An Improved Understanding of Nitrogen and Phosphorus Delivery Throughout the Mississippi/Atchafalaya River Basin: Results from Refined Regional SPARROW Models

By

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Goals of the recent SPARROW Modeling in the Mississippi/Achafalaya River Basin (MARB):

1. Refine the P and N loading to the Gulf of Mexico from the entire MARB (large spatial area).

2. Refine the description of where are the main contributing basins
(Rank contributing basins based on loads and yields).

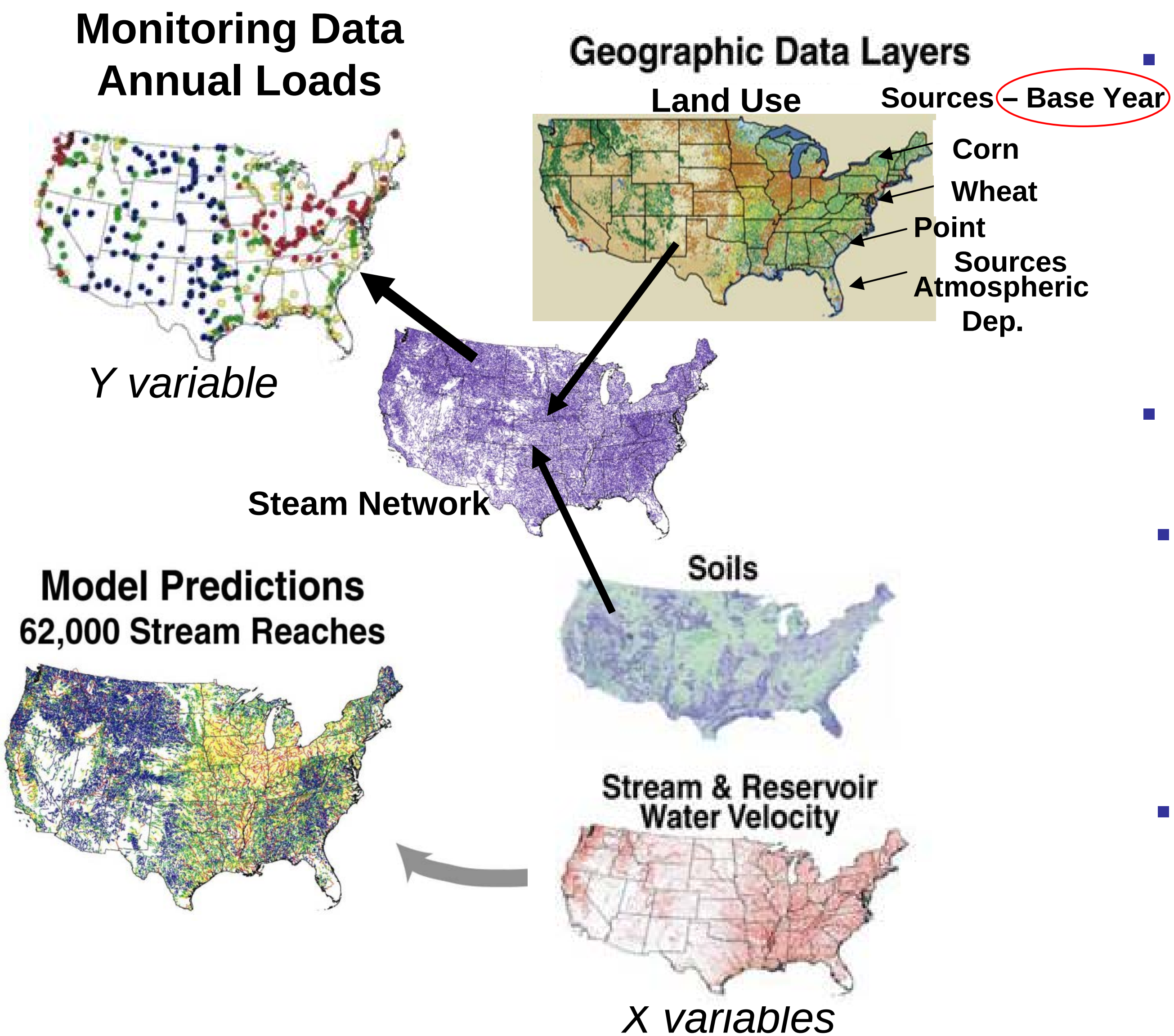
3. Refine the description of what are the main causes of the high loads (Describe the relative importance of nutrient sources).

4. Provide information to various Federal, State and Regional organizations to support regional interpretation and guide local, more indepth studies.

Approach - SPARROW Water-Quality Model –

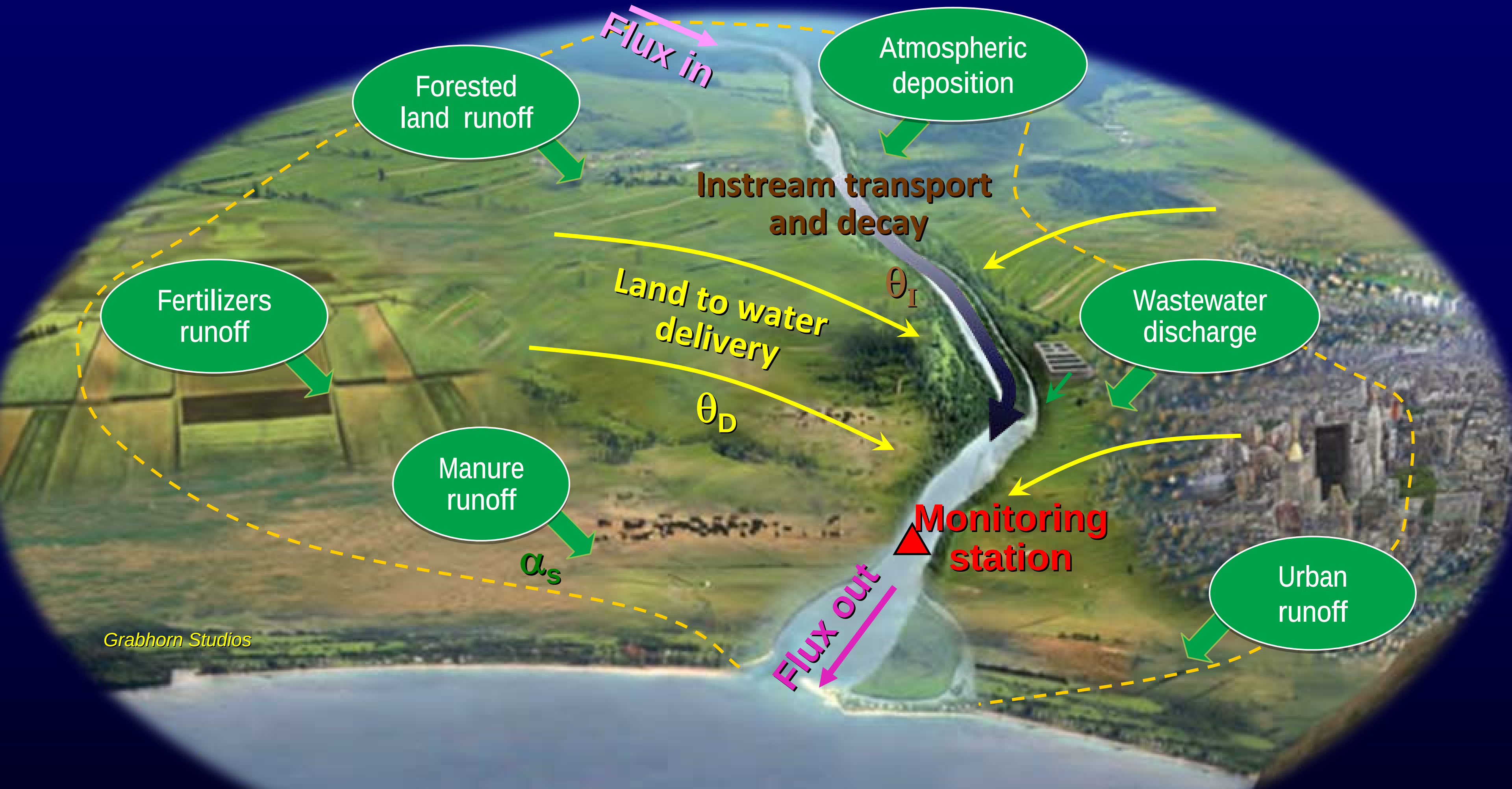
SPAtially Referenced Regression on Watershed Attributes

http://water.usgs.gov/nawqa/sparrow



- **Mass Balance Model with spatially variable deliveries. Hybrid statistical/ mechanistic process structure. Data-driven, nonlinear estimation of parameters**
- **Separates land and in-stream processes**
- **Predictions of mean-annual flux reflect long-term, net effects of nutrient supply and loss processes in watersheds**
- **Once calibrated, the model has physically interpretable coefficients; model supports hypothesis testing and uncertainty estimation**

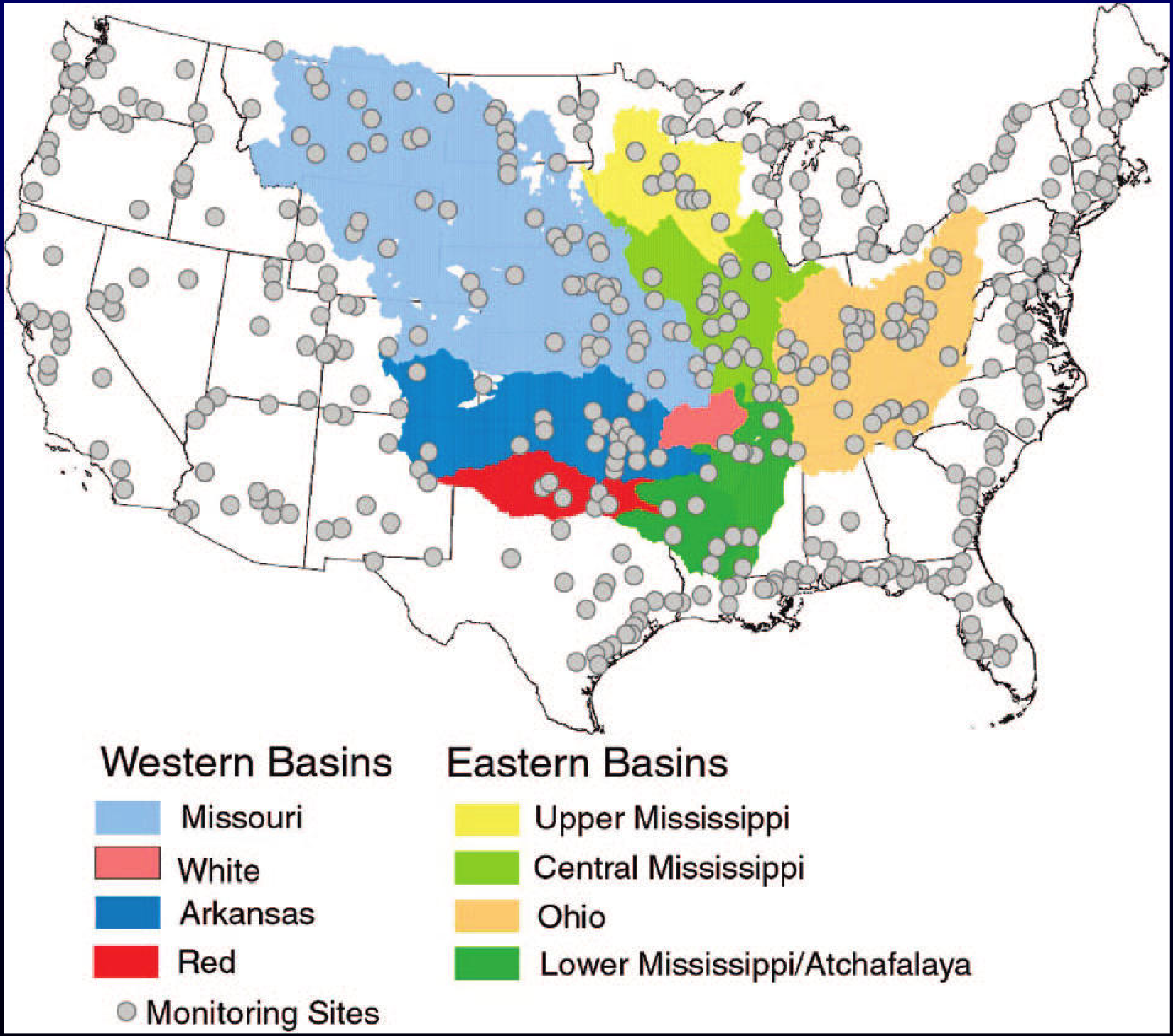
SPARROW: SPAtially Referenced Regression on Watershed Attributes Model



Mass Balance Modeling

Target = Flux out = Flux in + (α_s Sources x θ_D Delivery) – θ_I Instream Decay

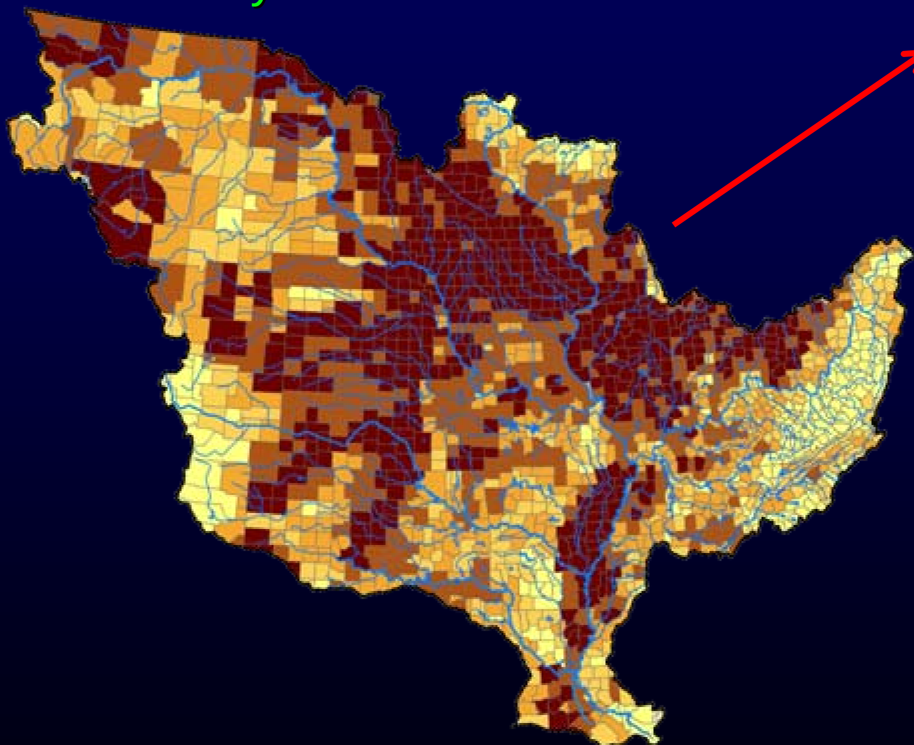
1992 National SPARROW Models were based on approximately 450 sites

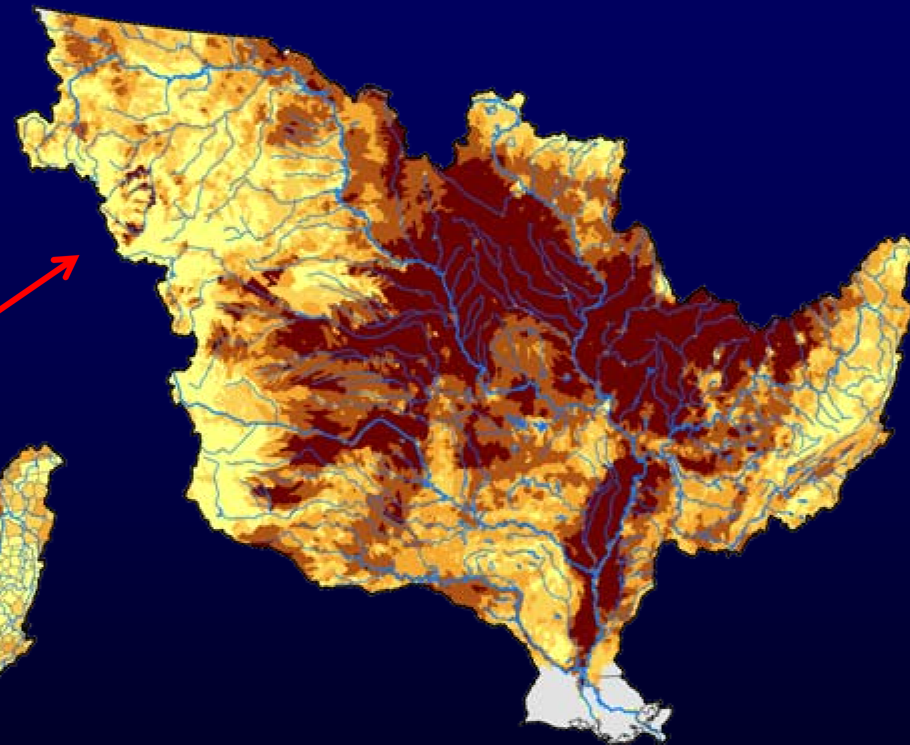


Source Information: Total Nitrogen

Fertilizer

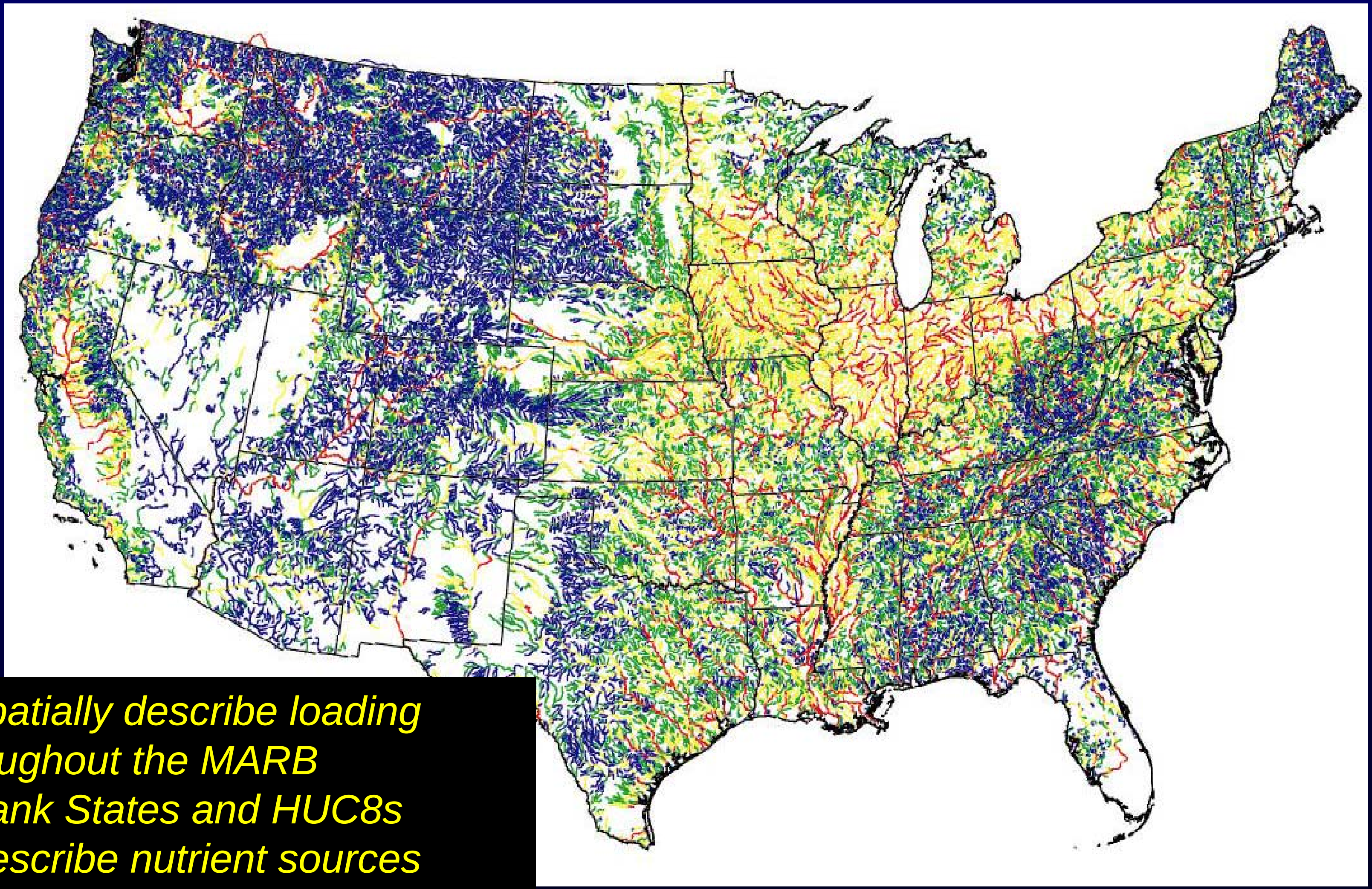
Example: 1992 Farm Fertilizer
TN inputs, kg
county→catchment





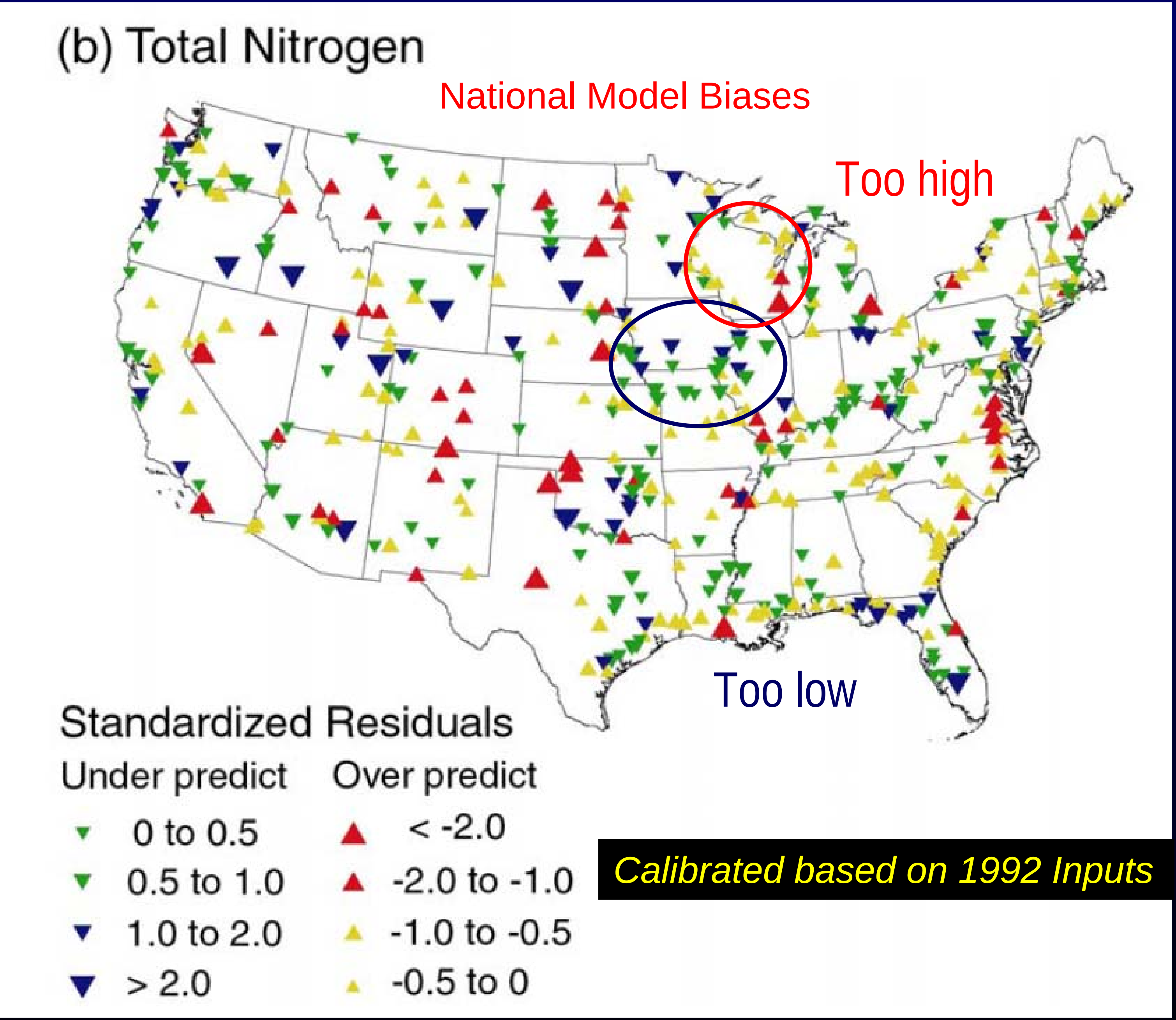
But in application used estimated 2002 Inputs

Predictions from a National SPARROW Model for 1992 and 2002



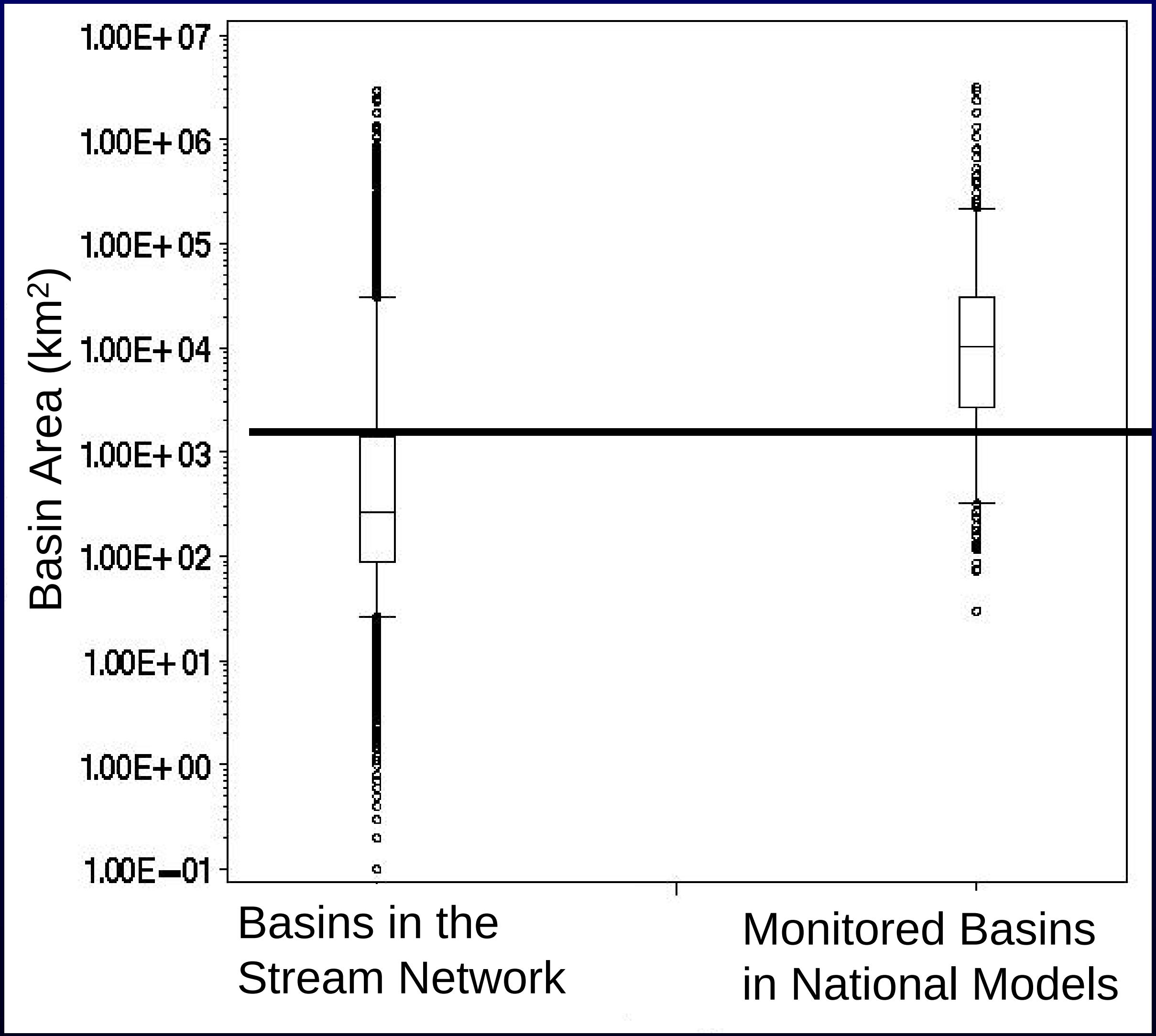
- *Spatially describe loading throughout the MARB*
- *Rank States and HUC8s*
- *Describe nutrient sources*

With a National SPARROW model available to predict loads from streams throughout the entire country, why would you want any other SPARROW models?



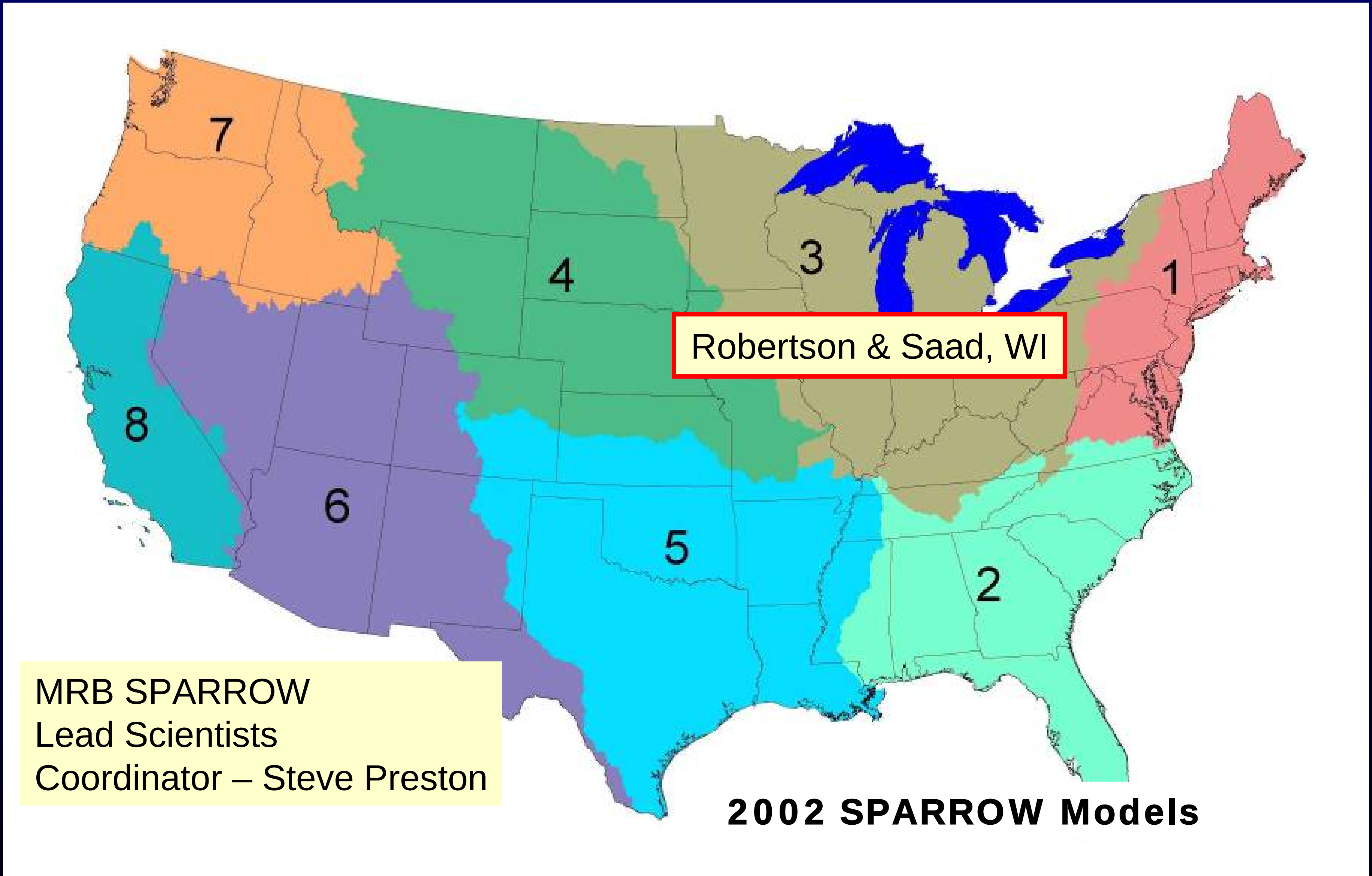
Calibrated based on 1992 Inputs

Distribution of Basin Areas in the Model and in the Calibration Data Set



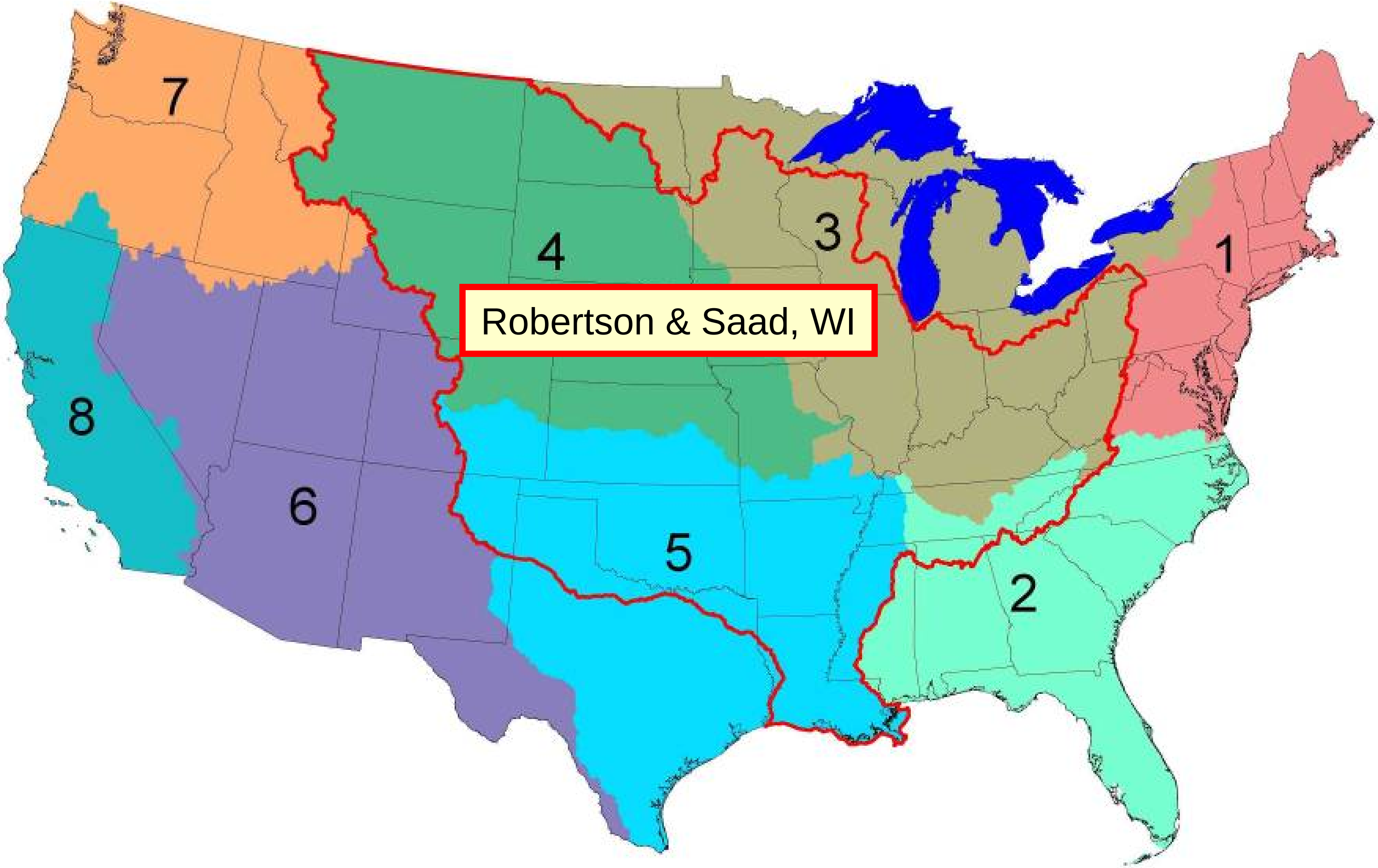
Not really sure how well the model estimates for areas that are smaller than the sites used for calibration

Regional Models part of the NAWQA Program

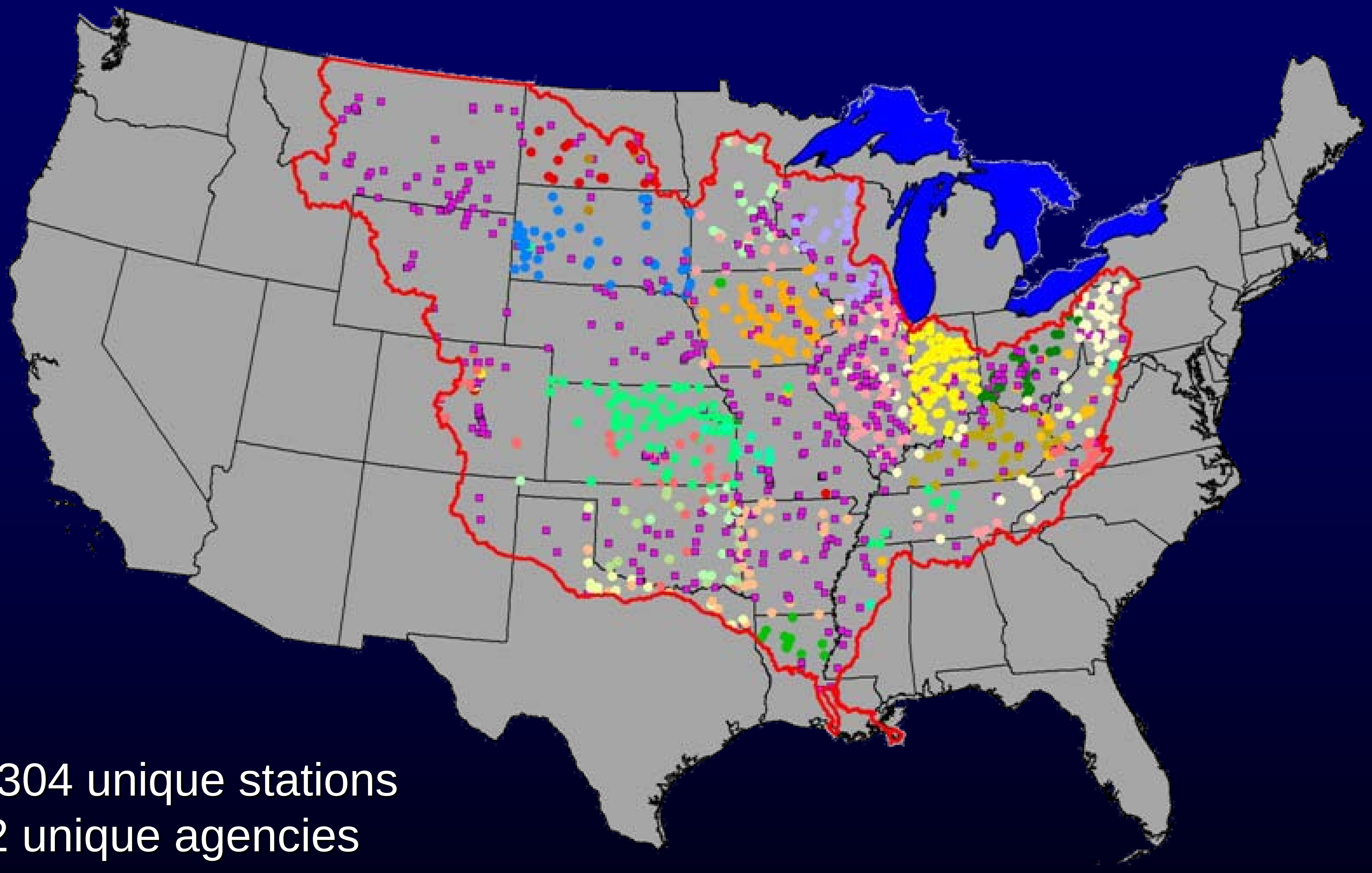


All Published in 2011 in JAWRA

Mississippi/Atchafalaya River Basin (MARB) SPARROW Models



MARB 2002 SPARROW Nutrient Load Sites

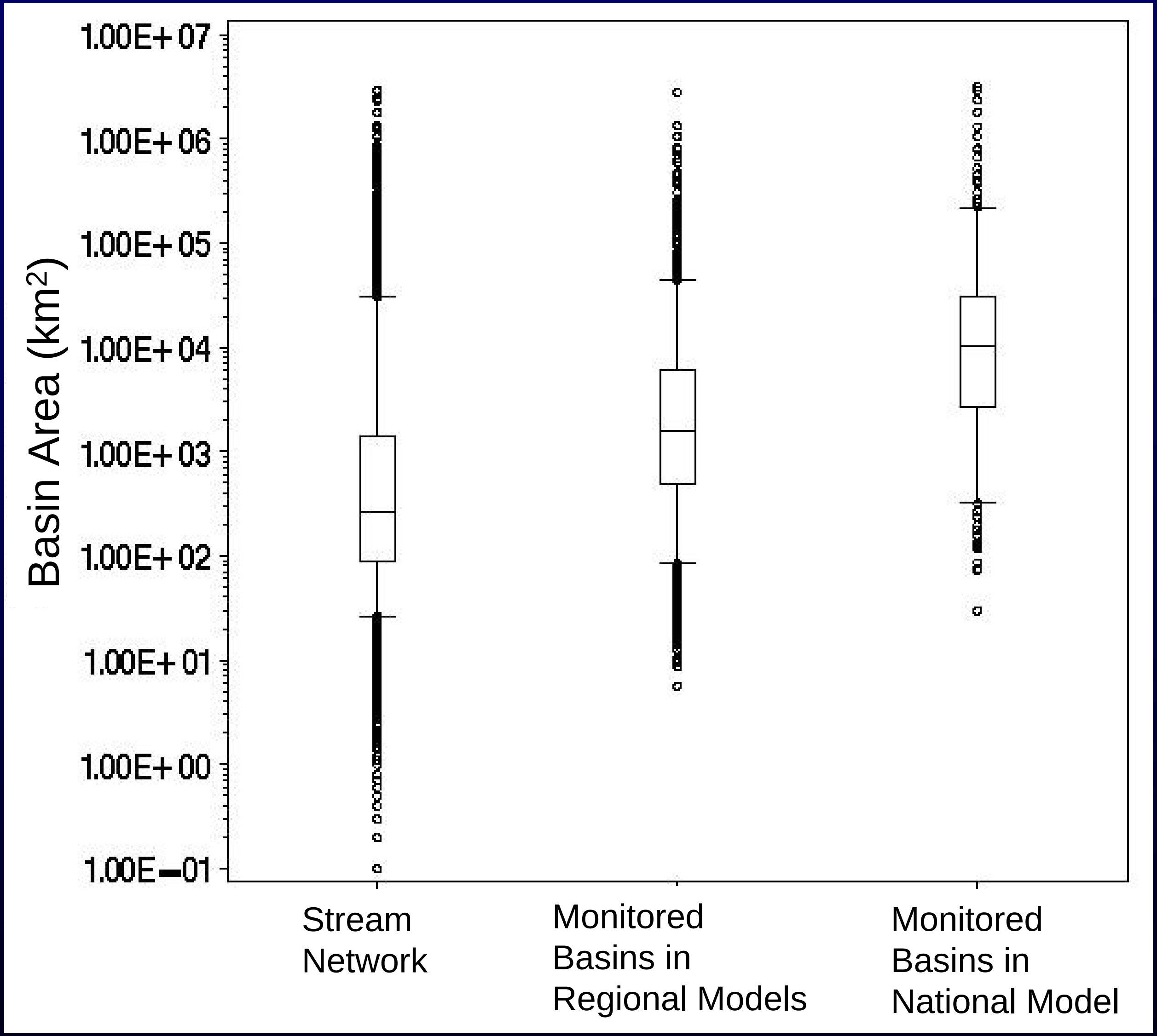


1,304 unique stations
52 unique agencies

USGS science for a changing world

Saad et al., 2011

Distribution of Basin Areas in the Model and in the Calibration Data Sets



Have more up-to-date information, and a much better idea of how models estimate conditions in smaller streams, but still not the smallest basins

SPARROW Sources and Transport Attributes for the 2002 SPARROW Models

NUTRIENT SOURCES (2002)

- **Actual Point Sources -WWTPs**
- Atmos. N deposition – (CMAQ)
- Farm fertilizer use allocated to major crops:
  - County fertilizer sales and expenditures; crop acreage
  - NLCD agricultural land use
  - State appl. rates (rotational, corn, soybeans, cotton, wheat, other crops)
- N_2 fixation – cultivated lands
- Animal manure:
  - Confined/Unconfined Animals
  - Confined > to crops & lost
- Natural and residual sources (lands in forest, barren, shrub)

LAND-TO-WATER DELIVERY

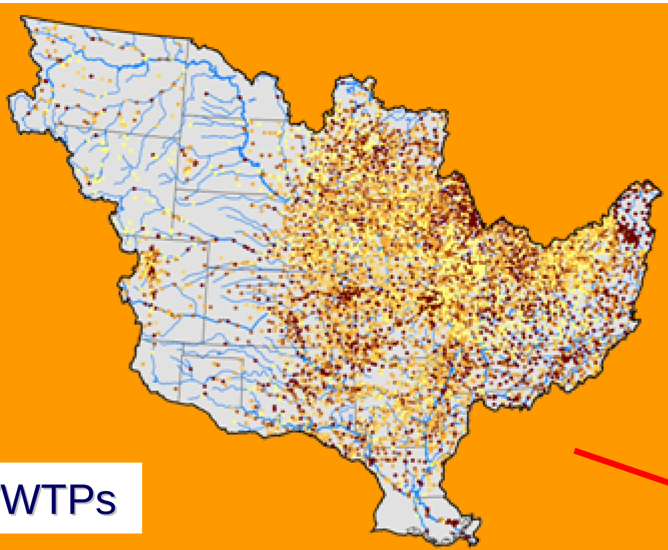
- Climate (precipitation, temperature)
- Soils (permeability)
- Topography/subsurface (slope, specific catchment area)
- **Artificial drainage (tiles, ditches, new ARSC coverage)**

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)

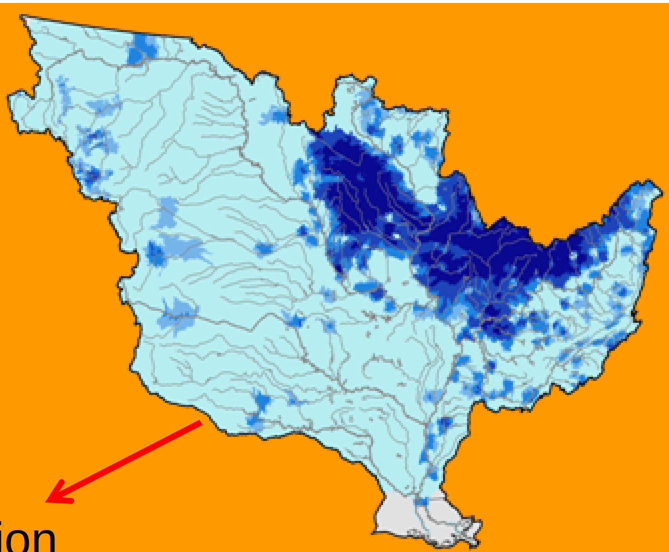
MARB SPARROW Model Calibration

One Source: 2002 Point (WWTP) TN inputs, kg

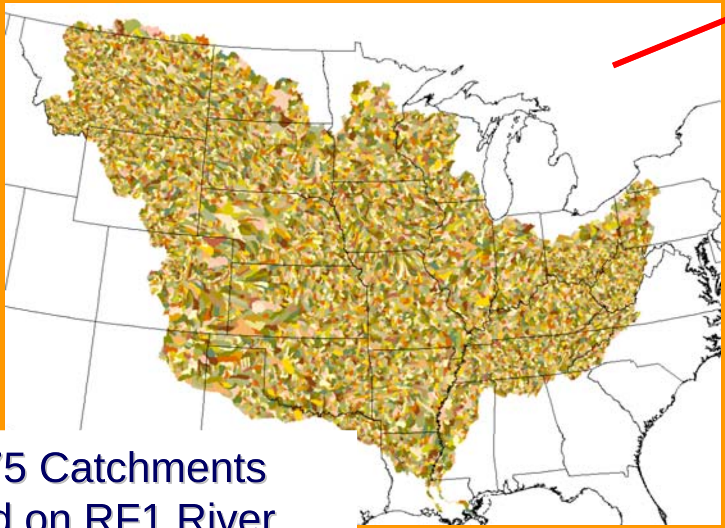


9,182 WWTPs

One Land-to-Water Delivery: Tile Drains



Calibration



24,475 Catchments based on RF1 River Network

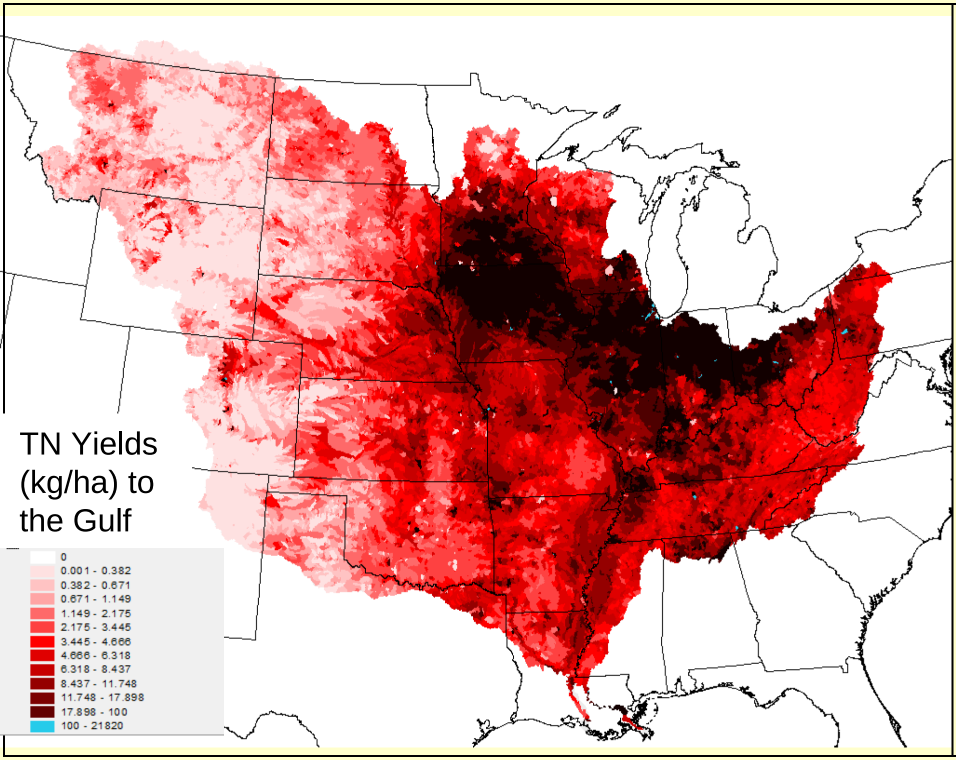
Long-term detrended Loads for 856 sites

SPARROW Total Nitrogen Model for MARB

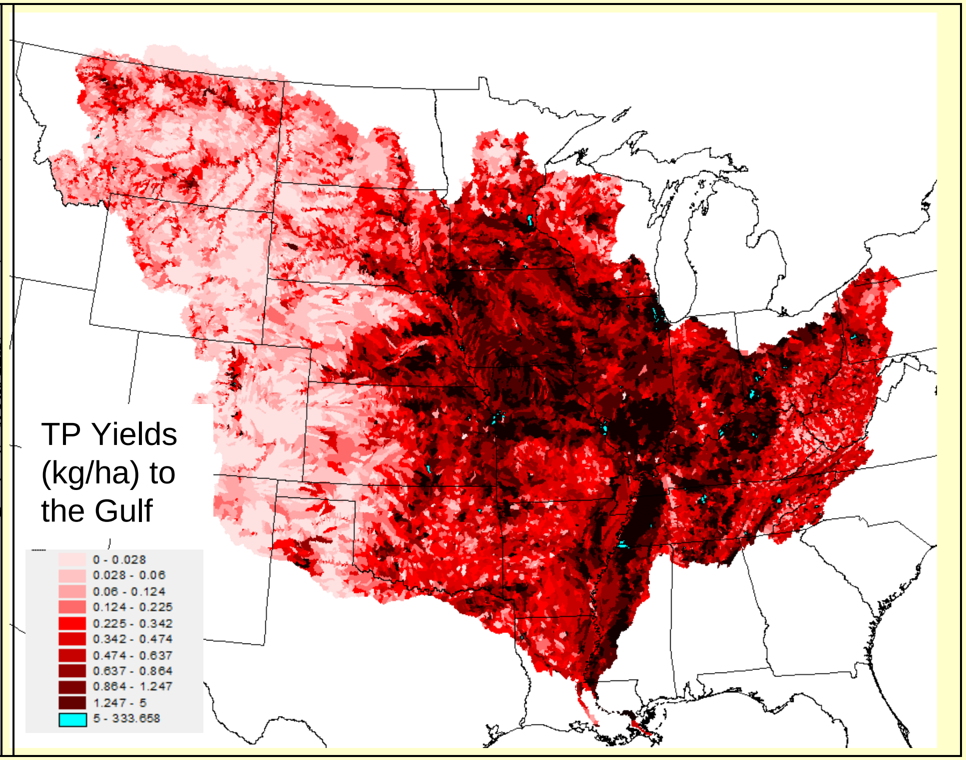
Sources	Parameter Estimate	St. Error	p value
Point Sources (WWTP)	**0.762**	**0.146**	**0.0000**
Urban & Open Areas	**833**	**224**	**0.0001**
Farm Fertilizers	**0.132**	**0.021**	**0.0000**
Confined Animal Manure	**0.164**	**0.035**	**0.0000**
Fixation & Assoc. Crop Inputs	**0.054**	**0.033**	**0.0501**
Atmos. Dep (CMAQ)	**0.199**	**0.026**	**0.0000**

Delivered Incremental Yields

Nitrogen



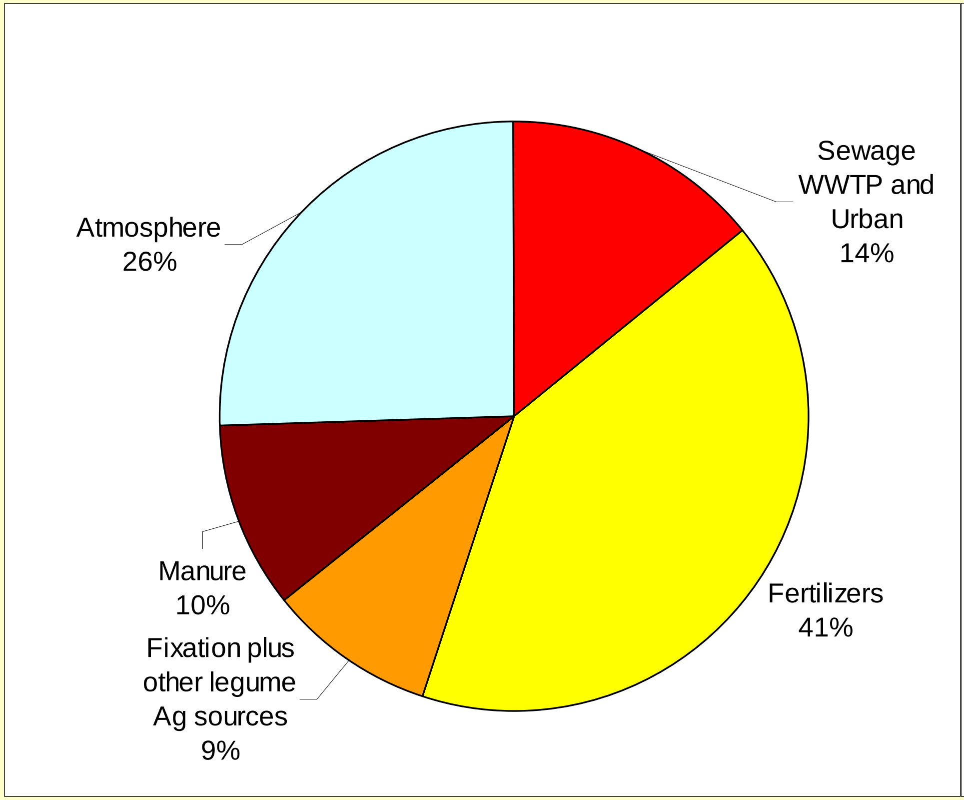
Phosphorus



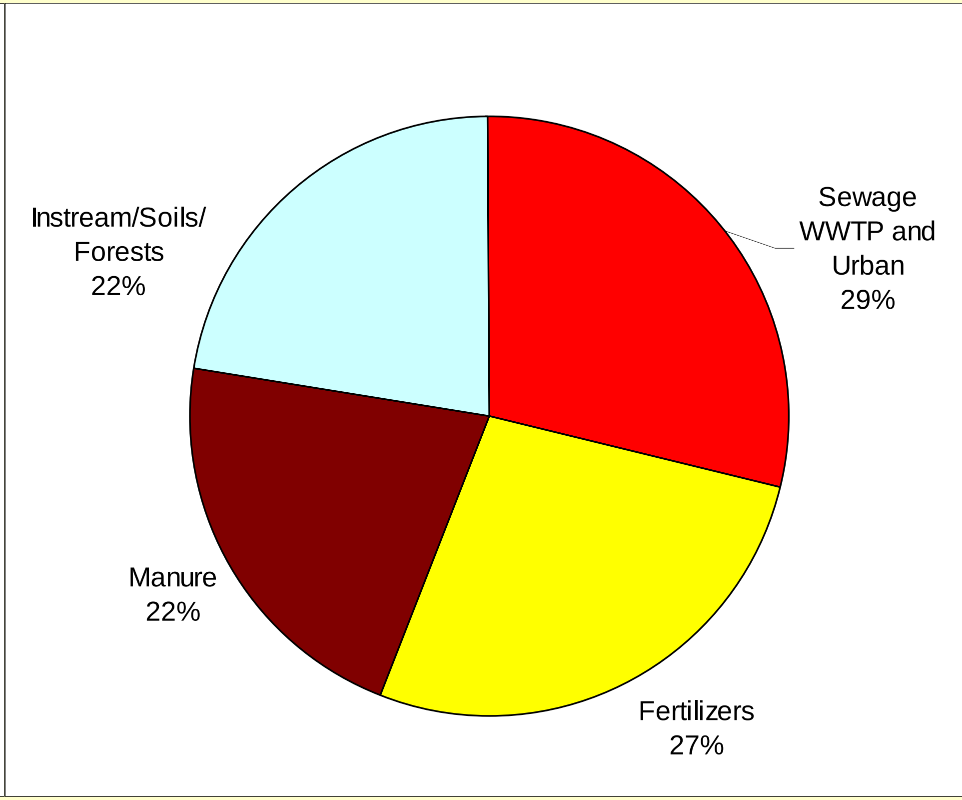
Robertson and Saad, 2013

Sources of Nutrients to the Gulf of Mexico

Total Nitrogen



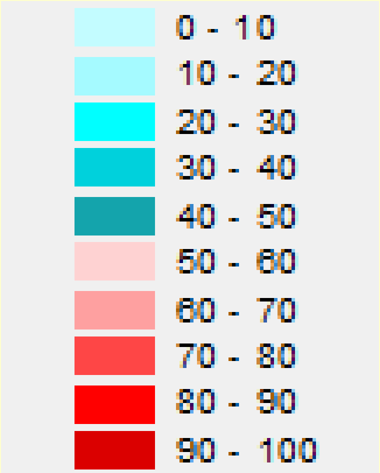
Total Phosphorus



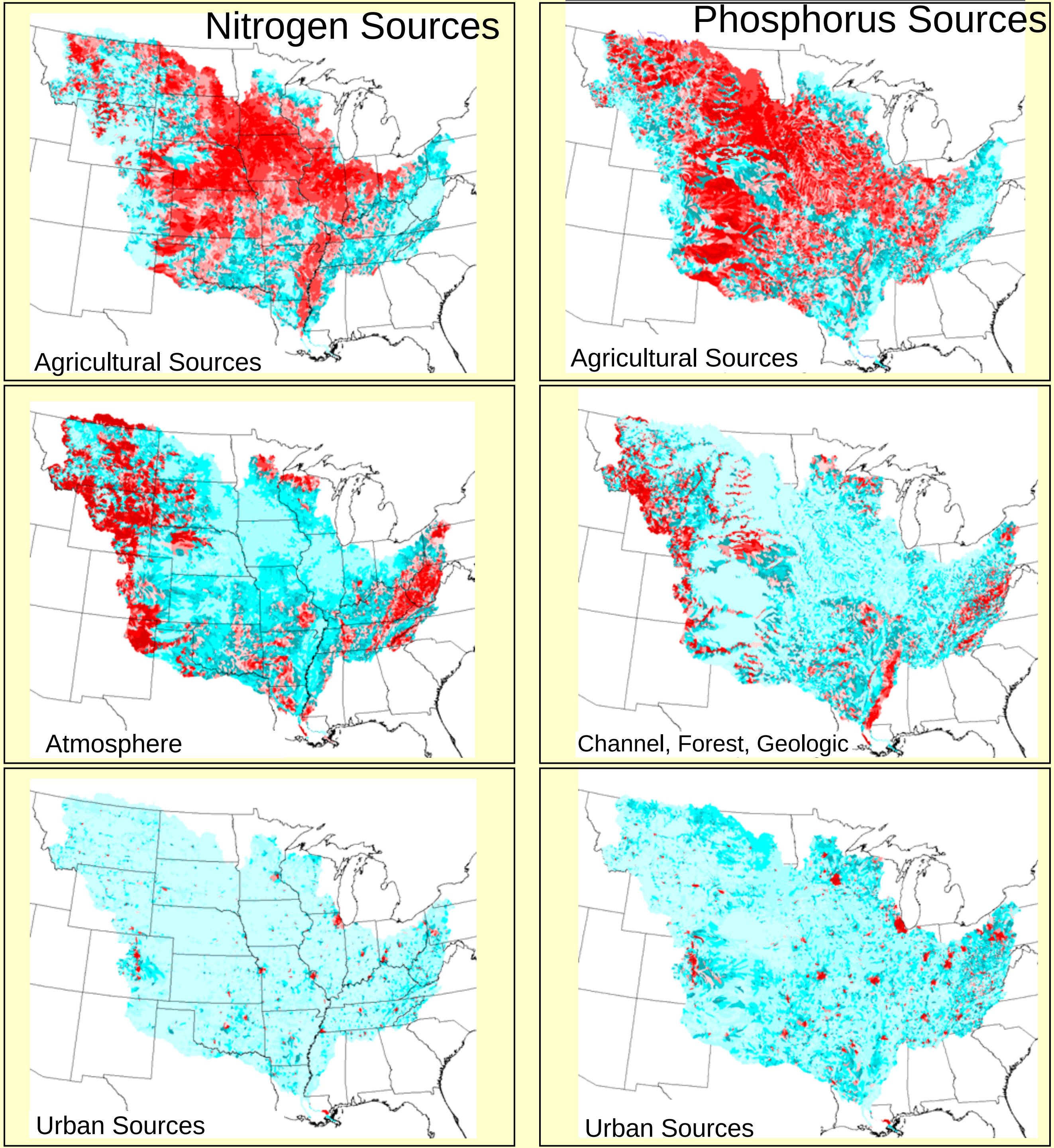
Robertson and Saad, 2013

Sources of Nutrients Throughout the MARB

Percent of Source to Total Incremental Load

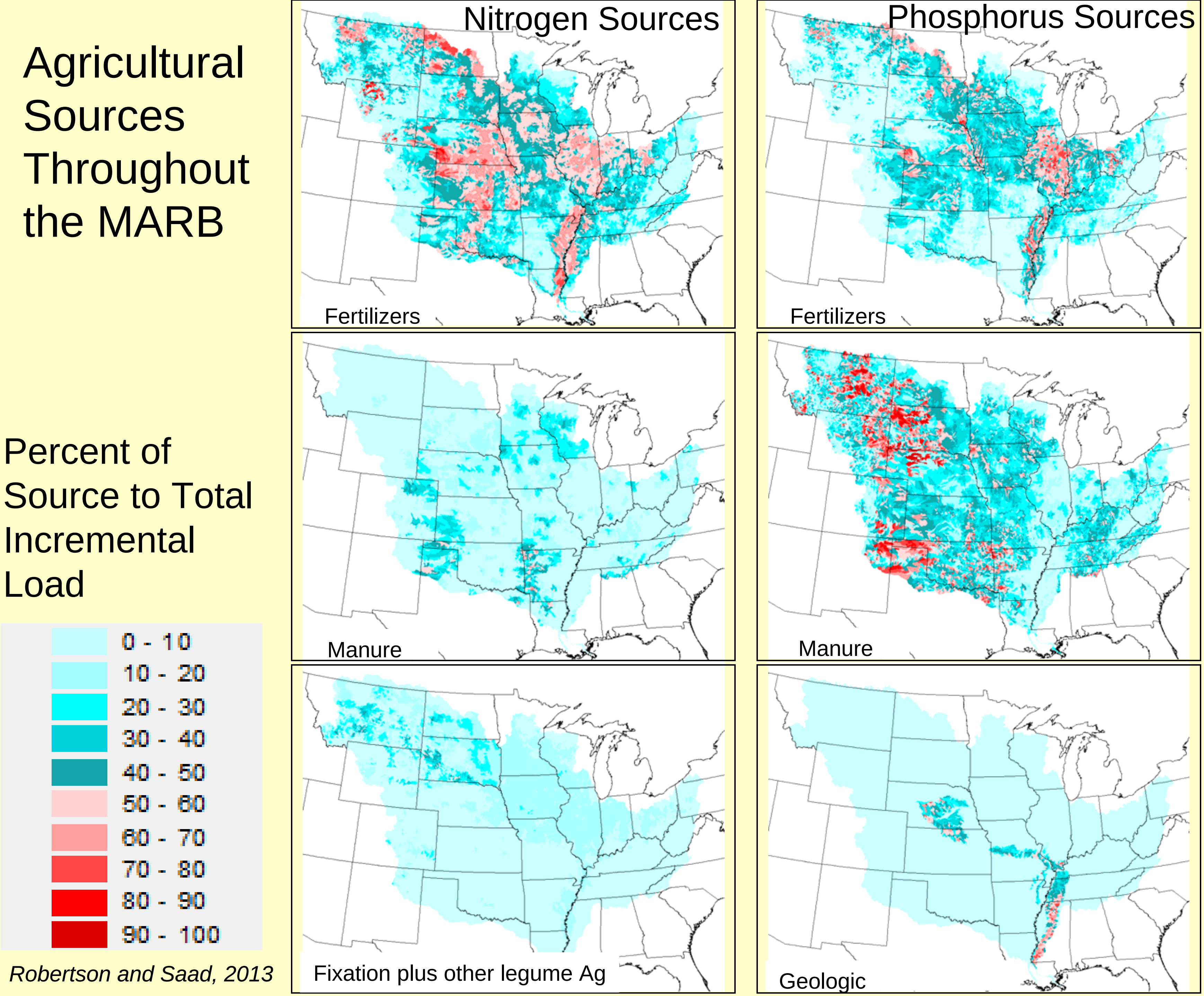


Robertson and Saad, 2013



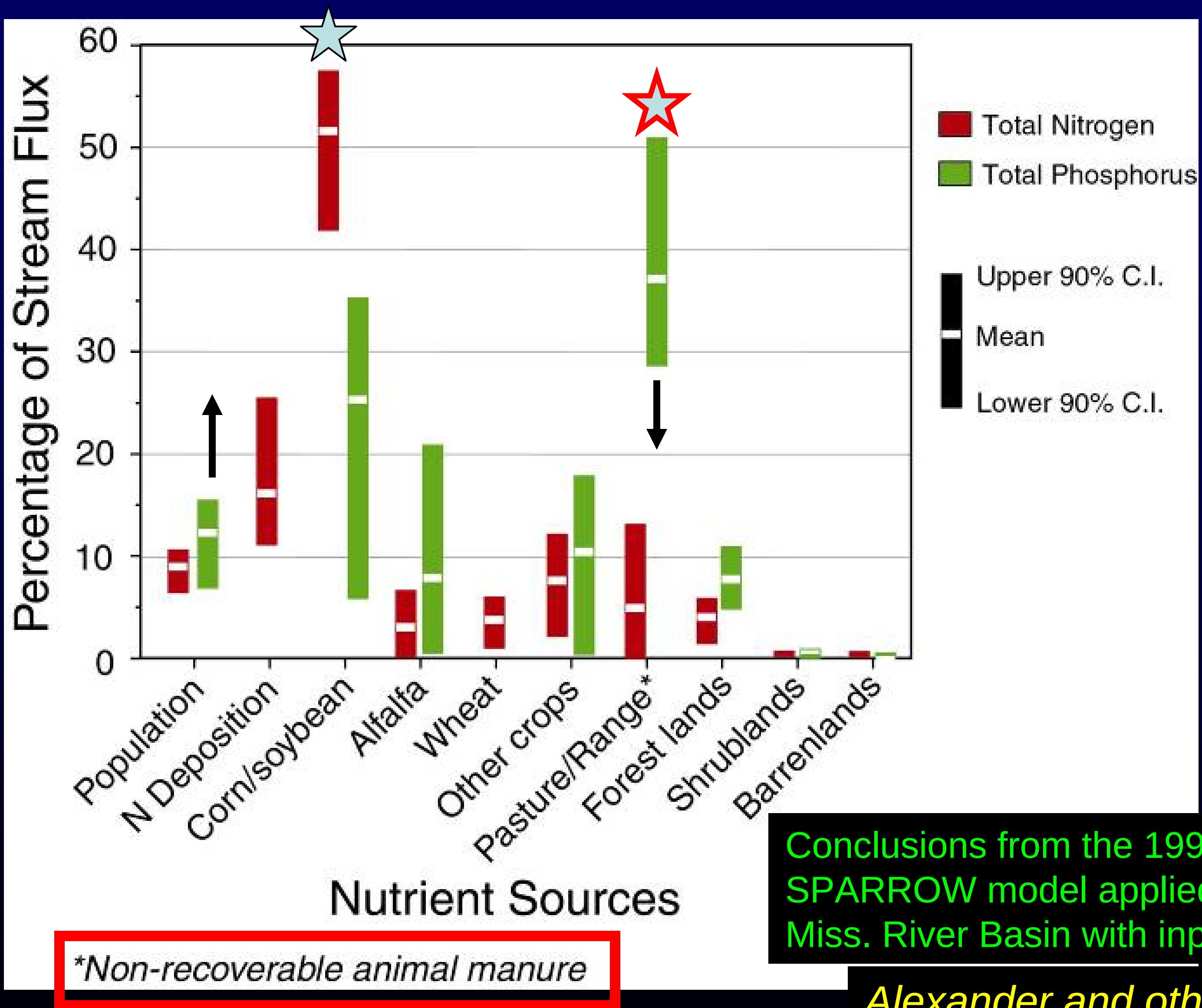
Agricultural Sources Throughout the MARB

Percent of Source to Total Incremental Load



Robertson and Saad, 2013

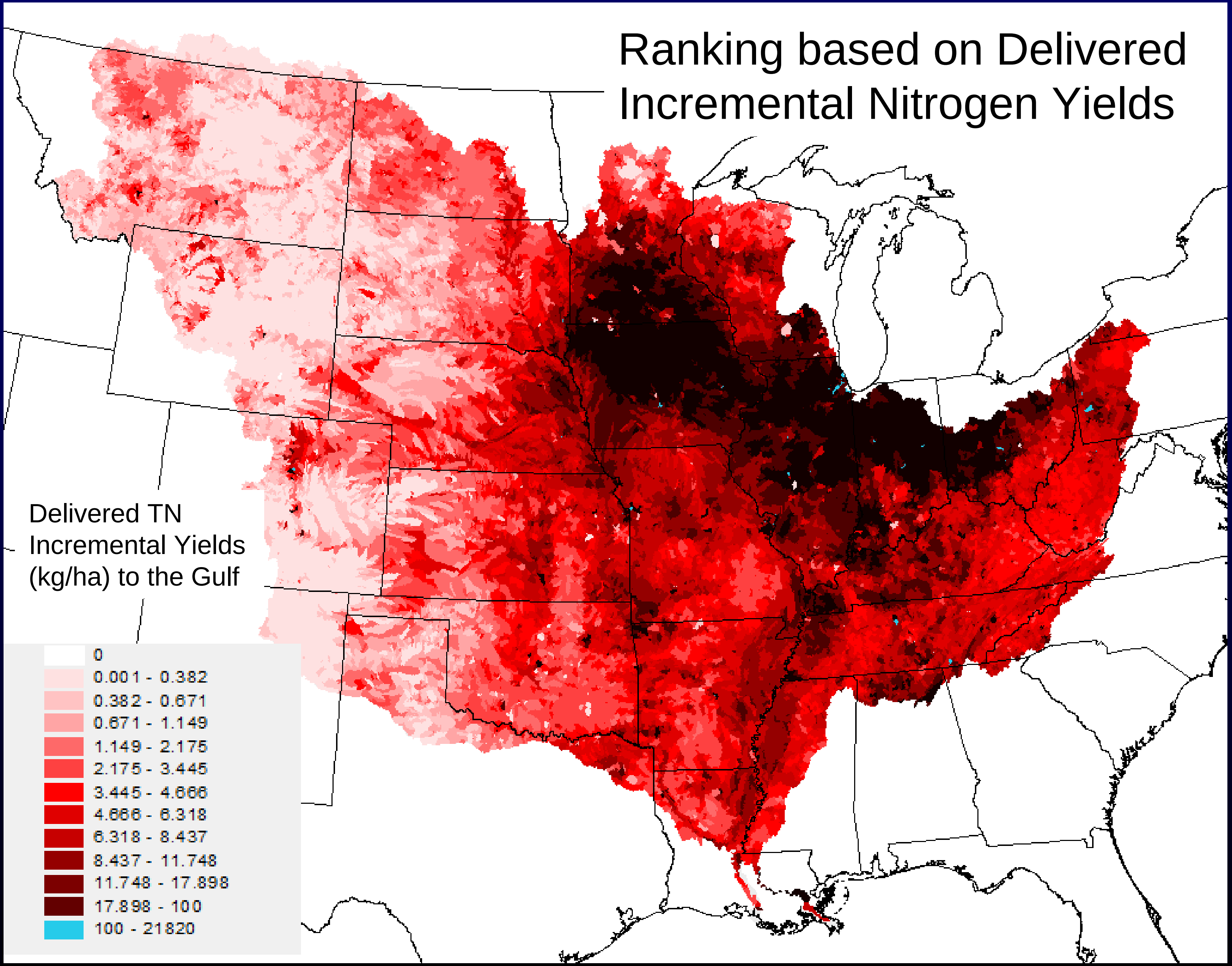
How does this compare with earlier SPARROW studies??



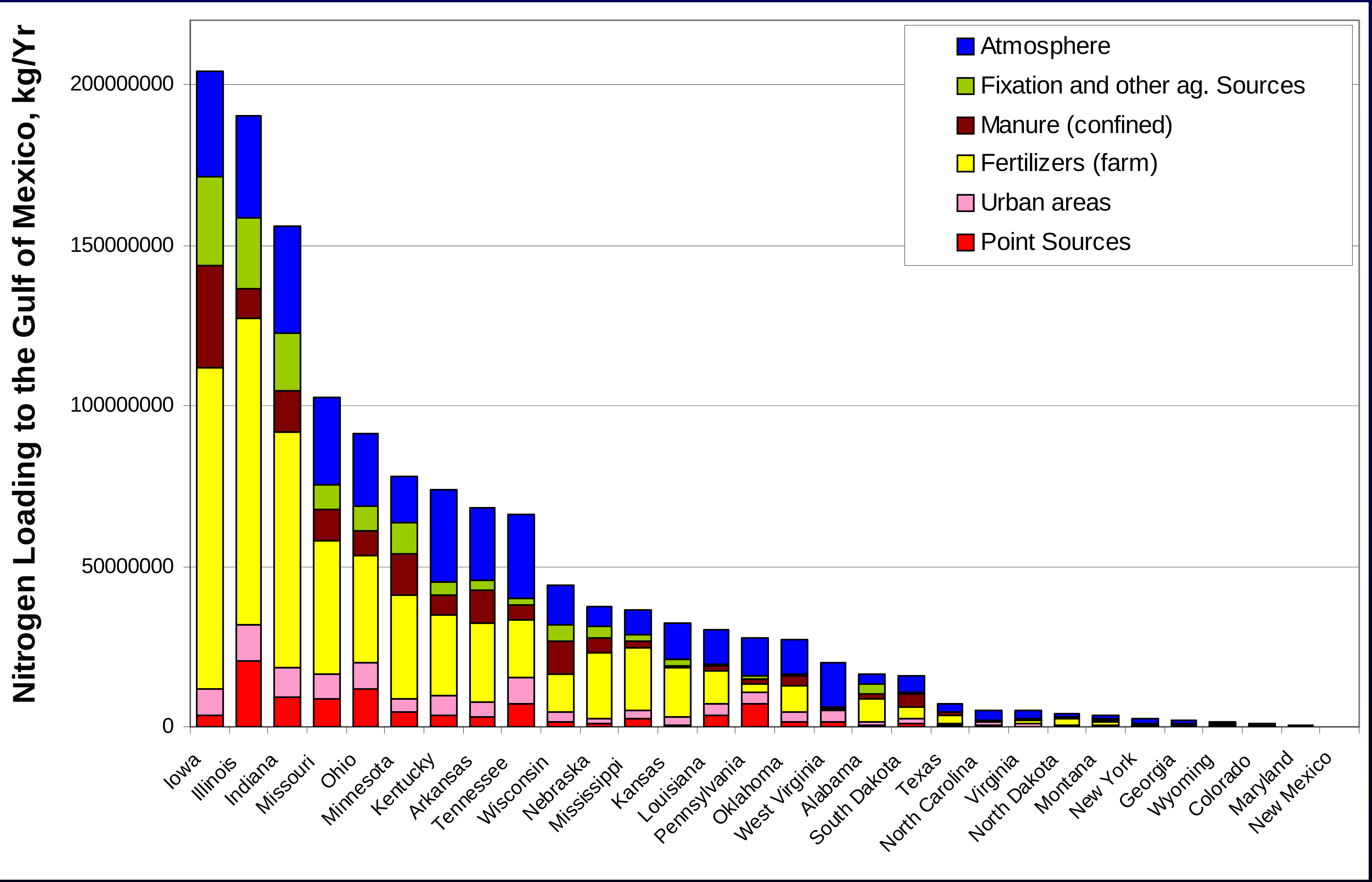
Conclusions from the 1992 National SPARROW model applied to the Miss. River Basin with inputs for 2002

Alexander and others, 2008

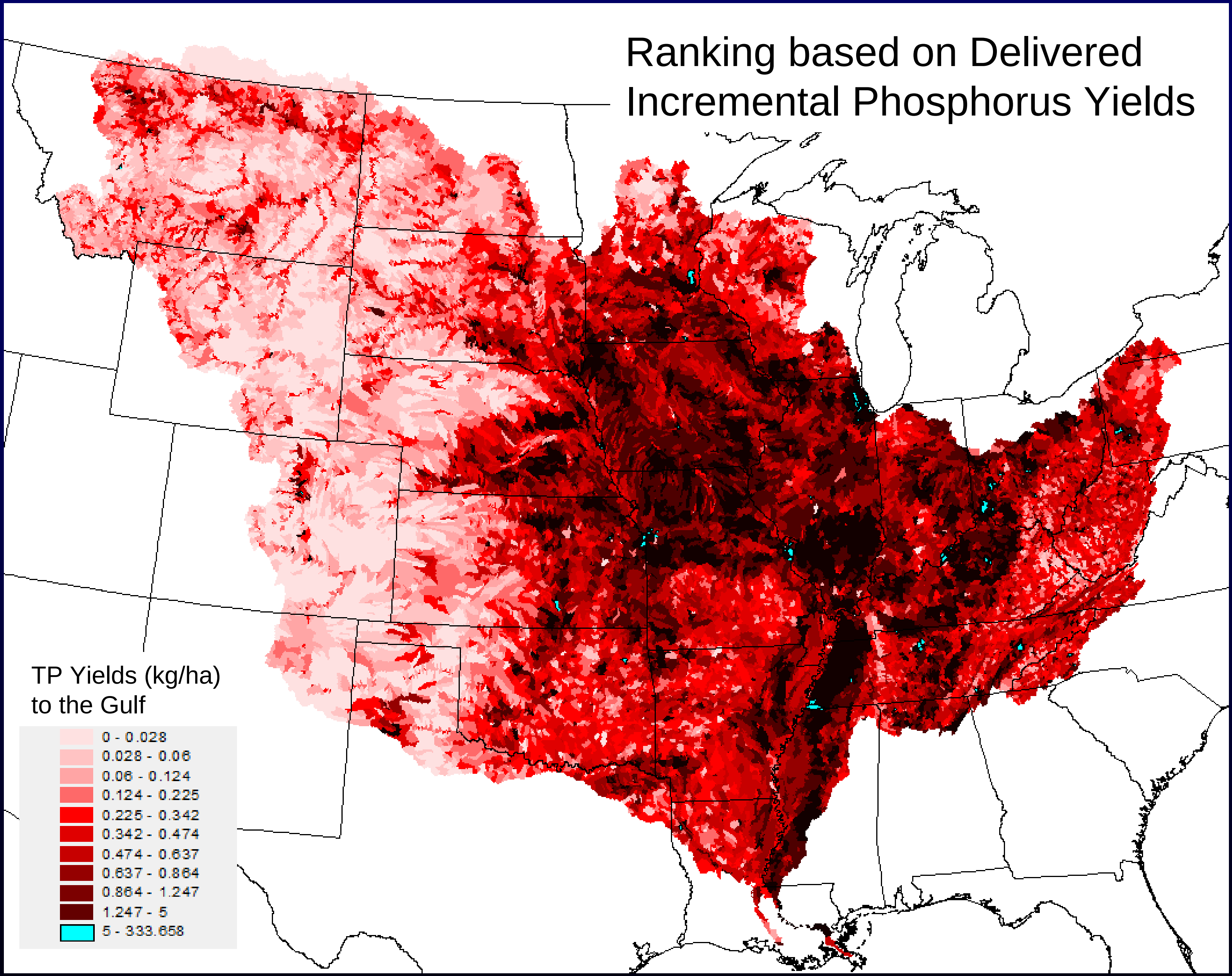
Ranking based on Delivered Incremental Nitrogen Yields



Ranking of State Contributions to the Gulf of Mexico from the MARB

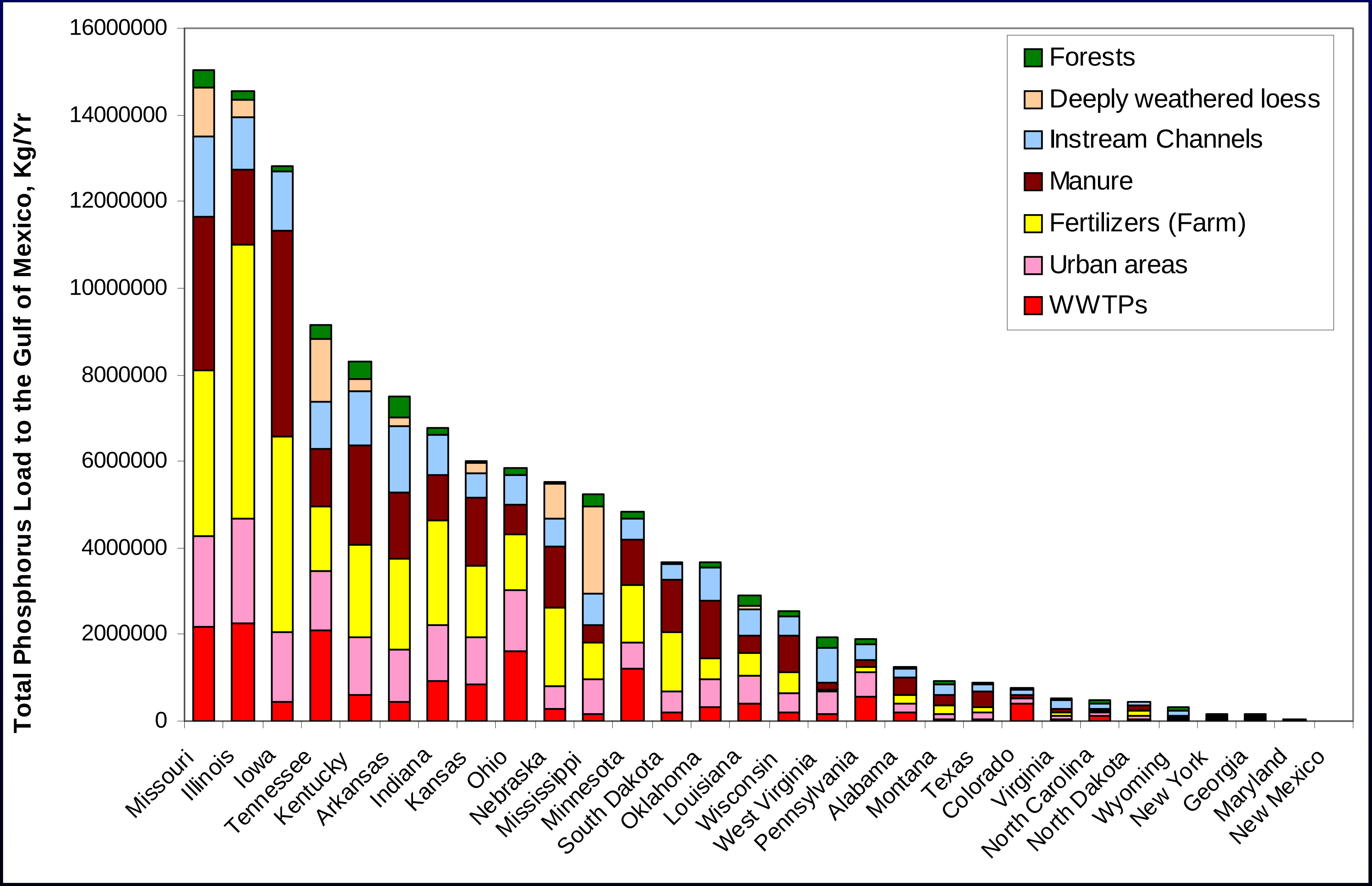


Robertson et al., 2014



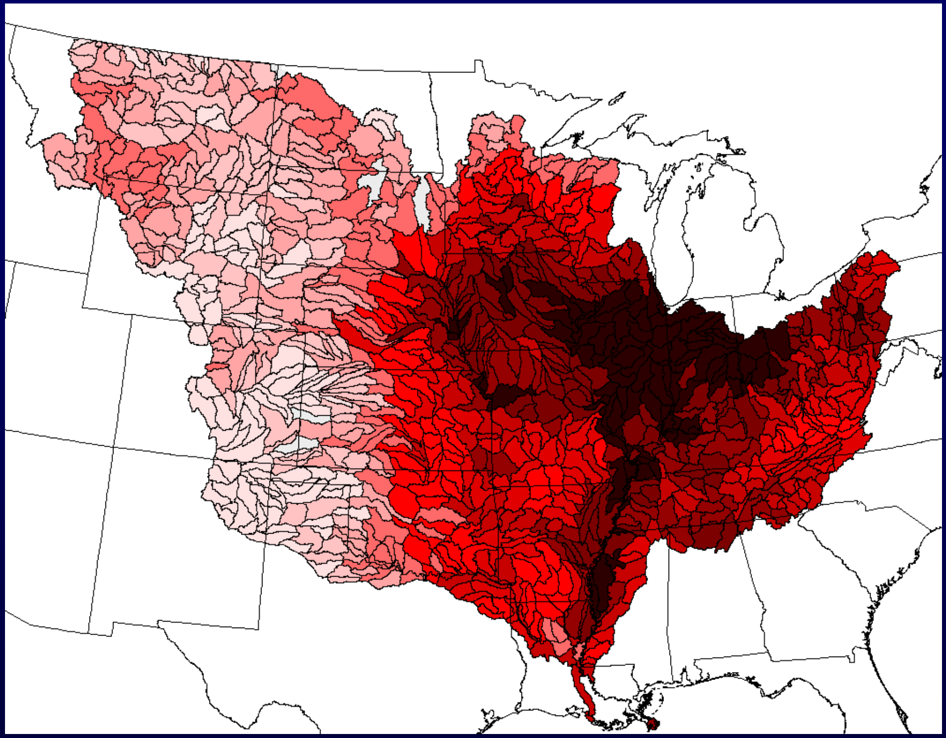
Robertson and Saad, 2013

Ranking of State Contributions to the Gulf of Mexico from the MARB

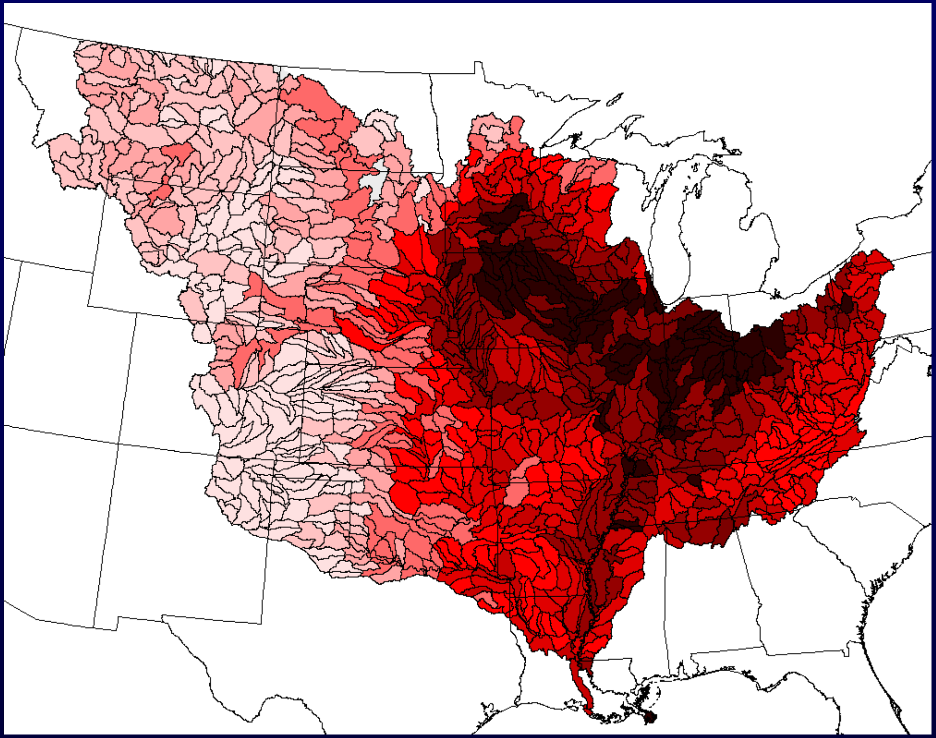


Robertson et al., 2014

Delivered Incremental Nitrogen Yields – Model Comparison

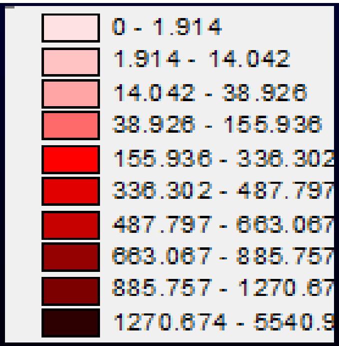


Original Model
(National 1992 model with 2002 input estimates)

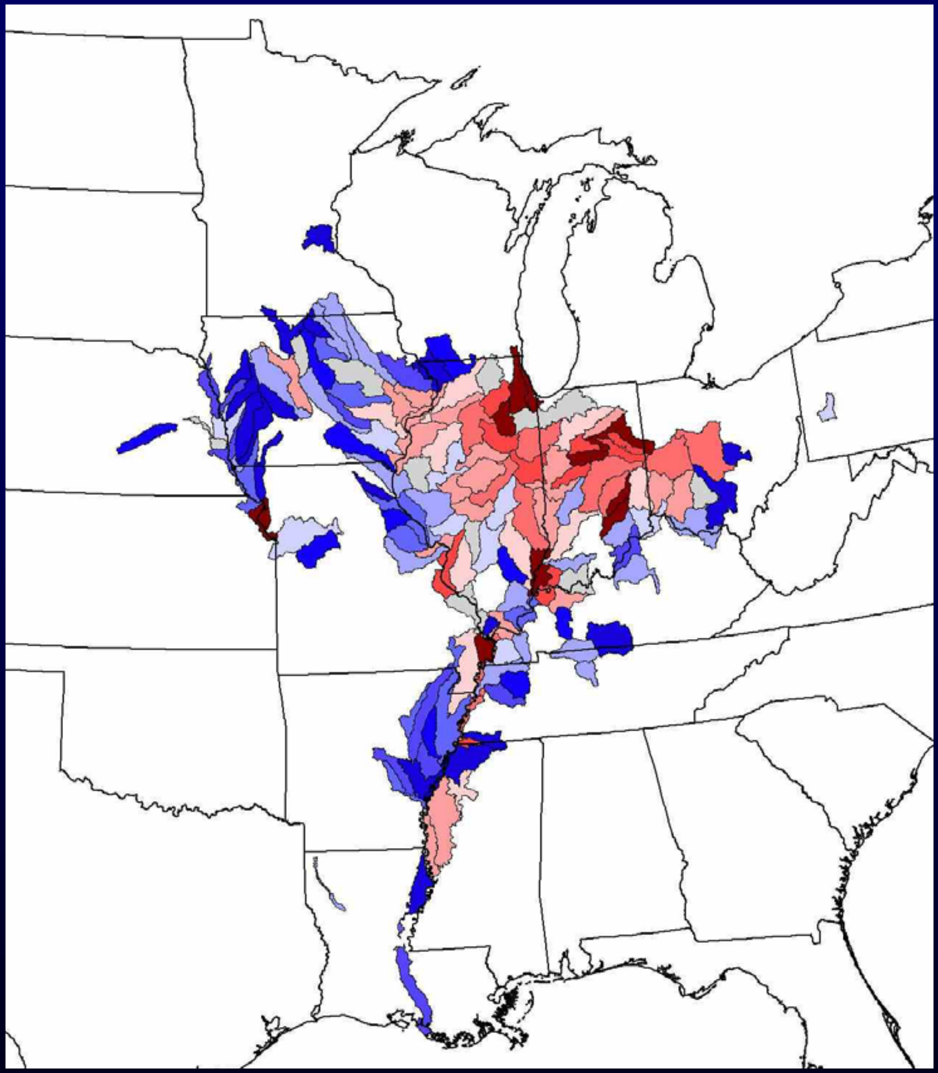


New Model
(MARB 2002 model with 2002 estimates)

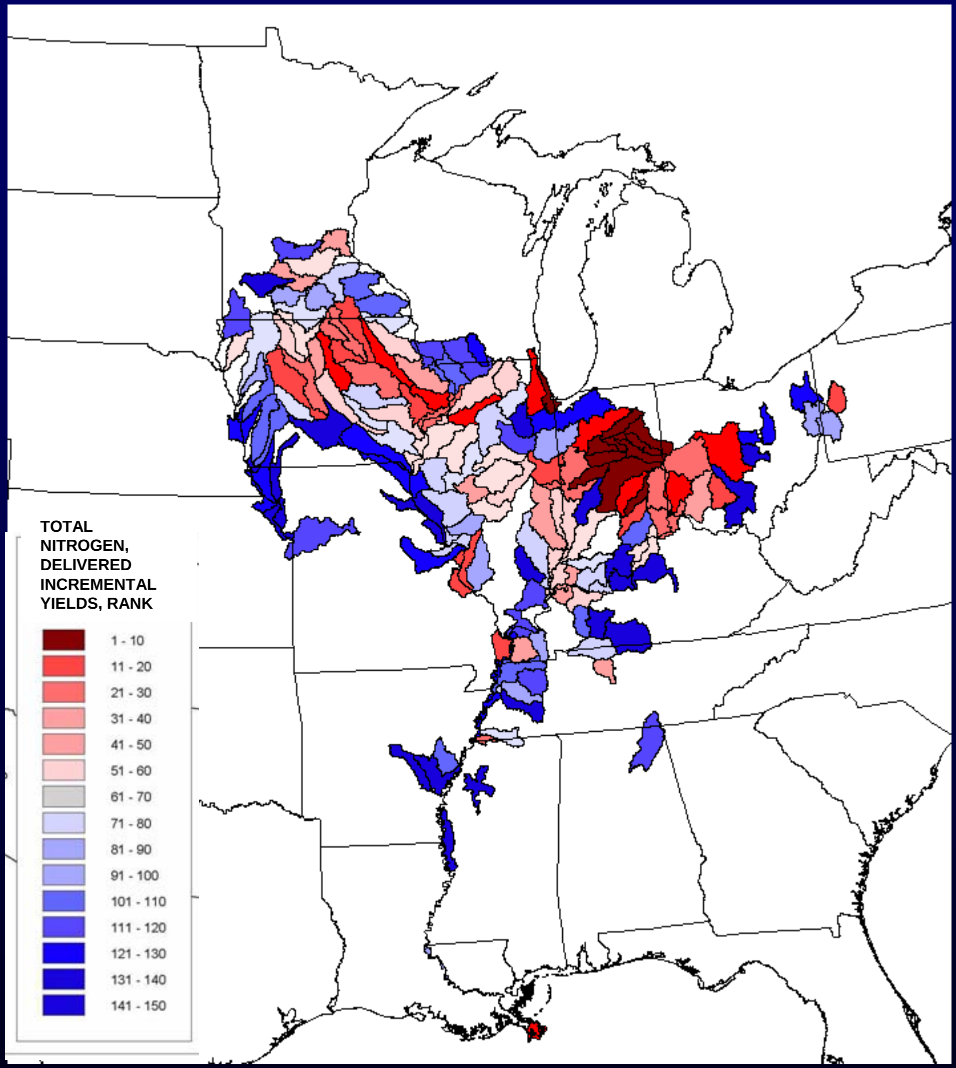
TN Yields (kg/km²) to the Gulf



Comparison of Top 150 Ranked HUC8's



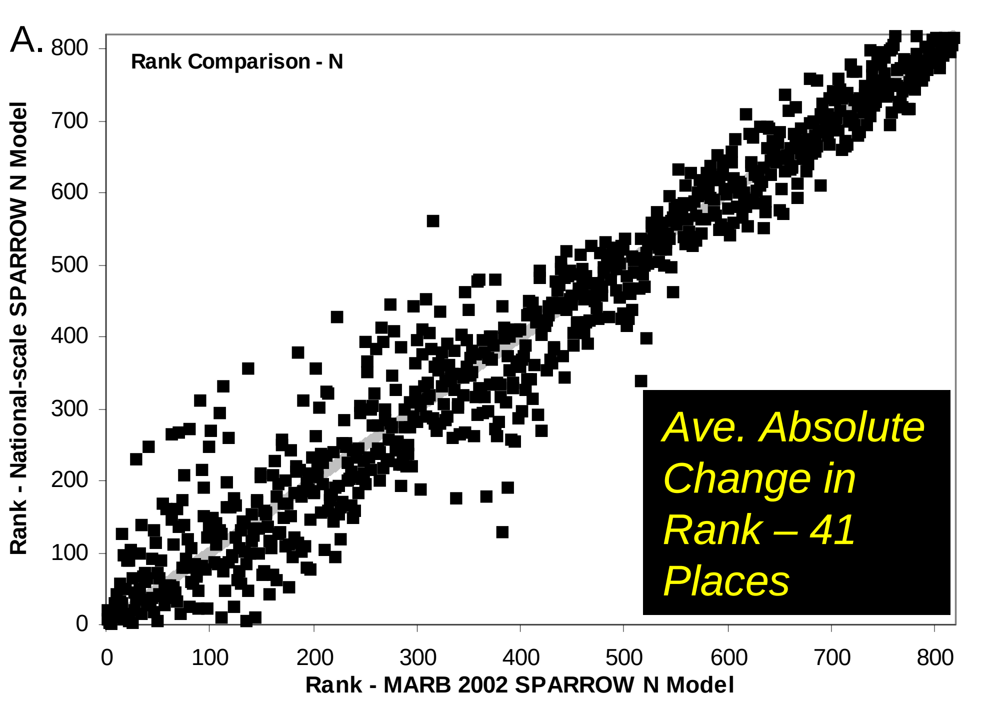
Original Model
(National 1992 model with
2002 input estimates)

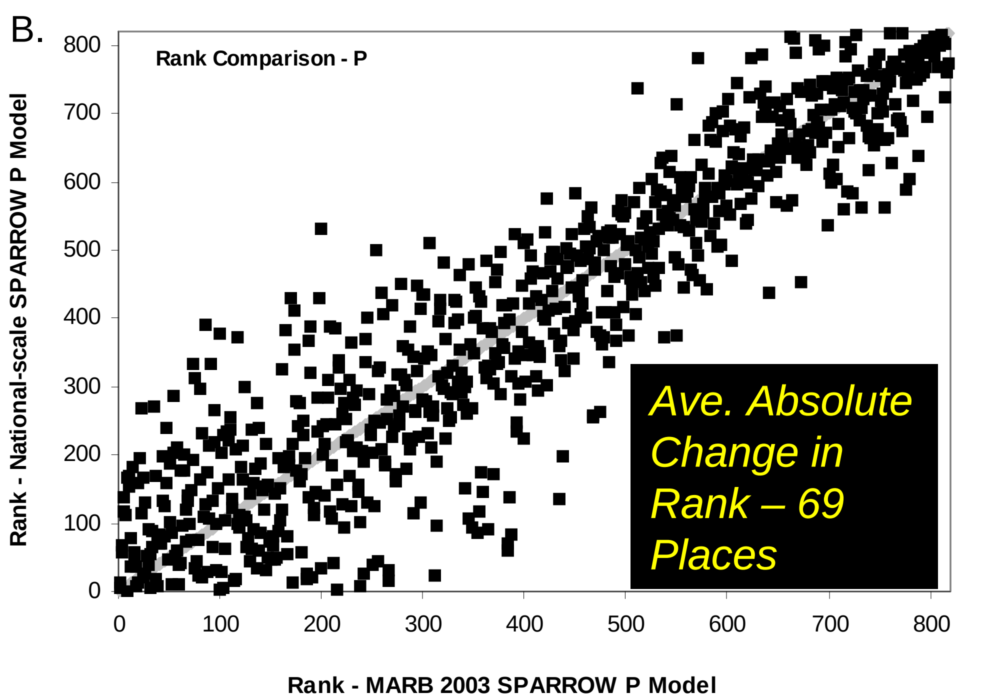


New (refined) Model
(MARB 2002 model
with 2002 estimates)

Comparison of Model Results

By HUC8

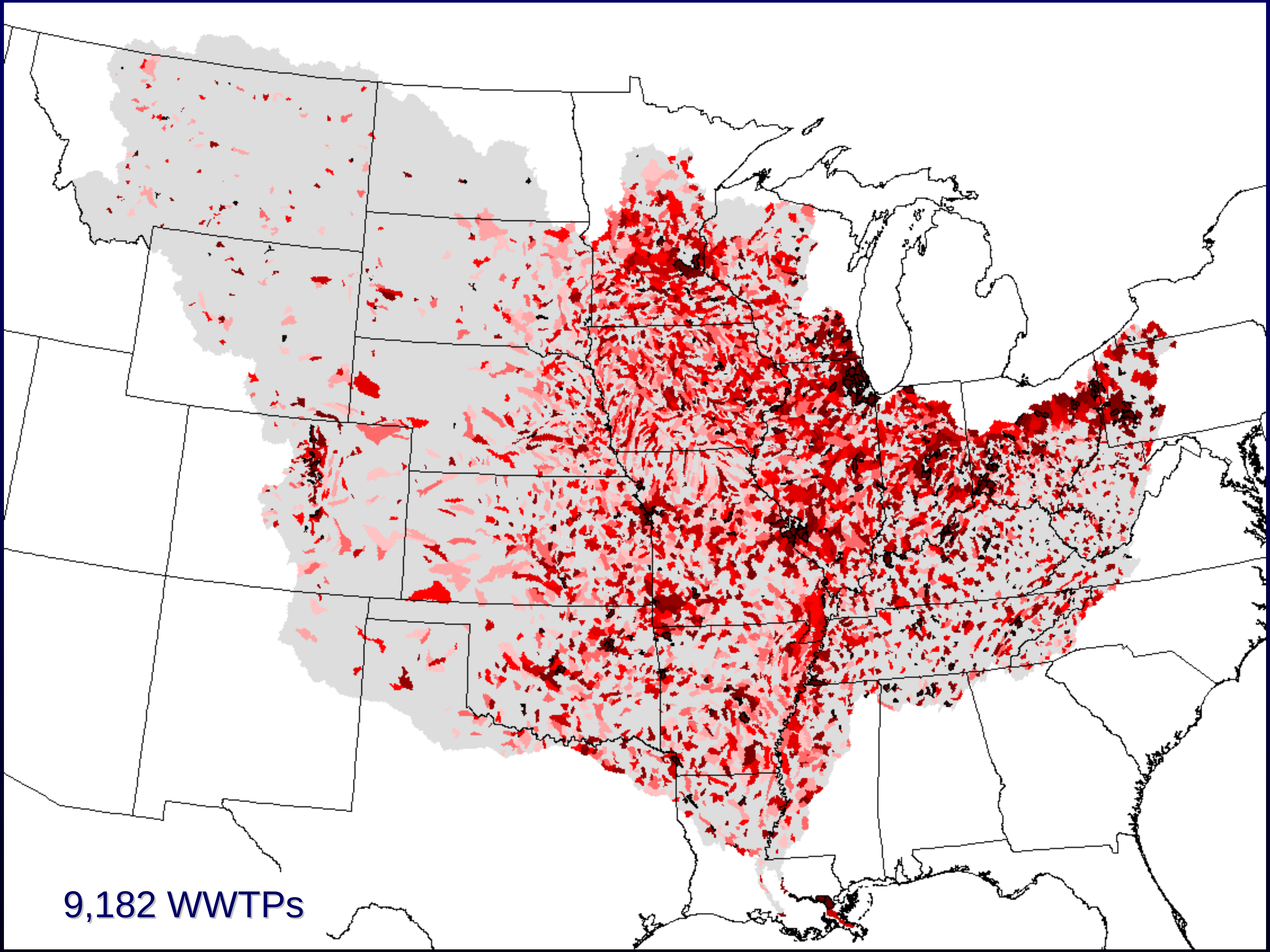




Why are there these differences?

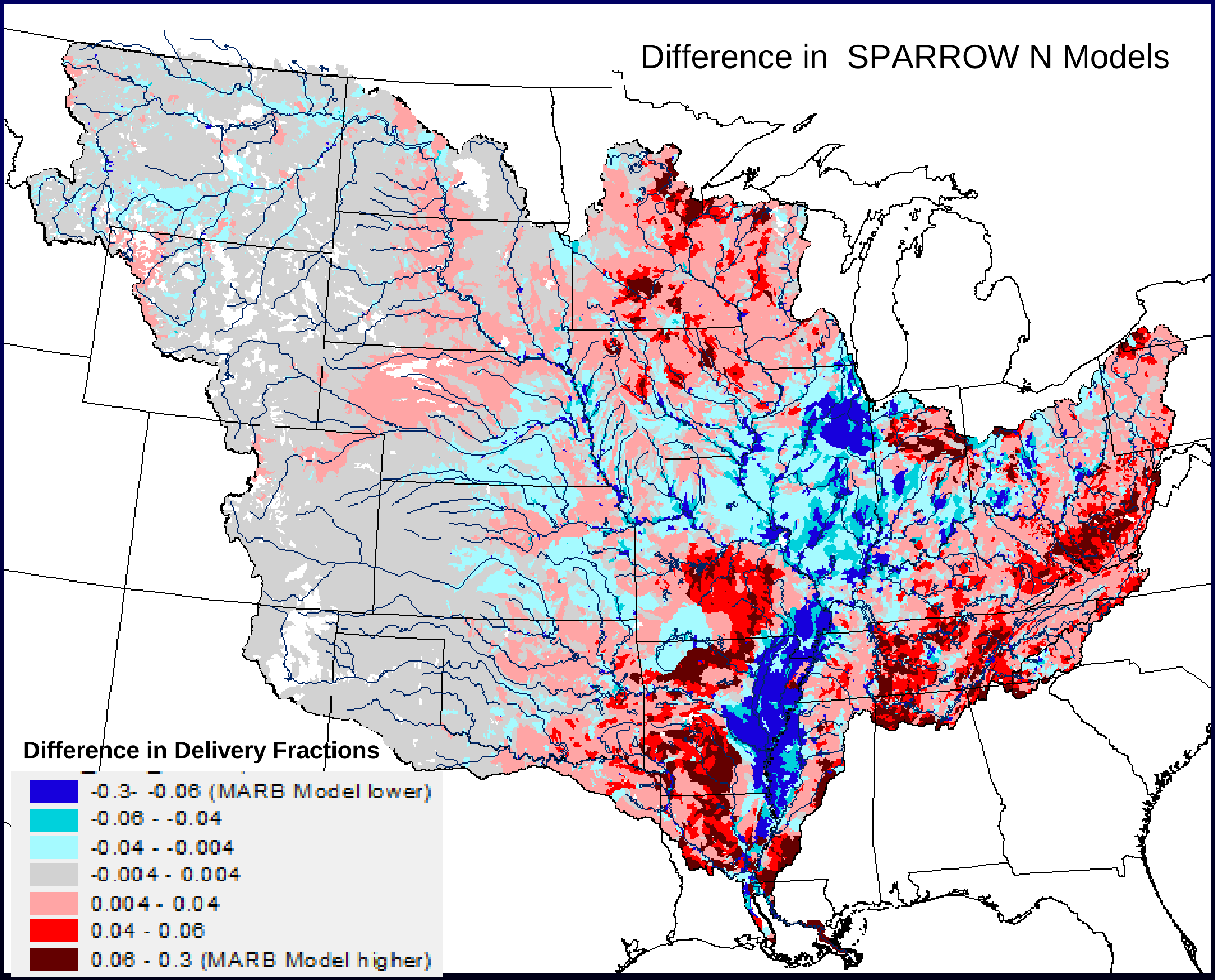
Robertson et al., 2014

2002 Point (WWTP) TN inputs

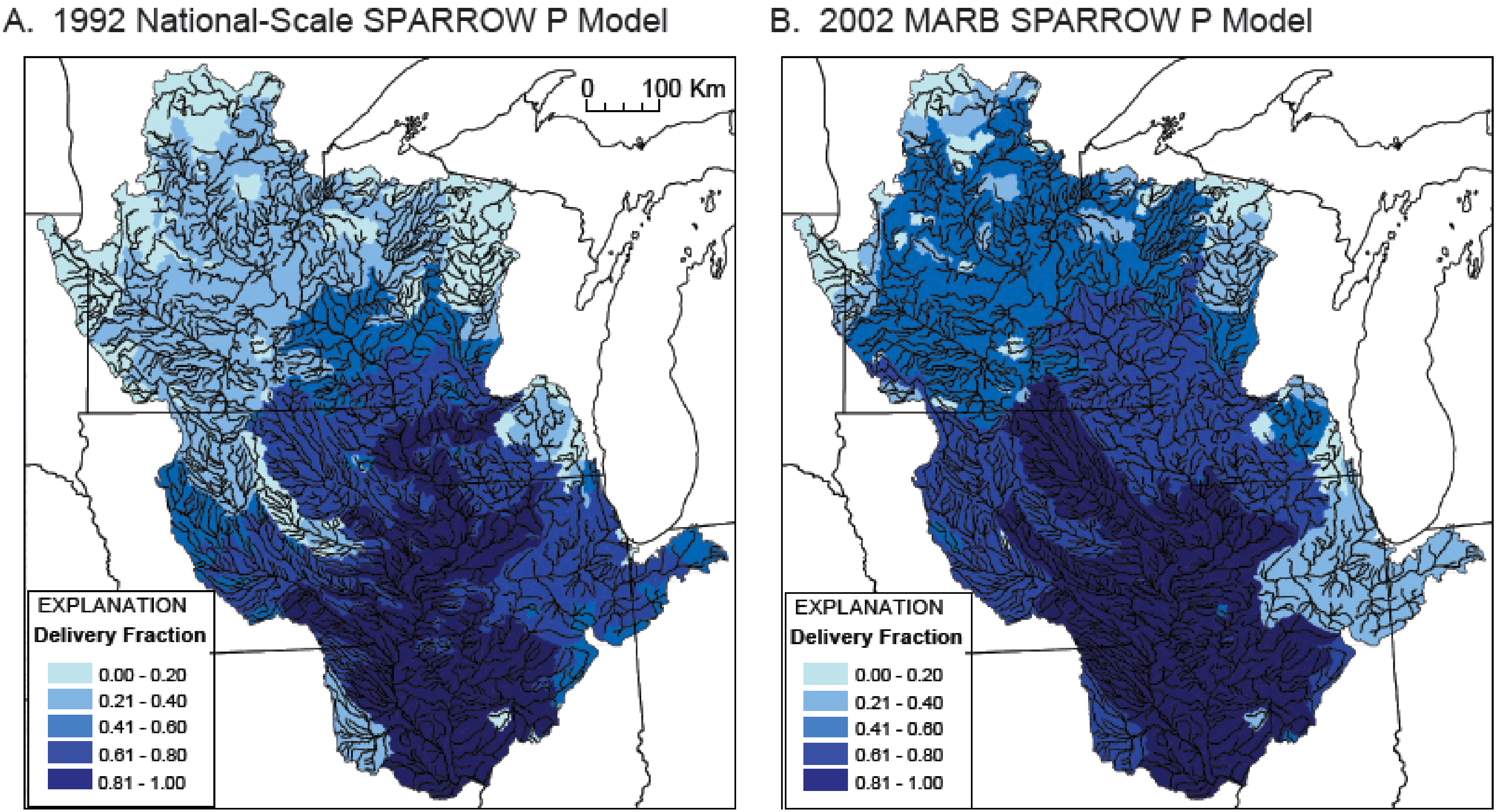


Original Models had point sources estimated from population in the basin.

Differences in Overall decay (land-to-water losses AND instream decay) demonstrated for Agricultural Inputs



Differences in Instream decay

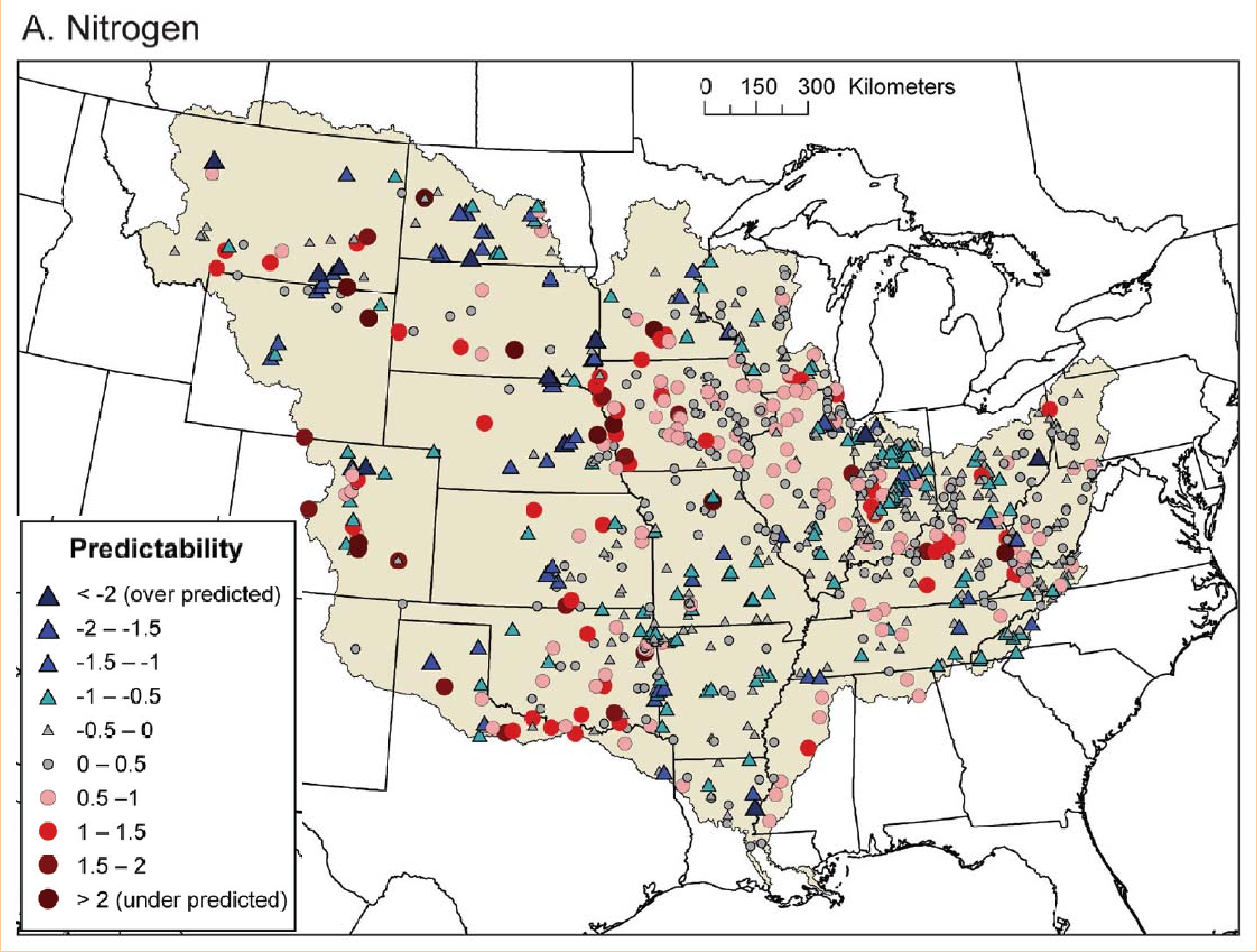


Original *Refined*

Refined MARB model has less instream losses (more delivery) especially from head water areas. Old model suggested concentrating BMPs near large rivers; Refined model suggests BMPs should be applied throughout.

Robertson et al., 2014

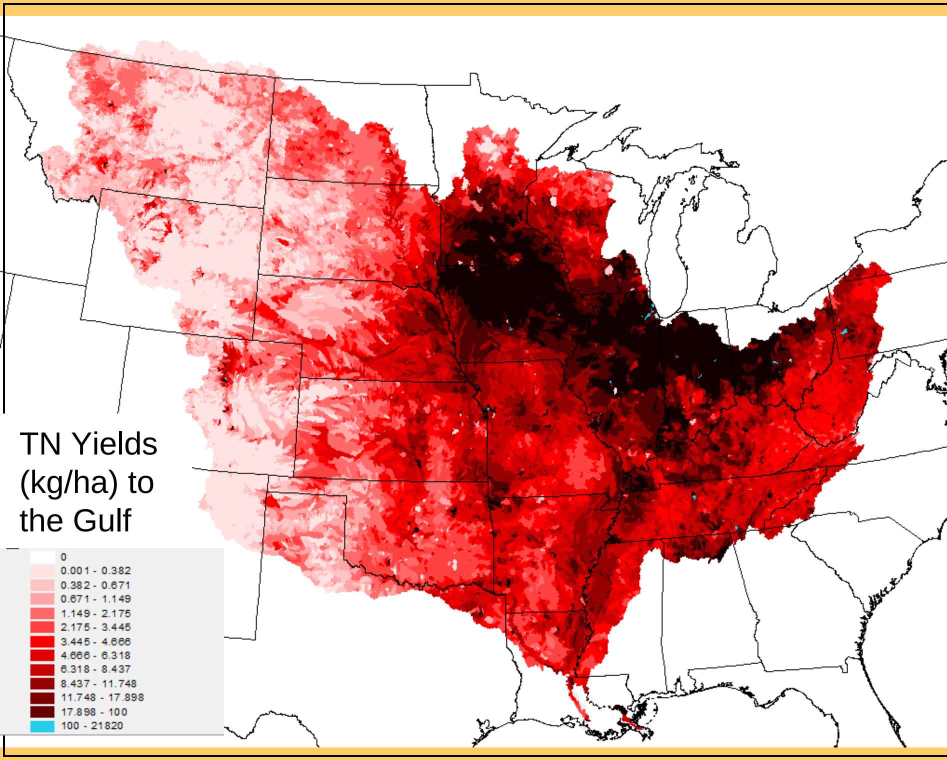
But which Models provide more accurate results?



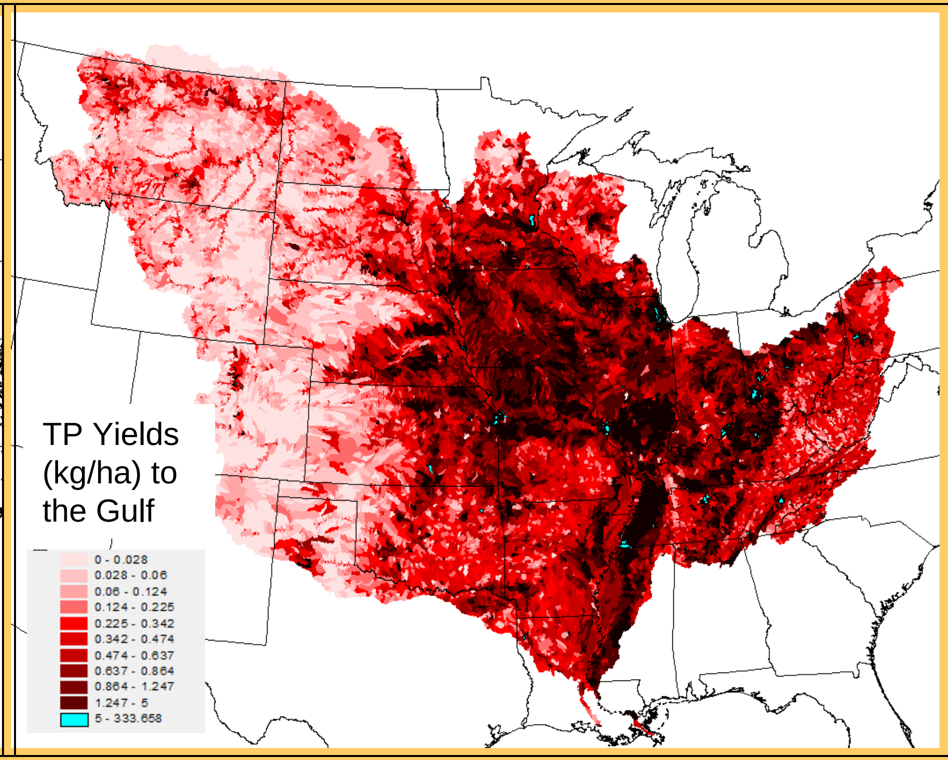
Which of the Models is Better?

Delivered Incremental Yields from the 2002 SPARROW Models

Nitrogen



Phosphorus



The revised 2002 MARB SPARROW models better predict the variability in loads throughout the Basin, especially loads in smaller basins.

Robertson and Saad, 2013

Methods to demonstrate results and help guide decisions > Nutrient Reduction Strategies

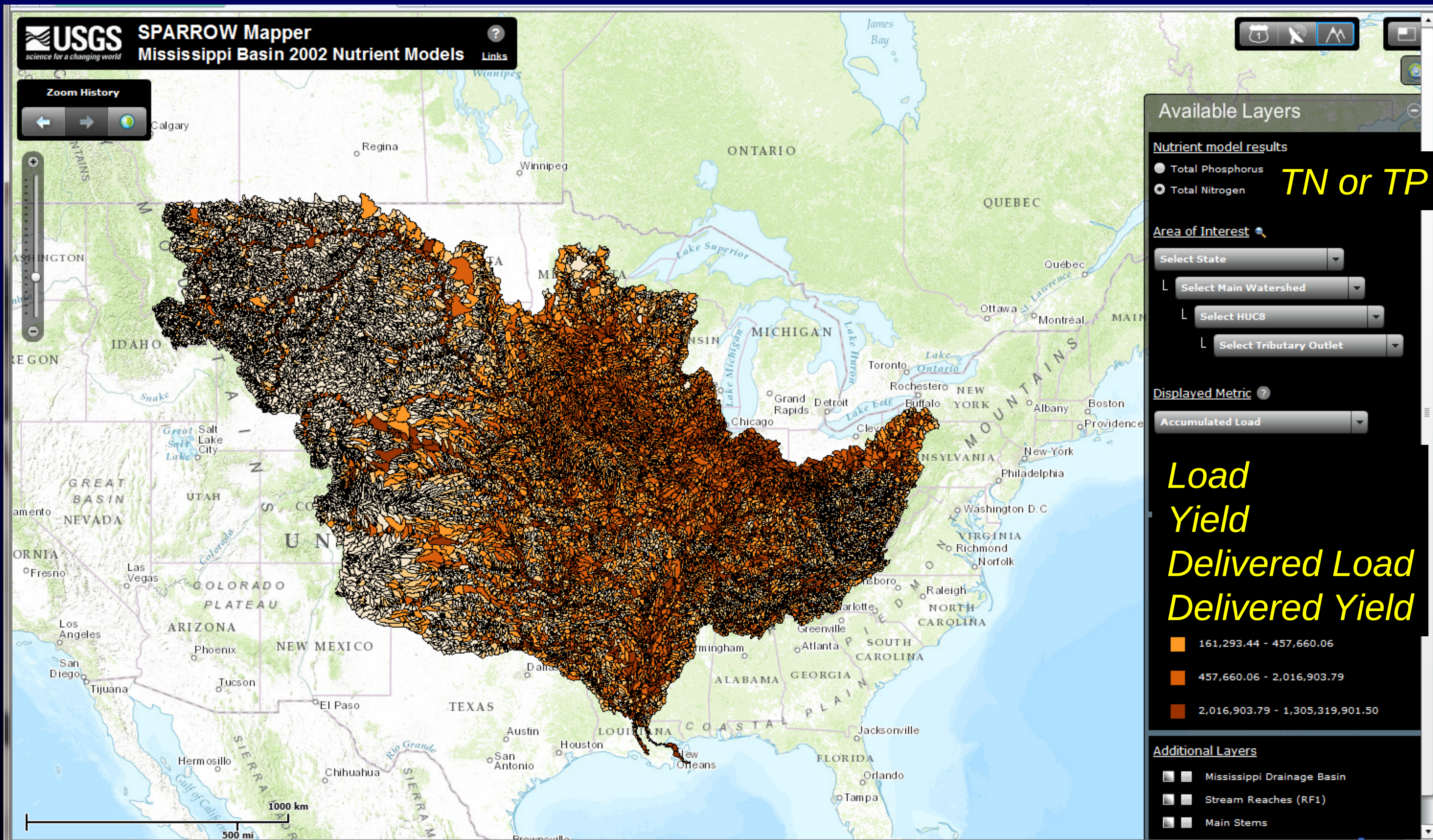
1. **SPARROW Mapper –**
   Easy and simple way to get SPARROW results, especially by hydrologic and political boundaries.

http://wim.usgs.gov/SparrowMRB3/SparrowMRB3Mapper.html#

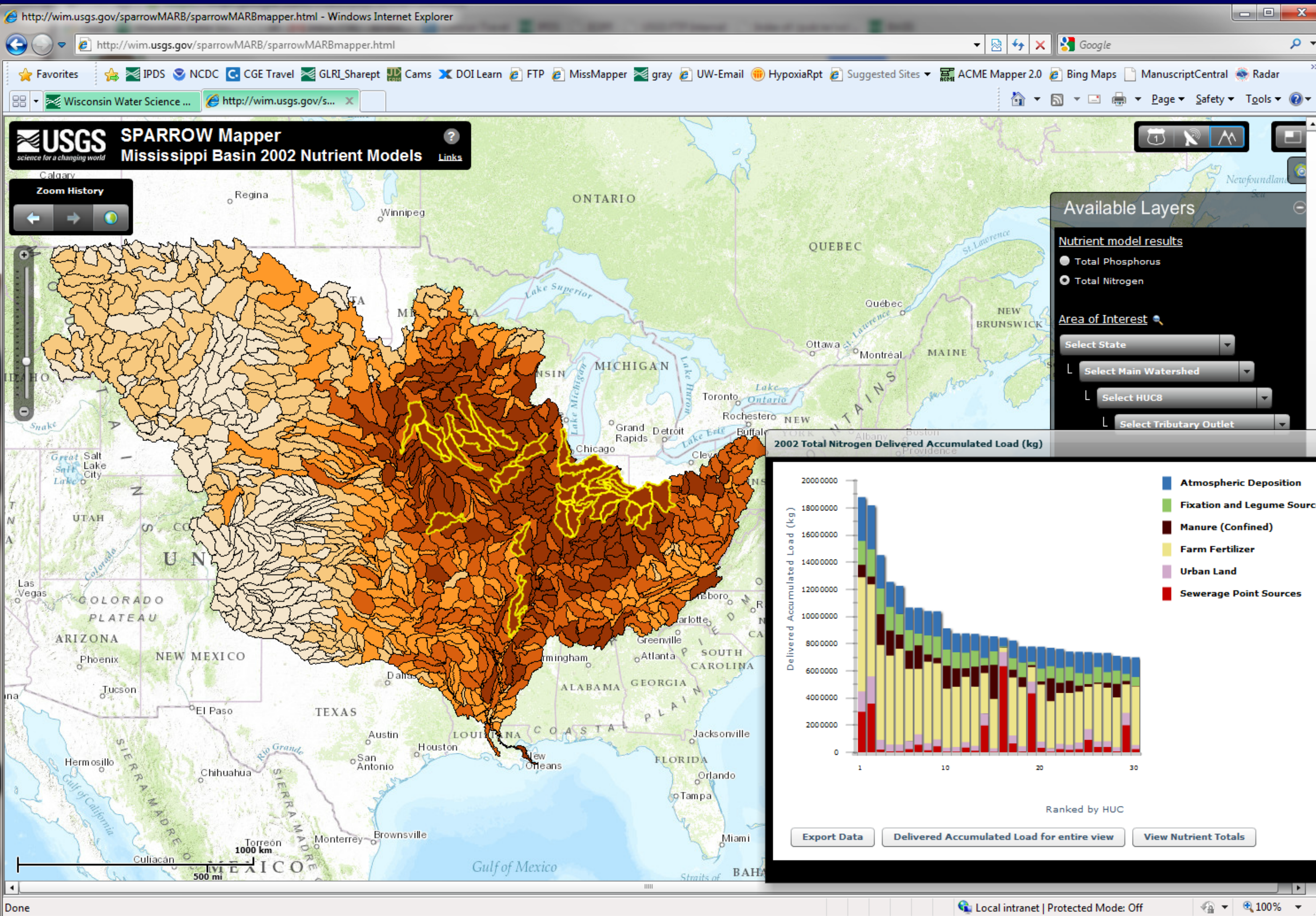
http://wim.usgs.gov/SparrowGL/SparrowGLMapper.html#

http://wim.usgs.gov/SparrowMARB/SparrowMARBMapper.html#

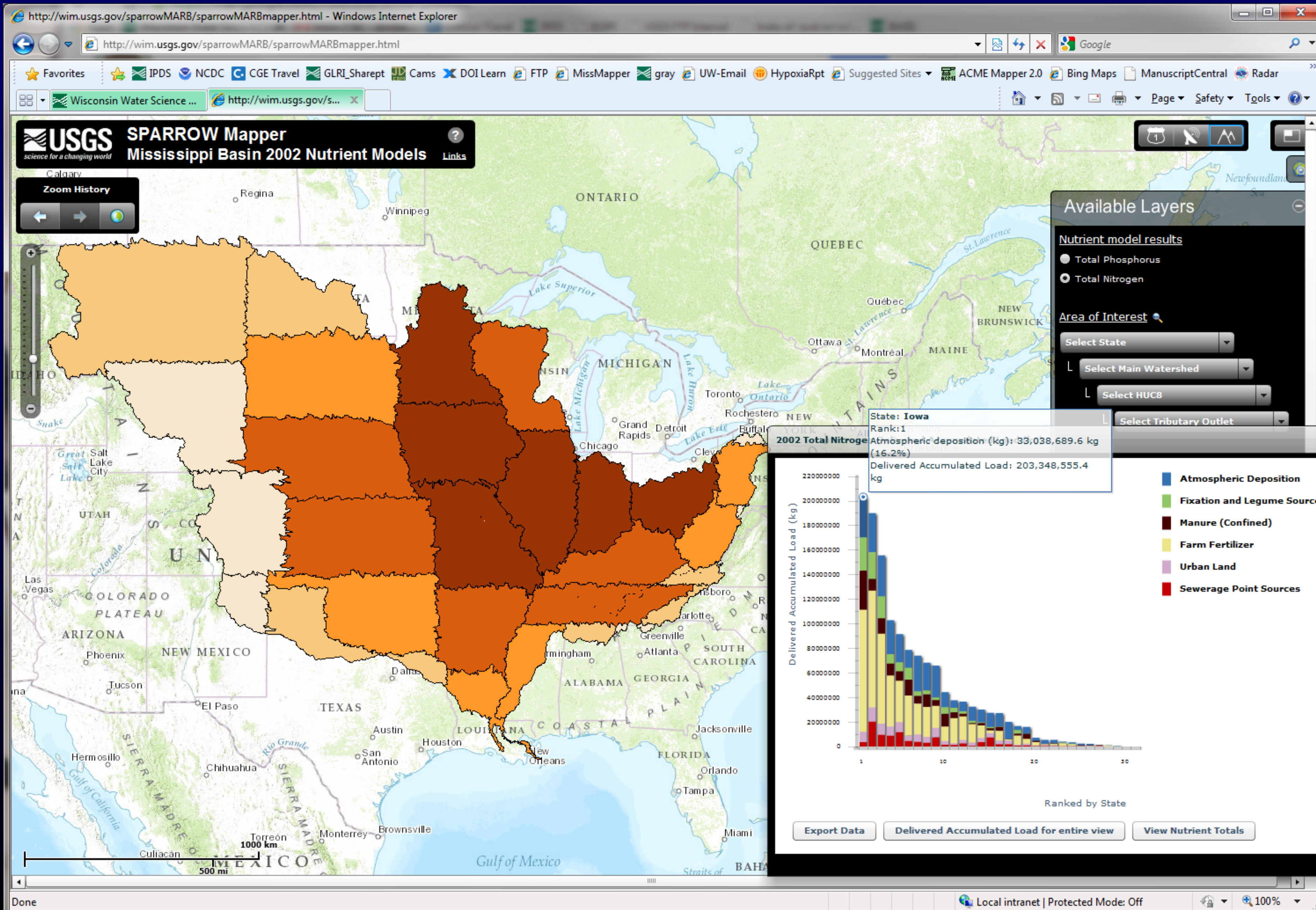
Mississippi/Atchafalaya River Basin (MARB) SPARROW MAPPER



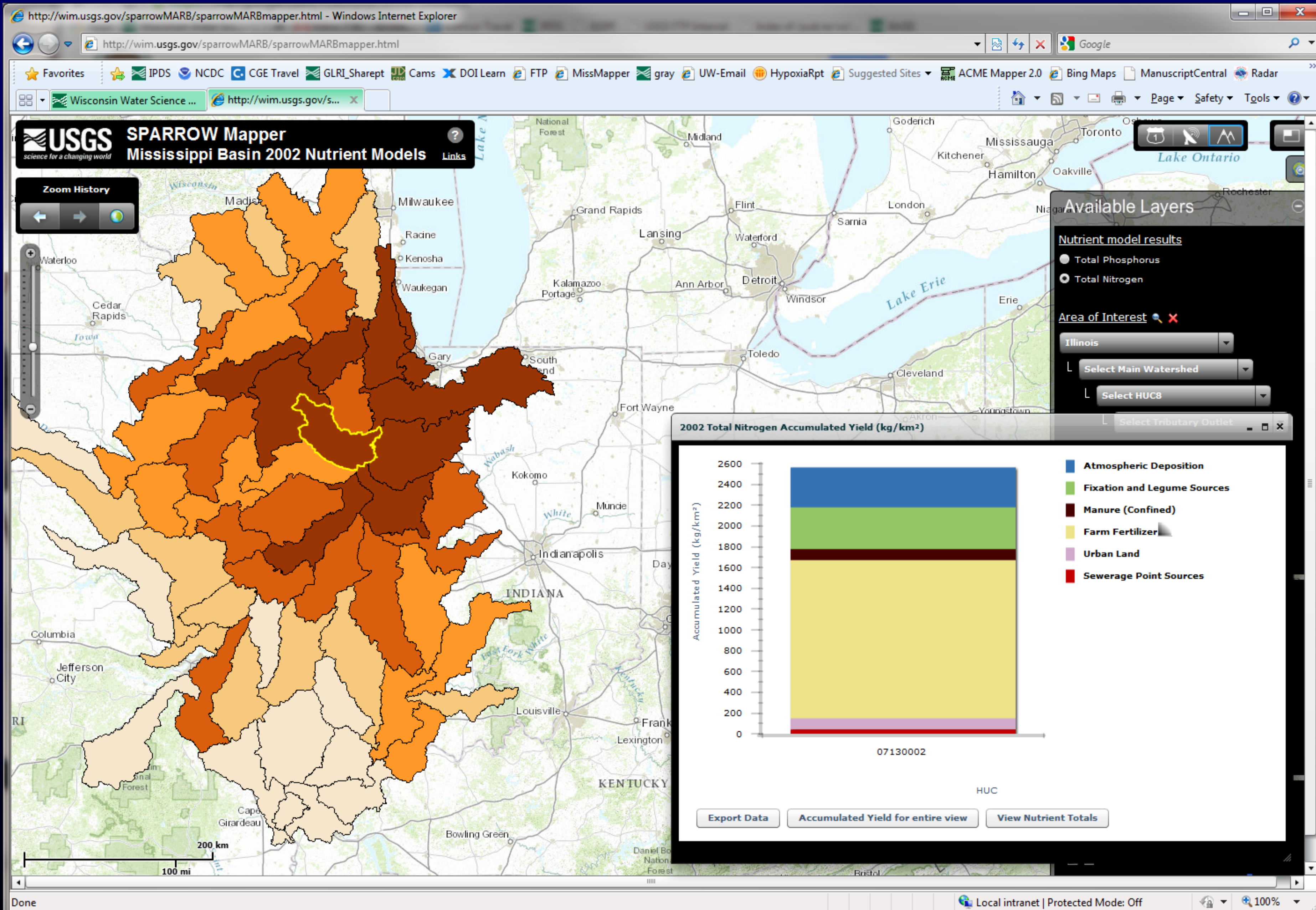
MARB SPARROW MAPPER

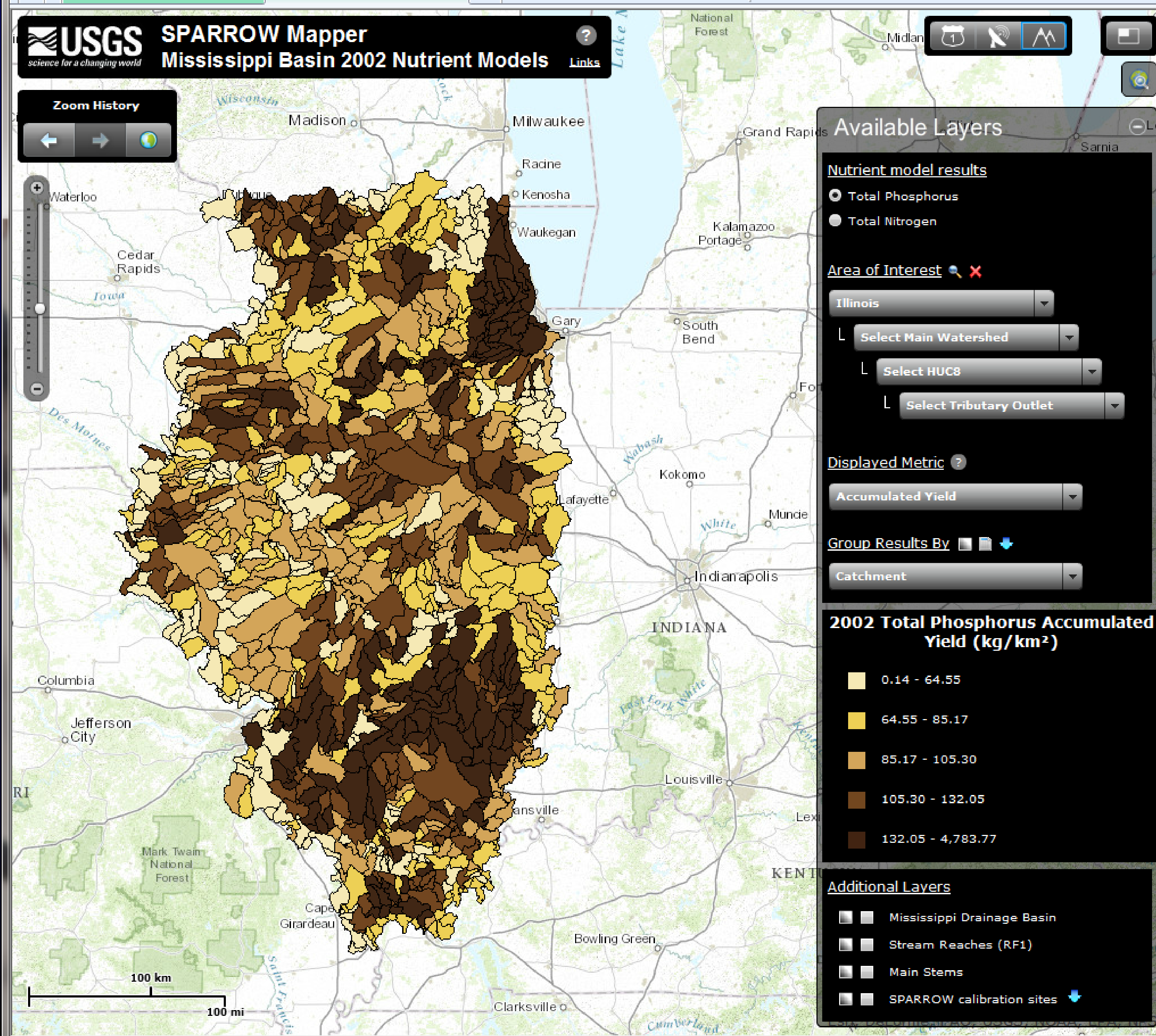


MARB SPARROW MAPPER



MARB SPARROW MAPPER




USGS
science for a changing world
SPARROW Mapper
Mississippi Basin 2002 Nutrient Models
Links
Zoom History
Available Layers
Nutrient model results
Total Phosphorus
Total Nitrogen
Area of Interest
Illinois
Select Main Watershed
Select HUC8
Select Tributary Outlet
Displayed Metric
Accumulated Yield
Group Results By
Catchment
2002 Total Phosphorus Accumulated Yield (kg/km²)
0.14 - 64.55
64.55 - 85.17
85.17 - 105.30
105.30 - 132.05
132.05 - 4,783.77
Additional Layers
Mississippi Drainage Basin
Stream Reaches (RF1)
Main Stems
SPARROW calibration sites
100 km
100 mi
Madison
Milwaukee
Racine
Kenosha
Waukegan
Waterloo
Cedar Rapids
Gary
South Bend
Grand Rapids
Kalamazoo
Portage
Kokomo
Lafayette
Muncie
Indianapolis
INDIANA
Columbia
Jefferson City
Louisville
Mark Twain National Forest
Cape Girardeau
Bowling Green
Clarksville
Sarnia
National Forest

Methods to demonstrate results and help guide decisions

2. Decision Support System Scientists/Managers – Capable of using to visualize SPARROW output and run various scenarios.

http://cida.usgs.gov/sparrow/

Booth et al., 2011

SPARROW Decision Support System

Find a Model by Geographic Location:

Select a region or state. When a state is selected, all models containing that state are listed.

Illinois

Find a Model by Modeled Constituent:

Any

Models matching your criteria (click a model to show details)

- Mississippi/Atchafalaya Basin Total Nitrogen Model - 2002
- Mississippi/Atchafalaya Basin Total Phosphorus Model - 2002
- National Suspended Sediment Model - 1992
- National Total Nitrogen Model - 1992
- National Total Organic Carbon Model
- National Total Phosphorus Model - 1992
- Total Nitrogen Model for the Great Lakes, Ohio, Upper Mississippi, and Souris-Red-Rainy Region - 2002
- Total Phosphorus Model for the Great Lakes, Ohio, Upper Mississippi, and Souris-Red-Rainy Region - 2002

Documentation and Further Reading

- What is SPARROW?
- What is SPARROW Decision Support?
- SPARROW Applications & Documentation
- SPARROW DSS FAQs

Tutorial Videos

Select a video...

Watch now >>

Found a bug or have a comment?

Please send bugs, suggestions and questions to the **SPARROW Decision Support System Administrator**.

Selected Model

Mississippi/Atchafalaya Basin Total Nitrogen Model - 2002

Explore this model in the Decision Support System >>

Modeled Constituent:	Nitrogen
Base Year:	2002
Stream Network:	Enhanced River Reach File 2.0 *Geometry and additional reach and network attribute data are available with the stream network data, which is available as a separate download.*
Model Updates:	View this model's updates

Watershed Based Sessions

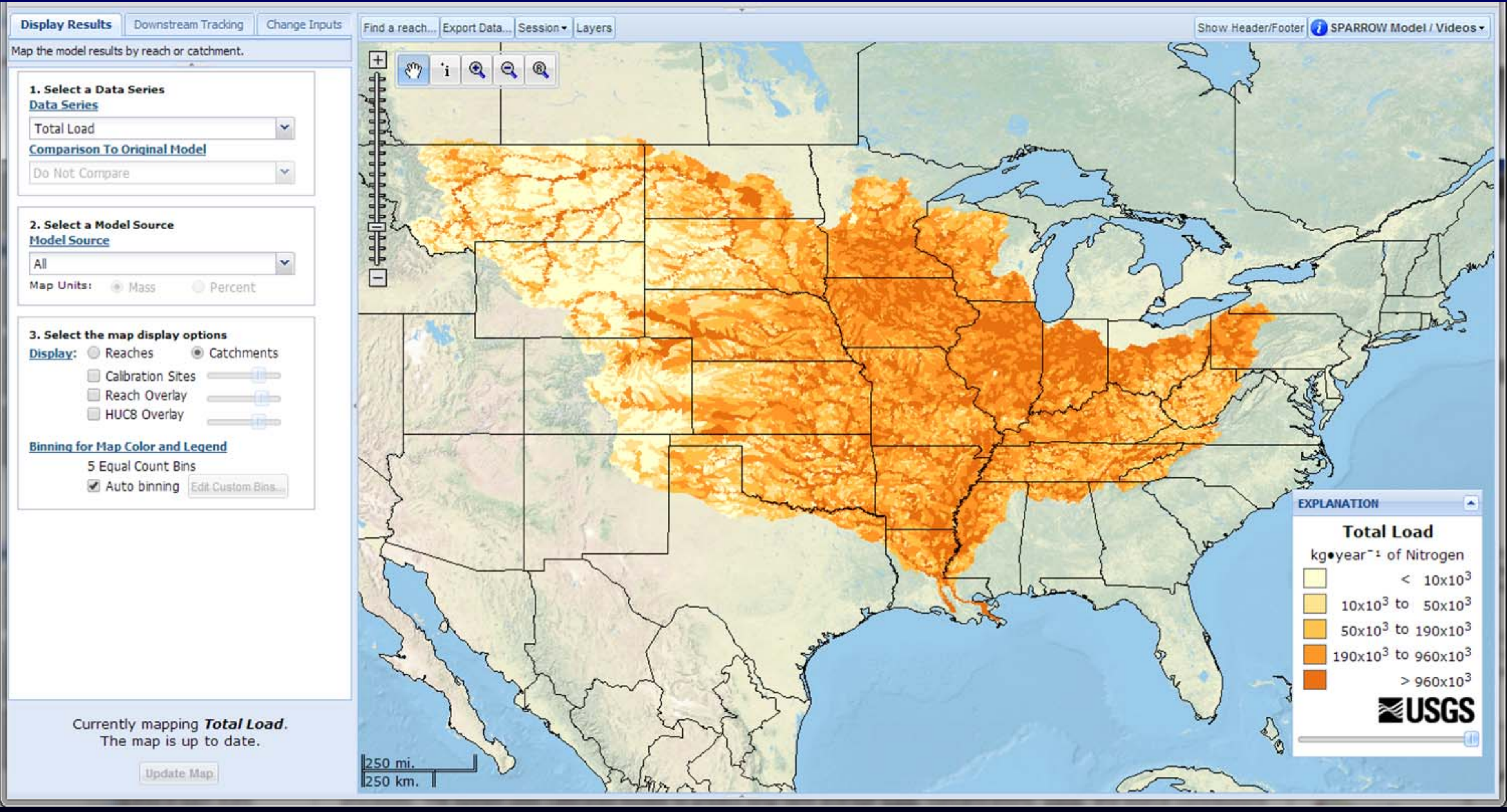
To start the DSS with the outlet river reach of a major watershed selected for downstream tracking, select a watershed and click *Go*.

Go >>

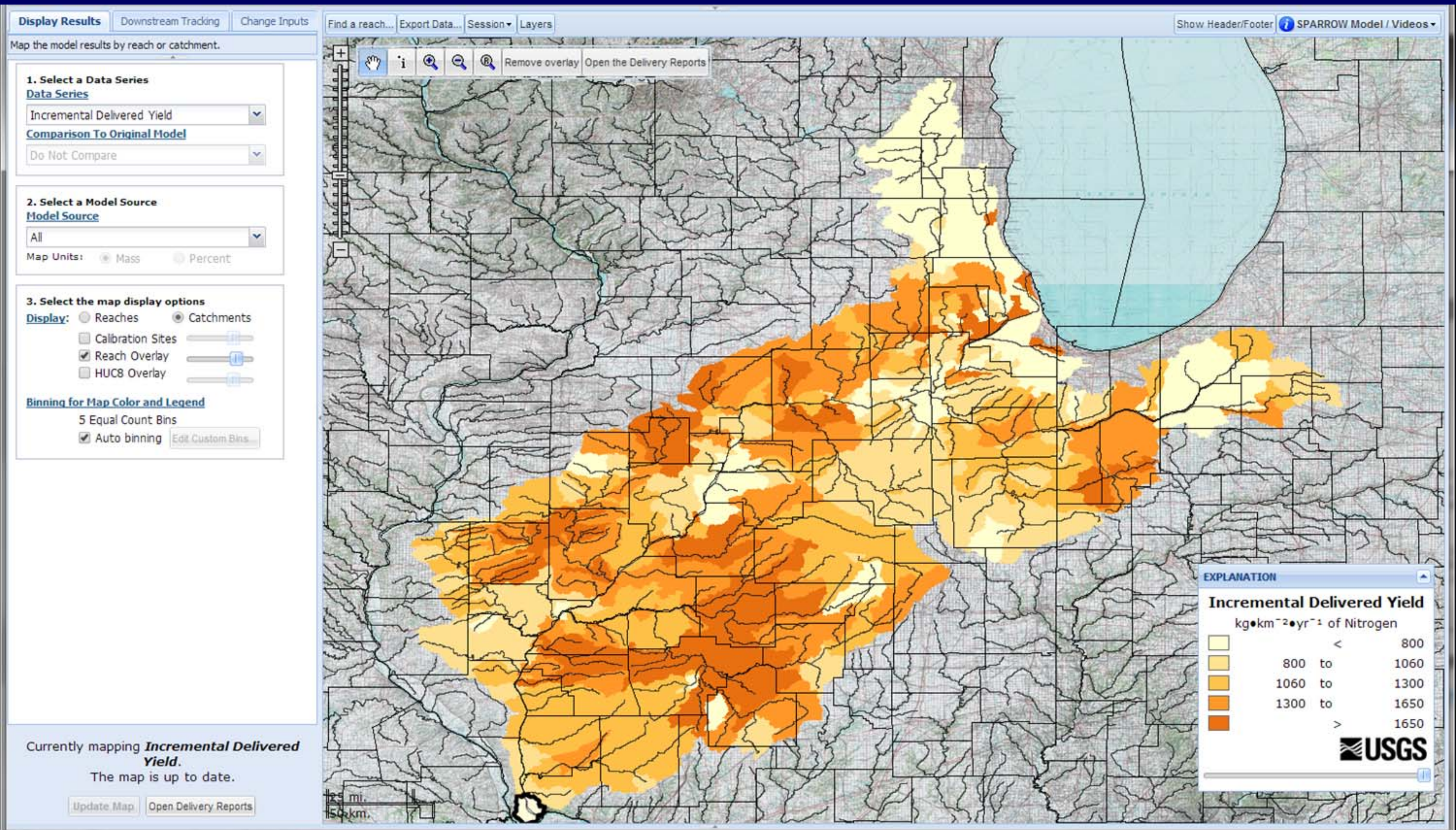
Scenario Based Sessions

To start the DSS with a predefined scenario, click on the link for one of the scenarios below.

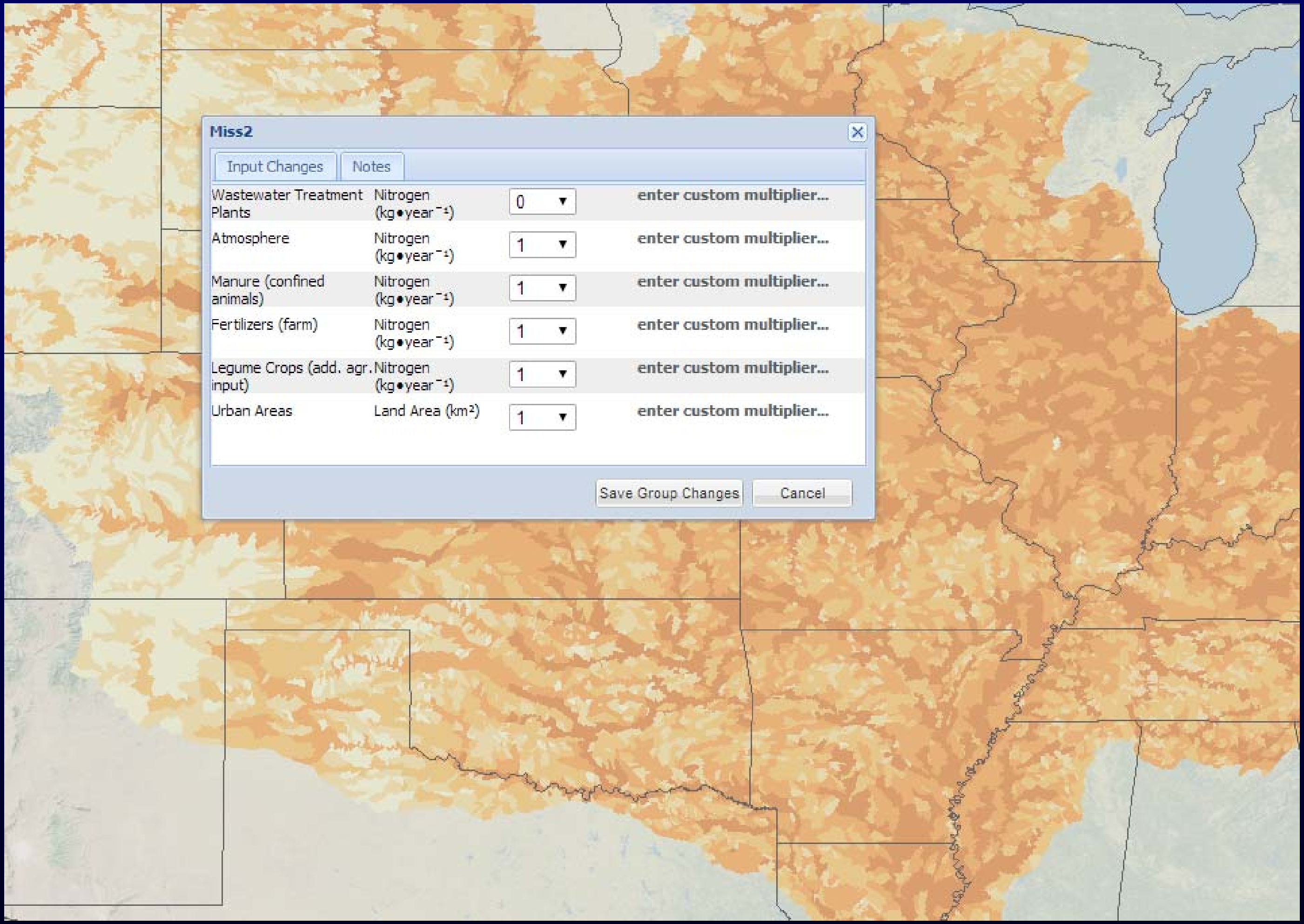
SPARROW Decision Support System



Downstream Tracking

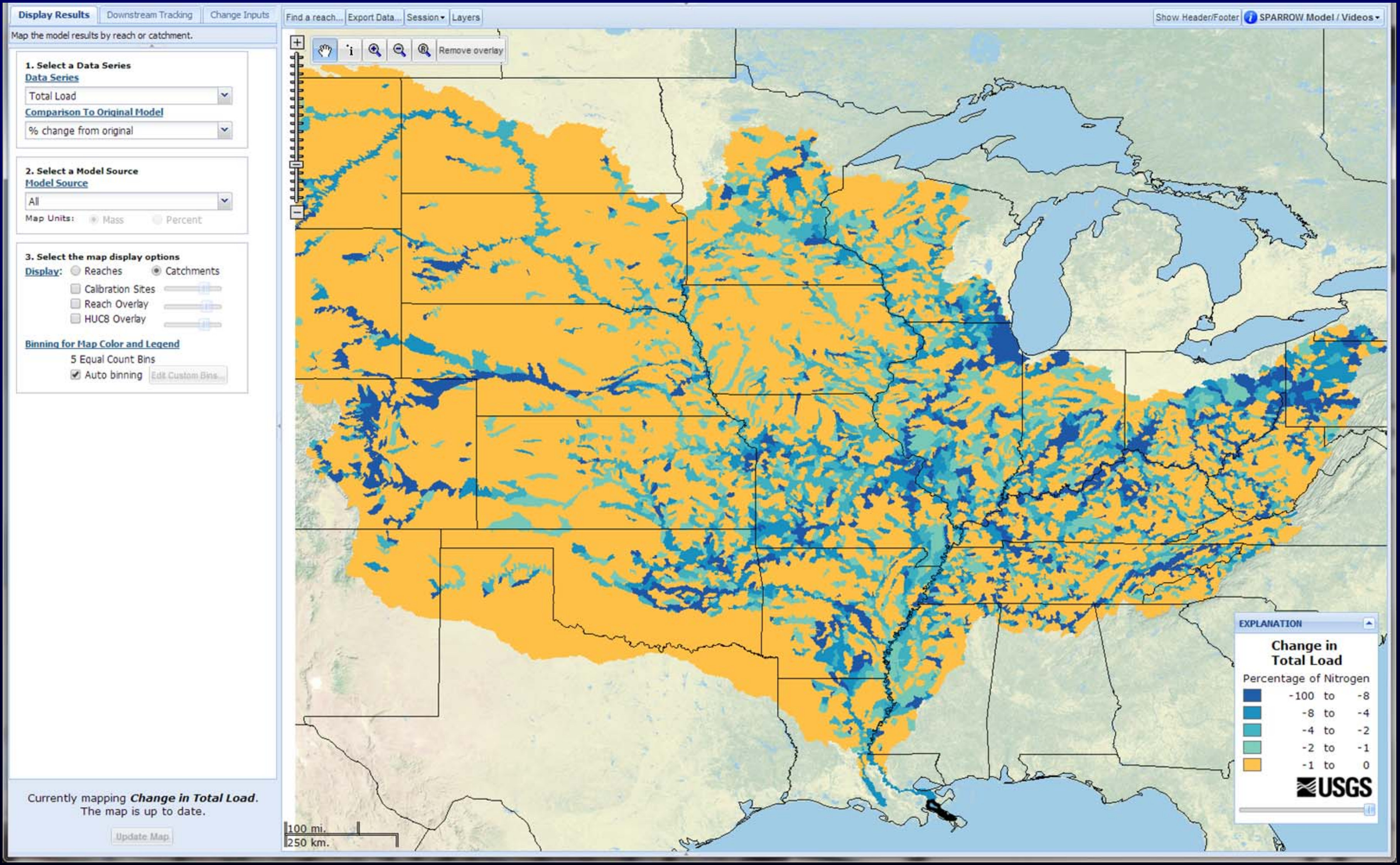


SPARROW Decision Support System



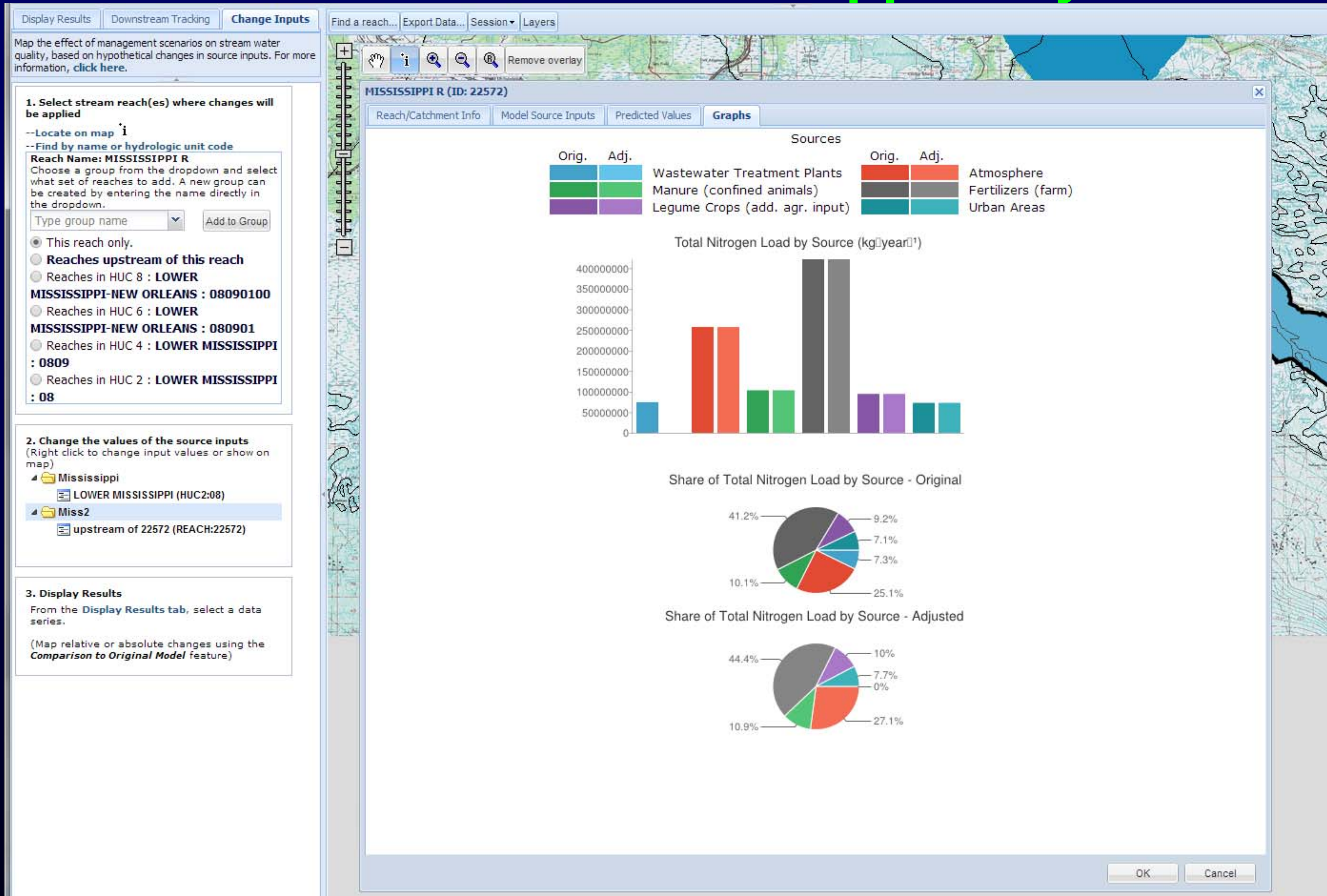
Scenario Testing

SPARROW Decision Support System



Scenario Results - Percent Changes in Incremental Yields

SPARROW Decision Support System



Scenario Results – Graphical Presentation of Changes

MISSISSIPPI R (ID: 22572)

Reach/Catchment Info | Model Source Inputs | **Predicted Values** | Graphs

Current Mapped Value: 949841714.36 kg•year⁻¹ of Nitrogen (Total Load)

Predicted Values (Data Series)

Source	Original (Nitrogen kg•year⁻¹)	% of Load (Orig.)	Adjusted (Nitrogen kg•year⁻¹)	% of Load(Adj.)	% Change
Total Load					
Wastewater Treatment Plants Tota...	74,342,311	7.3	0	0.0	-100
Atmosphere Total Load	257,334,451	25.1	257,334,451	27.1	0
Manure (confined animals) Total L...	103,350,153	10.1	103,350,153	10.9	0
Fertilizers (farm) Total Load	421,808,905	41.2	421,808,905	44.4	0
Legume Crops (add. agr. input) Tot...	94,585,801	9.2	94,585,801	10.0	0
Urban Areas Total Load	72,762,405	7.1	72,762,405	7.7	0
Total Load	1,024,184,025	100.0	949,841,714	100.0	-7
Incremental Load					
Wastewater Treatment Plants Incr...	37,170	6.1	0	0.0	-100
Atmosphere Incremental Load	384,528	62.6	384,528	66.6	0
Manure (confined animals) Increm...	0	0.0	0	0.0	0
Fertilizers (farm) Incremental Load	85,521	13.9	85,521	14.8	0
Legume Crops (add. agr. input) Inc...	0	0.0	0	0.0	0
Urban Areas Incremental Load	107,099	17.4	107,099	18.6	0
Incremental Load	614,317	100.0	577,147	100.0	-6

OK | Cancel

Obtaining SPARROW Information
Google: USGS Wisconsin

Obtaining SPARROW Information

SPARROW Watershed Modeling: Estimation of Nutrient and Sediment Transport

Principal Investigators: Dale M. Robertson and David A. Saad
Cooperators: Multiple
Period of Project: October 2005 – Continuing

Background | Online SPARROW tools | Mississippi/Atchafalaya (MARB) Models | MRB3 models | Binational (US/Canada) Models | Publications/presentations

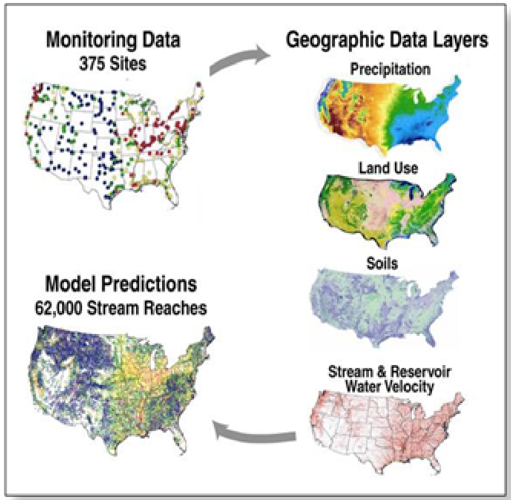
Quick Links:
- Mississippi/Atchafalaya River Basin (MARB) SPARROW Mapper
- Great Lakes, Ohio, Upper Mississippi, Red River Basins (MRB3) SPARROW Mapper
- SPARROW Decision Support System (MARB, MRB3, and National)
- Tracking the Source and Quantity of Nutrients to the Nation's Estuaries

Background

Declining water quality in rivers and streams has been linked to excessive losses of nutrients from their watersheds, particularly nitrogen and phosphorus. Excess nutrients are a major problem for water managers because they can cause algal blooms that increase costs to treat drinking water, limit recreational activities, and be toxic to humans and wildlife. Nutrient over-enrichment can also lead to eutrophication in downstream waterbodies, and deplete them of oxygen (hypoxia) that can threaten fish and other aquatic animals. Excessive nutrients can create problems both locally and regionally; one of the principal causes for the increasing size of the Gulf of Mexico hypoxic zone is believed to be the increasing supply of nitrogen delivered to the Gulf from the Mississippi River Basin.

To investigate regional nutrient contributions, the USGS National Water Quality Assessment (NAWQA) developed regional SPARROW models to assess conditions at a basinwide scale and provide predictions of water quality in unmonitored streams. These studies are part of NAWQA's broader status and trends assessments of stream chemistry, which are also investigating pesticides and ecosystem health. Since 2005, Wisconsin Water Science Center researchers have been modeling nutrients in three key river basins: the Mississippi/Atchafalaya River Basin (MARB); the U.S. portion of the Great Lakes Basin and the Ohio, Upper Mississippi and Red River Basins (MRB3); and the Mid-Continental Region of North America that includes the entire international Great Lakes basin (United States and Canada).

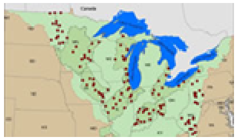
SPARROW (SPAtially Referenced Regressions On Watershed attributes) is a mass-balance watershed modeling technique for relating water-quality measurements to nutrient inputs and other watershed attributes. The SPARROW model relies on a network of monitoring stations and watershed measurements. SPARROW tracks the transport of nutrients from local inland watersheds to regional, coastal waters by explaining spatial patterns in stream water-quality conditions in relation to human activities and natural processes. The system uses calibrated models to predict long-term average loads, concentrations, yields, and source contributions (and associated error estimates) for all stream reaches within the modeled watersheds. SPARROW models have been developed for a variety of water-quality constituents and time periods.



Resources

Other Model Results:
- MARB results (1992 National SPARROW model)

Additional SPARROW Information:
- National USGS SPARROW web page
- SPARROW model documentation



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SPARROW Project Team
- Dale M. Robertson, Research Hydrologist
- David A. Saad, Hydrologist
- James Kennedy, Geographer
- Jim Rauman, Hydrologic Technician

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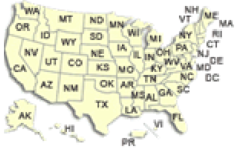

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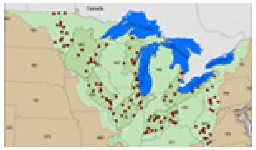

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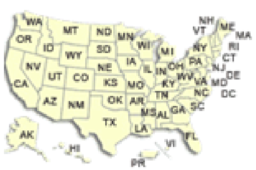

SPARROW Watershed Modeling: Estimation of Nutrient and Sediment Transport

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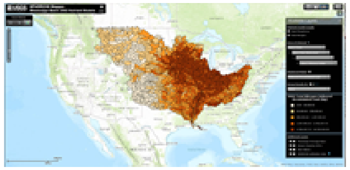
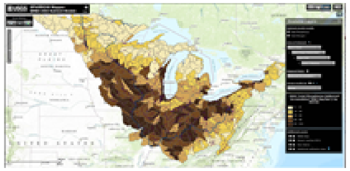
Online SPARROW Tools

Mississippi/Atchafalaya River Basin (MARB) SPARROW Mapper, 2002
This mapper displays SPARROW nutrient load and yield data and the importance of various nutrient sources for the MRB3 (U.S. part of the Great Lakes basin and the Ohio, Upper Mississippi, and Red River basins), given nutrient inputs similar to 2002. Rankings can be shown by major watershed, state, HUC8, tributary, and catchment. Nutrient data can be explored using maps and interactive graphs and tables. Modeling data can be exported as an Excel spreadsheet.

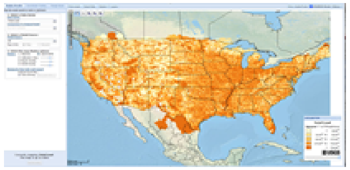


Great Lakes, Ohio, Upper Mississippi, Red River Basins (MRB3) SPARROW Mapper, 2002
This mapper displays SPARROW nutrient load and yield data and the importance of various nutrient sources for the entire Mississippi/Atchafalaya River basin, given nutrient inputs similar to 2002. Rankings can be shown by major watershed, state, HUC8, tributary, and catchment. Nutrient data can be explored using maps and interactive graphs and tables. Modeling data can be exported as an Excel spreadsheet.

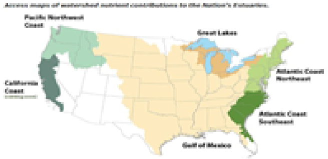
Great Lakes SPARROW Mapper, 2002
This mapper displays SPARROW nutrient load and yield data specifically for U.S. tributaries to the Great Lakes. The results are based on the SPARROW models developed for the Great Lakes, Ohio, Upper Mississippi, Red River Basins (MRB3).

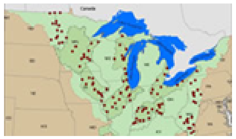


SPARROW Decision Support Tool
The SPARROW Decision Support System displays model predictions of water-quality conditions and sources by stream reach and catchment, tracks the transport to downstream receiving waters, and can be used to evaluate (quantify the effects of) management source-reduction scenarios. Complementary map overlays include land use, shaded relief, street-level data, and hydrologic unit boundaries. Models currently available include national nitrogen, phosphorus, and suspended sediment models as well as regional nutrient models.



Tracking the Source and Quantity of Nutrients to the Nation's Estuaries
This tool provides access to maps of watershed nutrient contributions to the Nation's Estuaries.





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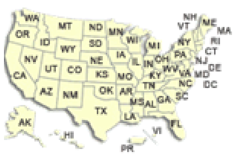

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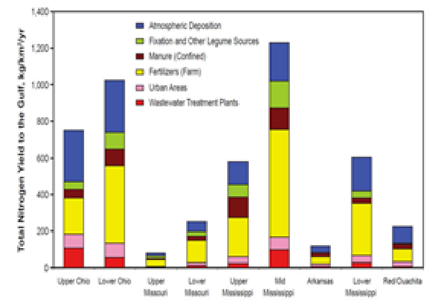
Mississippi/Atchafalaya River Basin

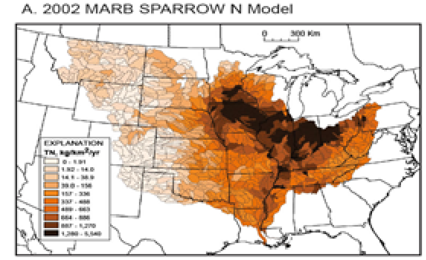
2002 Mississippi/Atchafalaya River Basin (MARB) SPARROW Models

To refine estimated sources of nutrients to the Gulf of Mexico, SPARROW models were developed specifically for the MARB using nutrient input information from 2002 and refined environmental-setting information. Results of these models were published in the Journal of Environmental Quality in 2013 and Journal of the American Water Resources Association in 2013. The refined models enabled USGS researchers to determine the importance of each nutrient source, particularly specific agricultural sources, more accurately than with previous models. Nutrient sources throughout the MARB are described in detail in the Journal of Environmental Quality in 2013.

These models demonstrated that:
- Highest nitrogen yields were from the Corn Belt (centered over Iowa and Indiana)
- Highest phosphorus yields were scattered throughout the MARB.
- Agricultural input (fertilizer, manure, and fixation) was the dominant source of nitrogen and phosphorus
- The 2002 refined SPARROW models showed that unconfined manure was a less important source of phosphorus than previous SPARROW models showed
- Urban sources (wastewater treatment plants and urban nonpoint) were more important than found with previous SPARROW models.

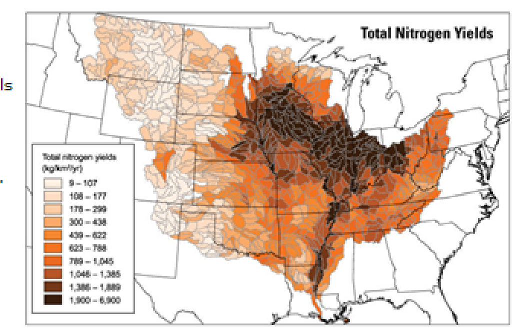


A. 2002 MARB SPARROW N Model



The newly estimated nitrogen and phosphorus yields throughout the MARB were used to re-rank the various HUC8s, states, and subbasins based on their relative nutrient contributions to the Gulf (described in detail in the Journal of the American Water Resources Association in 2014). Relatively small changes in area rankings (compared to previous models) were found for nitrogen, whereas larger changes were found for phosphorus. Spatial differences in yields from previous studies resulted from different descriptions of the dominant sources (N yields are highest with crop-oriented agriculture and P yields are highest with crop and animal agriculture and major WWTPs) and different descriptions of downstream transport. This information may help managers decide where efforts could have the largest effects (highest ranked areas) and thus reduce hypoxia in the Gulf of Mexico.

1992 Nation-Scale SPARROW Models



The 1992 Mississippi/Atchafalaya River Basin (MARB) portion of national-scale SPARROW models were primarily based on 1992 data and published in Environmental Science and Technology in 2008. Results from these models were used to evaluate watersheds throughout the MARB that deliver nitrogen and phosphorus to the Gulf of Mexico.
The 1992 MARB portion of the national SPARROW models showed:
- While Illinois, Iowa, Indiana, Missouri, Arkansas, Kentucky, Tennessee, Ohio, and Mississippi make up only one-third of the 30-state MARB area, they contribute more than 75% of nitrogen and phosphorus to the Gulf.
- Agricultural nonpoint sources contributed more than 70% of the nitrogen and phosphorus delivered to the Gulf, versus only about 9 to 12% from urban sources.
- Noncaptured animal manure on pasture and rangelands contribute nearly as much phosphorus as cultivated crops, 37% versus 43%, suggesting that the wastes of unconfined animals is a much larger source of phosphorus in the MARB than previously recognized.
- Atmospheric contributions also were important, accounting for 16% of nitrogen.

- Corn and soybean cultivation was the largest contributor of *nitrogen* to the Gulf. The study reported that 66%

References:

Robertson, D.M., Saad, D.A., Schwarz, G.E., 2014, Spatial Variability in Nutrient Transport by HUC8, State, and Subbasin Based on Mississippi/Atchafalaya River Basin SPARROW Models: Journal of the American Water Resources Association.

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Alexander, R.B., Smith, R.A., Schwarz, G.E., Boyer, E.W., Nolan, J.V., and Brakebill, J.W., 2008, Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environmental Science and Techology, v. 42, n. 3, p. 822-830.