: USGS Circular 1224.

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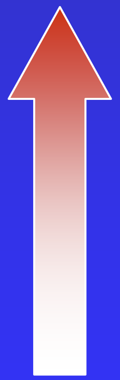
Why the Concern About Shallow Ground Water?

NAWQA data sets	Average well depth, ft	Nitrate MCL exceed., %
Domestic wells in agric. areas	170	22
Domestic wells (40 million users)	180	7
Public supply wells	550	3

Risk



Why the Concern About Nitrate?

- Methemoglobinemia first reported in U.S. in 1945—rare since MCL promulgated.
- Increased risk of non-Hodgkins lymphoma in Nebraska, NO_3 > 4 mg/L (Ward et al., 1996)
- Increased risk of bladder and ovarian cancers in Iowa, NO_3 > 2.5 mg/L (Weyer et al., 2001)

Ward et al., "Drinking-Water Nitrate and Health—Recent Findings and Research Needs," EHP, June 2005

- Few well-designed studies for cancer sites
- Combined effect of nitrate intake from food and water is difficult to evaluate

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Mitigation Cost

- Treatment
  - Nitrate removal from public well water can exceed $2 million per system
  - Annual operating cost is 4 – 5 times higher (up to $6 per 1,000 gal)
- Well abandonment
  - $600,000 for new community well typically

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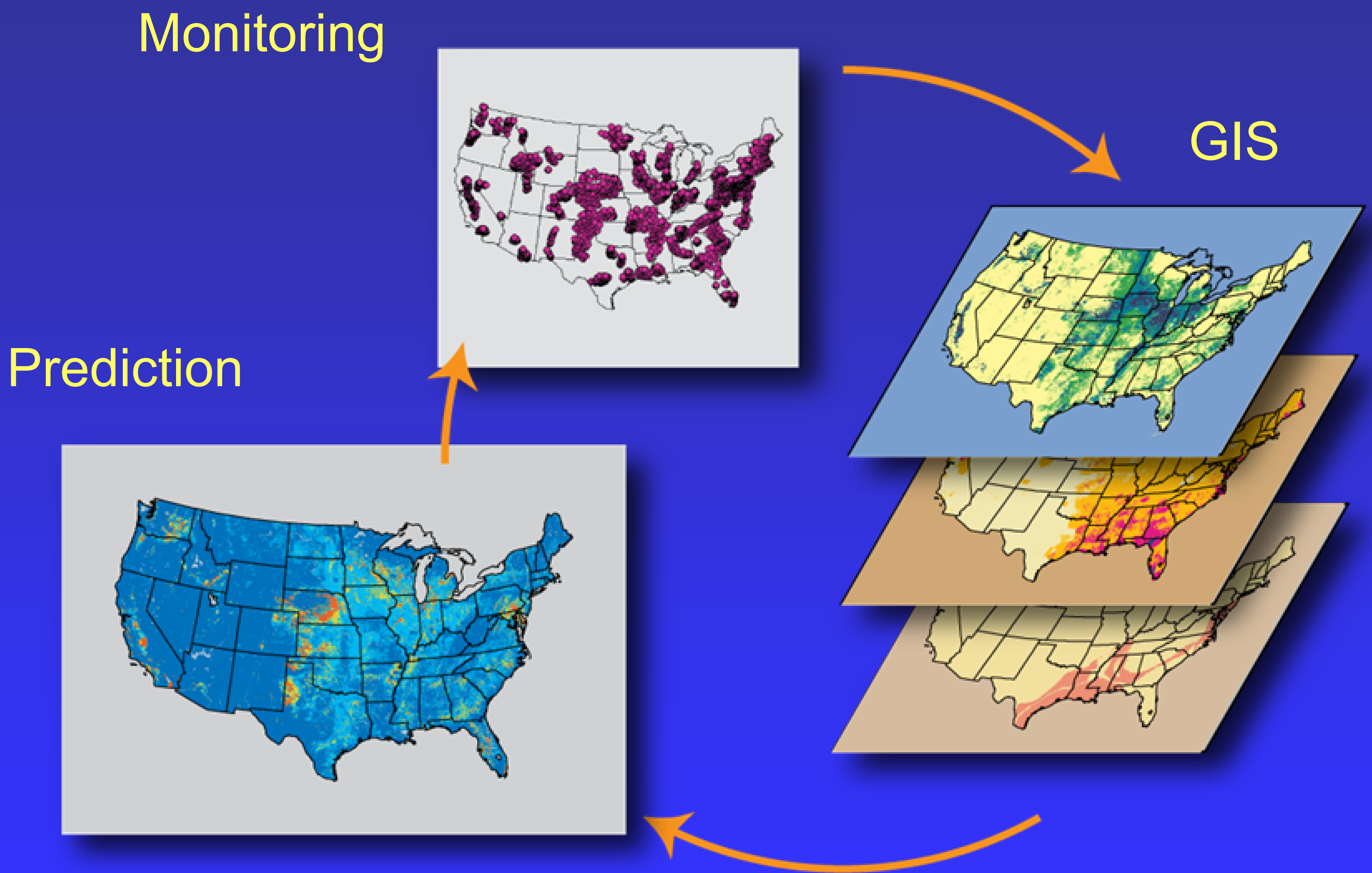
Monitoring
GIS
Prediction

National Example

Objectives:

- Use empirical models to identify variables that significantly influence nitrate concentration in ground water.
- Map contamination risk for the U.S.
- Characterize uncertainty.

Nonlinear Regression → Concentrations

$$c_{gwi} = \underbrace{\sum_{n=1}^{N} \beta_n X_{n,i}}_{\text{Load}} \bullet \underbrace{\exp(\sum_{j=1}^{J} \alpha_j T_{j,i})}_{\text{Transport}} \bullet \underbrace{\exp(\sum_{k=1}^{K} -\delta_k Z_{k,i})}_{\text{Attenuation}} + \varepsilon_i$$

c_{gwi} = mean nitrate concentration (mg/L) for ground-water network *i*
$X_{n,i}$ = average N load from source *n* in network *I*
$T_{j,i}$ = average transport factor *j* for network *i*
$Z_{k,i}$ = average attenuation factor *k* for network *i*
β_n = coefficient for N source *n*
α_j = coefficient for transport factor *j*
δ_k = coefficient for attenuation factor *k*
ε_i = model error for network *i*

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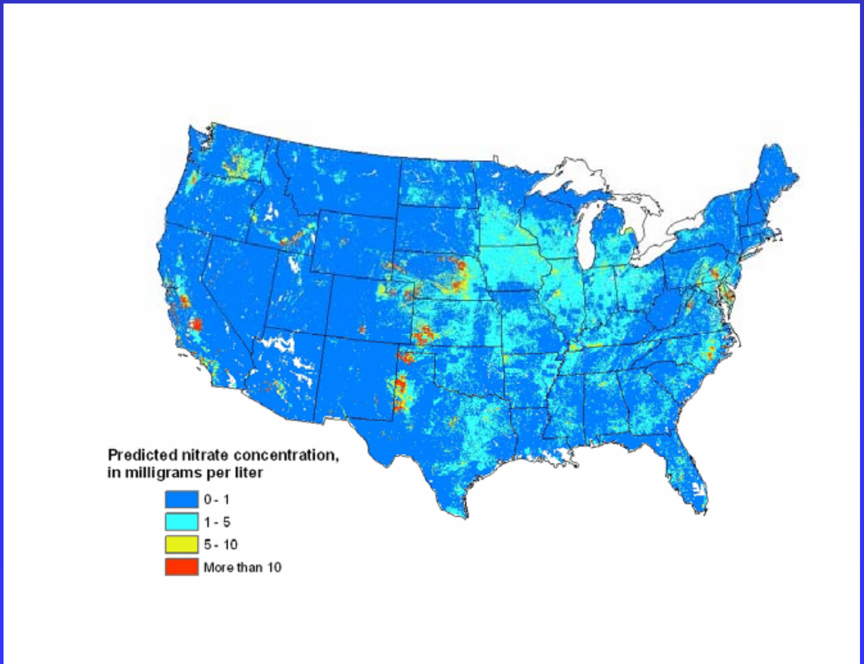
Two nonlinear models developed…

(1) Shallow ground water ($R^2 = 0.80$)

(2) Drinking water wells ($R^2 = 0.77$)



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Drinking Water Model

Parameter	Coeff. sign	Significance Level (p)
Nitrogen source (β)		
Farm fertilizer	+	<0.01
Confined manure	+	<0.01
Orchards/vineyards	+	0.04
Population density	+	0.04
Transport to aquifer (α)		
Water input[a]	+	<0.01
Semiconsolidated sands	+	0.02
Sandstone and carb. rocks	+	<0.01
Glacial deposits	–	0.02
Drainage ditch	–	<0.01
Hortonian overland flow	–	<0.01
Attenuation (δ)		
Fresh surface water withdrawal	–	<0.01
Irrigation tailwater recovery	–	<0.01
Dunne overland flow	–	<0.01
Well depth	–	0.18

[a]ratio of irrigated land to precipitation

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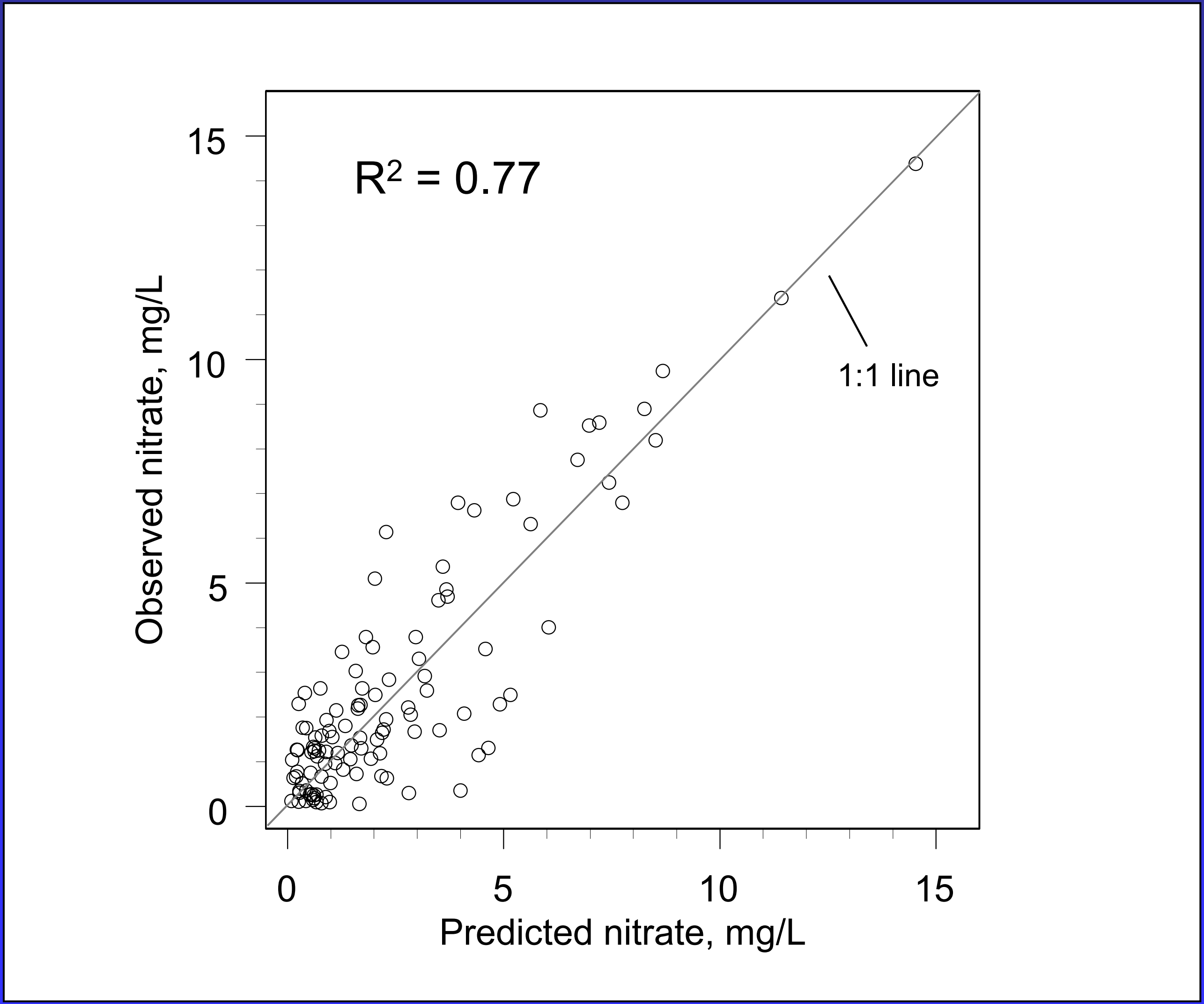
Model Fit



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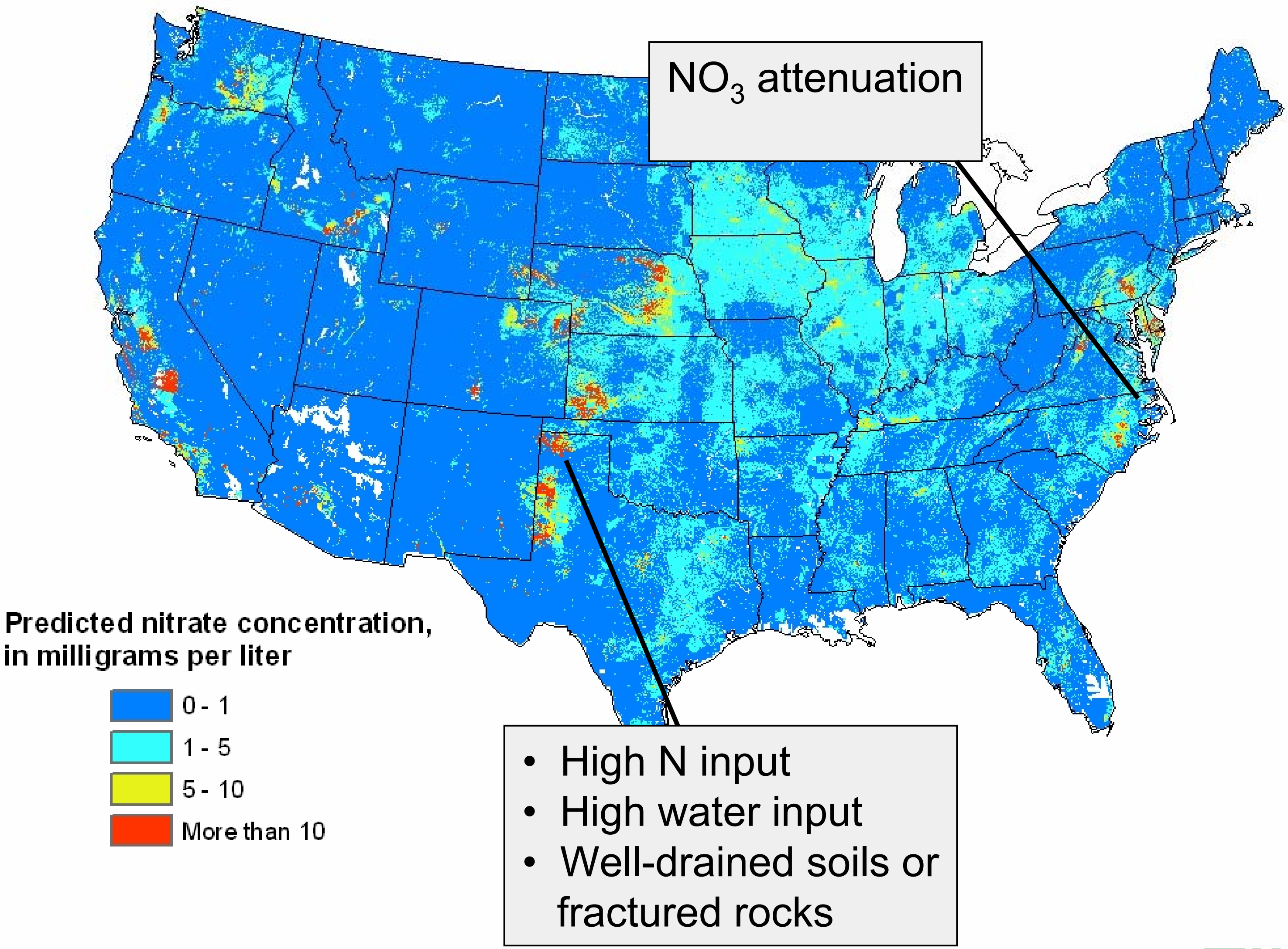
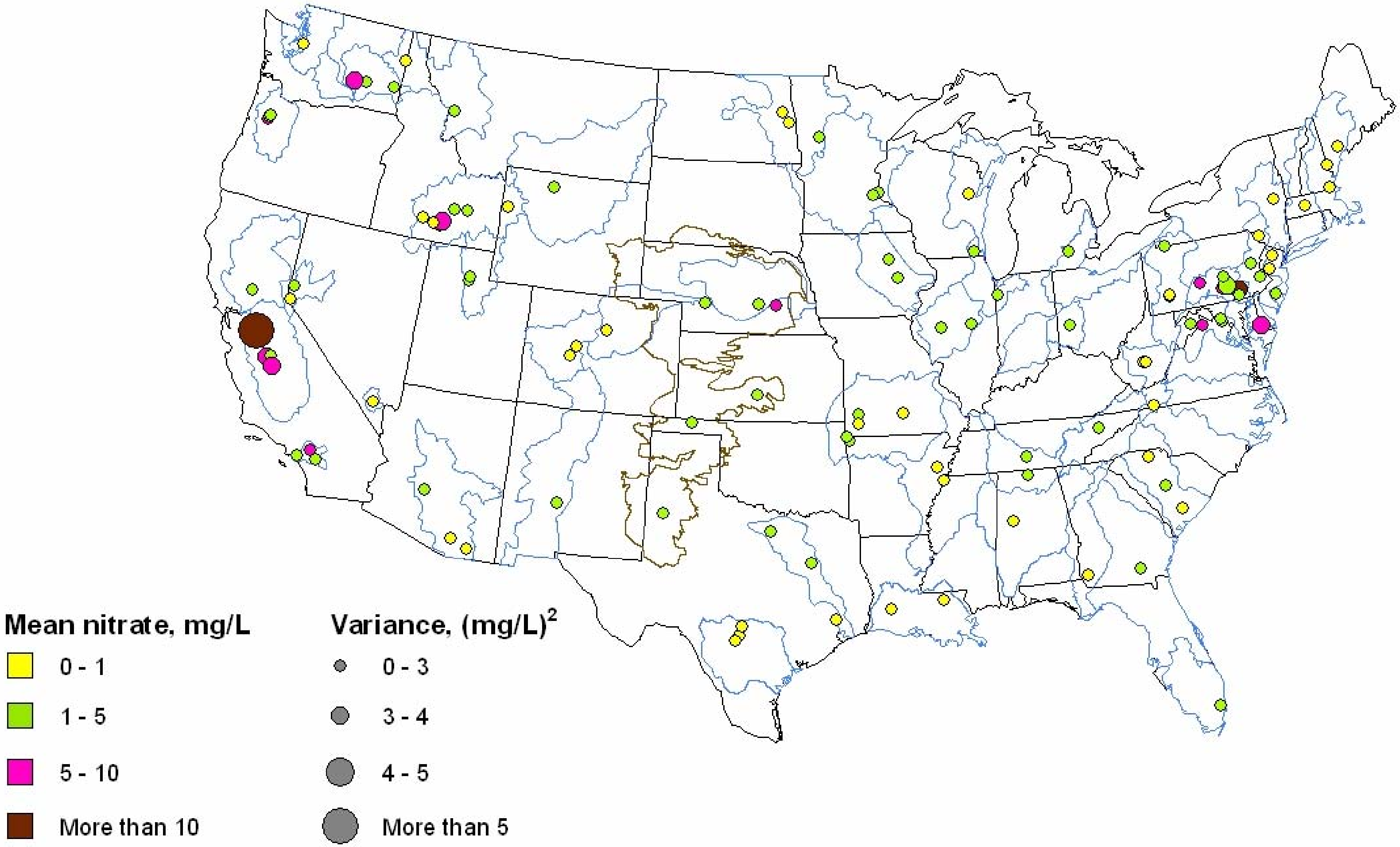
Prediction



NO_3 attenuation
Predicted nitrate concentration, in milligrams per liter
0 - 1
1 - 5
5 - 10
More than 10
• High N input
• High water input
• Well-drained soils or fractured rocks

Monte Carlo for Uncertainty



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Population Scenarios

Hypothetical depth — "shallow"

Typical depth

Model → Reduce risk by seeking deeper supplies.

Domestic well users in areas defined by depth

Predicted nitrate concentration range	30 ft	160 ft	Percent change
0 – ≤ 1 mg/L	19,400,000	20,000,000	+ 3
> 1 – ≤ 5 mg/L	13,300,000	13,000,000	– 3
> 5 – ≤ 10 mg/L	1,400,000	1,240,000	– 12
> 10 mg/L	528,000	467,000	– 12

1% of users

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Take home: National statistical models help…

- Identify areas for enhanced monitoring and protection.
- Identify aquifer vulnerability factors.
- Evaluate contamination scenarios.

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