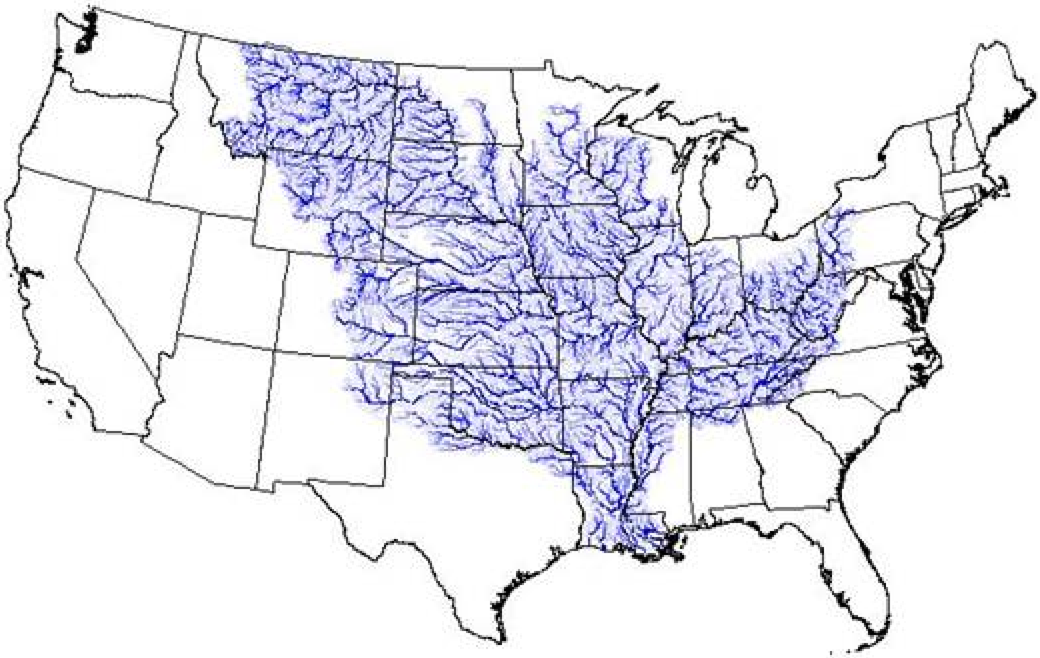
SPARROW Modeling in the Mississippi and Atchafalaya River Basins (MARB)



USGS/USEPA
WEBEX Meeting

June 29, 2007

Dale Robertson, Richard Alexander, and David Saad
U.S. Geological Survey

USGS
science for a changing world

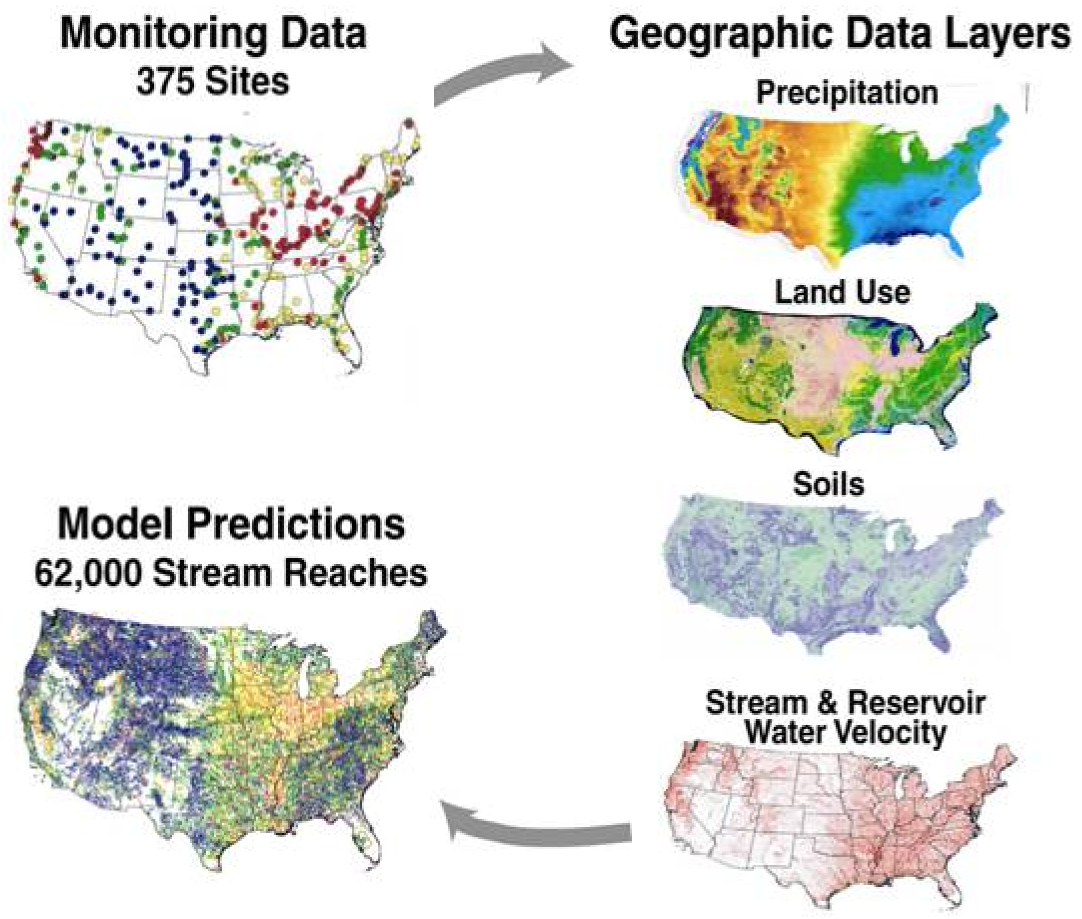
Outline

- Overview of SPARROW
- Recent advances in SPARROW and applications to the Mississippi/Atchafalaya R. Basin
- Summary of nitrogen and phosphorus results for large regional basins
- Preliminary watershed rankings – nutrient delivery to the Gulf
- Future SPARROW modeling

SPARROW Water-Quality Model

SPAtially Referenced Regression on Watershed Attributes

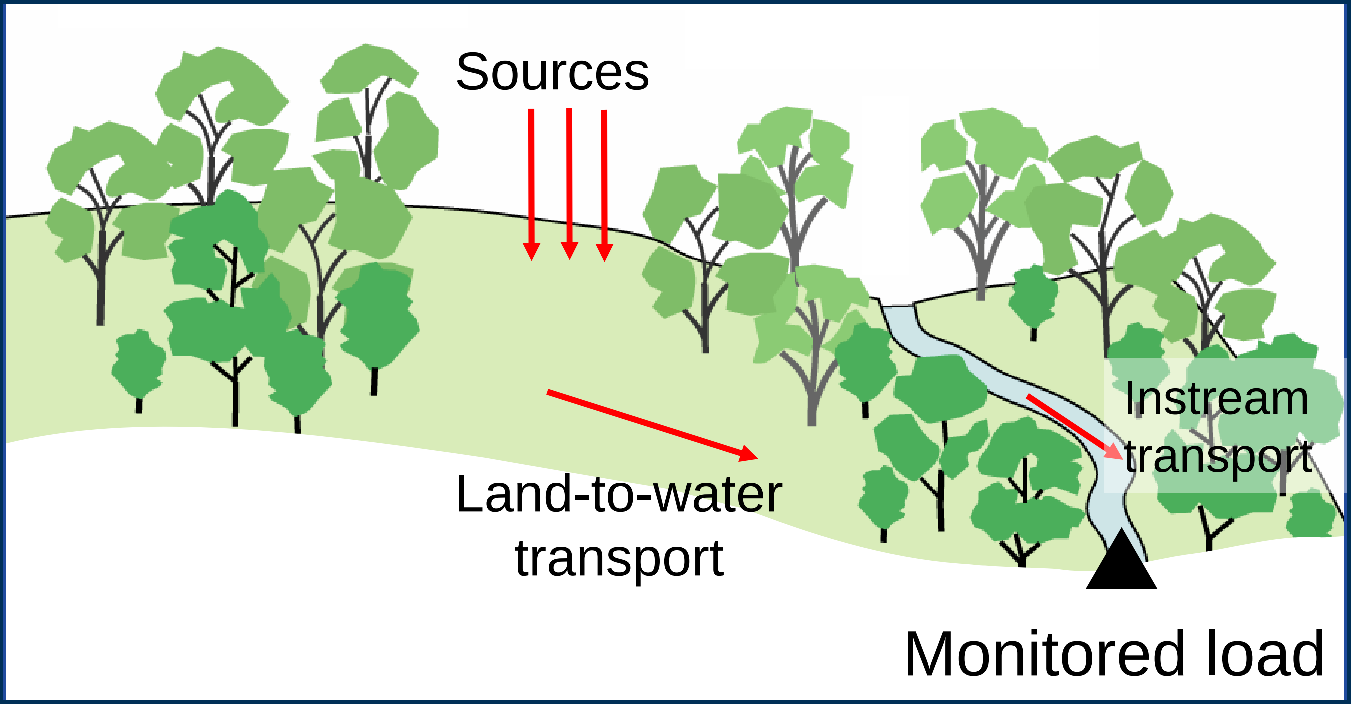
http://water.usgs.gov/nawqa/sparrow; Smith et al. 1997



- Hybrid statistical and mechanistic process structure; mass-balance constraints; data-driven, nonlinear estimation of parameters
- Spatially explicit; separates land and water processes
- Physically interpretable coefficients; model supports hypothesis testing and uncertainty estimation
- Predictions of mean-annual flux reflect long-term, net effects of nutrient supply and loss processes in watersheds

SPARROW modeling approach:

- Regress water-quality conditions (monitored load) on upstream sources and factors controlling transport
- Incorporates instream decay of nutrients



SPARROW→SPAtially Referenced Regressions On Watershed Attributes

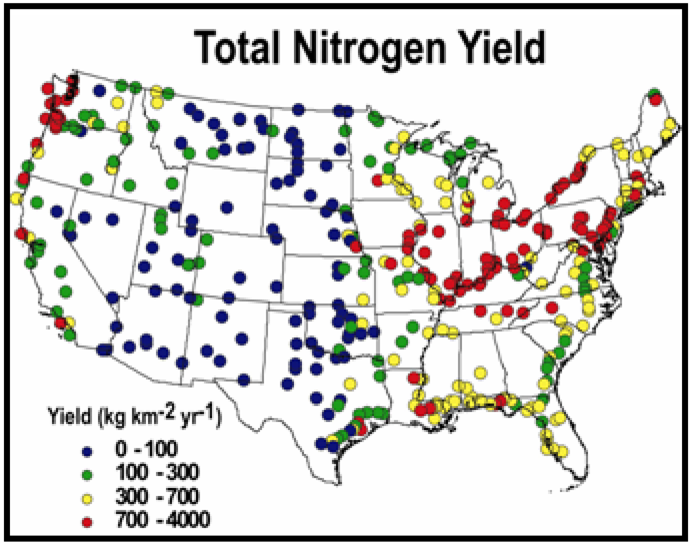
Nonlinear Regression Model

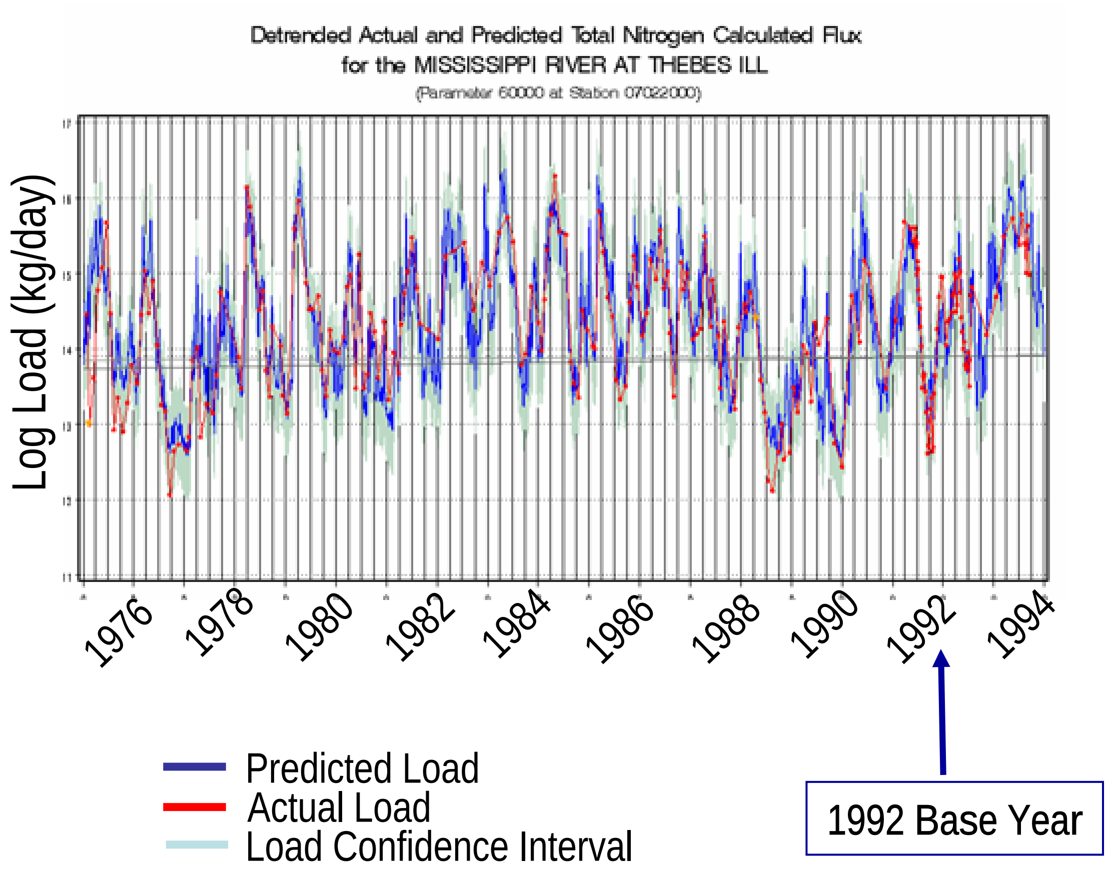
$$Load_i = \left\{ \sum_{j \varepsilon J(i)} \left[\sum_{n=1}^{N} S_{n,j} \, \beta_n \, e^{(\alpha' Z_j)} \right] e^{(-\delta' T_{i,j})} \right\} e^{(\varepsilon_i)}$$

Load — **Sources** (**For each watershed**) — **Land-to-water delivery** — **Instream decay** — **Error**

Estimation of mean-annual nutrient load at stream monitoring sites - Model Inputs

Mean-annual TN load for 1992 base year
(detrended; flow-adjusted 1975-2000)

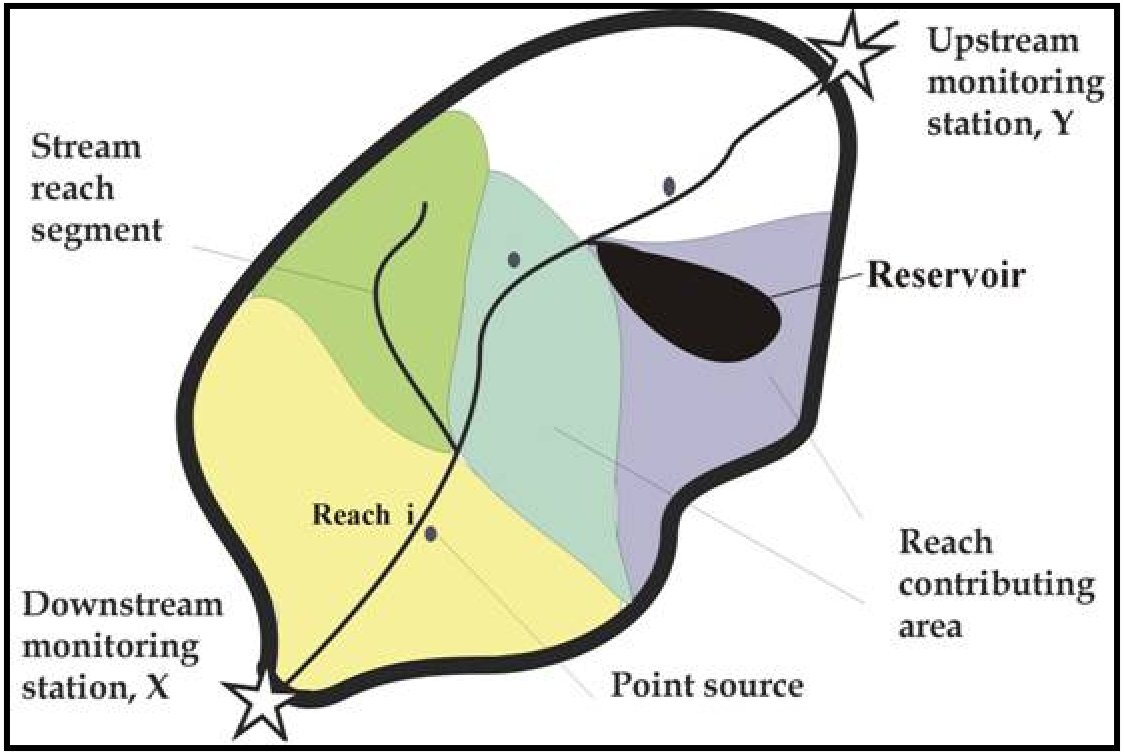




SPARROW's Reach-Scale Mass Balance

Reach network relates watershed data to monitored loads

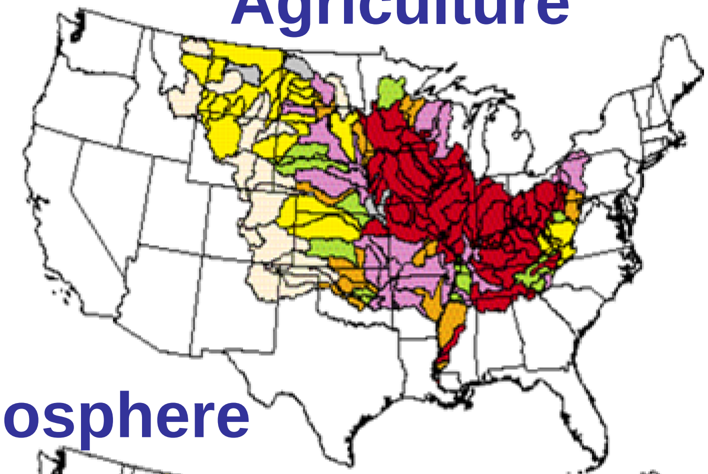
Load leaving a reach	=	Load generated within upstream reaches and transported to the reach via the stream network	+	Load originating within the reach's incremental watershed and delivered to the reach segment



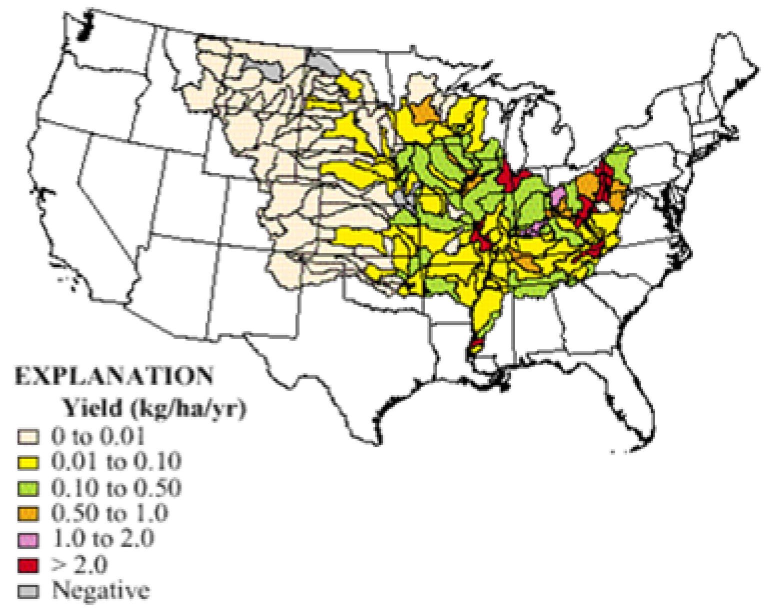
Earlier SPARROW Results

Total Nitrogen Delivery to the Gulf of Mexico
1987 Base Year

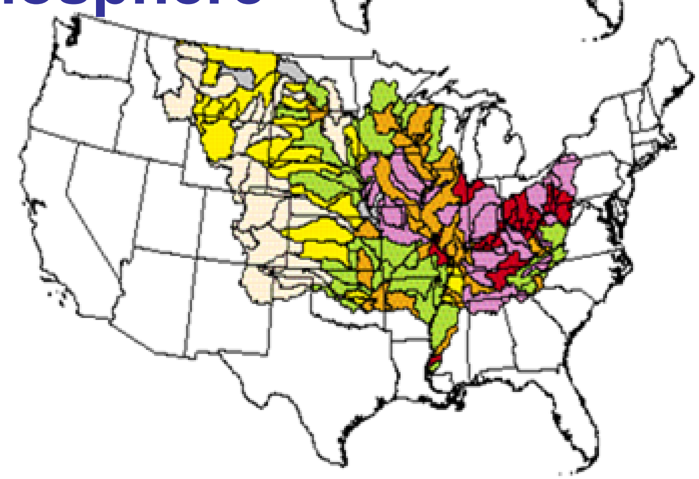
Agriculture



Municipal Wastewater



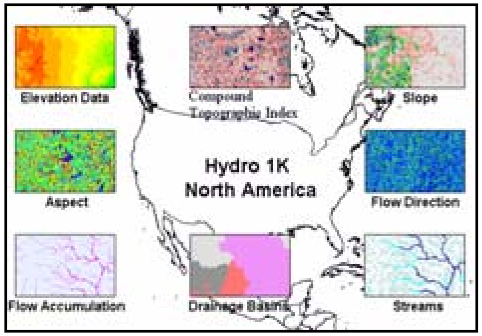
Atmosphere

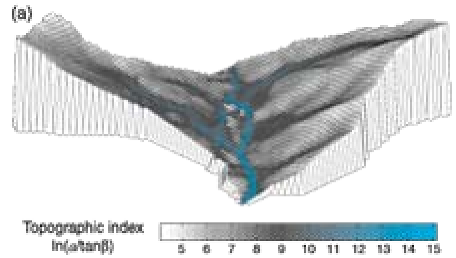


Alexander et al. 2000, Nature

Recent Advances in SPARROW

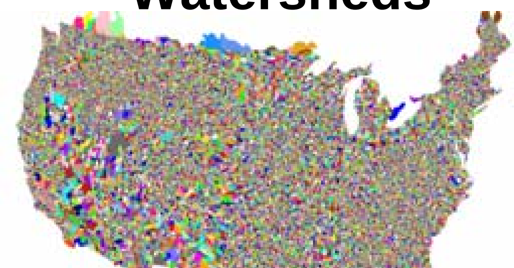
Topography

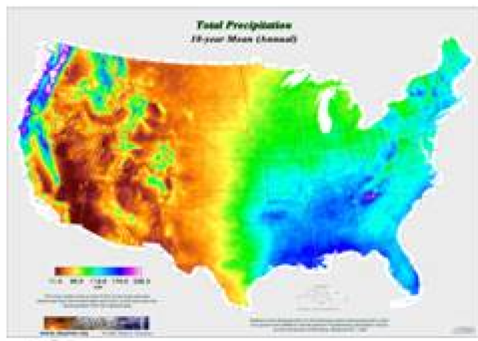


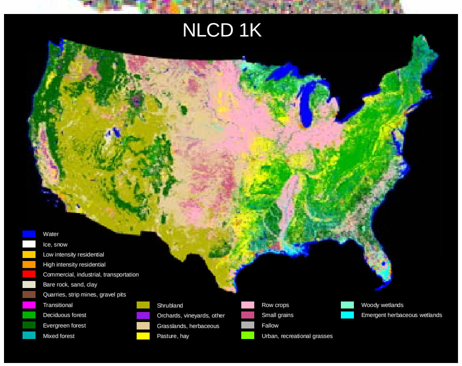


Climate

Watersheds







Land Use

Artificial Drainage

- **Model structure:** specification, flux-routing algorithms, stream monitoring loads, documentation
- **Data infrastructure:** climate, 1-km DEM, 30-m NLCD land use, cropping and drainage systems
- **Result:**
  - Added complexity
  - Model accuracy improved by 20%

SPARROW Sources and Transport Features

NUTRIENT SOURCES (1992)

- Urban and population sources
- Atmospheric N deposition
- Farm fertilizer use allocated to major crops:
  - County fertilizer sales and expenditures; crop acreage
  - NLCD agricultural land use
  - State application rates (corn, soybeans, cotton, wheat, other crops)
  - Corn/soybean rotations
- N_2 fixation – cultivated lands
- Animal manure:
  - Non-recoverable on pasture/rangelands
  - Recoverable on crops
- Natural and residual sources (lands in forest, barren, shrub)

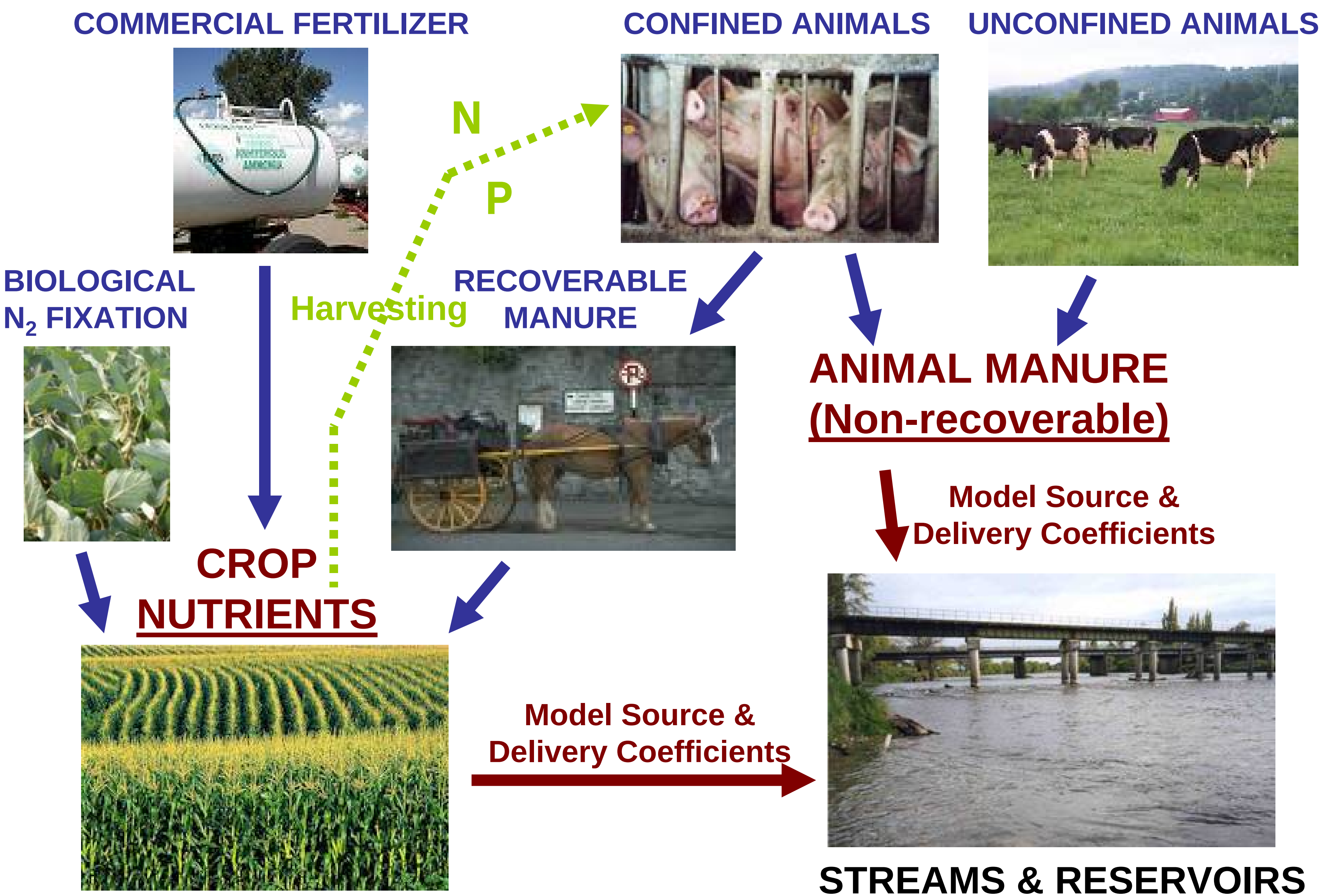
LAND-TO-WATER DELIVERY

- Climate (precipitation, temperature)
- Soils (permeability)
- Topography/subsurface (slope, specific catchment area)
- Artificial drainage (tiles, ditches)

AQUATIC ATTENUATION

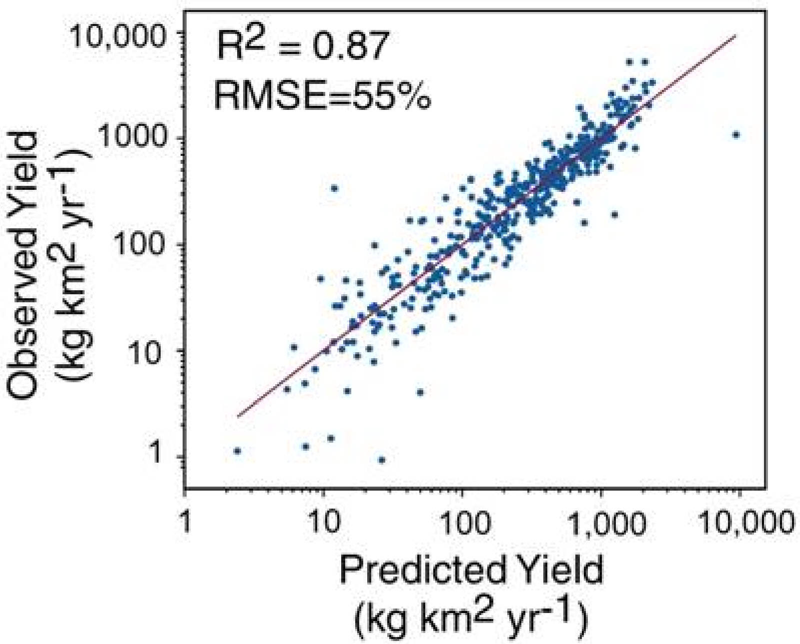
- Streams
  - First-order decay ~ f(water travel time, flow and depth)
- Reservoirs
  - First-order decay ~ f(areal hydraulic load—ratio of outflow to surface area)

SPARROW Delivery of Agricultural Nutrients to Streams



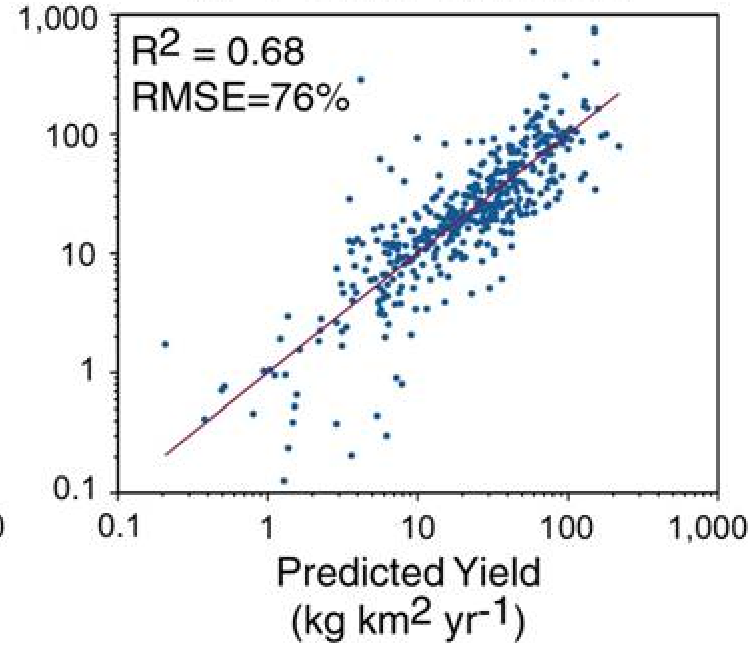
The Improved SPARROW Nutrient Models Observed vs. Predicted Yield

Total Nitrogen
(N=425monitoring sites)



18 model coefficients:
- 10 sources
- 6 landscape transport
- continuous stream and reservoir decay

Total Phosphorus
(N=425 monitoring sites)



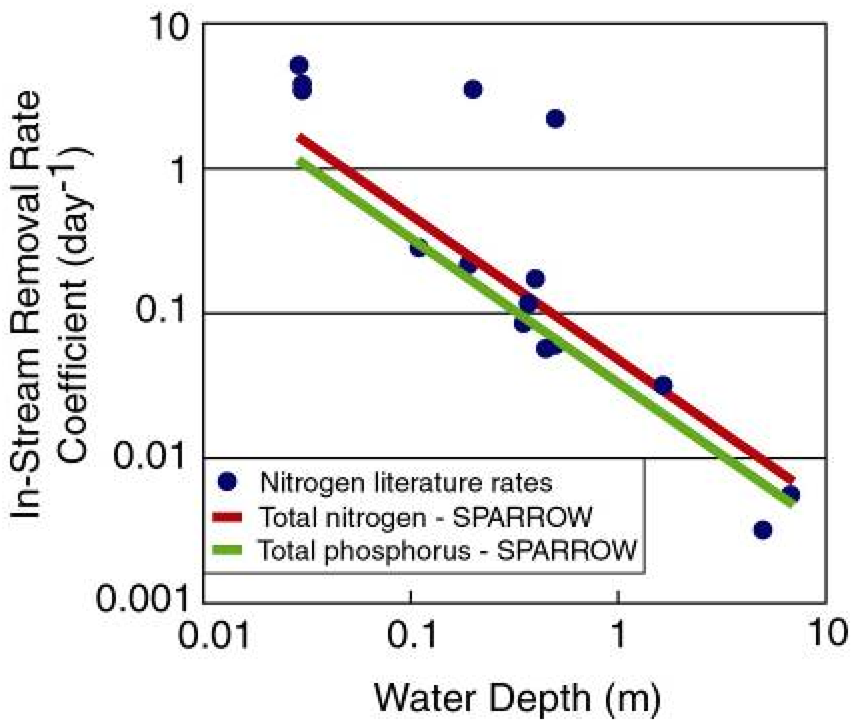
15 model coefficients:
- 8 sources
- 5 landscape transport
- continuous stream and reservoir decay

Stream and Reservoir Transport for 1992

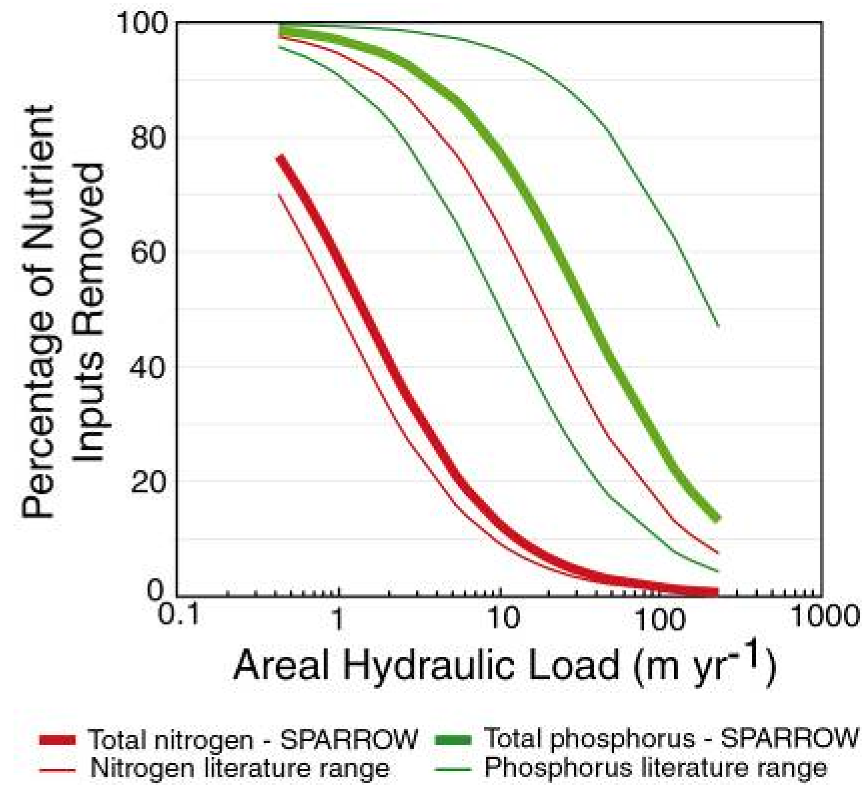
SPARROW Rates of Aquatic Nutrient Loss

Nutrient removal rate declines in larger rivers and more rapidly flushed reservoirs

STREAMS

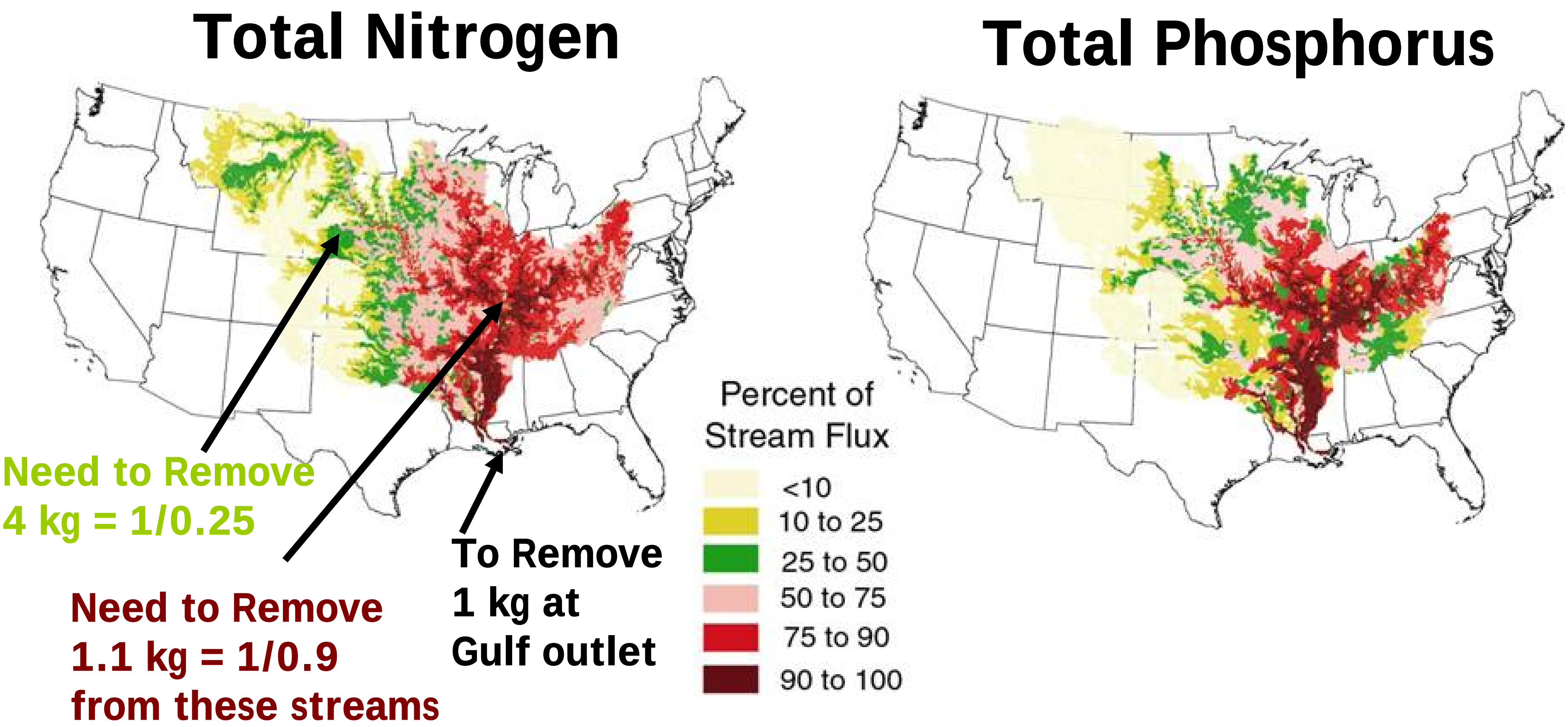


RESERVOIRS

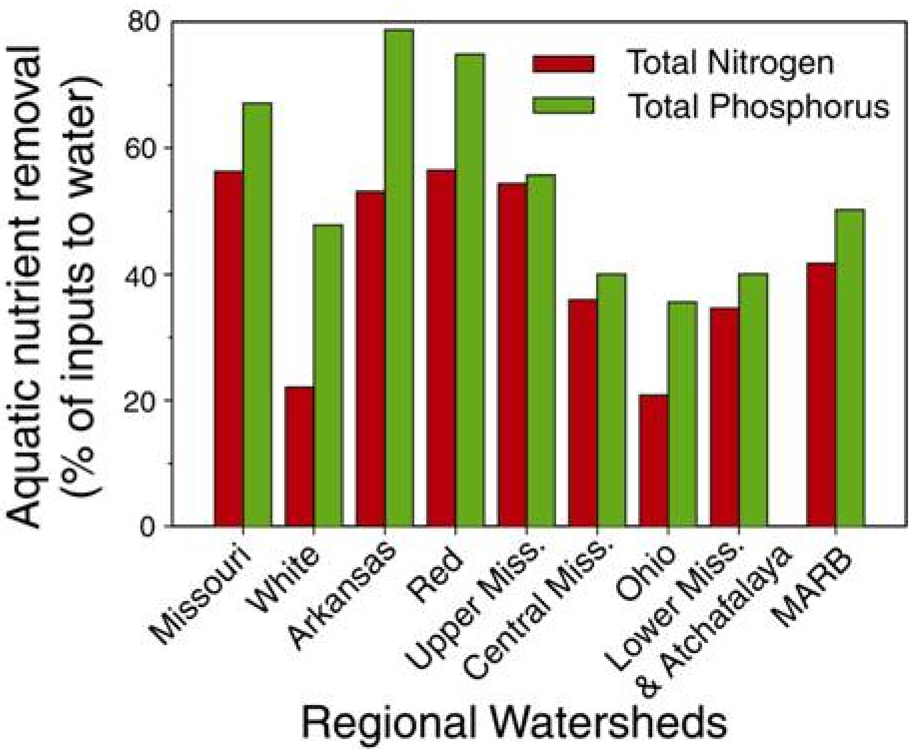


Nitrogen literature rates from Howarth et al. 1996; Seitzinger et al. 2002; Bohlke et al. 2004; Mulholland et al. 2004)

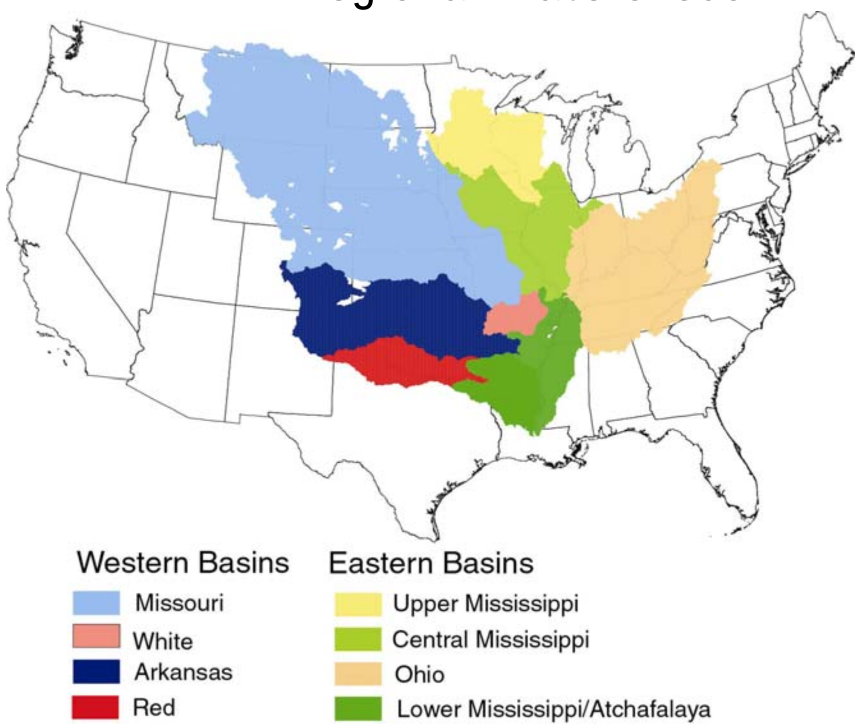
Percentage of Stream Nutrients Delivered to the Gulf of Mexico



Aquatic Removal of Nutrients in MARB Regional Watersheds - 1992



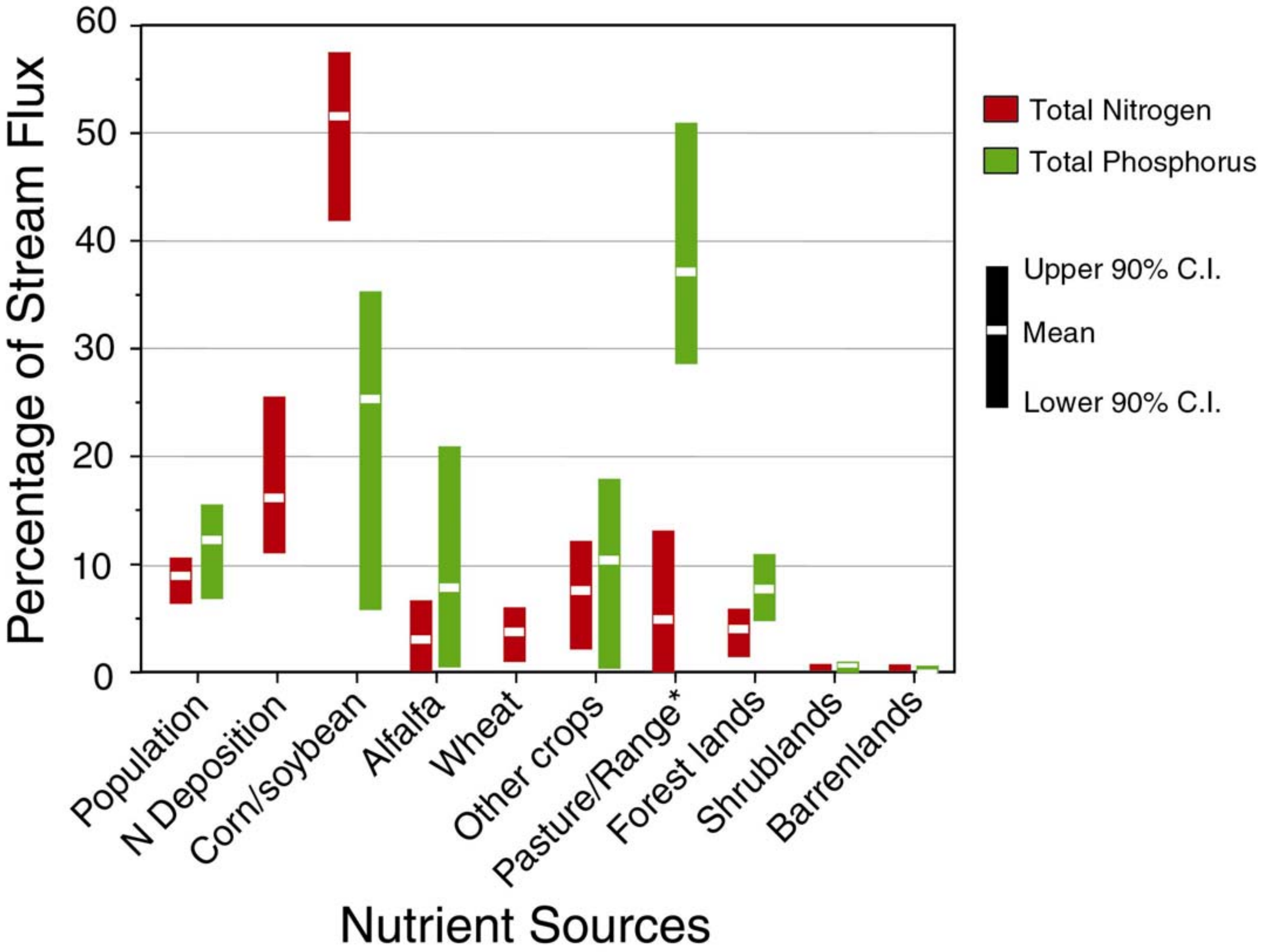
Regional Watersheds



Nutrient Source Contributions to Stream Flux: Types and Regional Geography

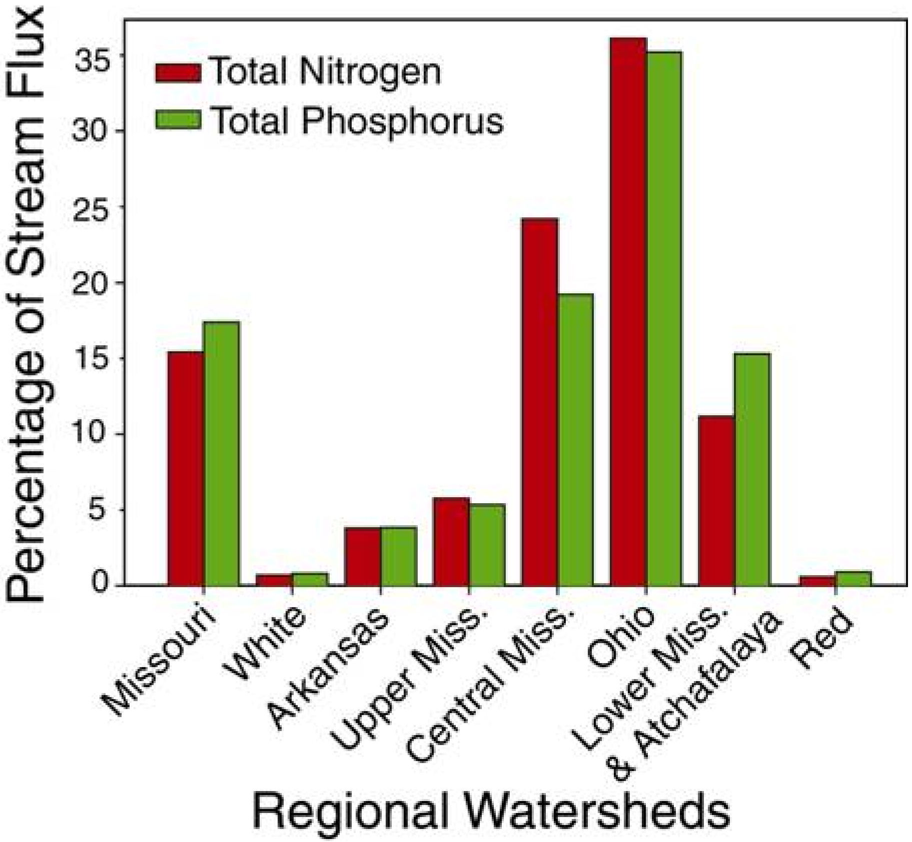
Sources Contributions to Stream Nutrient Flux - 1992

Mississippi River at St. Francisville, LA



**Non-recoverable animal manure*

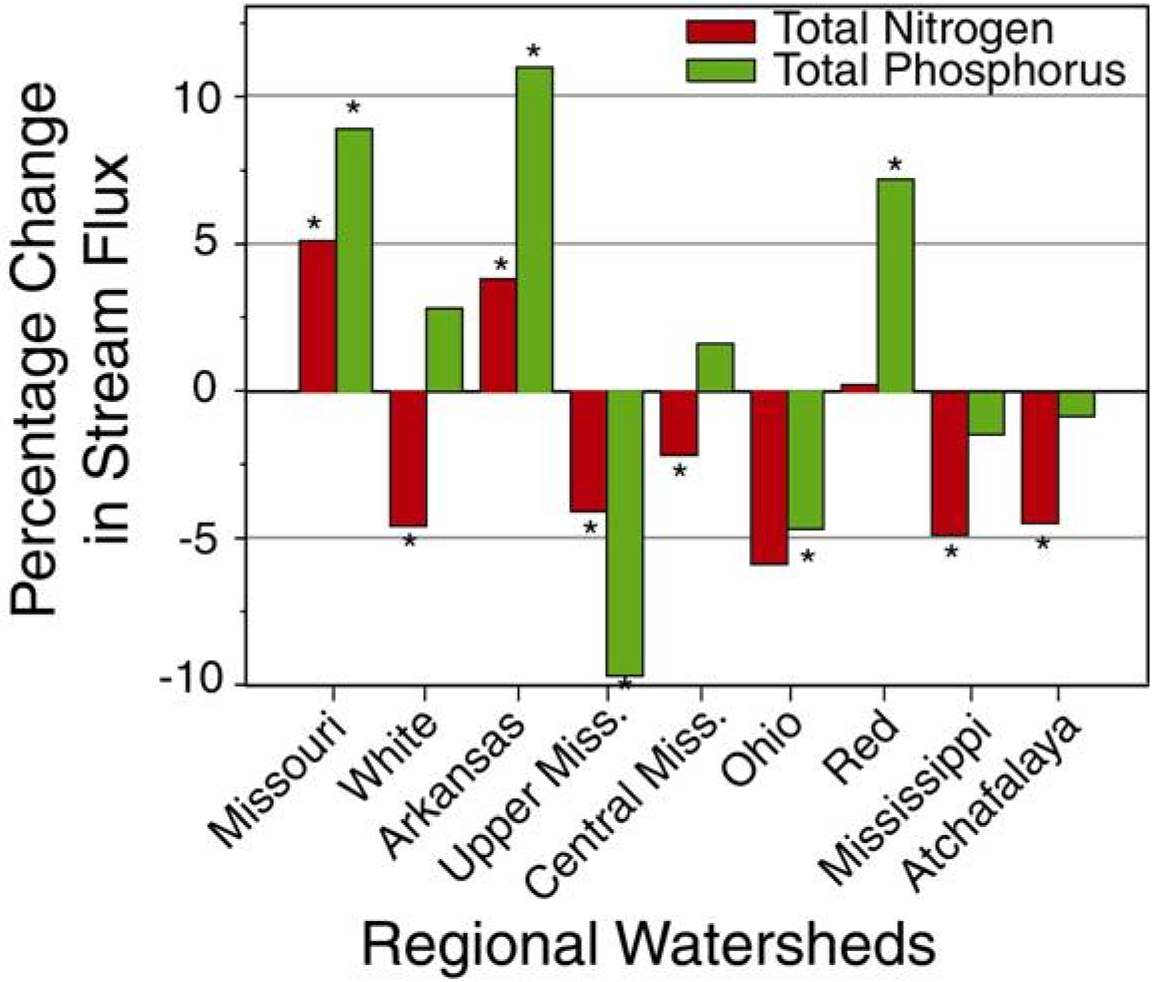
Regional Contributions to the Stream Nutrient Flux to the Gulf of Mexico - 1992



Changes in Stream Nutrient Flux, 1992 to 2002

- Simulate changes in flow-adjusted stream nutrient flux
- Account for changes in population and agriculture (animal manure; crop fertilizer application, acreage, and production)
- Account for changes in harvested nutrients with changes in marginal rate of crop production
- Assume steady-state conditions with constant model coefficients over time

Simulated Changes in Flow-Adjusted Nutrient Flux, 1992 to 2002



- Changes in flux typically less than 5%
- Geography of 2002 source shares are generally unchanged from 1992

**statistically sig. (p<0.06)*

MARB Watershed Rankings

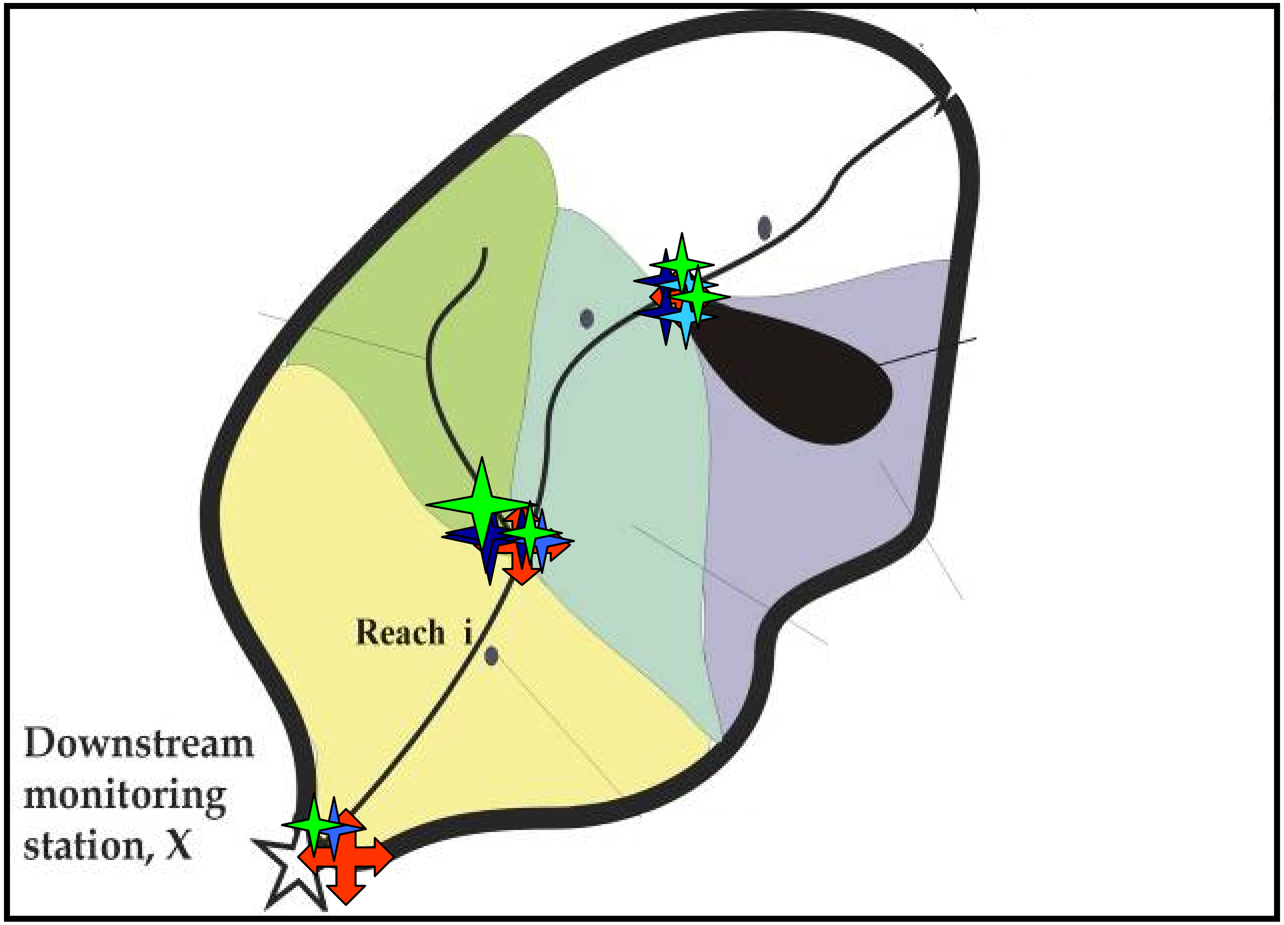
Nutrient Delivery to the Gulf of Mexico for 1992

Preliminary watershed rankings based on nutrient delivery to the Gulf

Try to answer questions that have been popping up during past discussions.

Future SPARROW modeling
- Additional Refinements to the SPARROW models

Definitions:



Load – Total amount of a constituent transported – (kgs)

Yield – Total amount of a constituent transported per unit area – kg/km^2

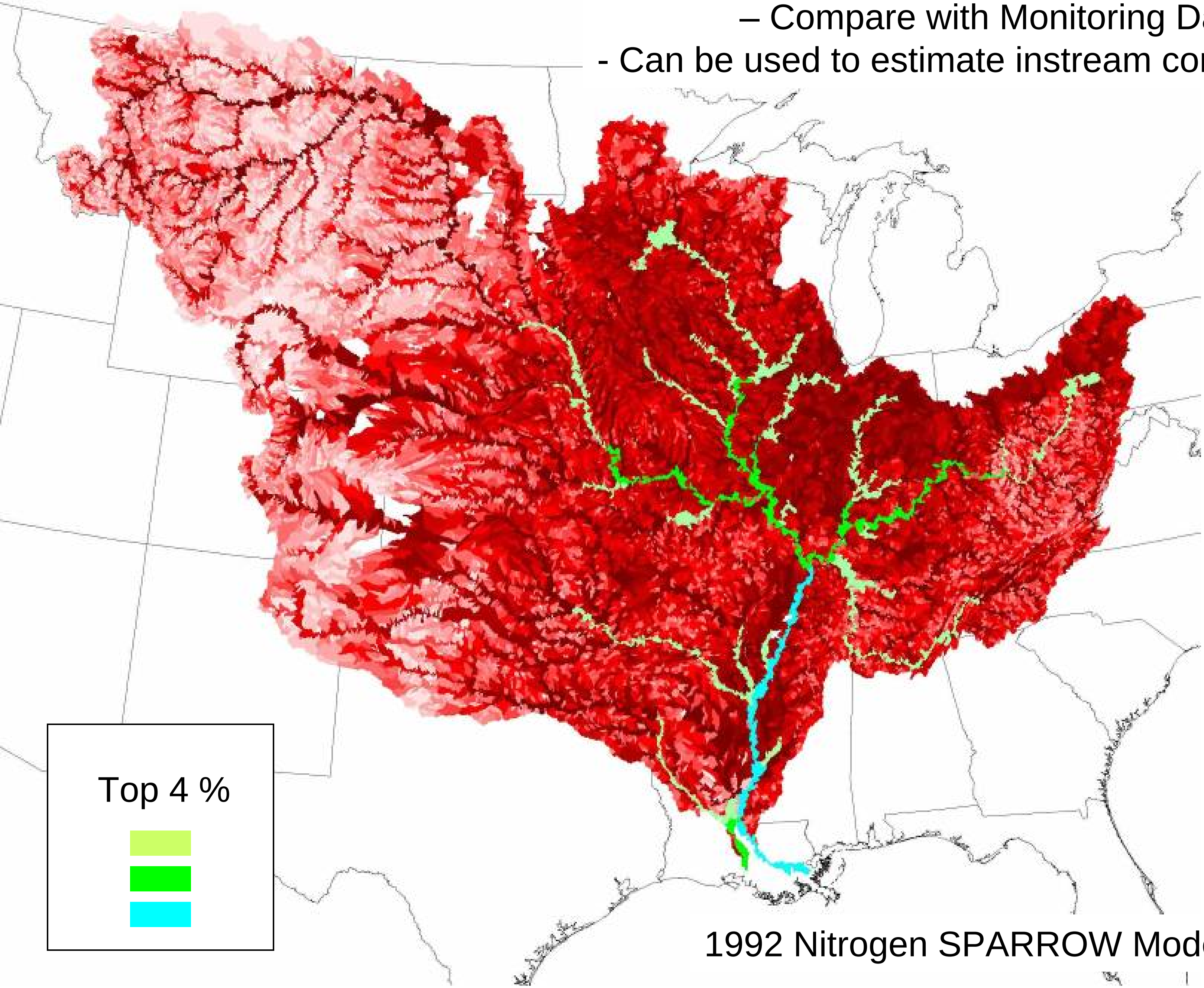
Incremental Yield – Amount of a constituent transported per unit area between two points – kg/km^2

Delivered Incremental Yield – Amount of a constituent transported per unit area between two points that is delivered or transported to some specific point – kg/km^2

Total Nitrogen Load

– Compare with Monitoring Data

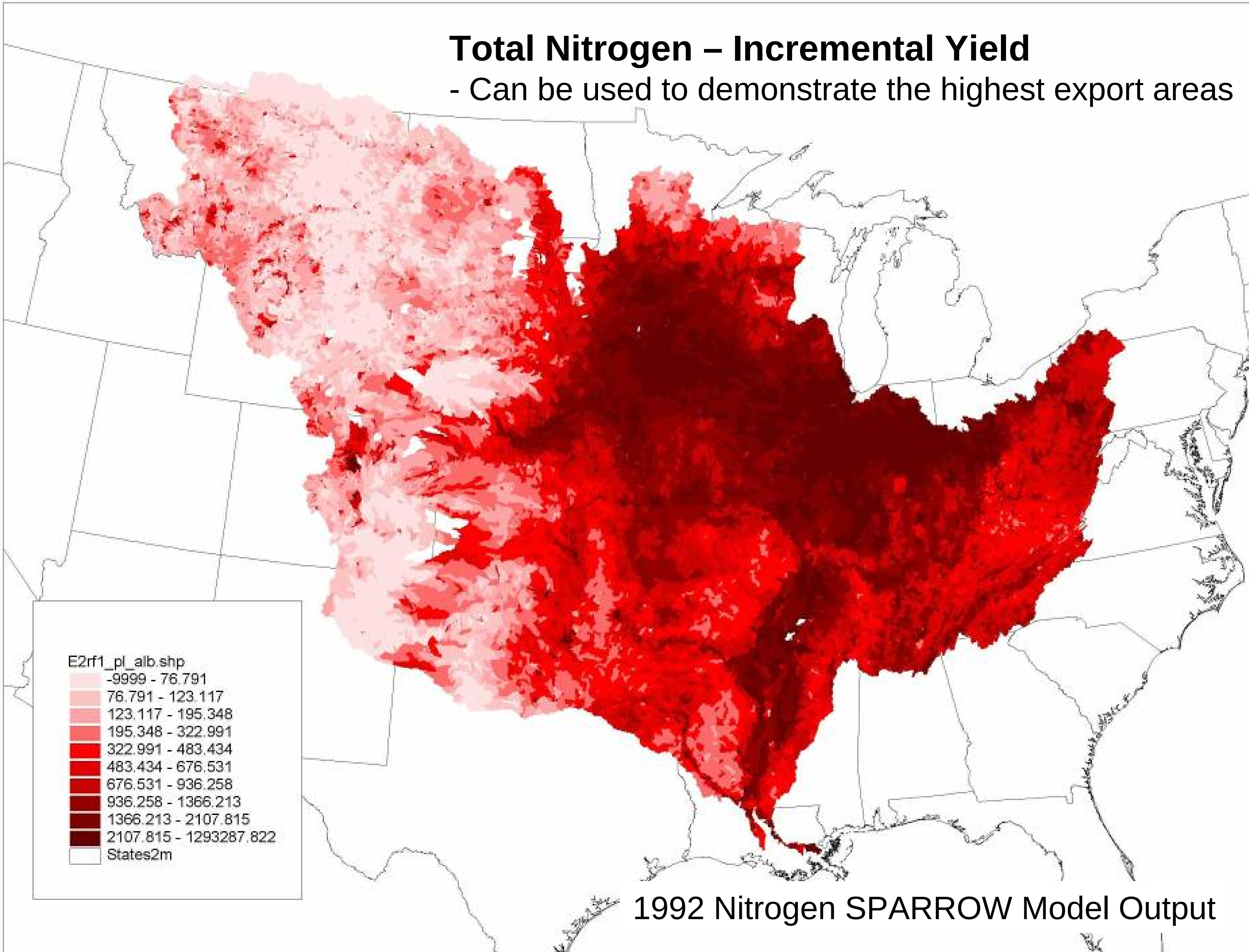
- Can be used to estimate instream concentrations



1992 Nitrogen SPARROW Model Output

Total Nitrogen – Incremental Yield

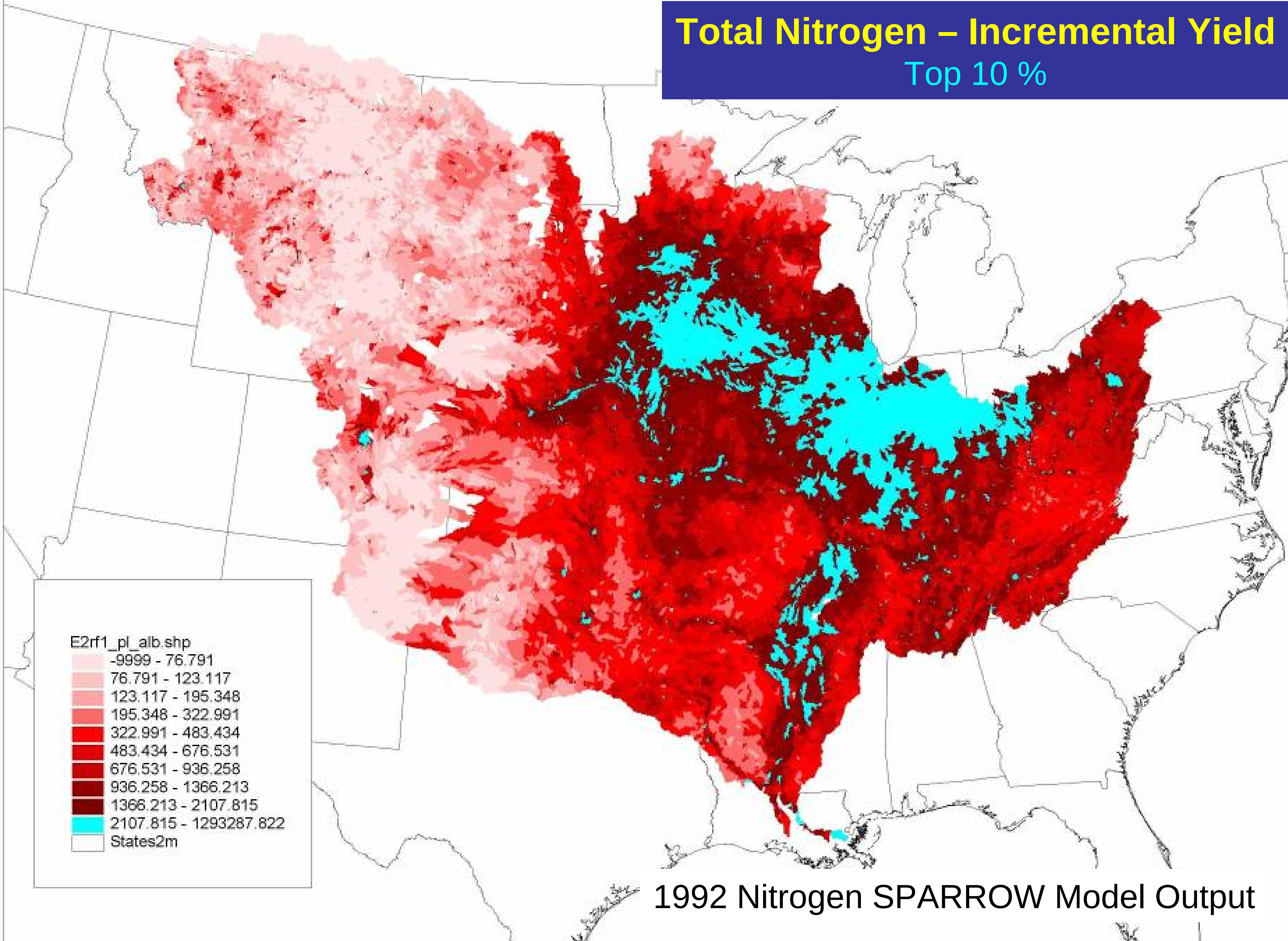
- Can be used to demonstrate the highest export areas



1992 Nitrogen SPARROW Model Output

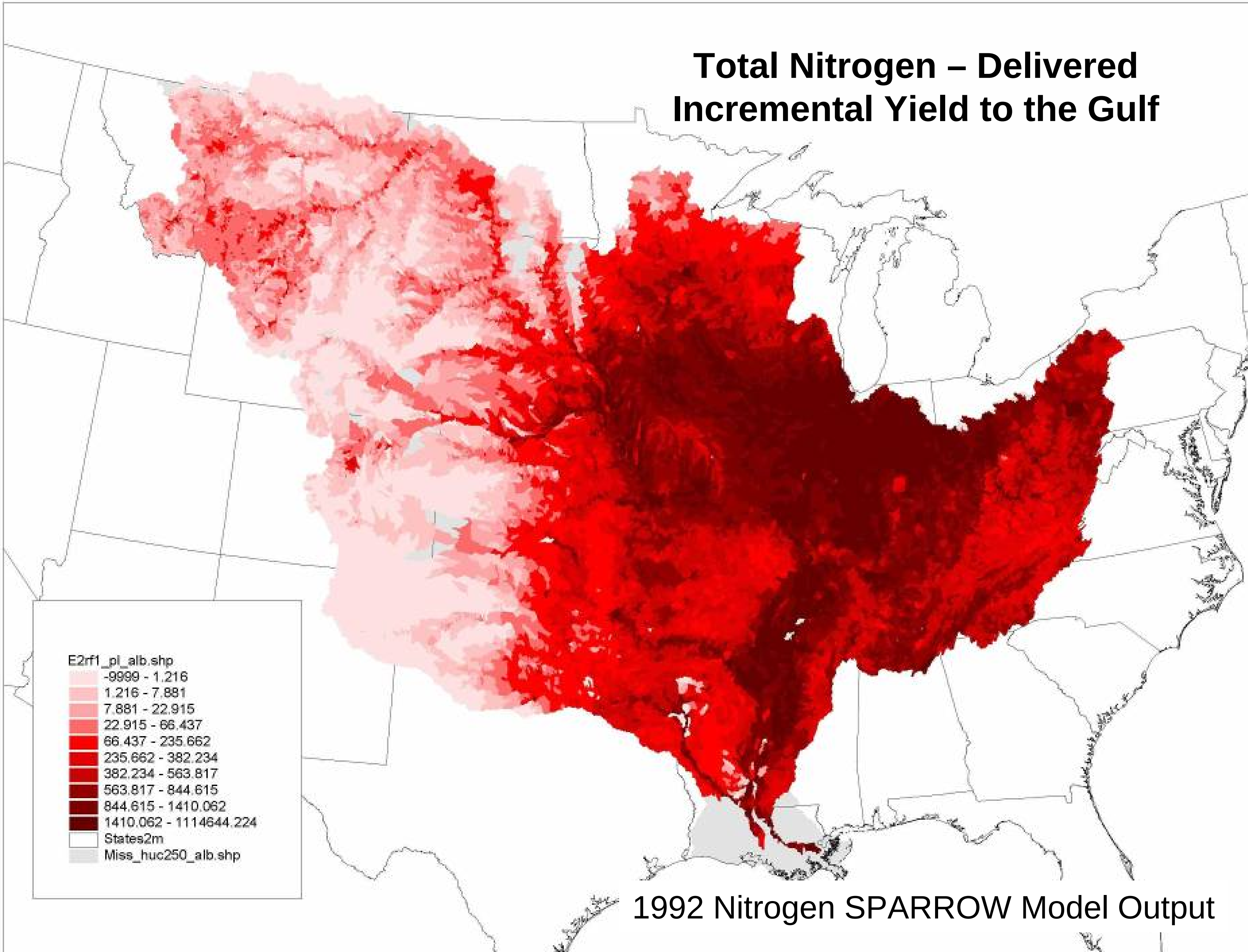
Total Nitrogen – Incremental Yield

Top 10 %



1992 Nitrogen SPARROW Model Output

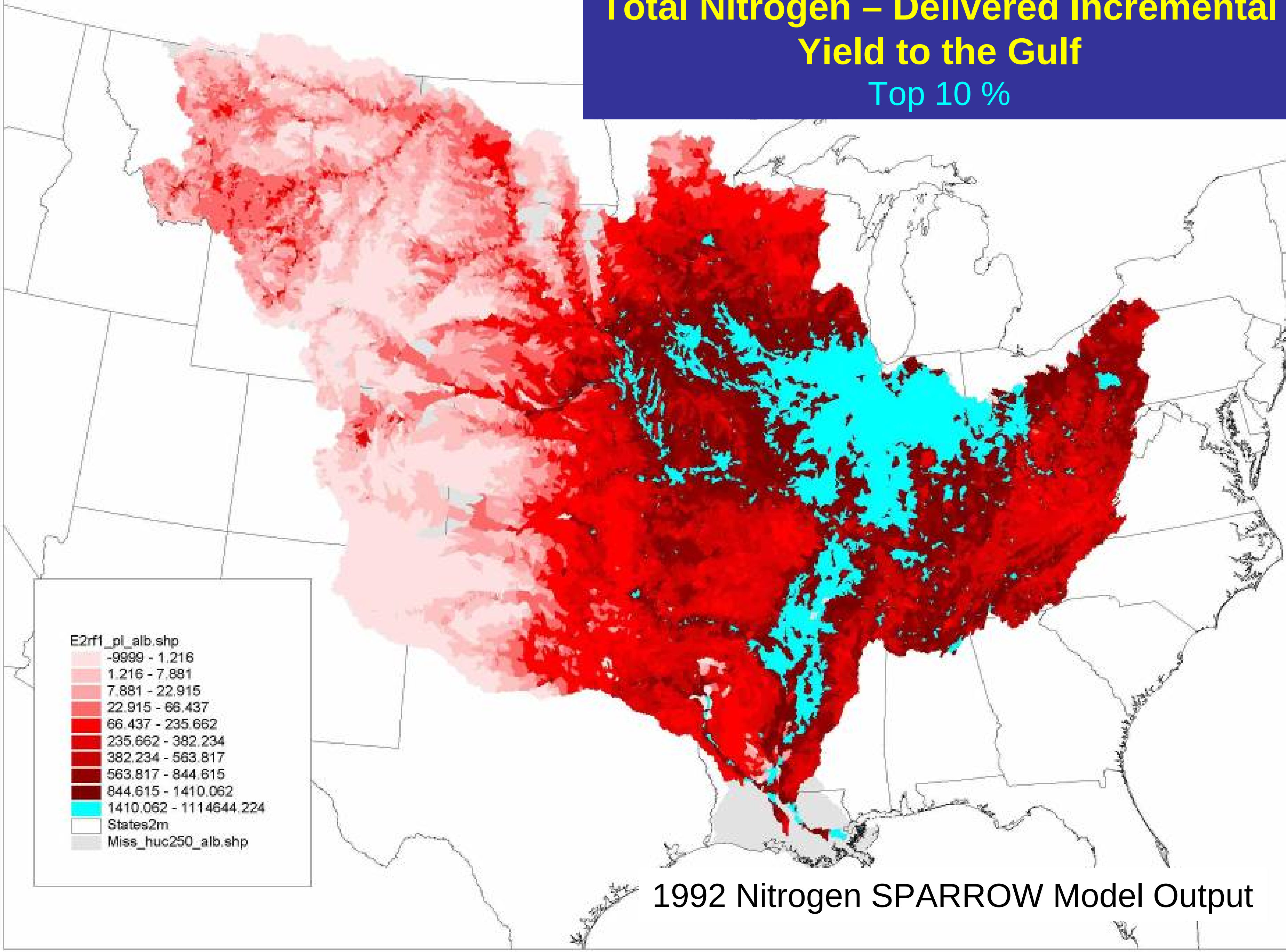
Total Nitrogen – Delivered Incremental Yield to the Gulf



1992 Nitrogen SPARROW Model Output

Total Nitrogen – Delivered Incremental Yield to the Gulf

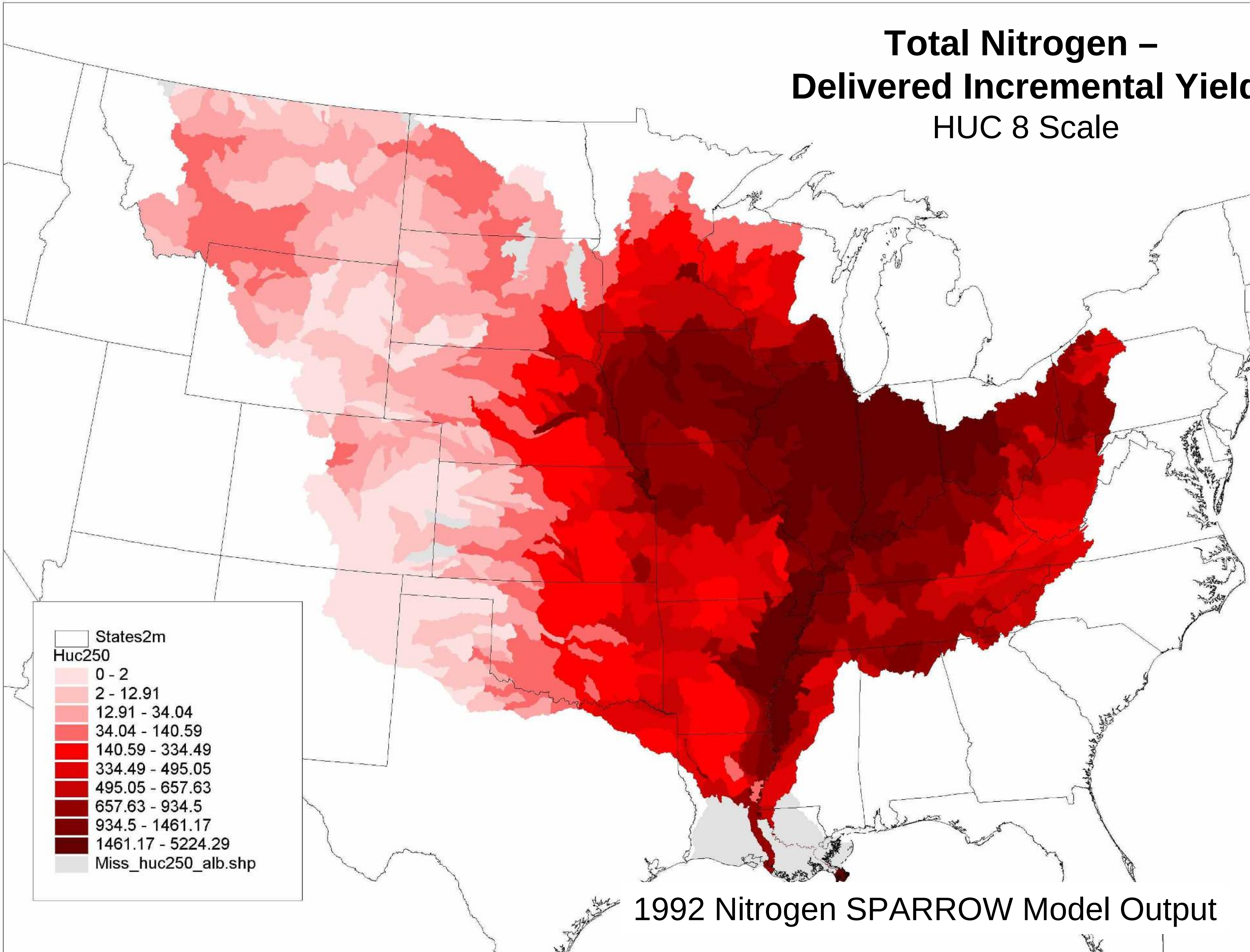
Top 10 %



1992 Nitrogen SPARROW Model Output

Total Nitrogen – Delivered Incremental Yield

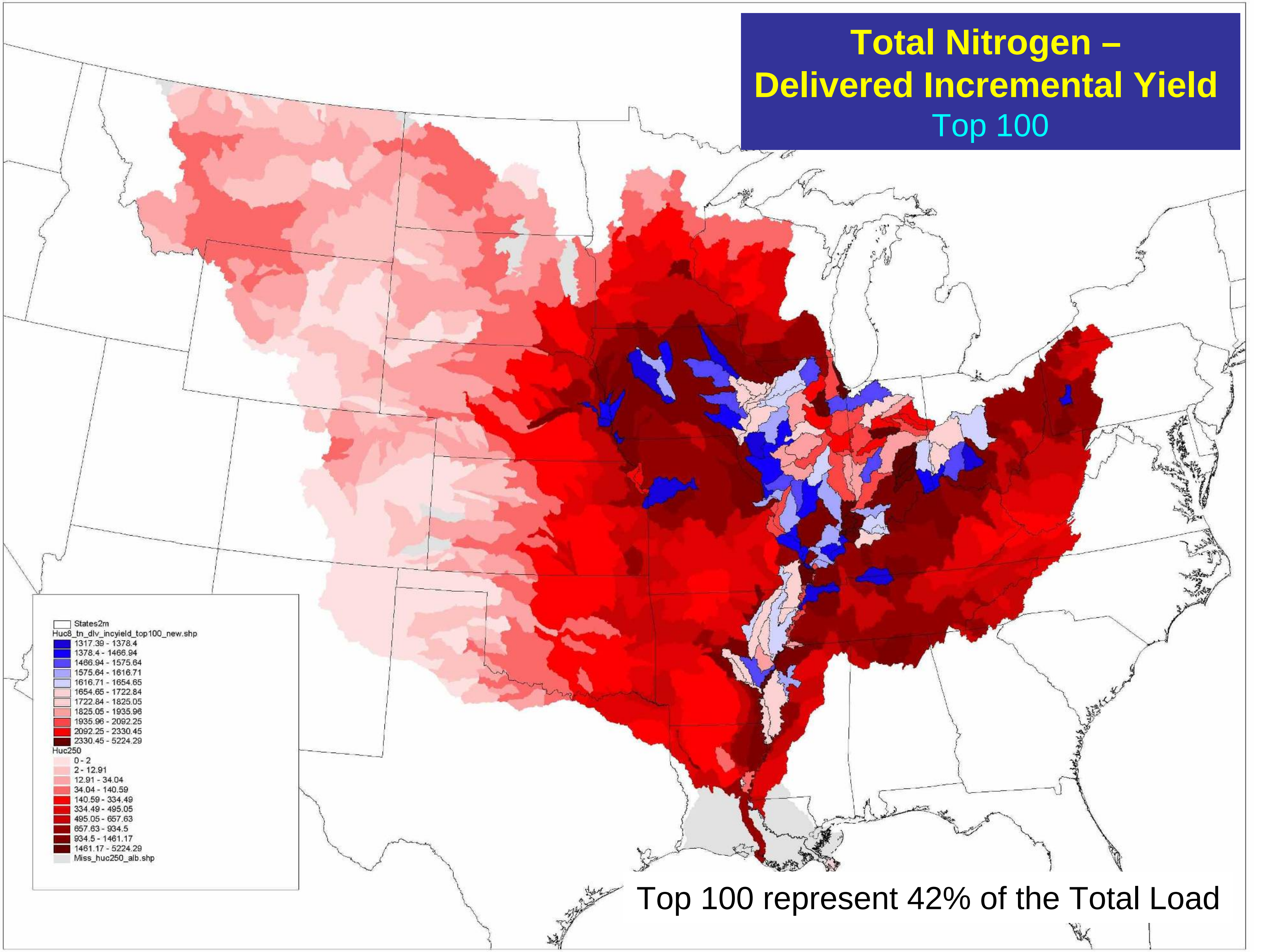
HUC 8 Scale



1992 Nitrogen SPARROW Model Output

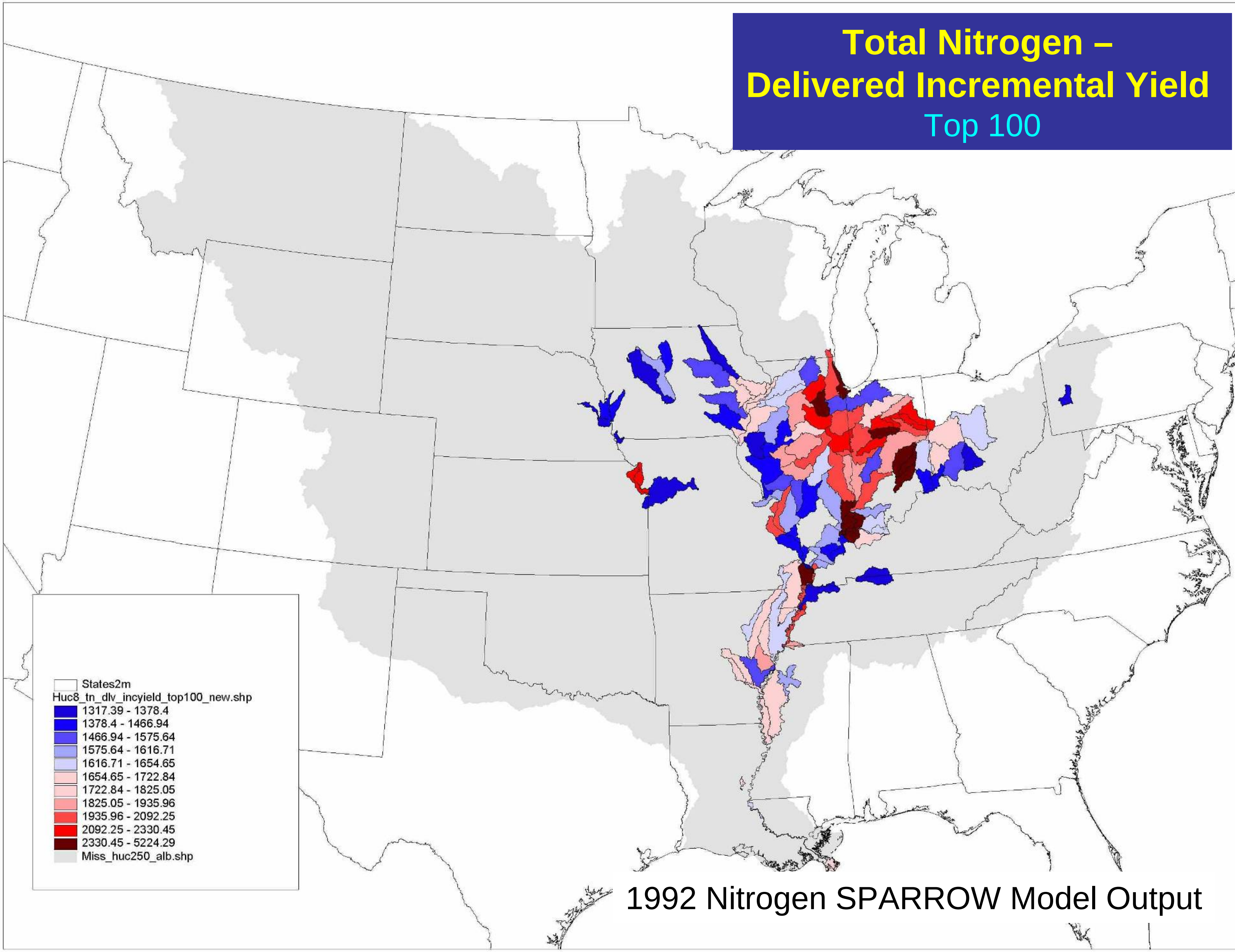
Total Nitrogen – Delivered Incremental Yield

Top 100

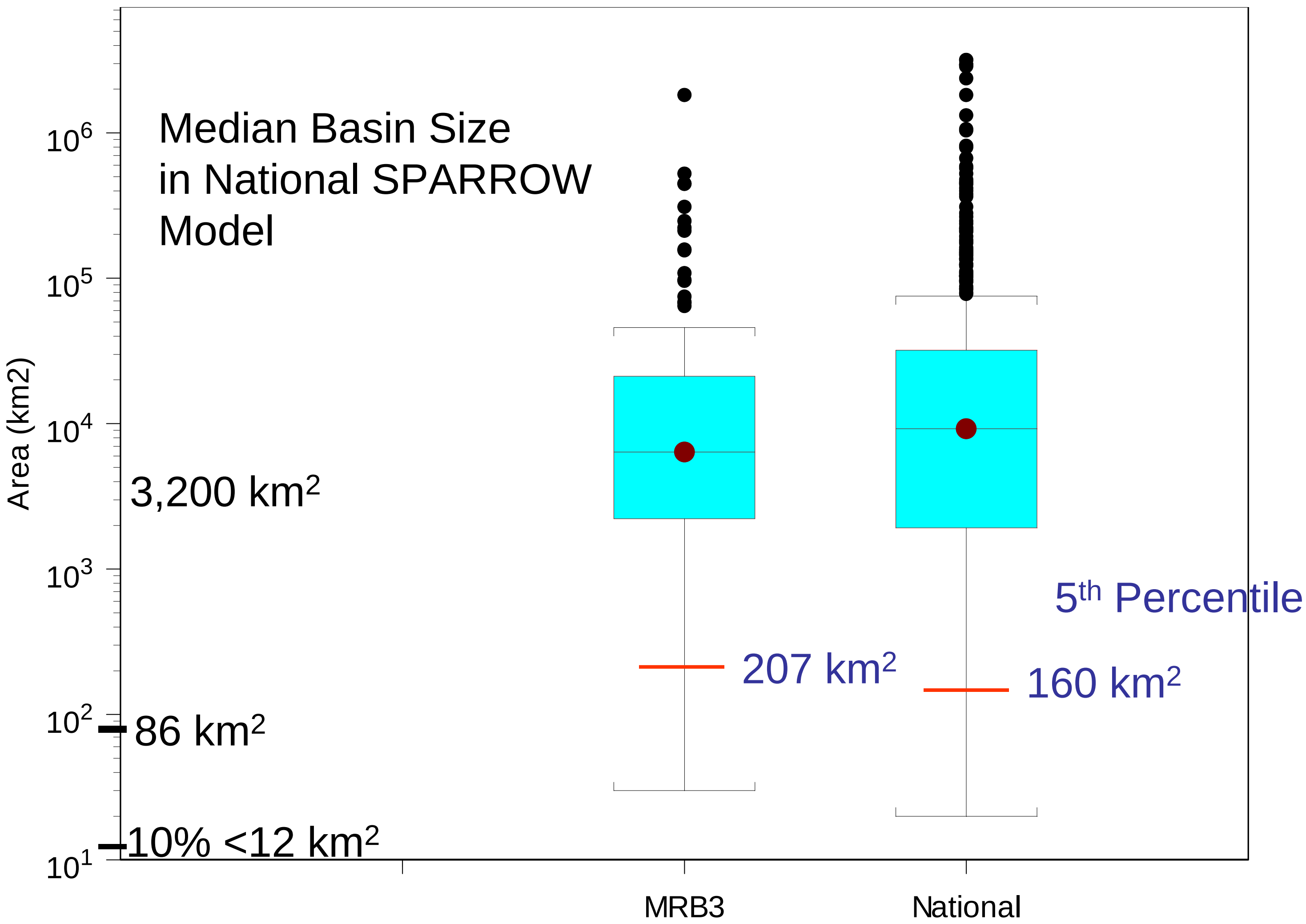


Top 100 represent 42% of the Total Load

Total Nitrogen – Delivered Incremental Yield
Top 100



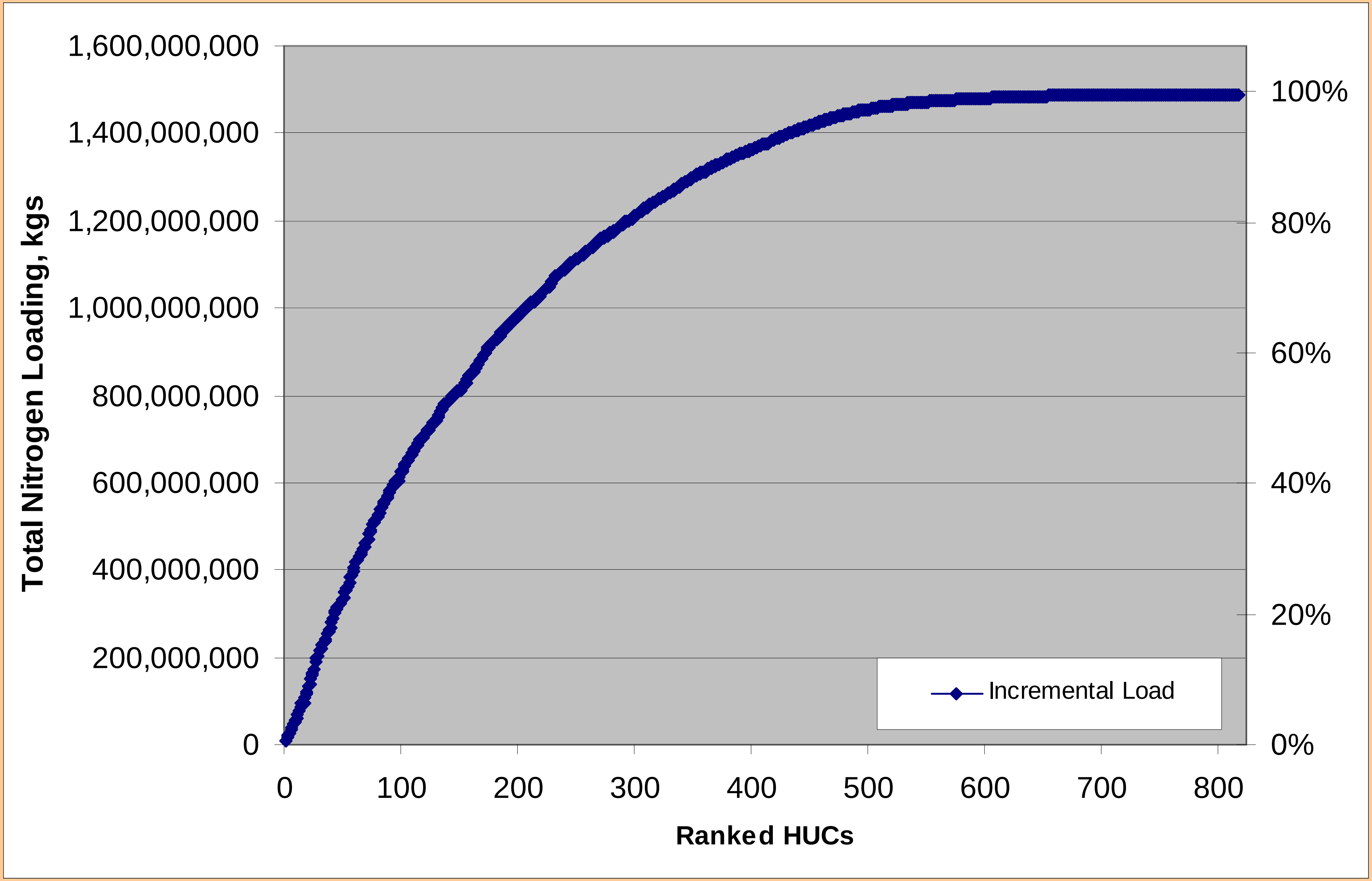
1992 Nitrogen SPARROW Model Output



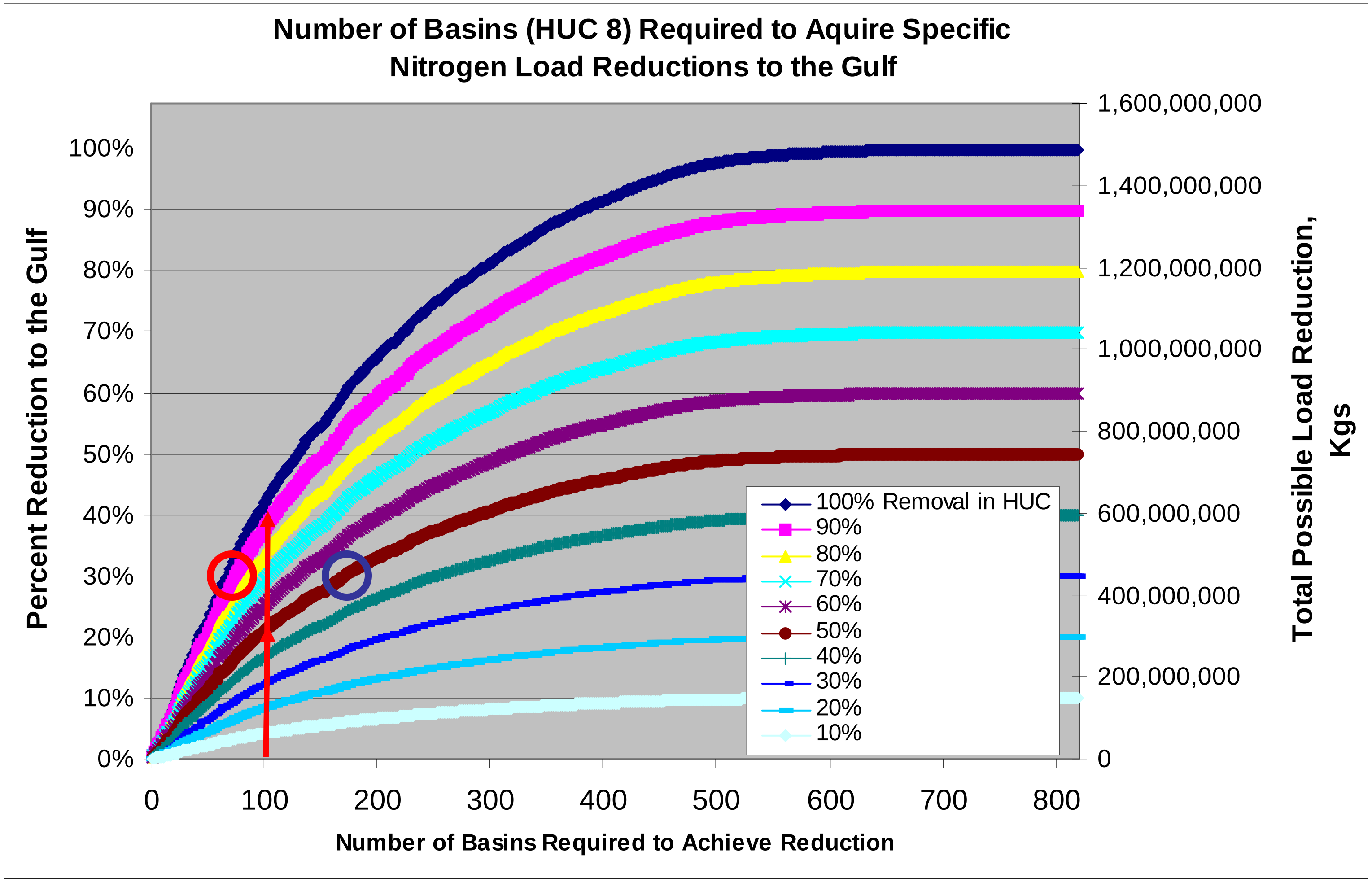
Calibration Basins for SPARROW Models

National SPARROW model best used to predict for Basins > 200 km^2

Accumulated Nitrogen Loading



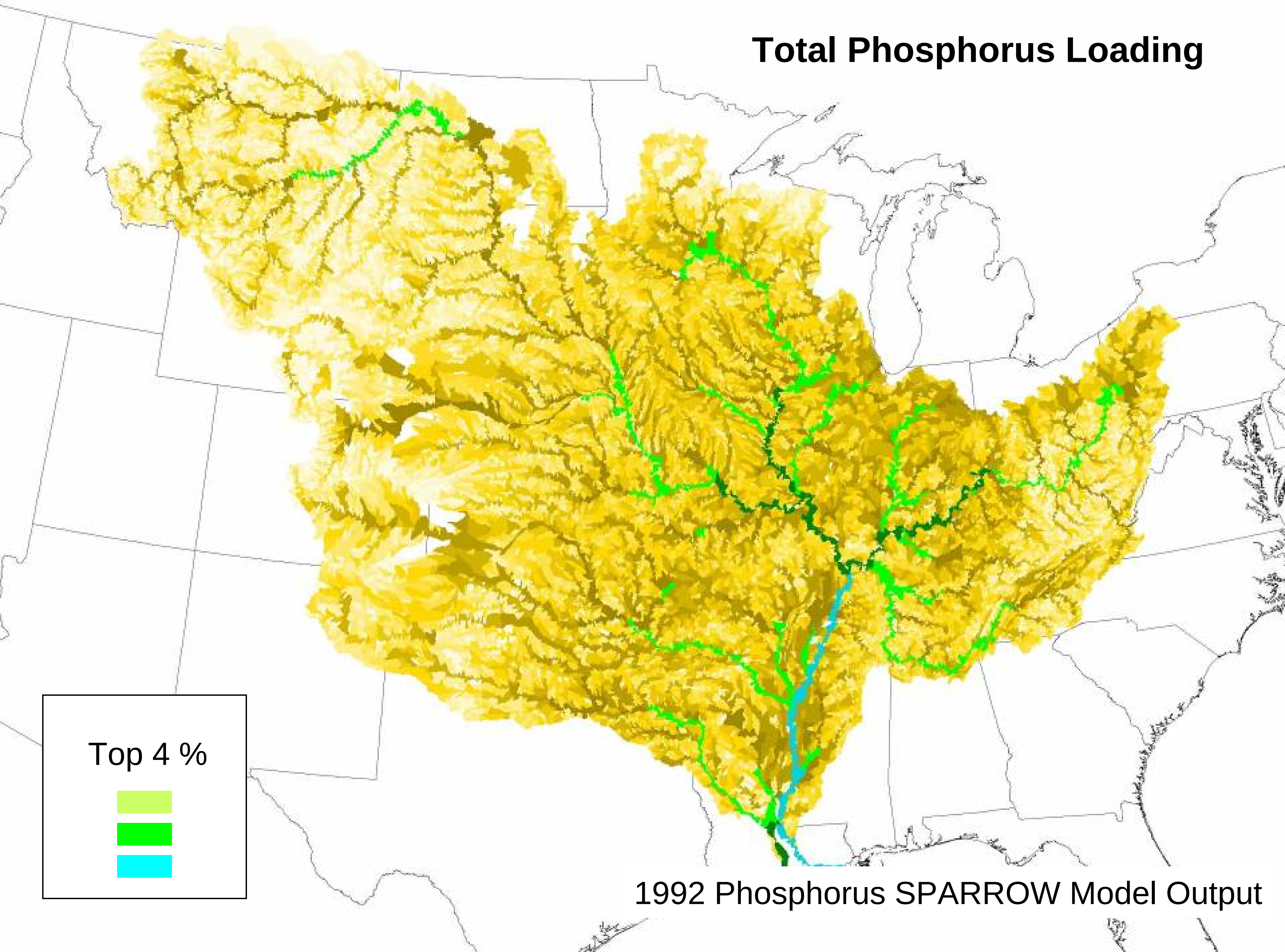
1992 Nitrogen SPARROW Model Output



To Obtain a 30% Reduction in the Total Nitrogen Load

- With a 100% Removal in TN Load, it would require the top 68 HUCs
- With a 50% Removal in TN Load, it would require the top 171 HUCs

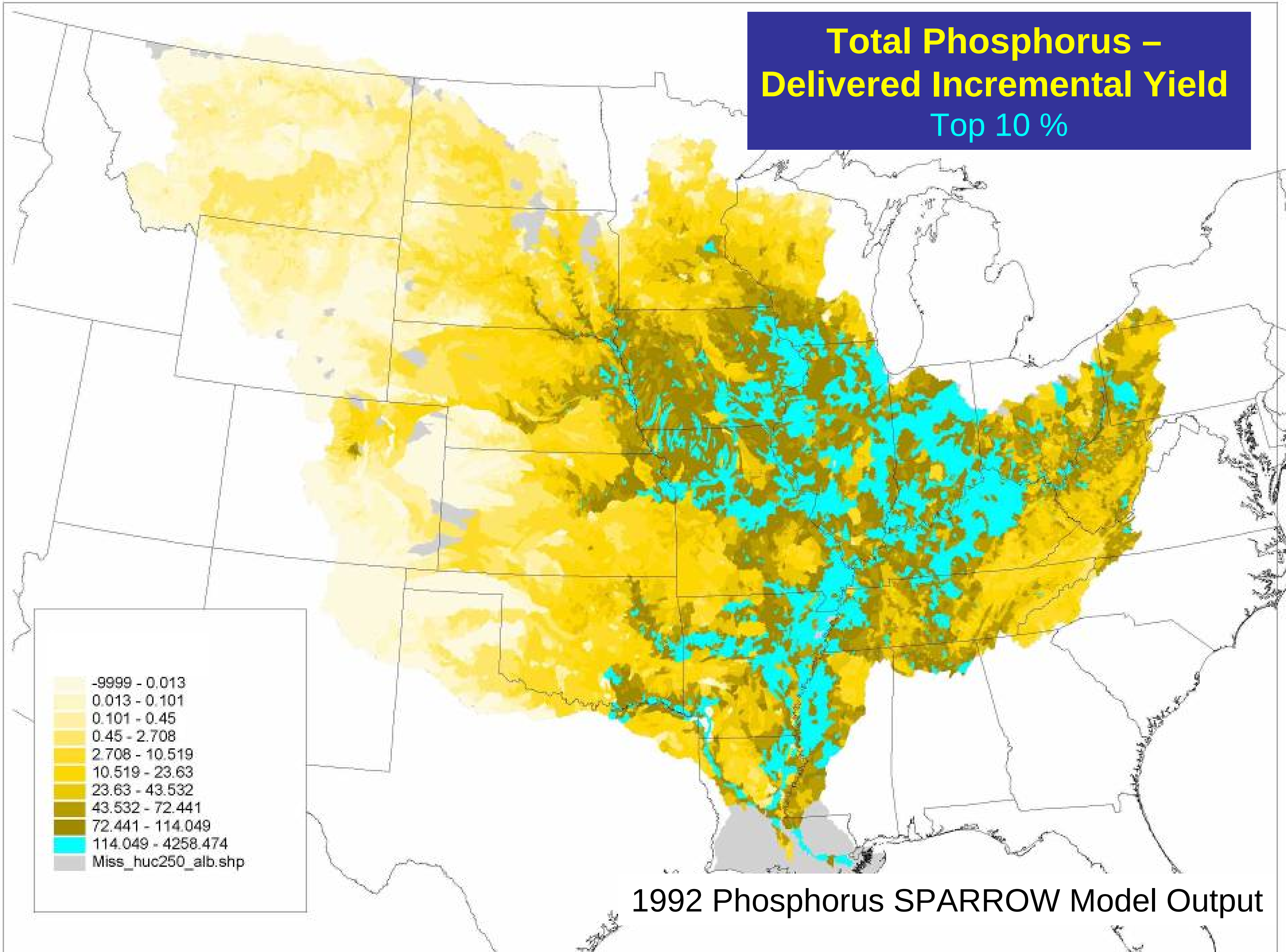
Total Phosphorus Loading



1992 Phosphorus SPARROW Model Output

Total Phosphorus – Delivered Incremental Yield

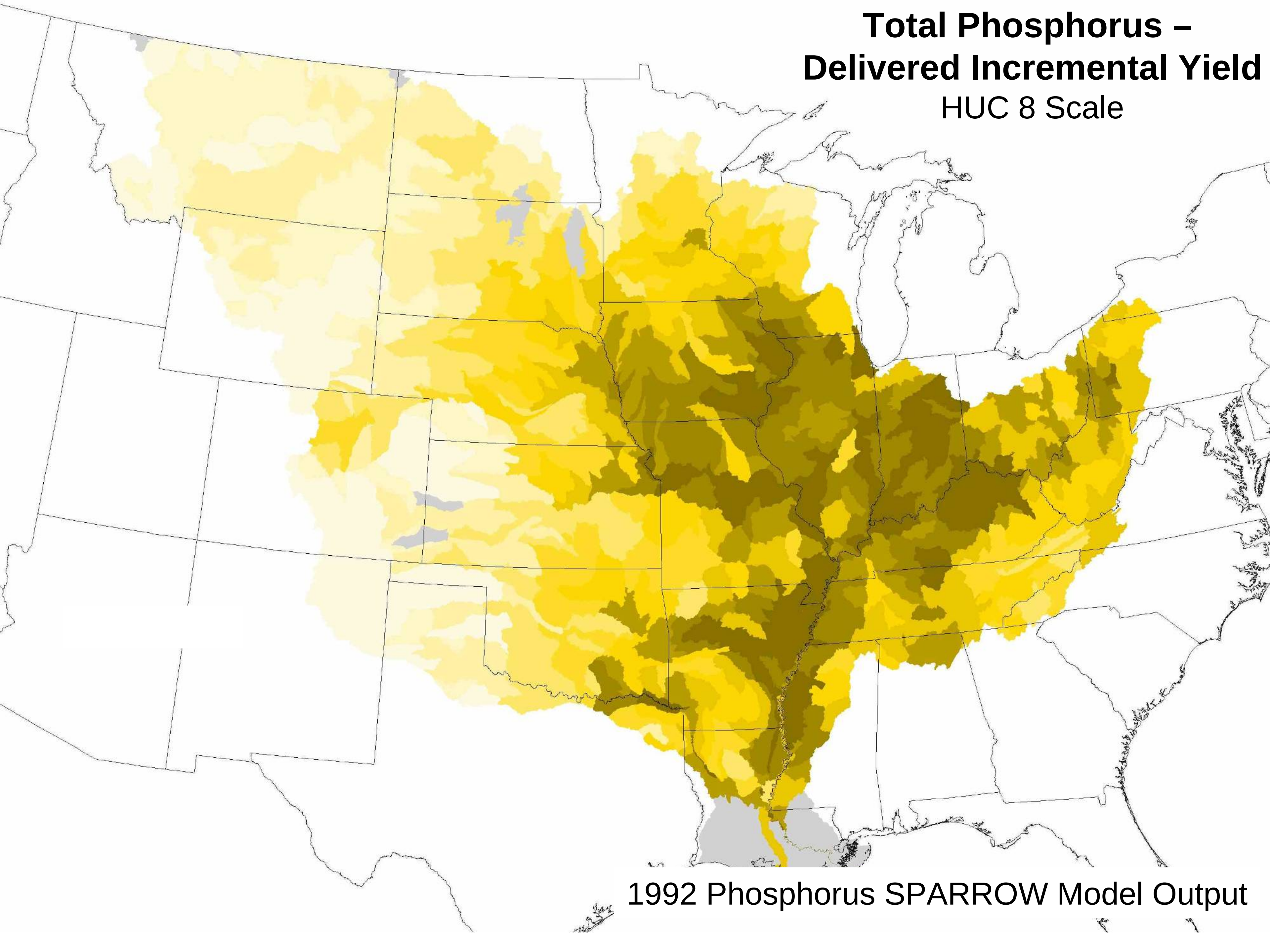
Top 10 %



1992 Phosphorus SPARROW Model Output

Total Phosphorus – Delivered Incremental Yield

HUC 8 Scale

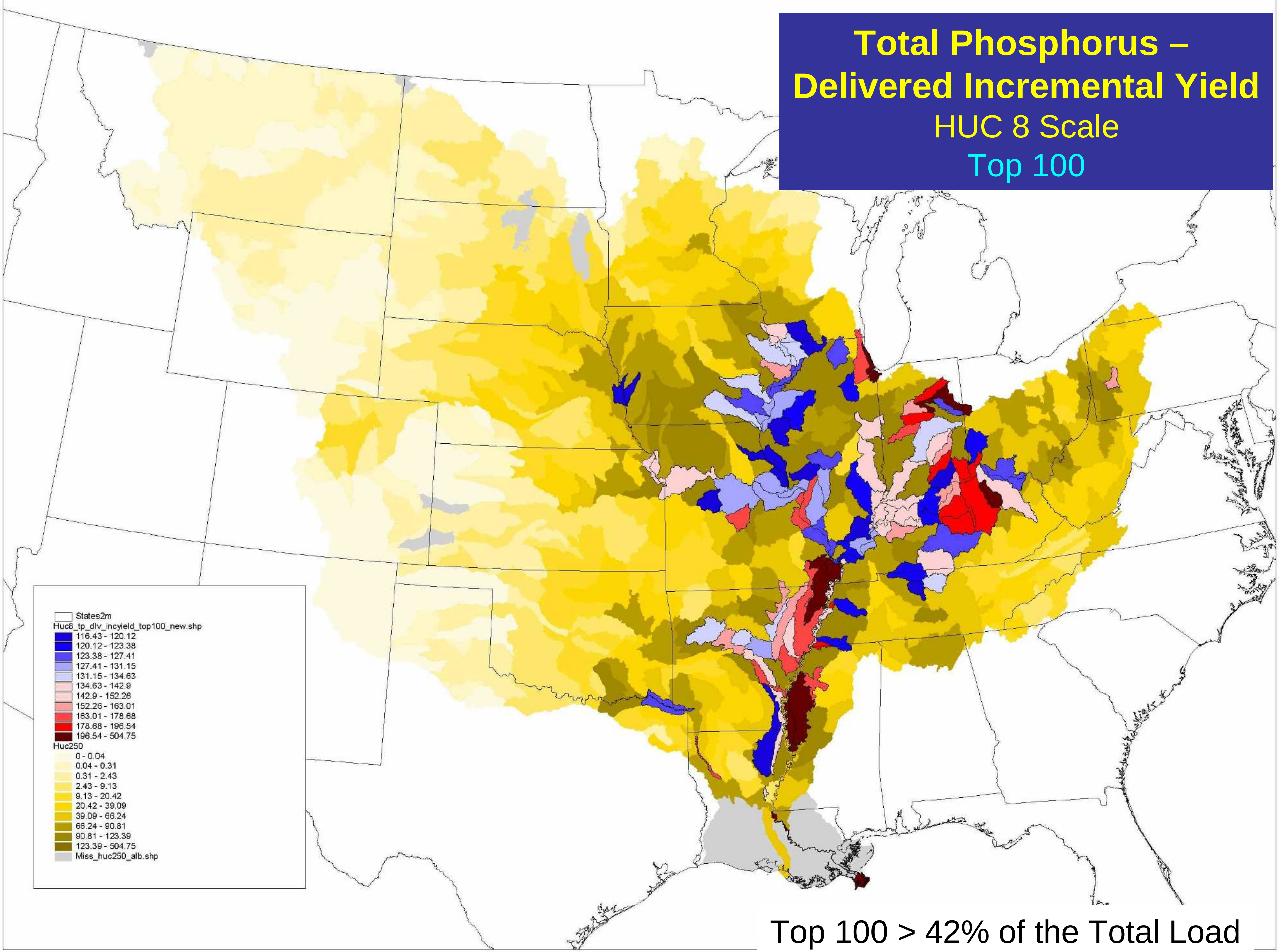


1992 Phosphorus SPARROW Model Output

Total Phosphorus – Delivered Incremental Yield

HUC 8 Scale

Top 100

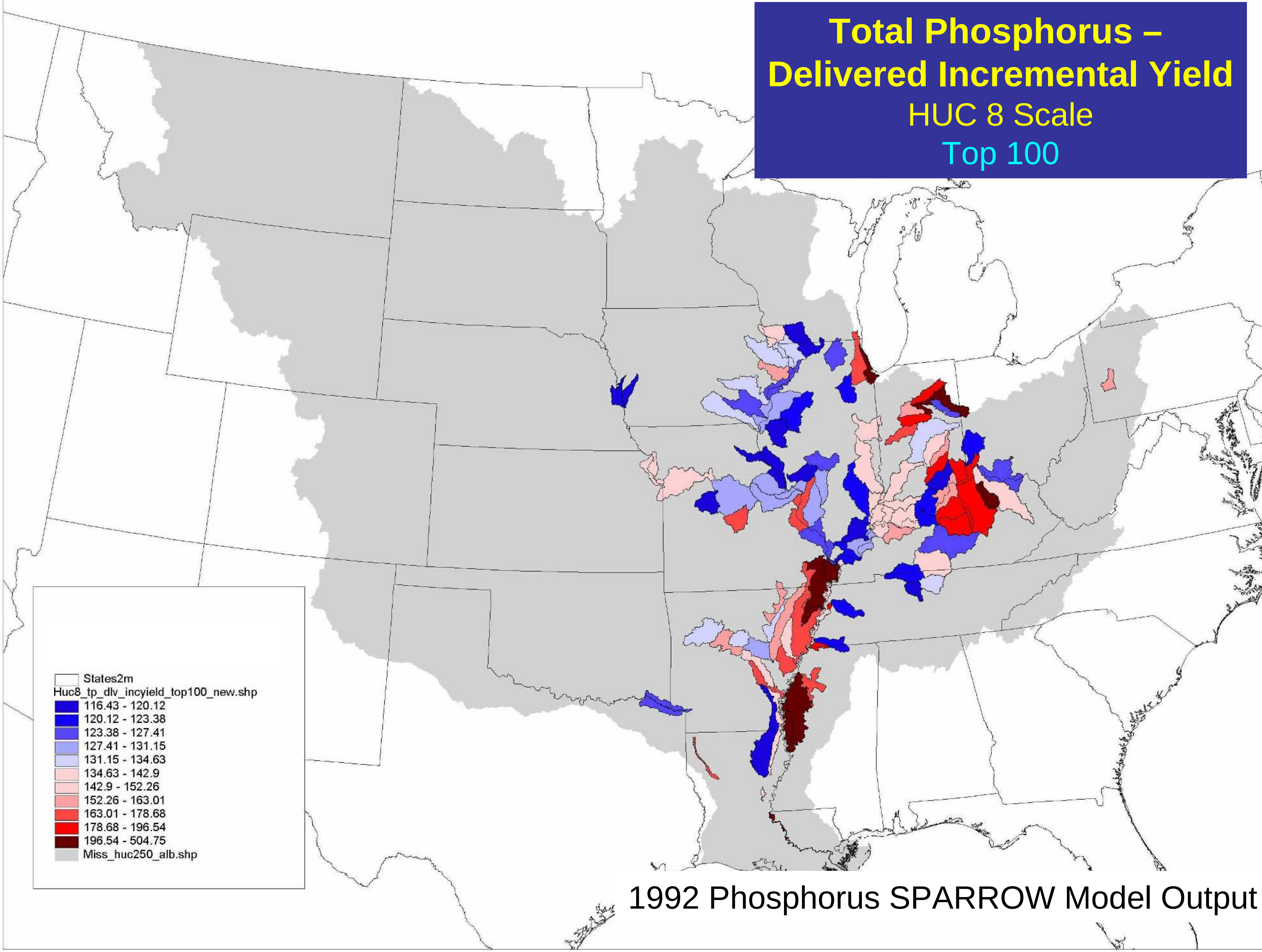


Top 100 > 42% of the Total Load

Total Phosphorus – Delivered Incremental Yield

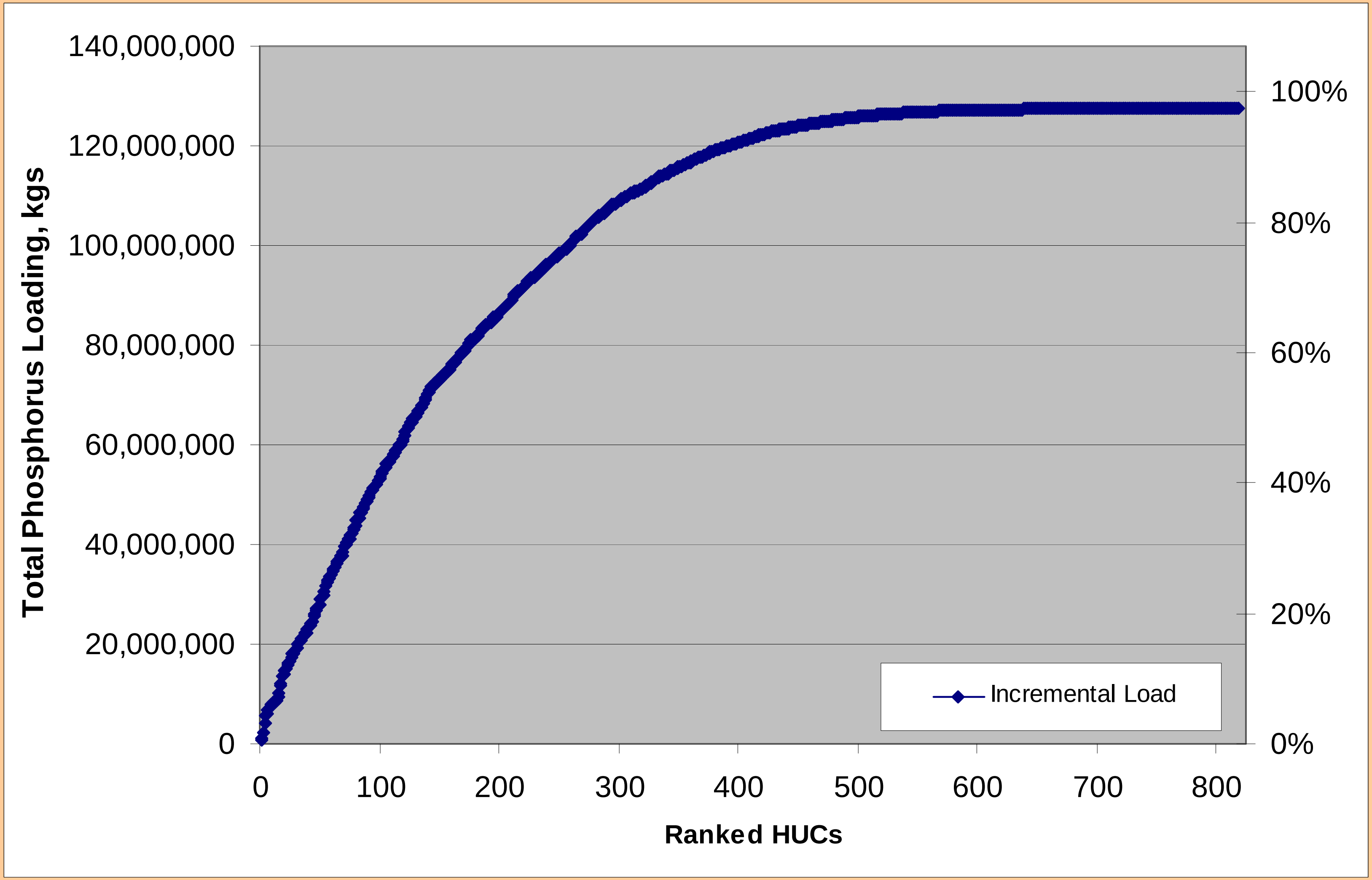
HUC 8 Scale

Top 100

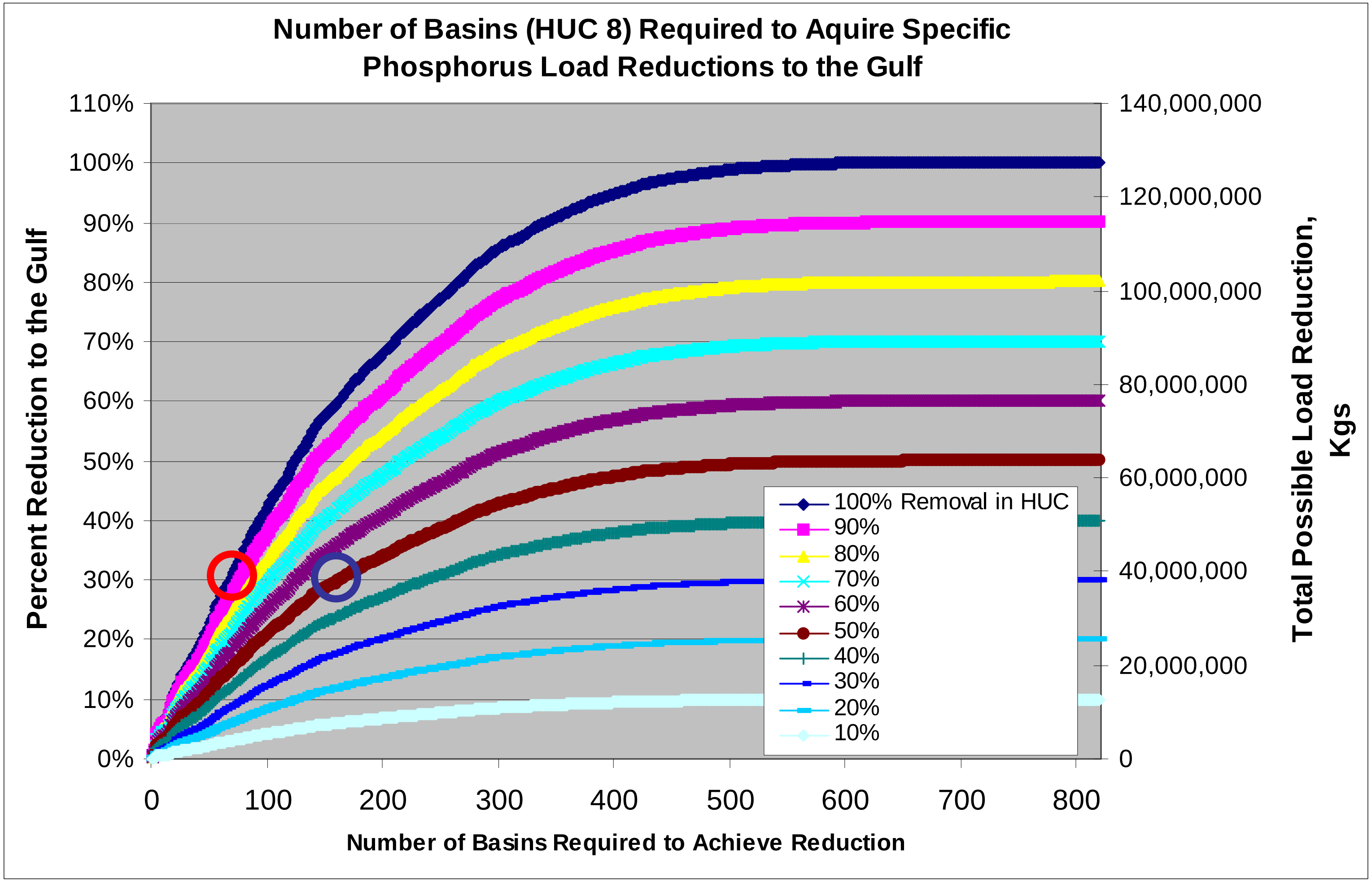


1992 Phosphorus SPARROW Model Output

Accumulated Phosphorus Loading



1992 Phosphorus SPARROW Model Output

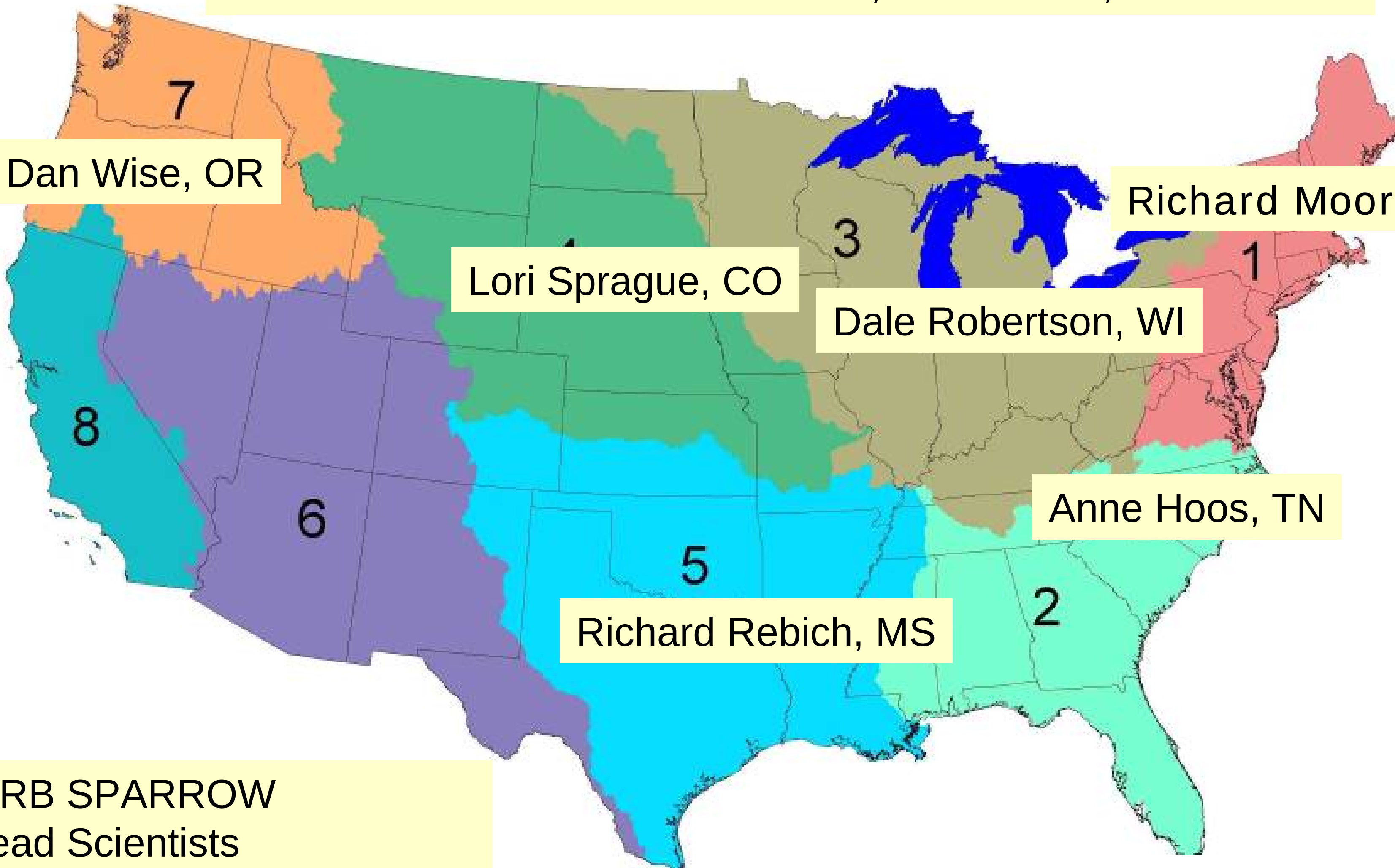


To Obtain a 30% Reduction in the Total Phosphorus Load

- With a 100% Removal in TP Load, it would require the top 70 HUCs
- With a 50% Removal in TP Load, it would require the top 162 HUCs

U.S. Geological Survey SPARROW models

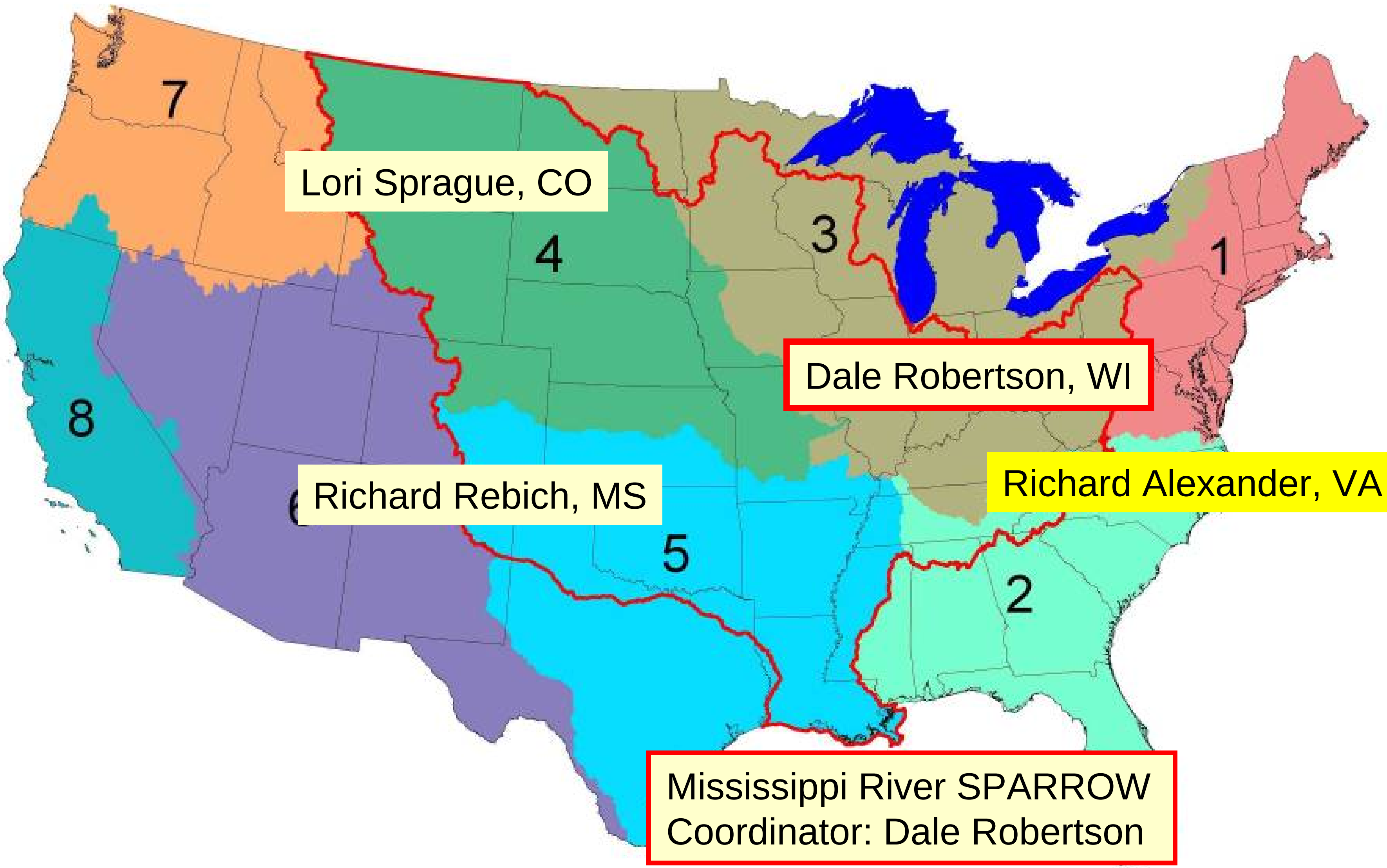
National Model – Richard Alexander, G. Schwarz, and R. Smith



MRB SPARROW
Lead Scientists
Coordinator – Steve Preston

1992 and 2002 Models

Mississippi River SPARROW Model



Future Improvements from Regional SPARROW Models

1. **Better spatial resolution** – More sites and especially more smaller sites, should lead to more accurate predictions at smaller scales.

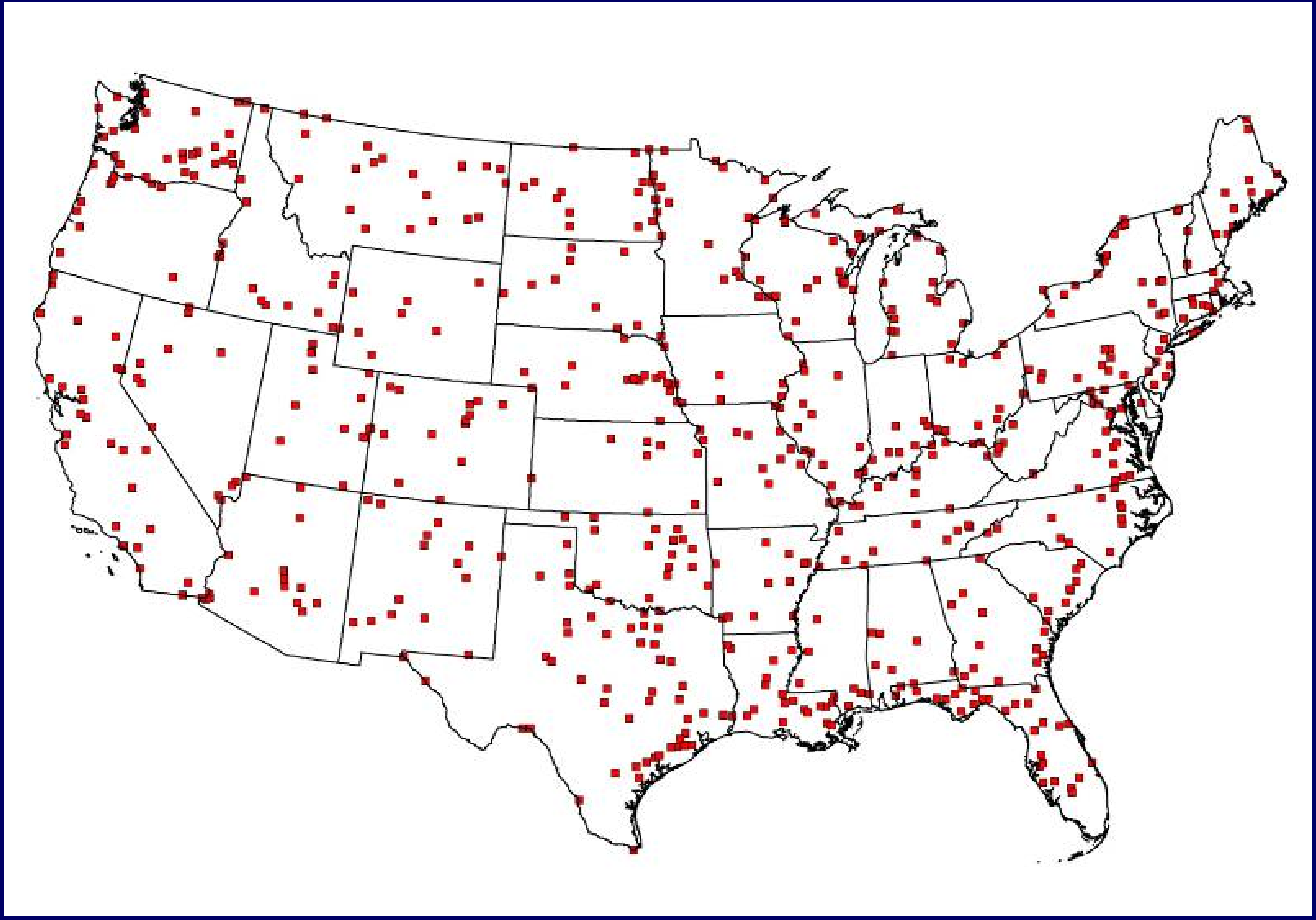
2. **Further reductions in biases.**

3. **Better definition of source terms** – better point-source data, more sites in unique areas, possible better local GIS inputs.

4. **Better able to address more regional and local questions.**

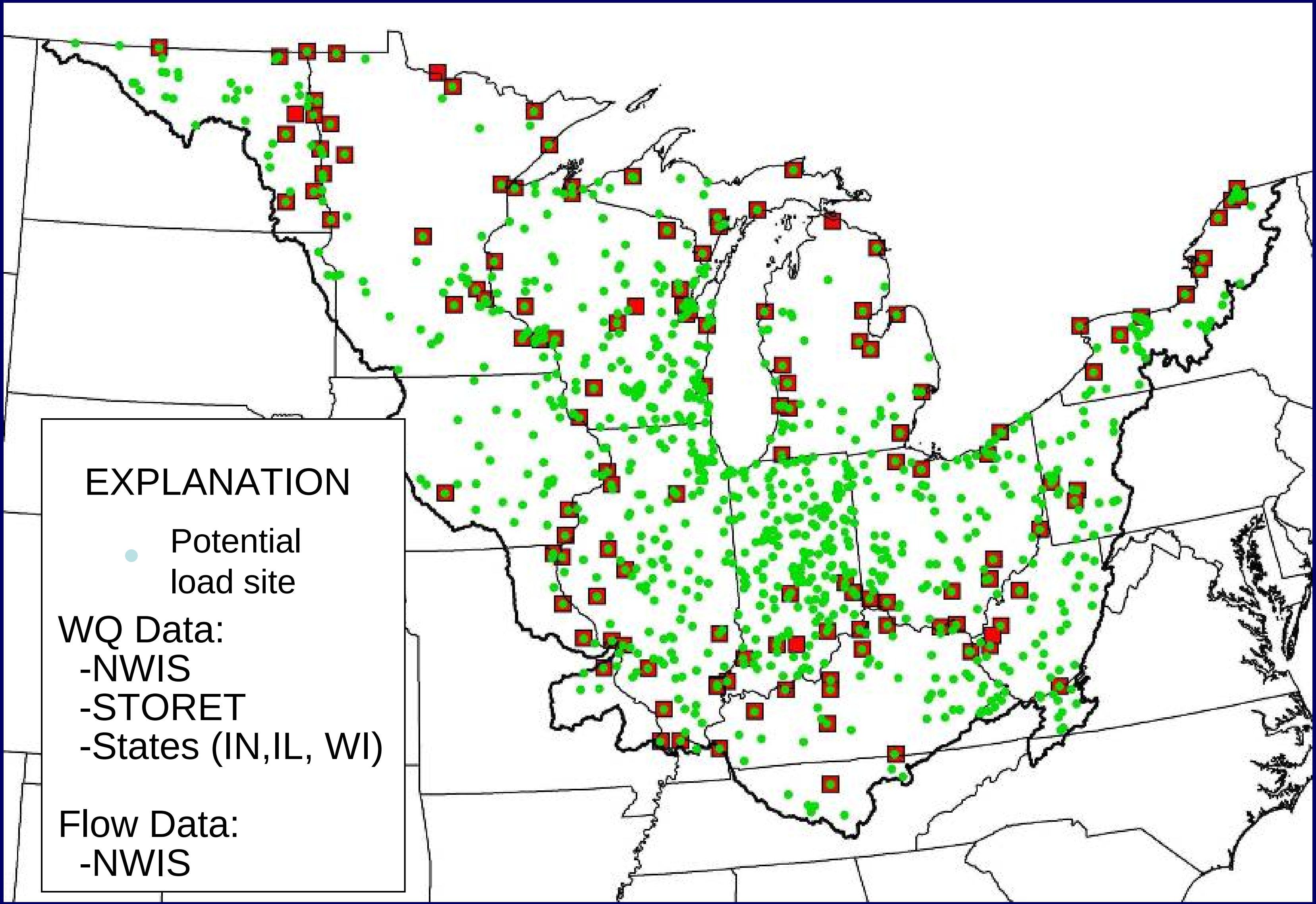
Approximately 475-600 sites used in National SPARROW Models

(Number of sites used in models varies by constituent)

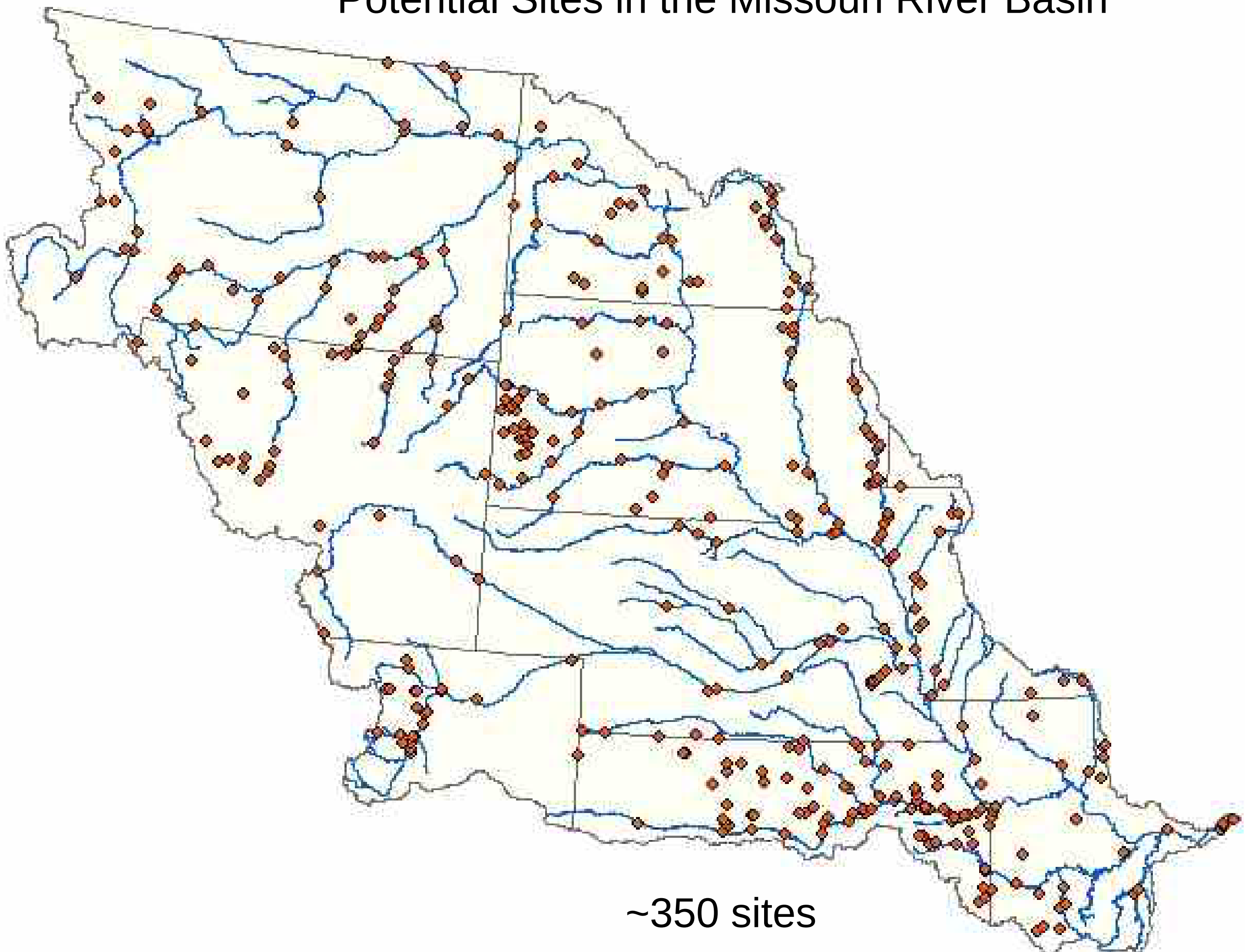


Additional Sites to be Added for Model Calibration

~1000 Potential Load Sites for MRB3 SPARROW Model



Potential Sites in the Missouri River Basin



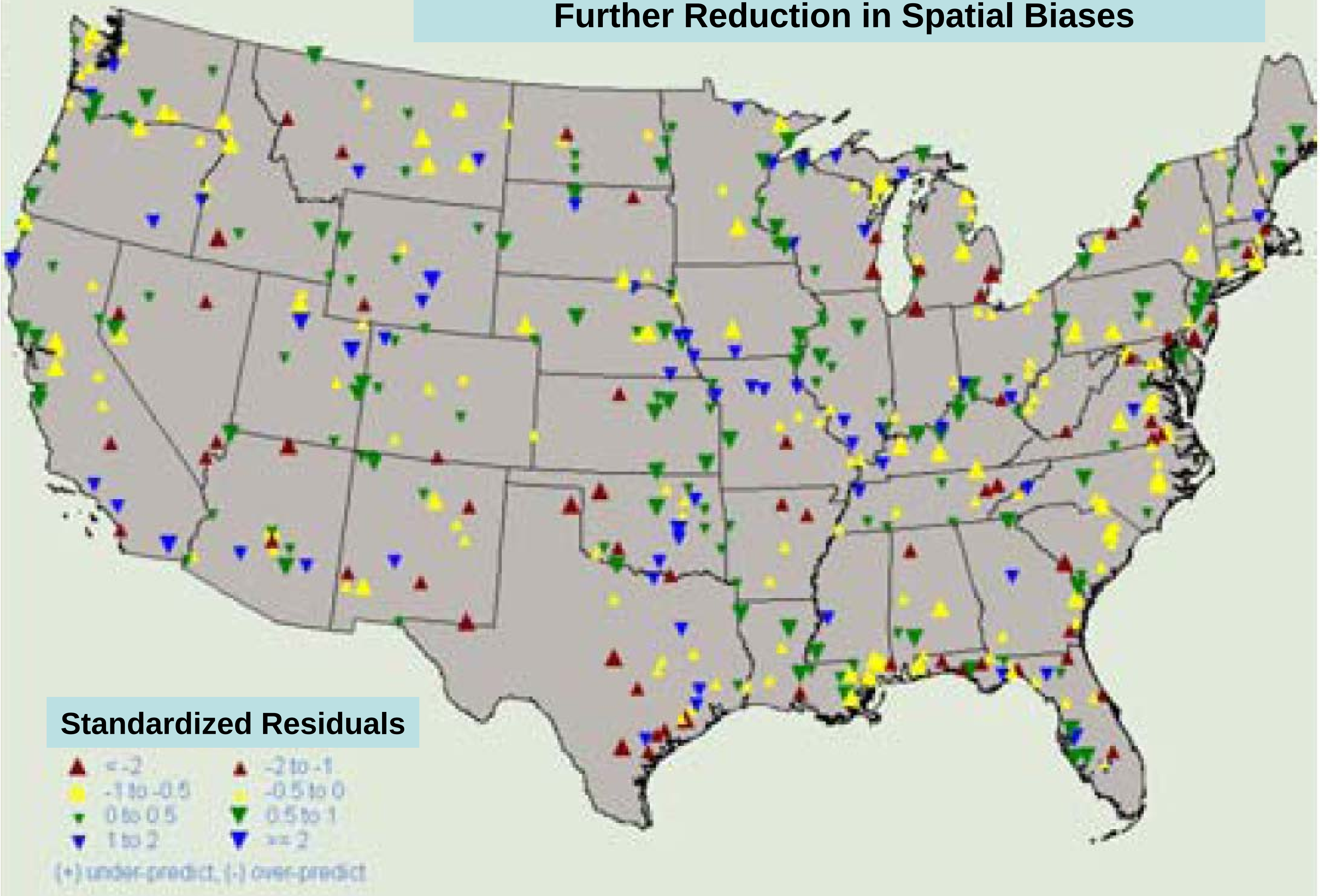
~350 sites

~750-1000 sites in the Lower Mississippi River Basin

EXPLANATION

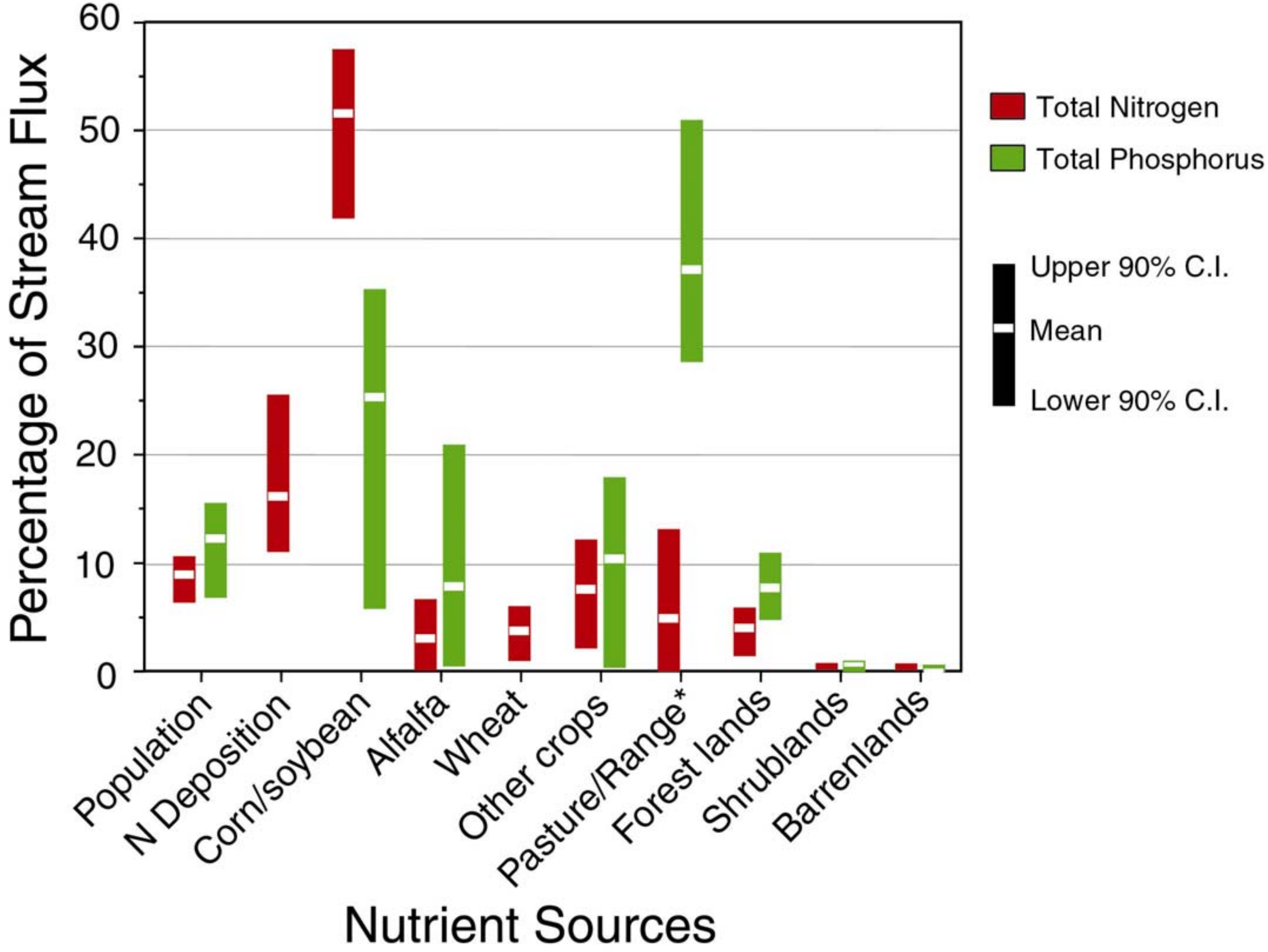
◆ All QW Sites

Standardized Residuals Map for Total Phosphorus
Further Reduction in Spatial Biases



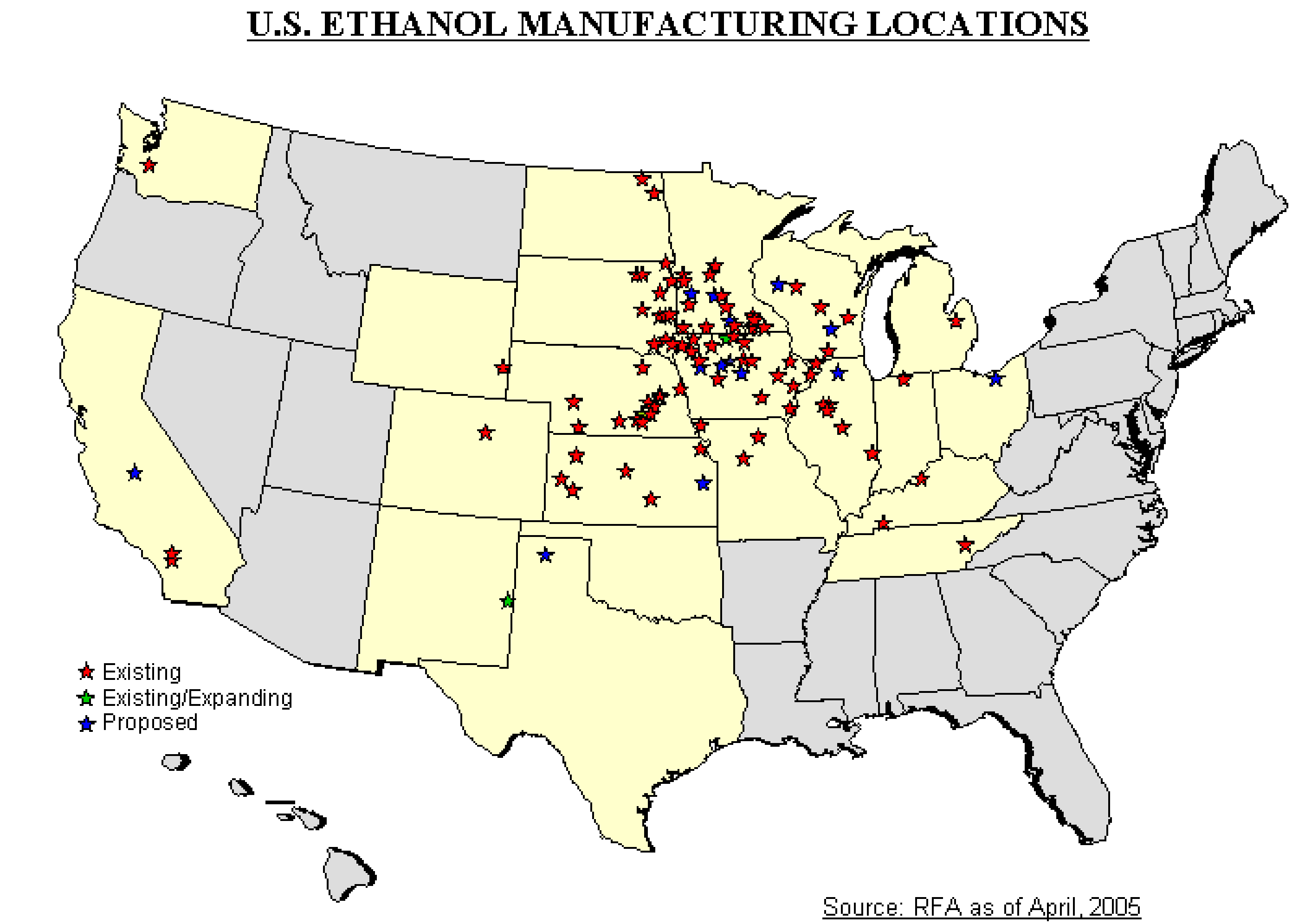
Refinement of Source Contributions to Stream Nutrient Flux

Mississippi River at St. Francisville, LA



**Non-recoverable animal manure*

Better able to address more regional and local questions



Source: RFA as of April, 2005