Estimates of Nitrogen and Phosphorus Loads and Yields for the Lower Mississippi Texas-Gulf Basin

Preliminary SPARROW Results

Presentations to Texas Water Resources Partners
August 31 – September 2, 2010

U.S. Department of the Interior
U.S. Geological Survey

Regional Assessments

Regional assessments funded through the USGS NAWQA Program

Task 1 – Trend reports; completed in 2007; USGS SIR 2007-5090

Task 2 – SPARROW models; began in 2008; completed in 2010

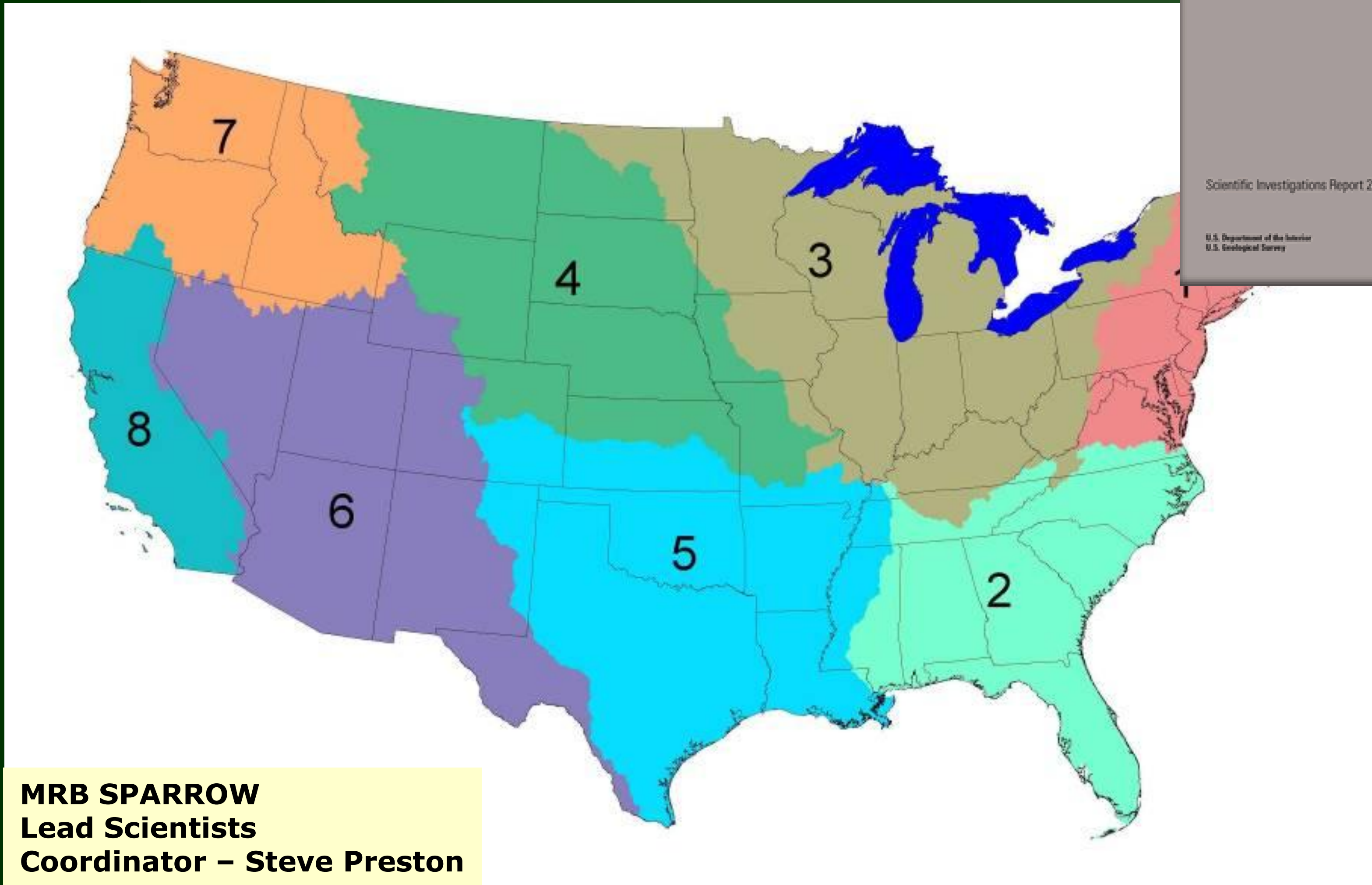

USGS
science for a changing world

National Water-Quality Assessment Program

Trends In Nutrient and Sediment Concentrations and Loads In Major River Basins of the South-Central United States, 1993-2004

Scientific Investigations Report 2007–5090

U.S. Department of the Interior
U.S. Geological Survey



MRB SPARROW
Lead Scientists
Coordinator – Steve Preston

- **All regional models and support documentation will be published in dedicated series of Journal of American Water Resources Association, late 2010 early 2011**
- **Lower Mississippi Texas-Gulf paper – should receive USGS approval by mid-September and be submitted to journal for peer review**

Purpose of today's meeting

- Present preliminary SPARROW results for Texas published in paper
- Give examples of how results can be used
- Request suggestions for other cooperator presentations

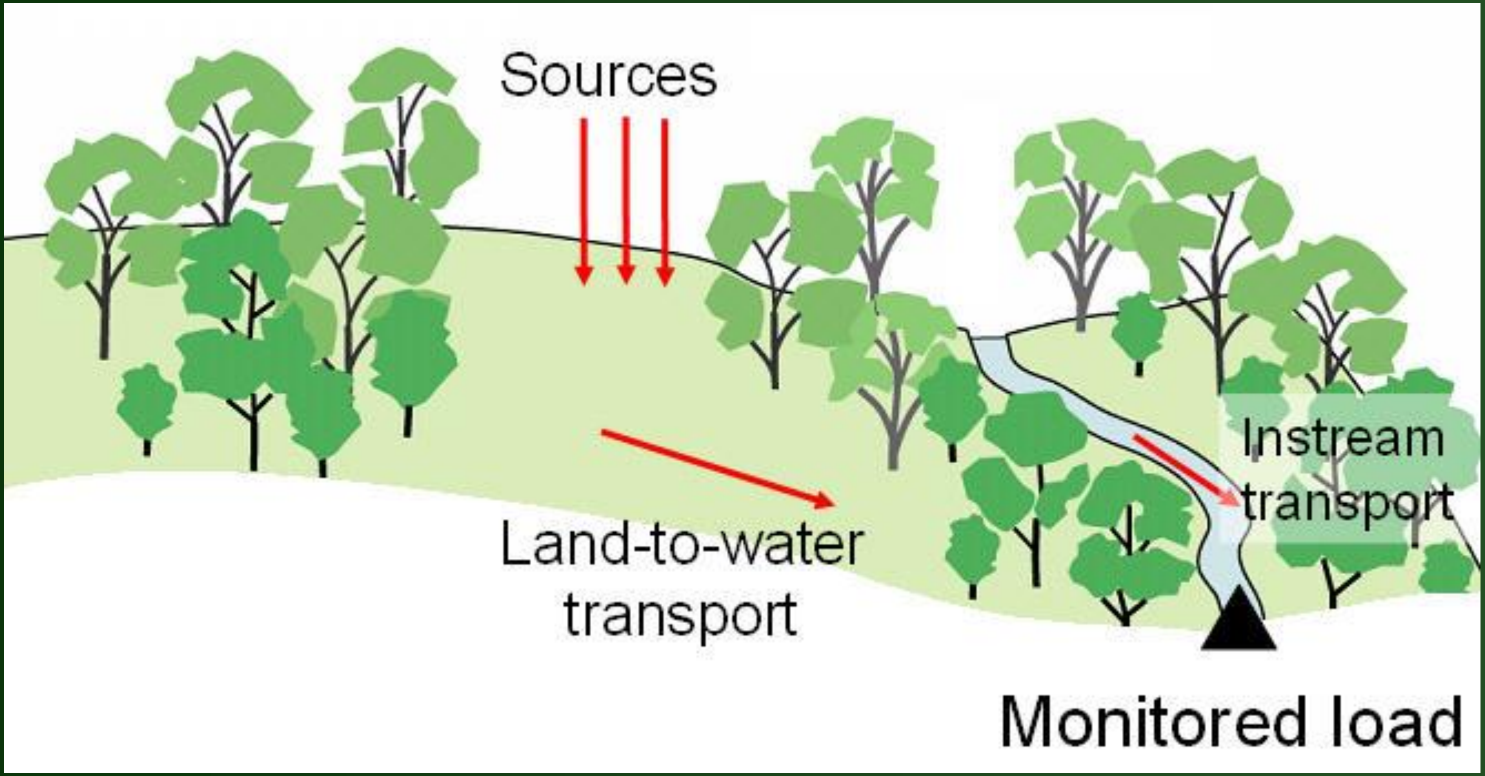
Presentation Outline

- Overview of SPARROW model
- Lower Mississippi Texas SPARROW model
  - Study area
  - Assembly of input data
  - Study area results
  - Texas results
- Examples of SPARROW model applications
- Summary

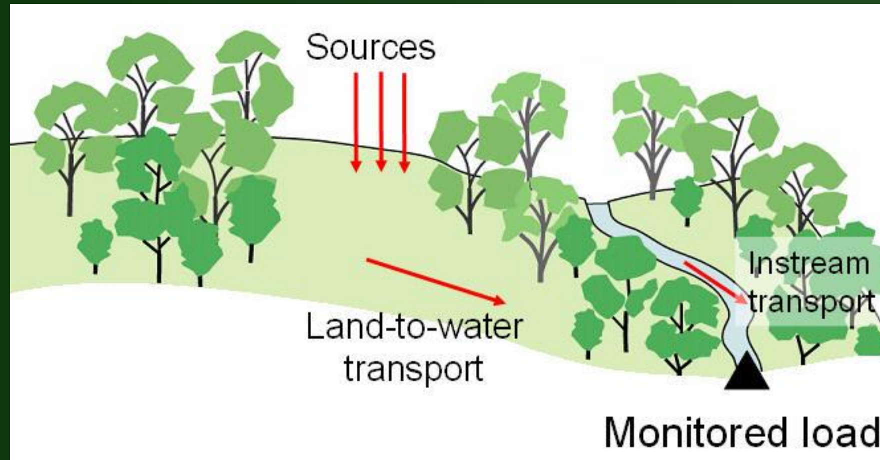
What is SPARROW?

- SPAtially Referenced Regression on Watershed Attributes (Smith et al., Water Resour. Res., 1997)
- Regression-based model - model is calibrated and adjusted to monitored loads
- Hybrid mechanistic – includes transport, loss, mass-balance, etc.
- Static model - centered on a specific target year; typically a year where spatial data have been assembled

SPARROW model concept



USGS



$$\text{Load}_i = \left\{ \sum_{j \in J(i)} \left[\sum_{n=1}^{N} S_{n,j} \, \beta_n \exp(-\alpha' Z_j) \right] \exp(-\delta' T_{i,j}) \right\} \exp(\epsilon_i)$$

Load

Sources

Land-to-water transport

Instream transport/ loss

Error

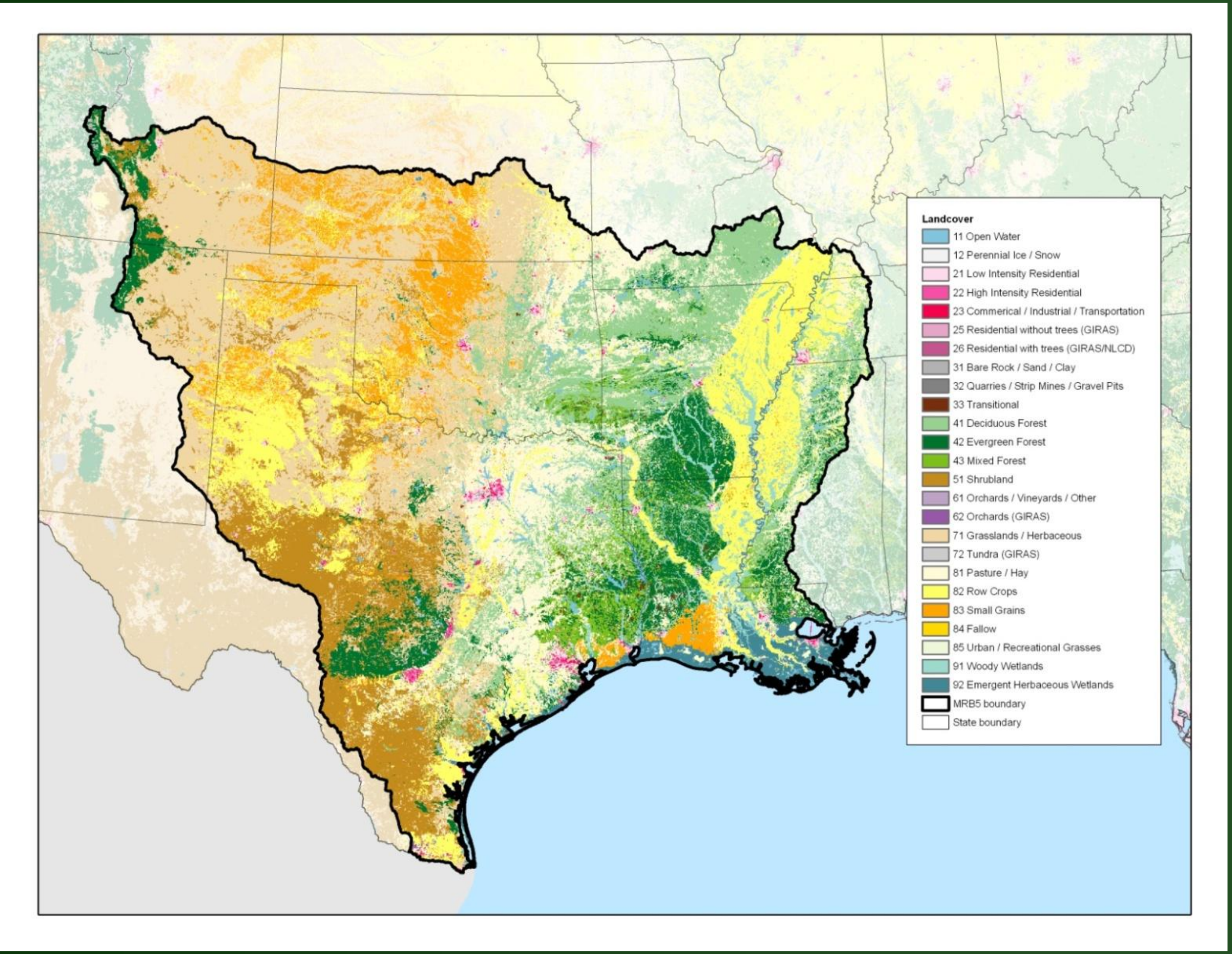
USGS

Study Area

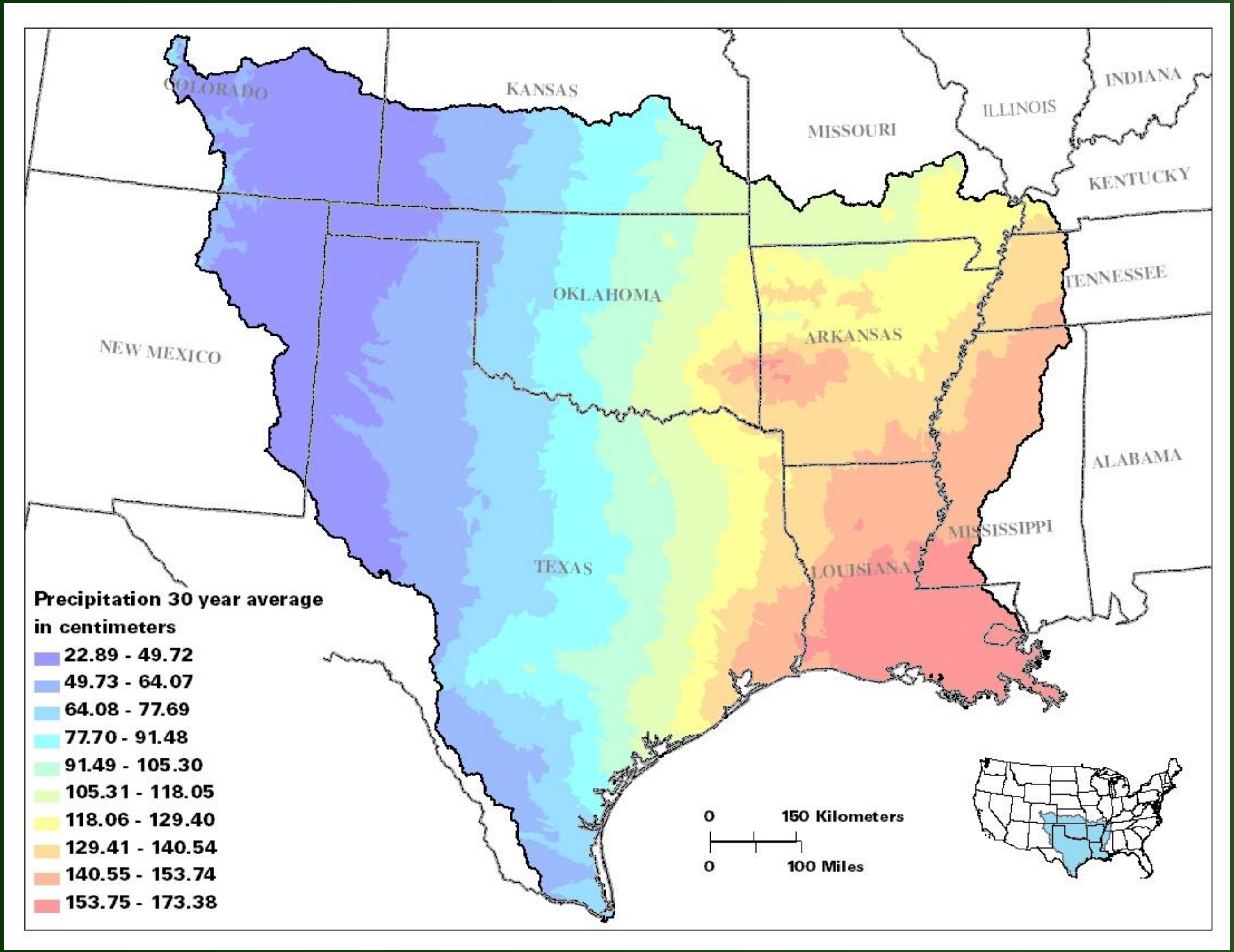
- South-Central United States – Lower Mississippi, Arkansas-White-Red, and Texas-Gulf Basins
- 11 States
- USGS Study Area Team:
  - Richard Rebich, MSWC
  - Natalie Houston, Patty Ging, and Evan Hornig, TWSC
  - Scott Mize, LWSC

USGS

Land Use


Landcover
11 Open Water
12 Perennial Ice / Snow
21 Low Intensity Residential
22 High Intensity Residential
23 Commerical / Industrial / Transportation
25 Residential without trees (GIRAS)
26 Residential with trees (GIRAS/NLCD)
31 Bare Rock / Sand / Clay
32 Quarries / Strip Mines / Gravel Pits
33 Transitional
41 Deciduous Forest
42 Evergreen Forest
43 Mixed Forest
51 Shrubland
61 Orchards / Vineyards / Other
62 Orchards (GIRAS)
71 Grasslands / Herbaceous
72 Tundra (GIRAS)
81 Pasture / Hay
82 Row Crops
83 Small Grains
84 Fallow
85 Urban / Recreational Grasses
91 Woody Wetlands
92 Emergent Herbaceous Wetlands
MRB5 boundary
State boundary

Rainfall



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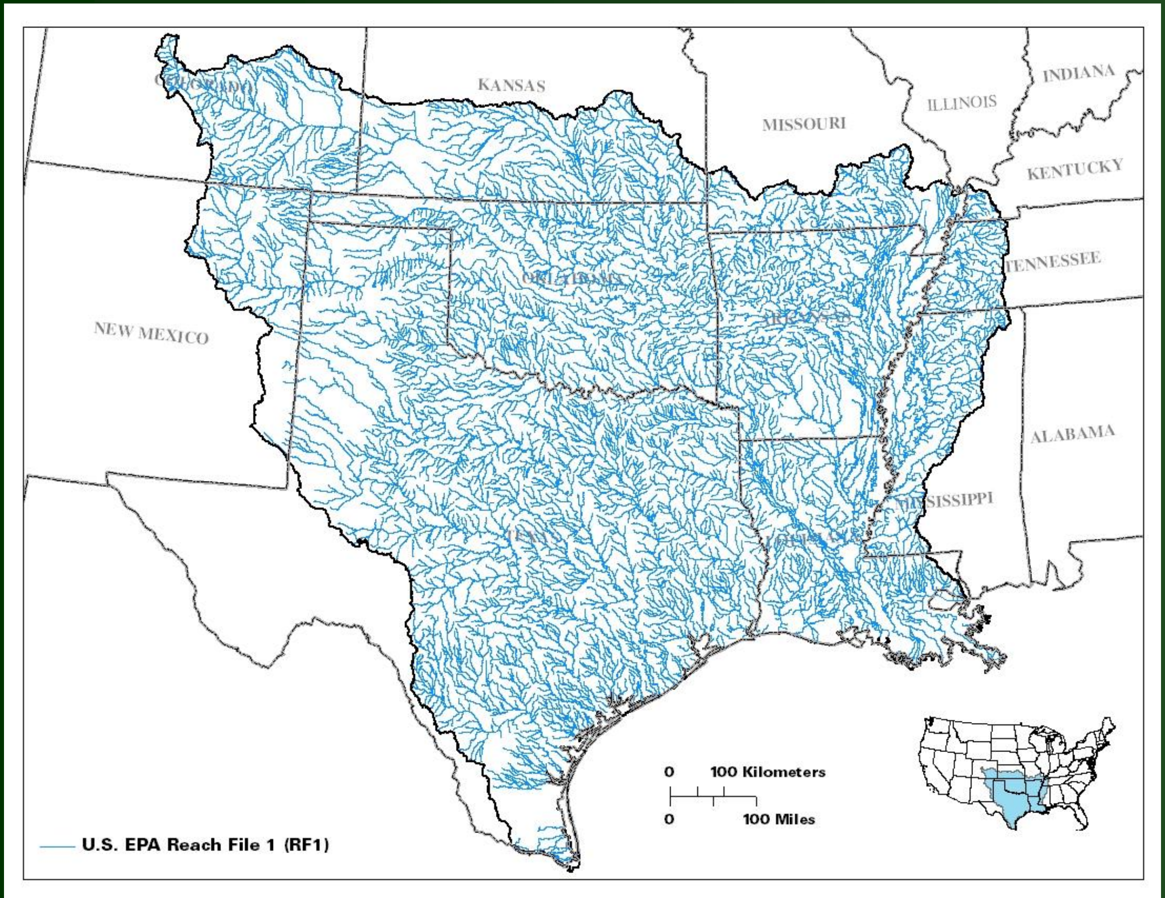
Starts with reach network



The E2RF1 digital stream network from the U.S. Environmental Protection Agency was used for this study

There were 8,375 stream reaches and catchments in the study area

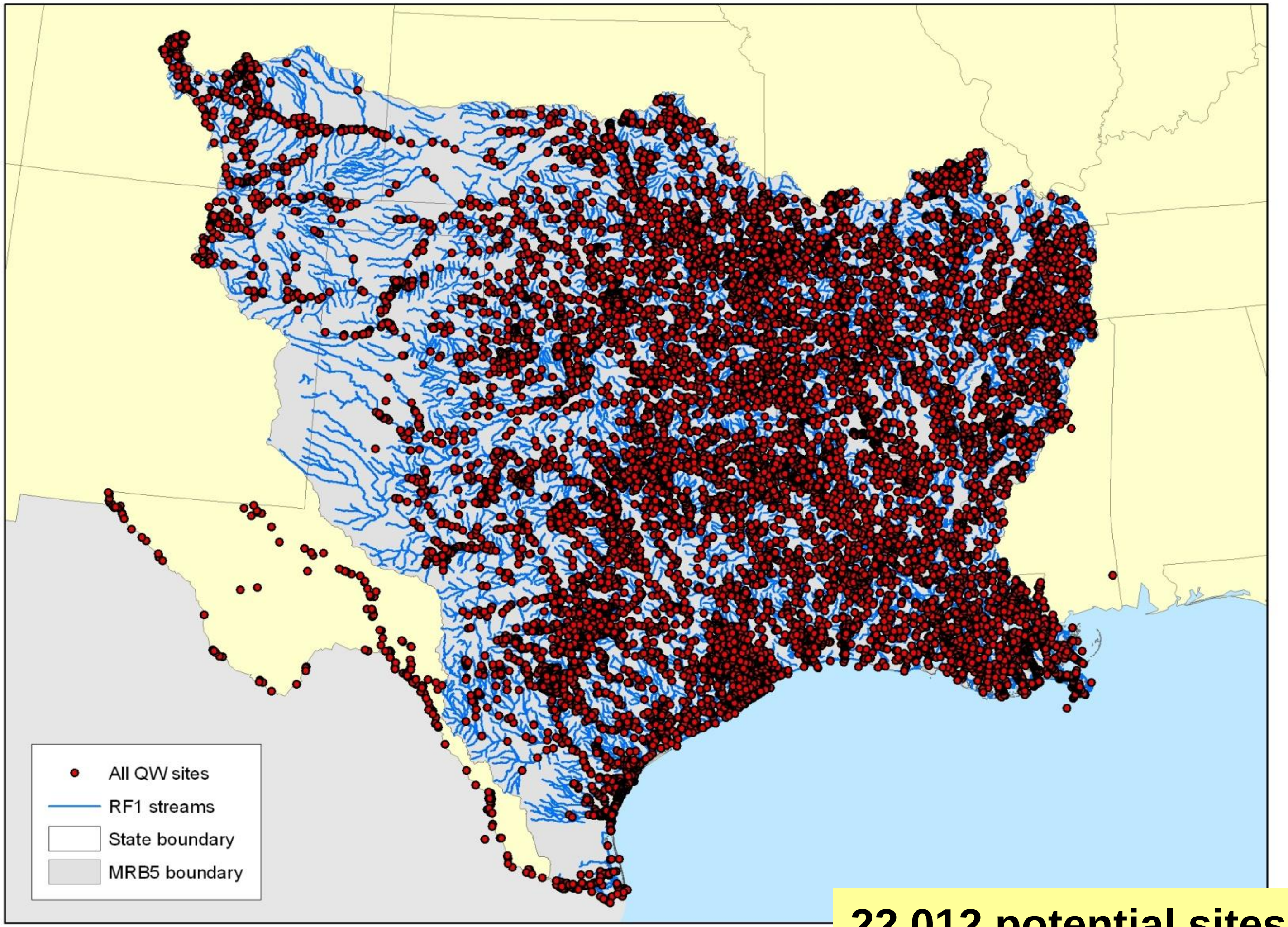
USGS

Load estimates

Assemble sample/concentration data

- Used the following datasets:
  - USGS-NWIS
  - EPA-STORET
  - Kansas Department of Health and Environment
  - Louisiana Department of Environmental Quality
  - Mississippi Department of Environmental Quality
  - Texas Commission on Environmental Quality
  - Oklahoma Department of Environmental Quality
- Started with 22,012 sites that had at least one sample/concentration

Sites with water-quality data



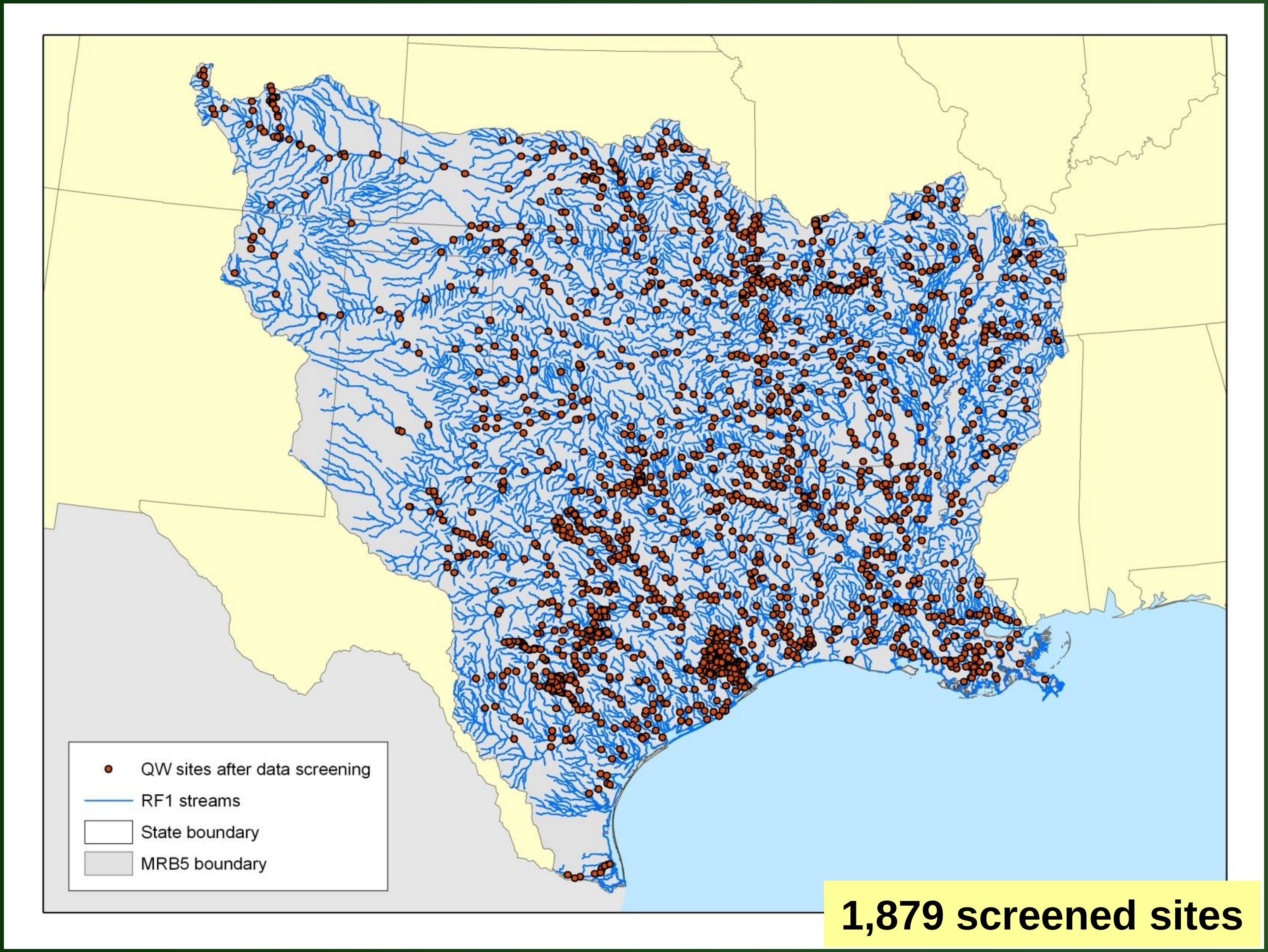
22,012 potential sites

Data Screening

- Once sites were identified, then criteria to screen:
  - 25 samples
  - At least 5 years of data within 7 years of target year
  - Or, at least 2 years of data within 2 years of target year
- This screening left 1,879 sites

USGS

Screened water quality sites



1,879 screened sites

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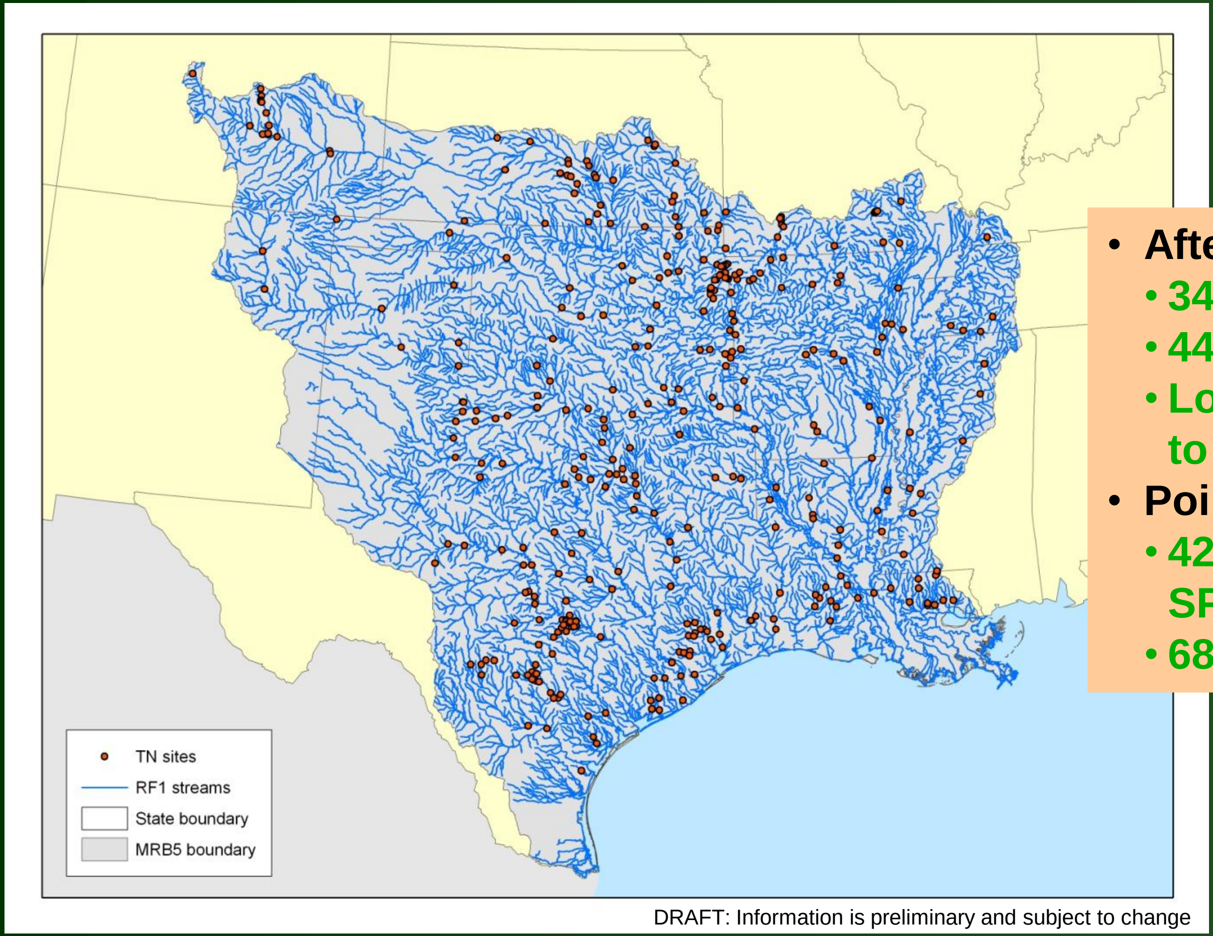
Final Load Sites



- **After flow gage match,**
  - **344 total nitrogen sites**
  - **442 total phosphorus sites**
  - **Load estimates de-trended to 2002**
- **Point of reference,**
  - **425 total sites in National SPARROW model**
  - **68 were in the study area**

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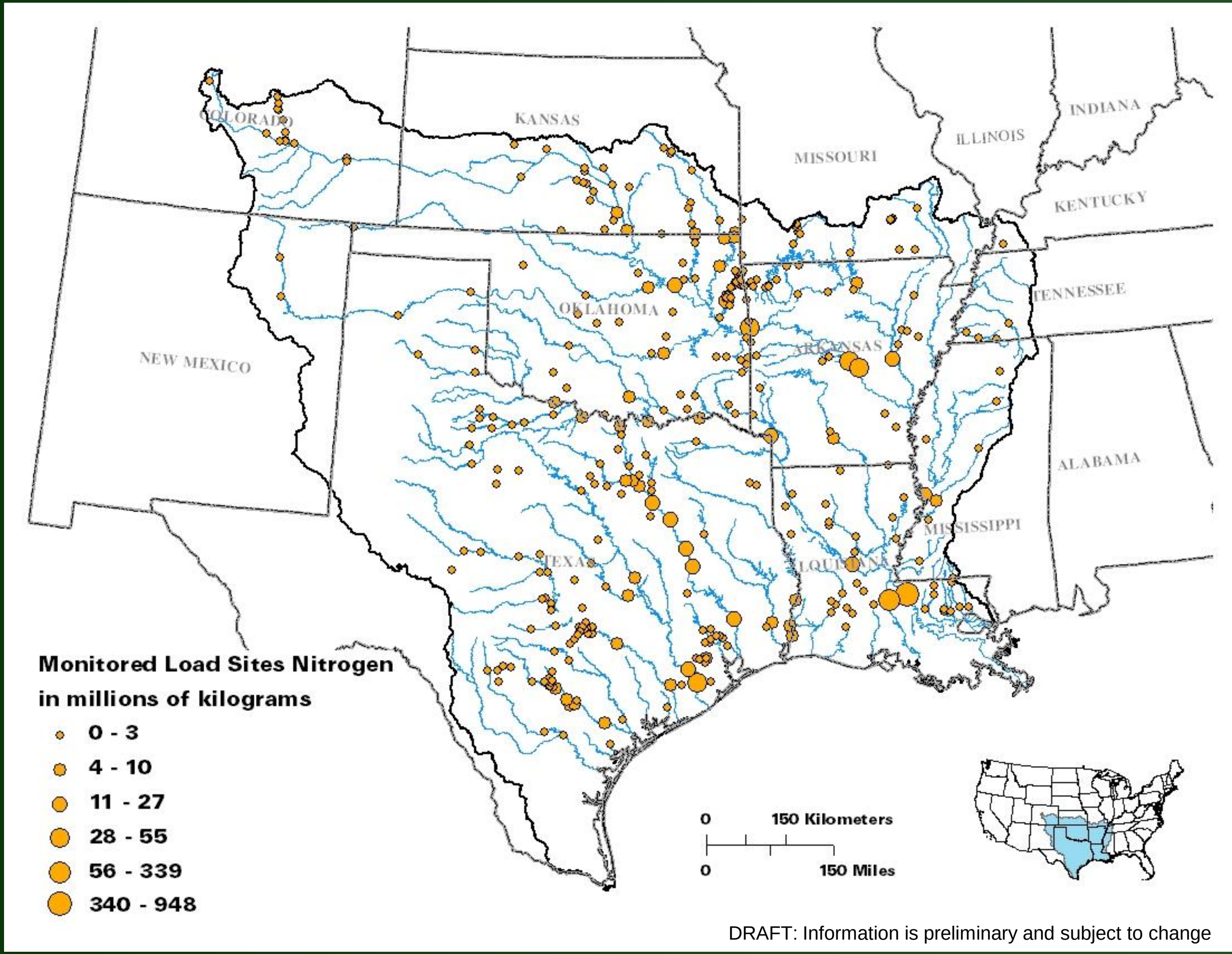
Range of total nitrogen load at monitored sites



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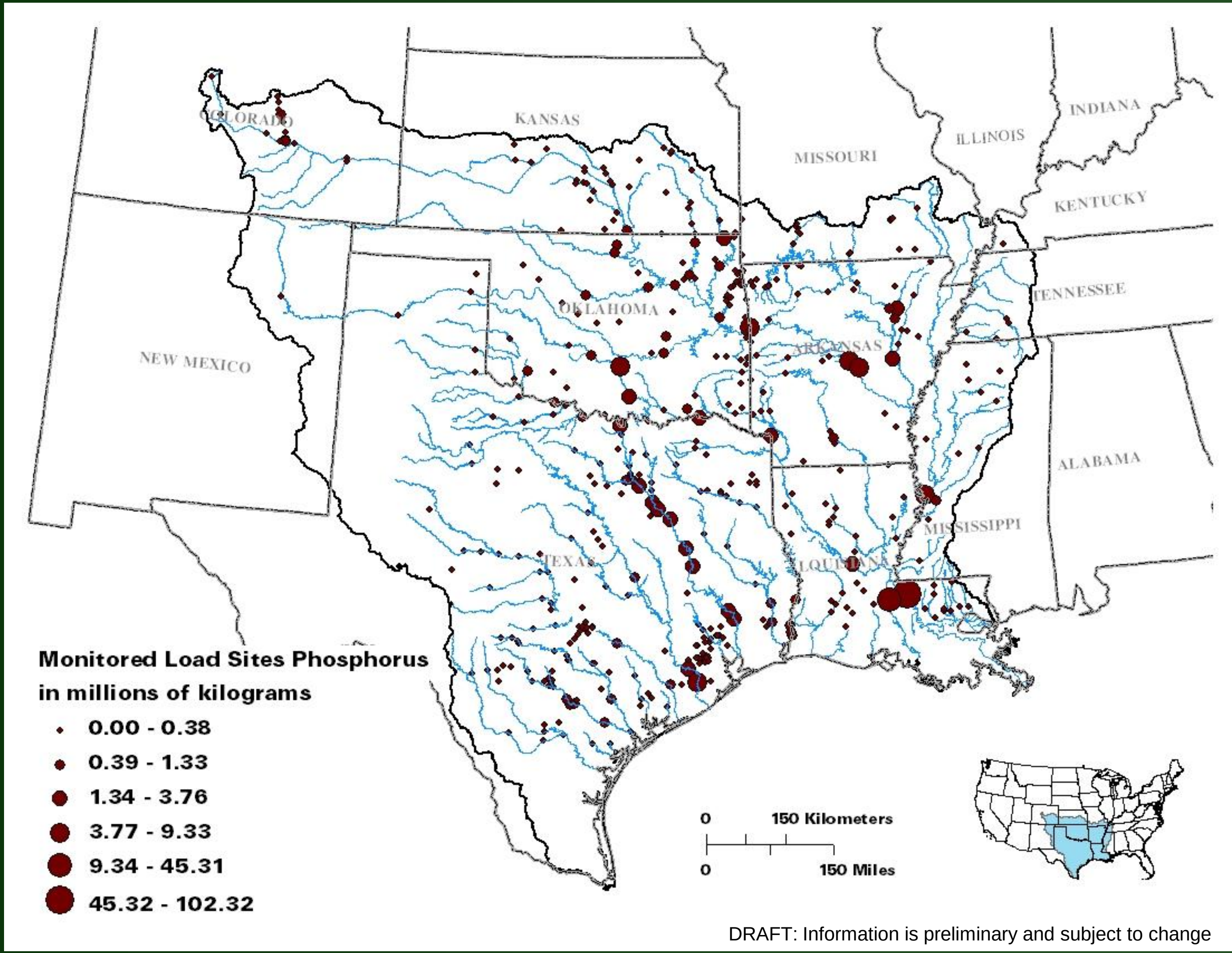
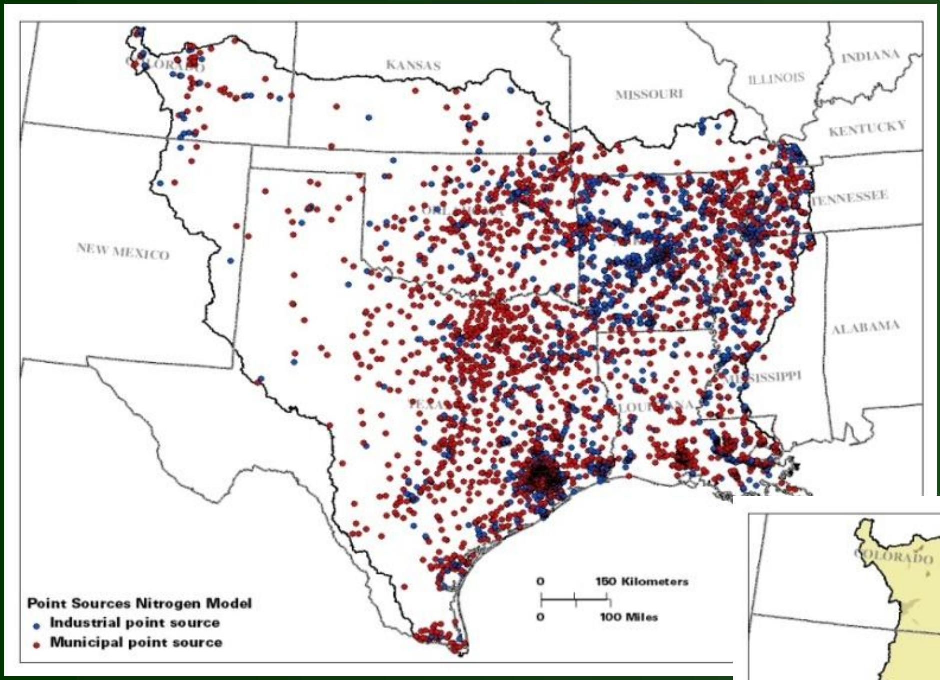
Range of total phosphorus load at monitored sites



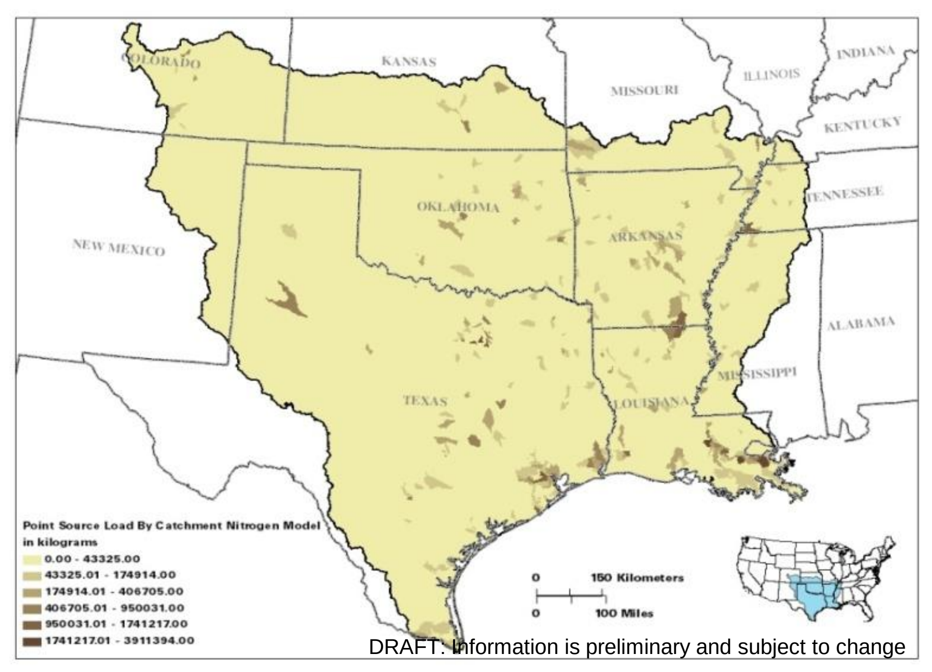
Source Data Used in Total Nitrogen Model

Target Year for Model - 2002

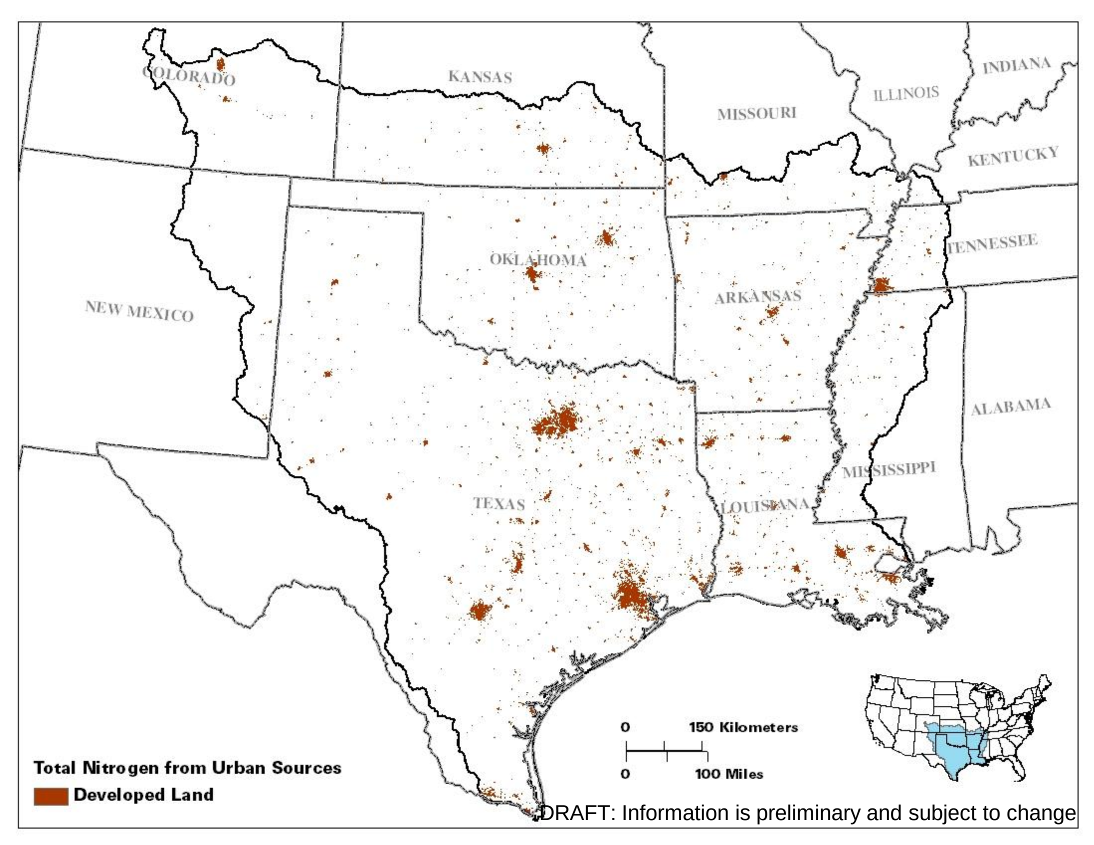
Point Sources



- Data from USEPA's Permit Compliance System
- Used actual load data where available
- In unavailable, load data were estimated



Developed Land



- **Data from 2001 NLCD**
- **Developed land: low, medium, high, and open spaces**
- **Represents urban nonpoint runoff**

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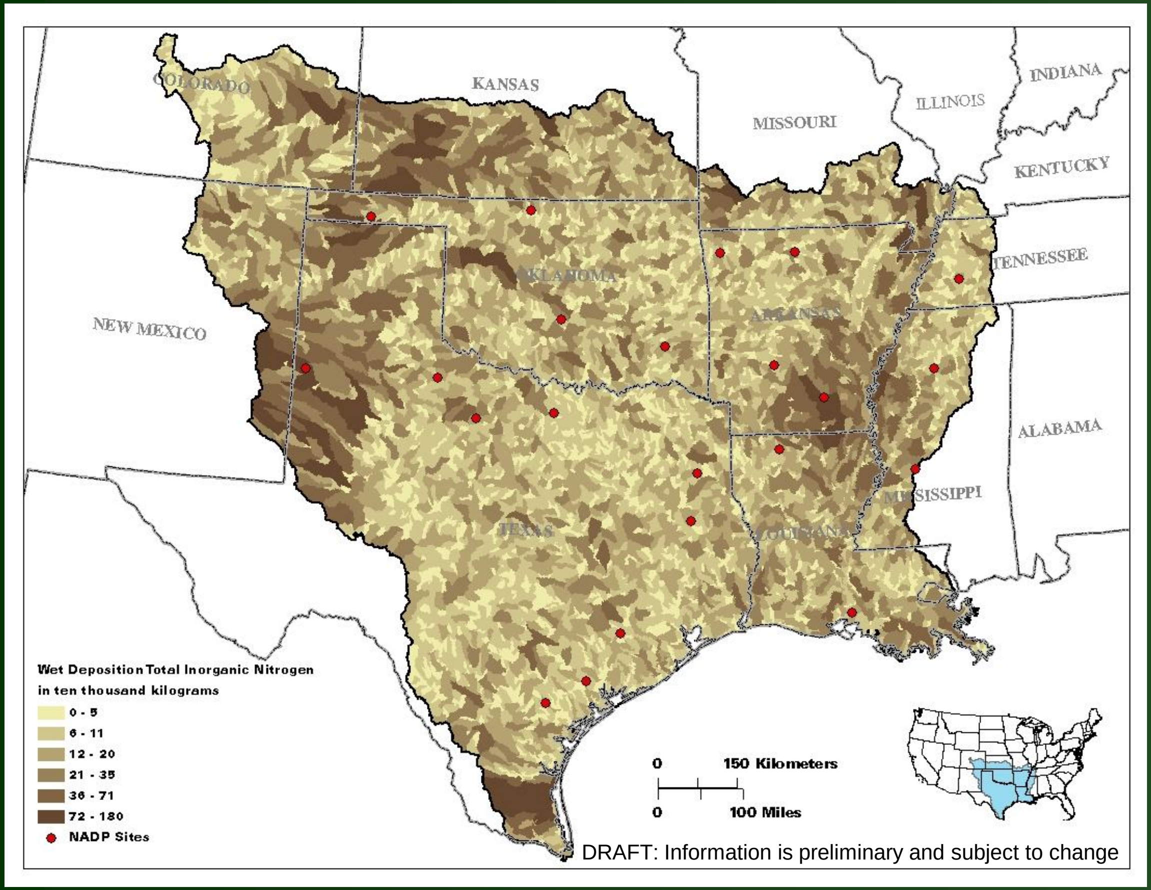
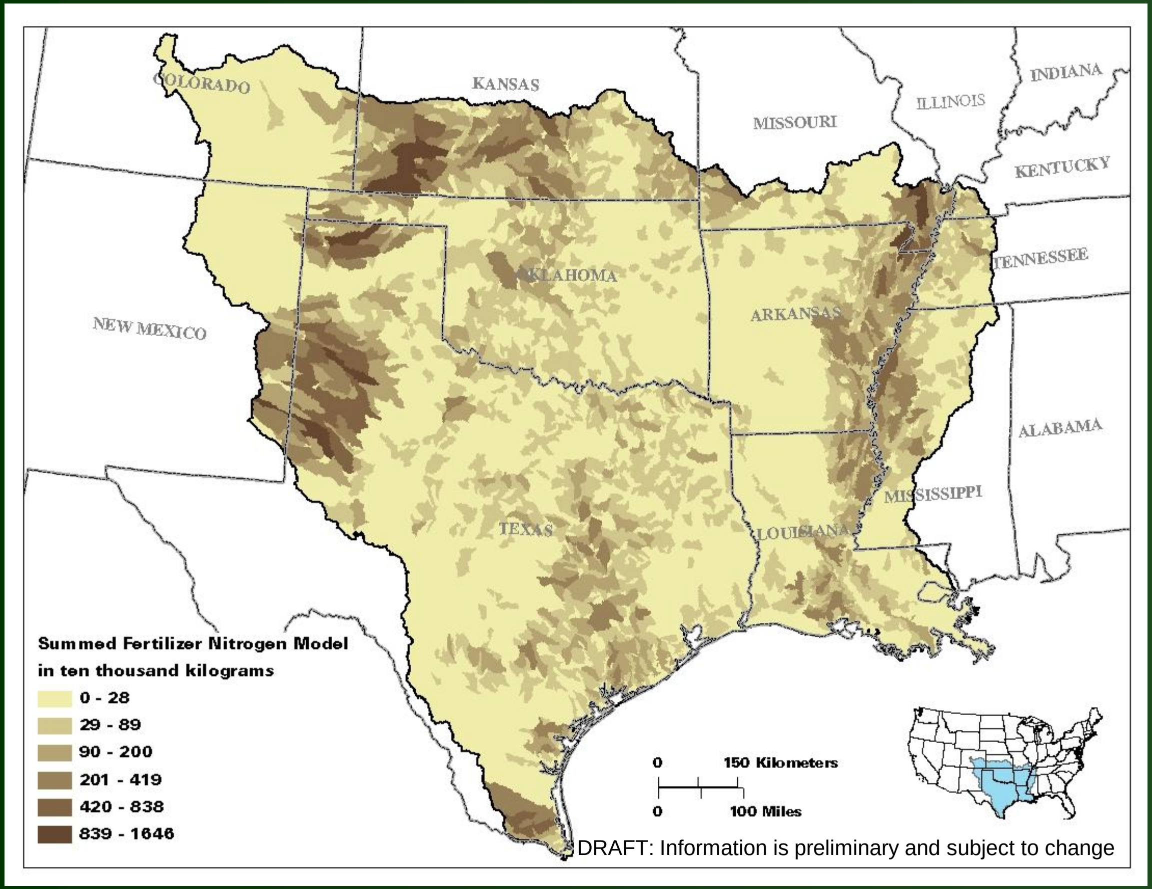
Atmospheric Deposition



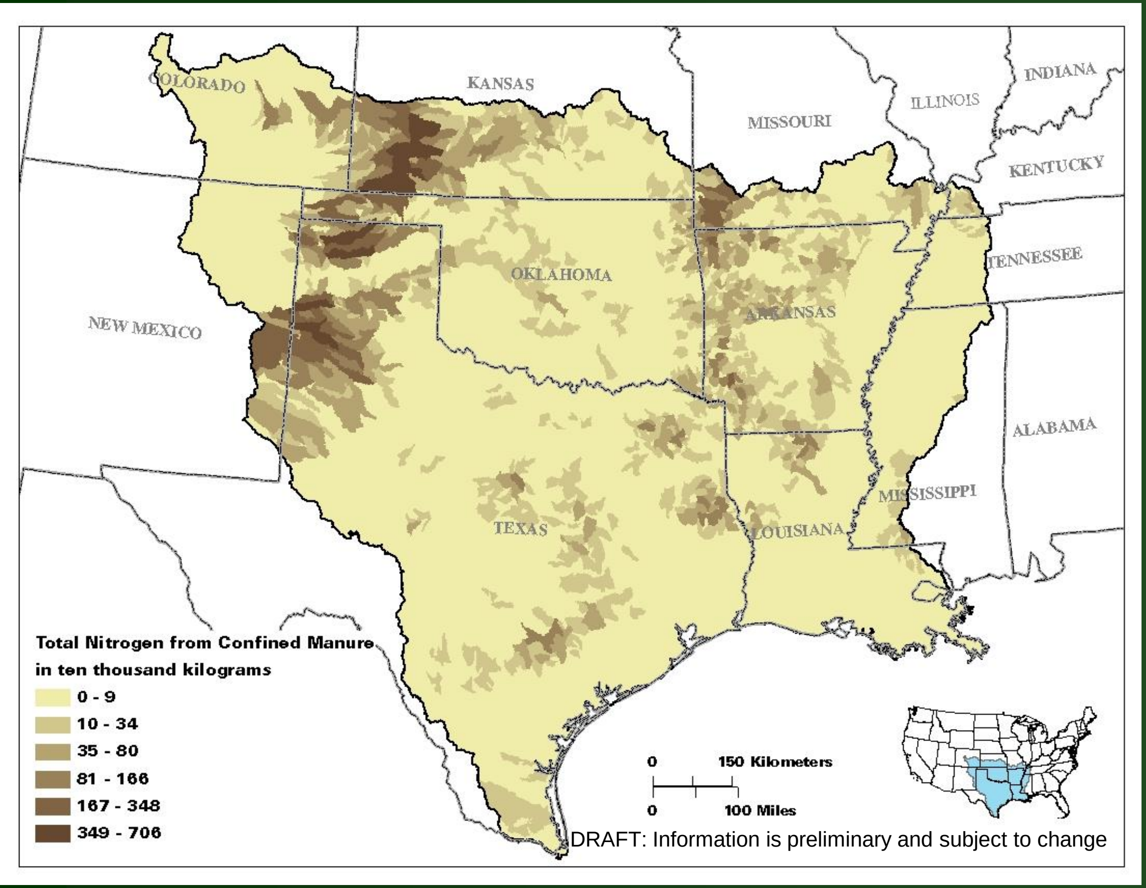
- Data from 28 active USGS NADP/NTN wet deposition sites in the study area
- Data used in the model are total inorganic nitrogen
- Mostly ammonia, some nitrate
- De-trended to 2002

Fertilizer applied to crops



- Data from USDA NASS service
- County level sales data
- Data are available annually

Livestock Manure from Confined Feeding Operations



- **Data from USDA NASS service**
- **Livestock manure generated at feeding operations (confined) applied to crops**
- **Data are available every 5 years**

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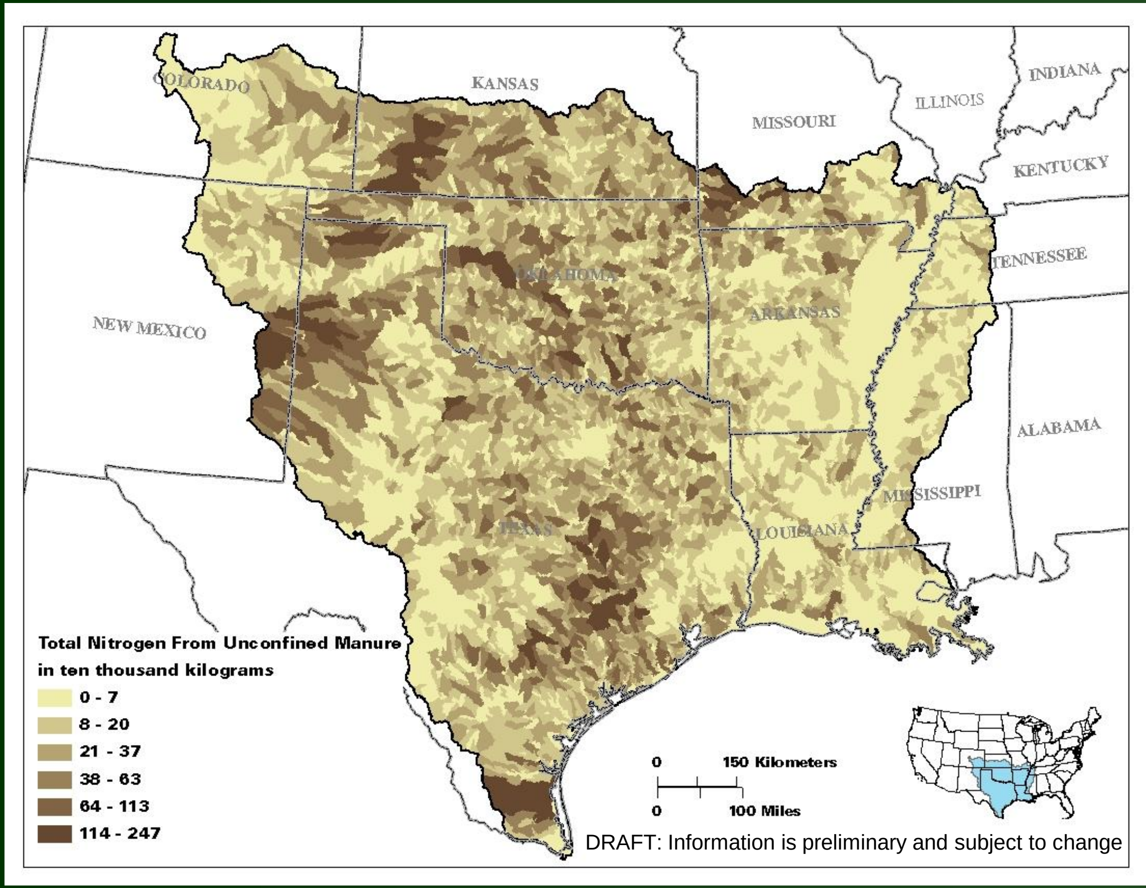
Livestock Manure from Pastures (unconfined)



- Data from USDA NASS service
- Livestock manure generated from pastures (unconfined)
- Data are available every 5 years

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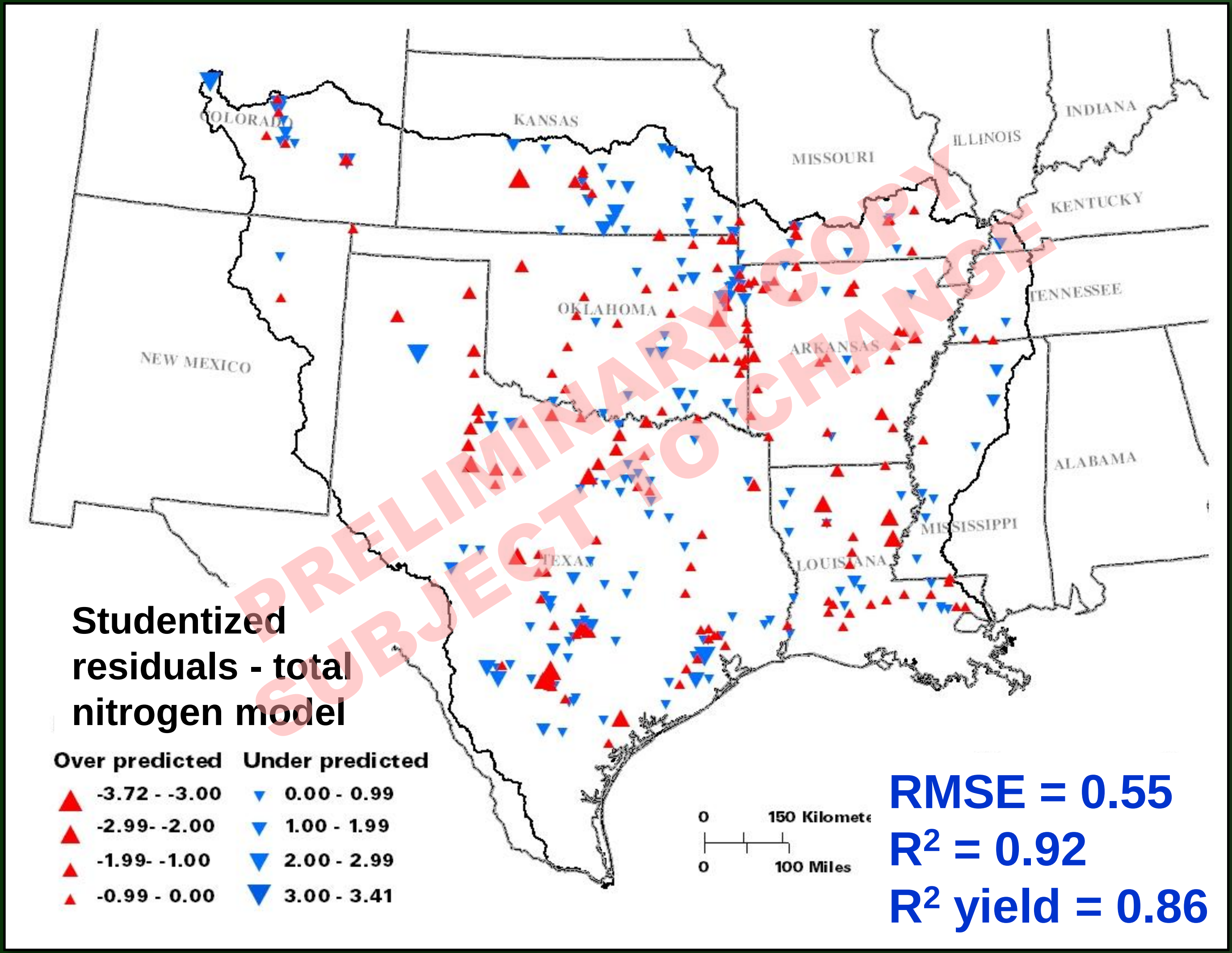
Delivery and Loss Variables in Final Total Nitrogen Model

- Delivery terms
  - Average annual precipitation
  - Overland flow term
- Loss terms
  - In-stream loss - first order decay equations
    - Three flow regimes:
      - <50 cfs
      - between 50 and 1000 cfs
      - >1000 cfs;
  - Reservoir loss

Distribution of total nitrogen model residuals

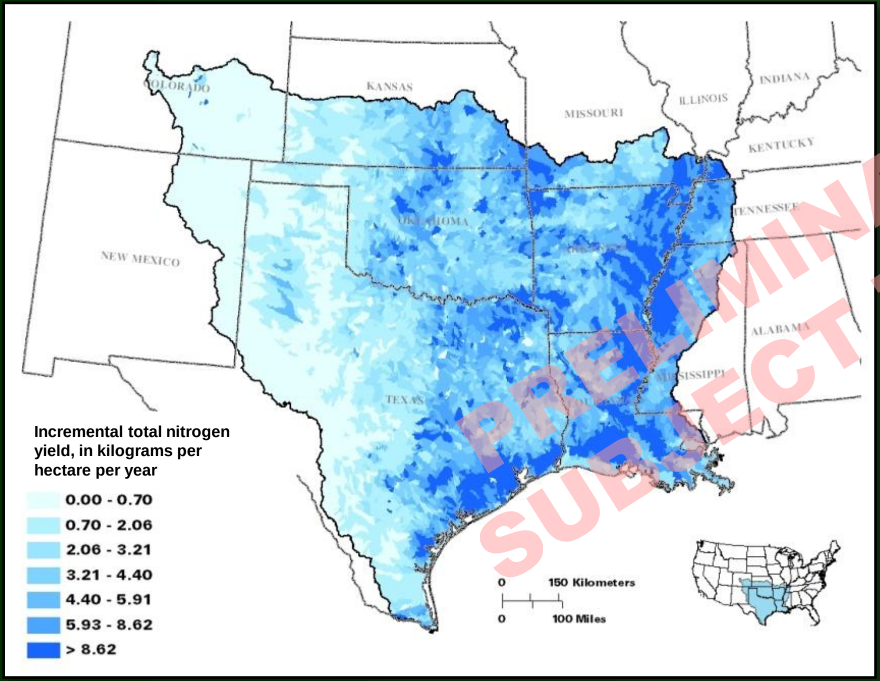


Definition of Terms

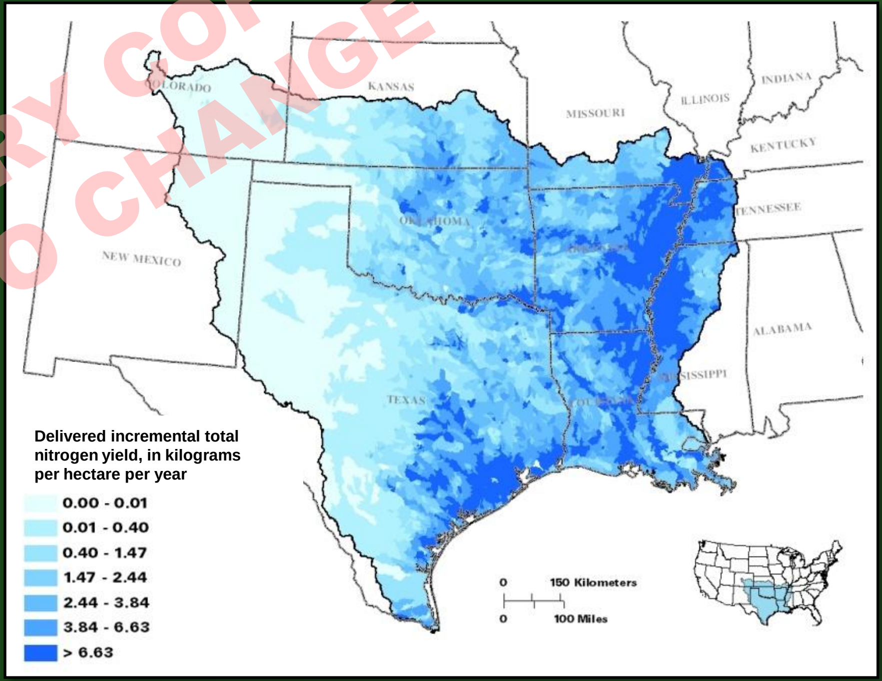
- **Yield – Load divided by drainage area**
- **Incremental – load or yield generated for each reach catchment delivered to local streams**
- **Delivered – amount of incremental load or yield delivered to target area (in this case, Gulf); based on multiplying incremental load or yield by delivery fraction**

Total Nitrogen Yield Results

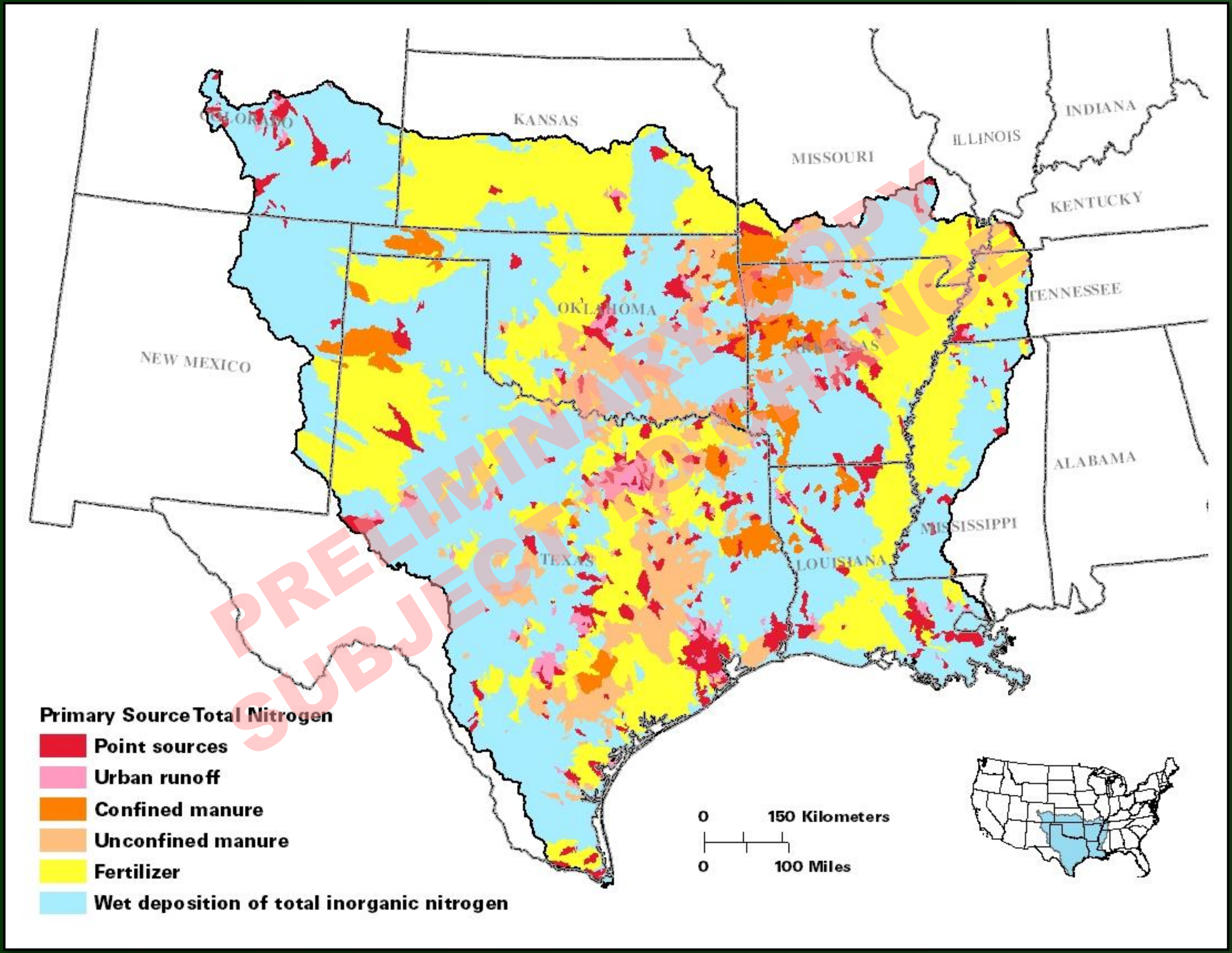
Delivered to local streams



Delivered to the Gulf of Mexico



Primary Sources of Nitrogen



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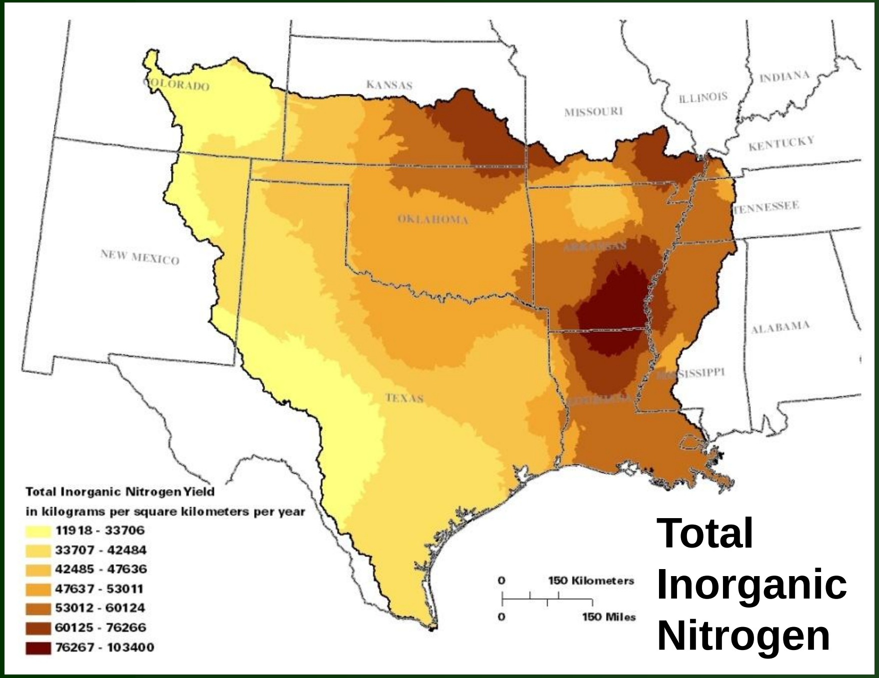
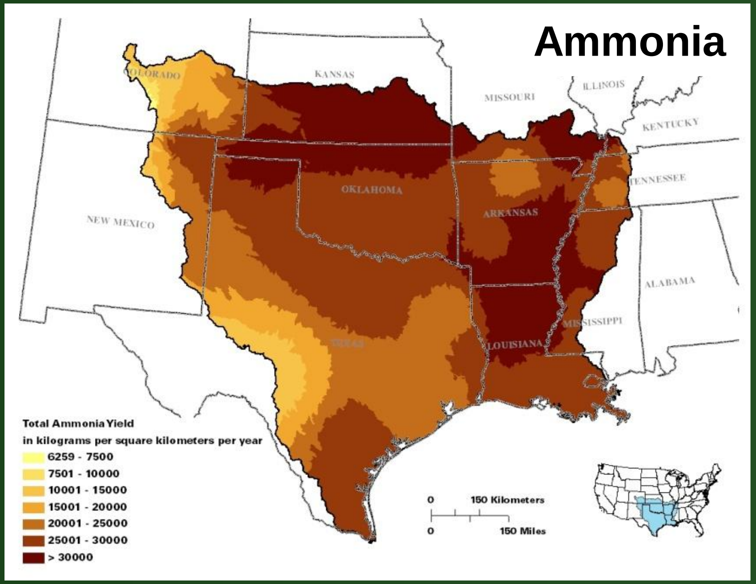
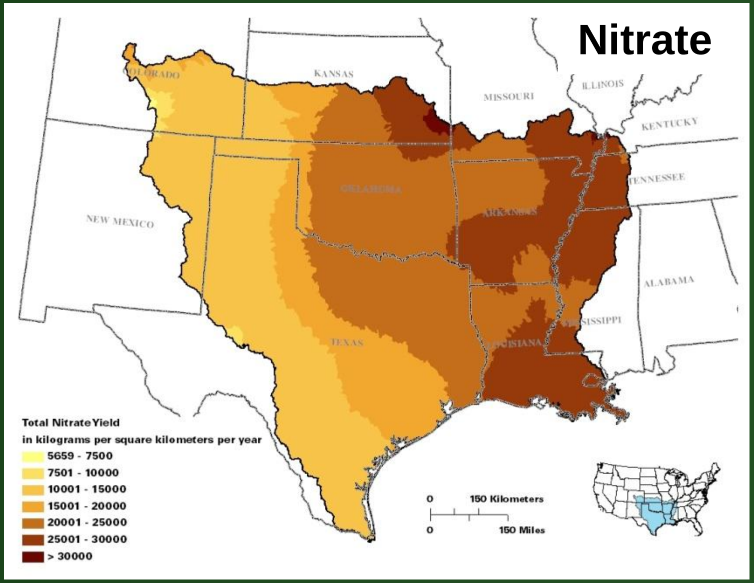
Atmospheric Deposition







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Sources Used in Final Total Phosphorus Model

- Fertilizer
- Livestock manure - confined feeding operations and pastures (unconfined)
- Urban runoff
- Point sources
- Phosphorus attached to sediment from in channel erosion
- Phosphorus from background sources (forest, scrub, barren)

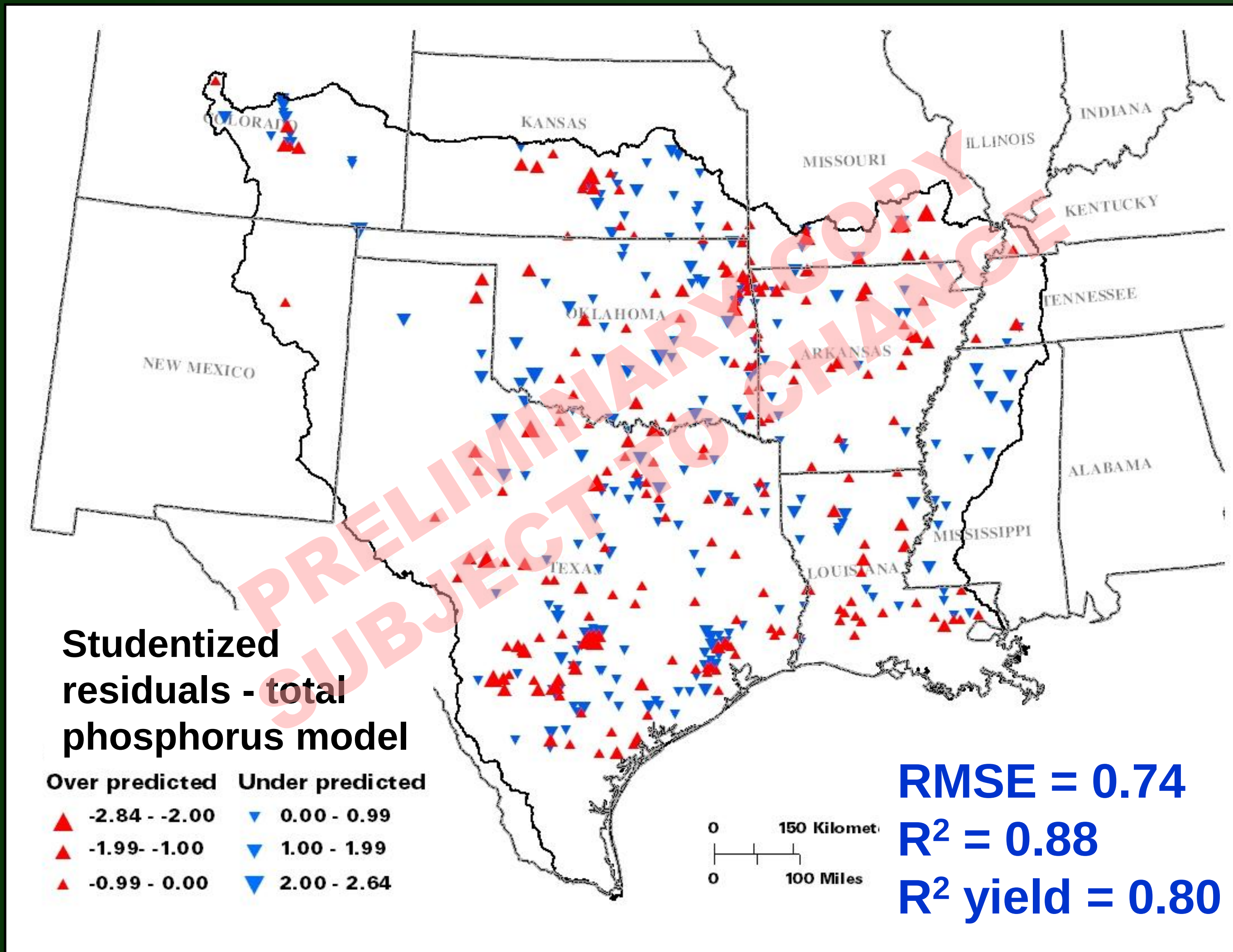
Note: Total phosphorus loads from Upper Mississippi River were considered a boundary condition for this regional SPARROW model

USGS

Delivery and Decay Variables in Final Total Phosphorus Model

- Delivery terms
  - Average annual precipitation
  - Overland flow term
  - K-factor; soil erosion factor from USLE
- Loss terms
  - In-stream loss - first order decay equations
    - Three flow regimes:
      - <50 cfs
      - between 50 and 1000 cfs
      - >1000 cfs;
  - Reservoir loss

Distribution of total phosphorus model residuals



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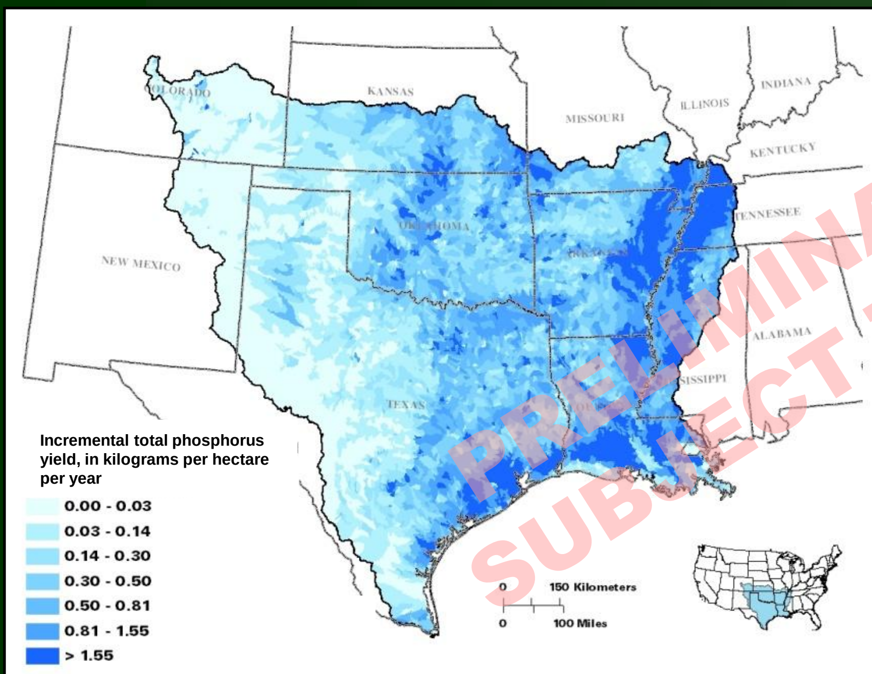
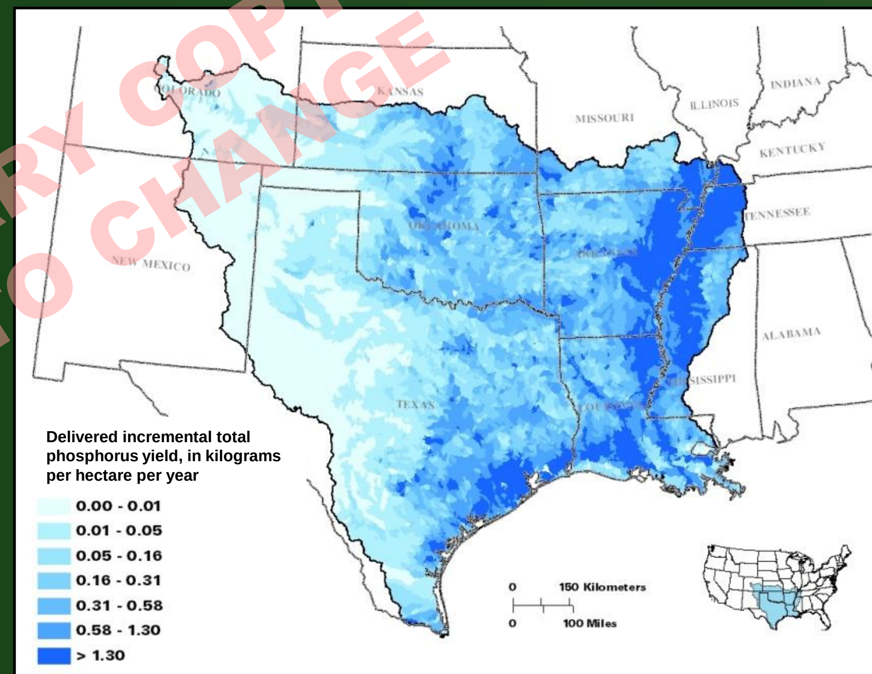
Total phosphorus yield results

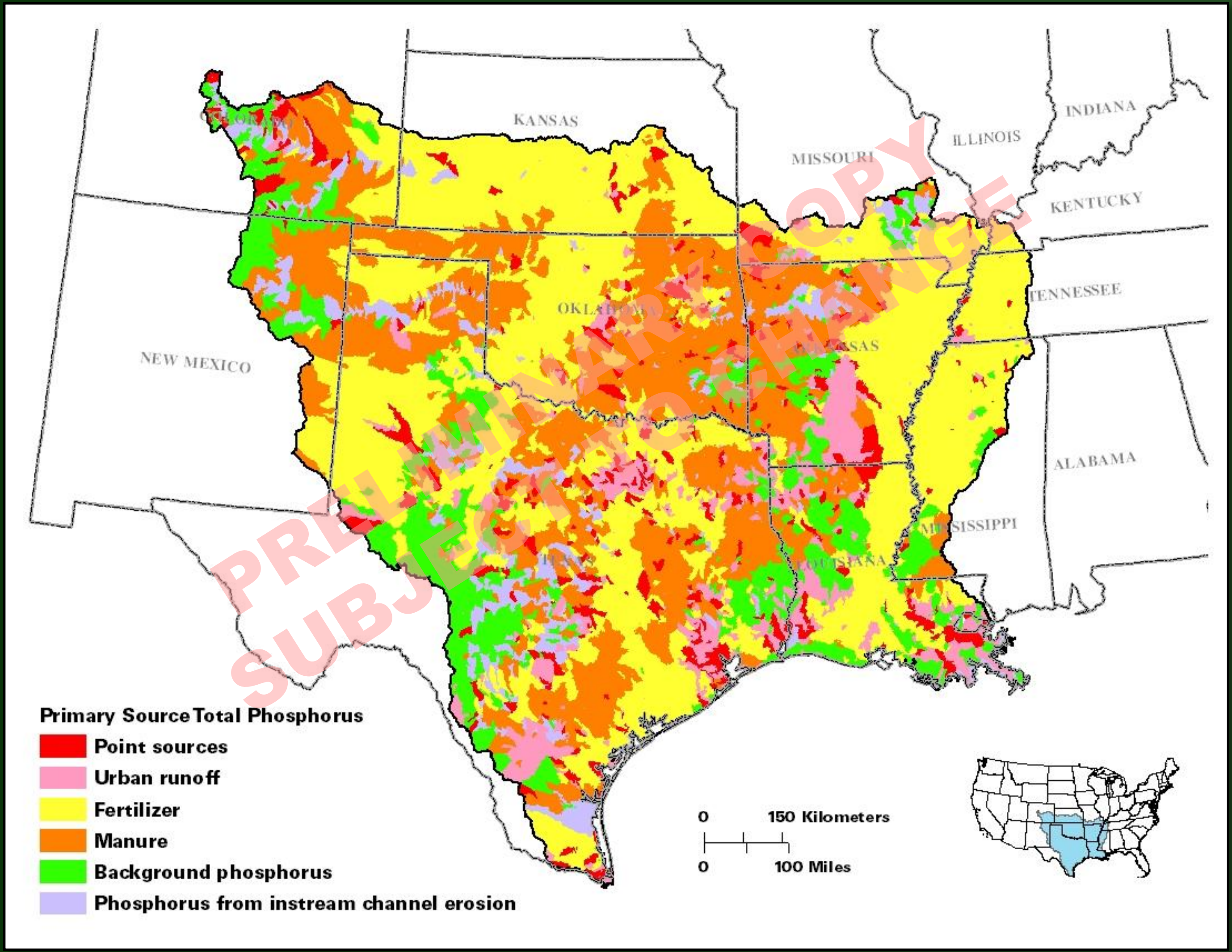
Delivered to local streams



Delivered to the Gulf of Mexico



Sources of phosphorus



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Published Results - Texas

- Delivered Load and Yield Table by Estuary
- Maps of Delivered Incremental Yield by Estuary

Delivered Loads and Yields by Estuary – Total Nitrogen

Nitrogen model results by estuary

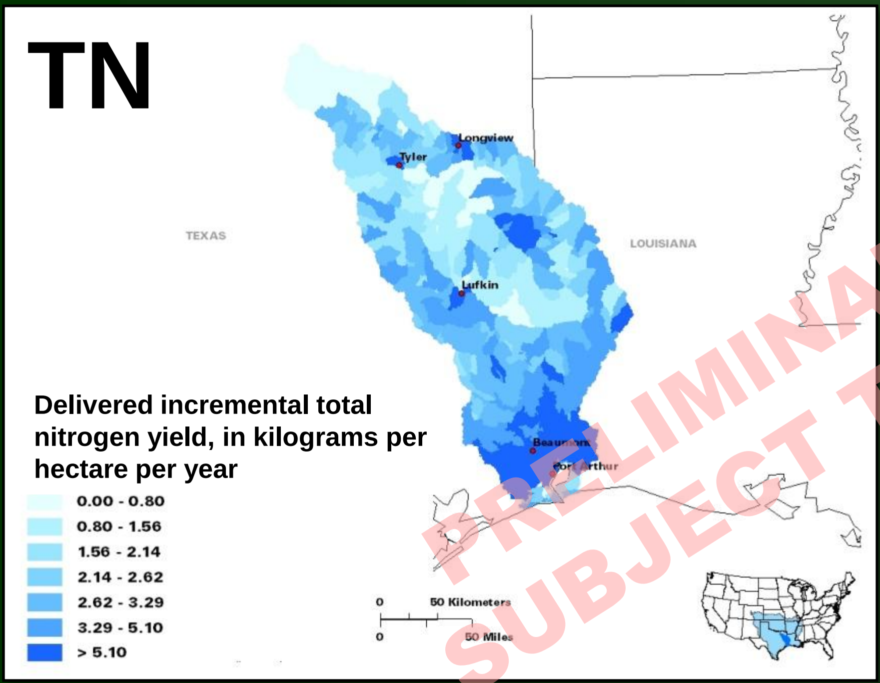
Estuary[a]	Delivered load, mT/yr	Standard error for delivered load, mT/yr	Lower 90th percentile confidence interval for delivered load, mT/yr	Upper 90th percentile confidence interval for delivered load, mT/yr	Delivered yield, kg/ha/yr	Standard error of delivered yield, kg/ha/yr	Lower 90th percentile confidence interval for deliverd yield, kg/ha/yr	Upper 90th percentile confidence interval for deliverd yield, kg/ha/yr
Lake Borgne	3272.0	2317.5	1328.8	8147.5	2.1	1.5	0.8	5.1
Mississippi River	182538.0	124809.9	54315.7	340733.5	3.0[b]	-----[b]	-----[b]	-----[b]
Barataria Bay	1964.7	1361.6	632.8	4377.3	3.4	2.4	1.1	7.6
Atchafalaya River/Terrebonne Bay	92850.4	63744.1	37547.5	198075.4	3.6	2.4	1.4	7.6
Mermentau River	3158.5	2261.3	1002.3	6908.5	3.5	2.5	1.1	7.7
Calcasieu River	6521.5	4510.3	2169.0	17922.9	**5.9**	4.1	2.0	16.2
Neches/Sabine Rivers	20646.6	14177.8	6749.7	45245.0	3.8	2.6	1.2	8.3
Trinity River/Galveston Bay	40497.6	28108.9	13386.9	82093.5	**6.6**	4.6	2.2	13.3
Brazos River	24501.1	16840.8	8435.1	56605.4	2.0	1.4	0.7	4.6
Colorado River/Matagorda Bay	16306.1	11212.6	5856.8	28728.8	1.3	0.9	0.5	2.4
San Antonio/Quadalupe Rivers	9680.1	6656.3	3306.6	25895.3	3.6	2.5	1.2	9.7
Aransas River	2763.6	1948.8	1080.8	6186.8	**4.3**	3.0	1.7	9.7
Nueces River/Corpus Christi Bay	2328.0	1609.6	787.5	5355.4	0.5	0.4	0.2	1.2
Upper Laguna Madre	2234.1	1545.7	763.9	4015.7	1.5	1.0	0.5	2.6
Lower Laguna Madre	2440.8	1688.2	869.2	6882.6	2.3	1.6	0.8	6.4

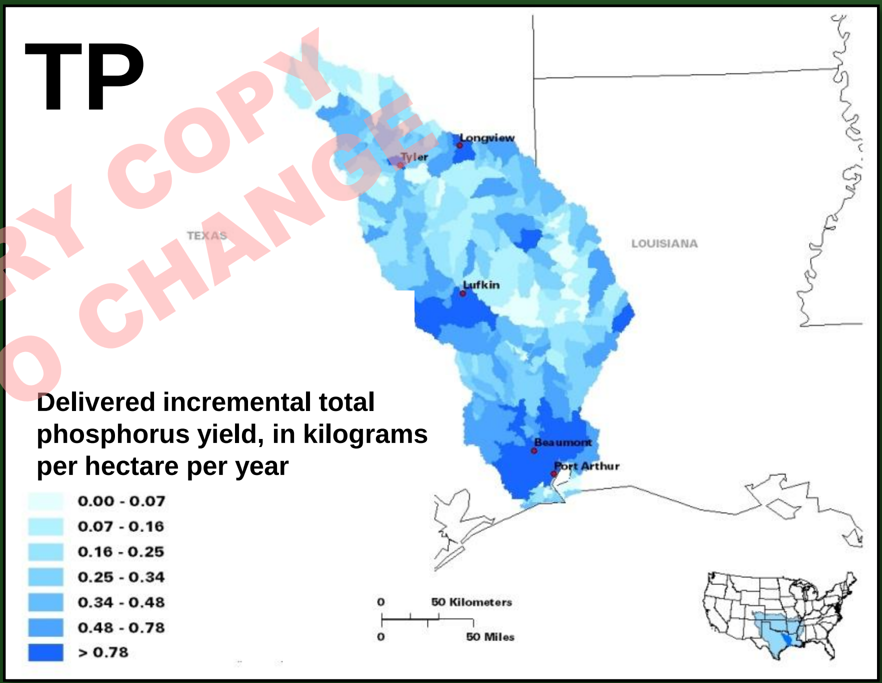
Delivered Loads and Yields by Estuary – Total Phosphorus

Phosphorus model results by estuary

Estuary[a]	Delivered load, mT/yr	Standard error for delivered load, mT/yr	Lower 90th percentile confidence interval for delivered load, mT/yr	Upper 90th percentile confidence interval for delivered load, mT/yr	Delivered yield, kg/ha/yr	Standard error of delivered yield, kg/ha/yr	Lower 90th percentile confidence interval for deliverd yield, kg/ha/yr	Upper 90th percentile confidence interval for deliverd yield, kg/ha/yr
Lake Borgne	700.6	616.9	183.4	1870.7	0.4	0.4	0.1	1.2
Mississippi River	41182.4	33536.6	6920.8	119084.5	0.7[b]	-----[b]	-----[b]	-----[b]
Barataria Bay	400.5	369.0	87.2	949.3	0.7	0.6	0.2	1.7
Atchafalaya River/Terrebonne Bay	15034.7	12285.5	2817.3	43948.3	0.6	0.5	0.1	1.7
Mermentau River	922.6	794.0	194.9	2801.4	**1.0**	0.9	0.2	3.1
Calcasieu River	1370.0	1127.4	327.9	3742.8	**1.2**	1.0	0.3	3.4
Neches/Sabine Rivers	2958.8	2419.0	617.6	8456.5	0.5	0.4	0.1	1.6
Trinity River/Galveston Bay	6233.2	5122.3	1333.3	18986.0	**1.0**	0.8	0.2	3.1
Brazos River	3282.0	2679.7	666.2	9909.2	0.3	0.2	0.1	0.8
Colorado River/Matagorda Bay	2169.1	1774.4	521.8	5450.0	0.2	0.1	0.0	0.4
San Antonio/Quadalupe Rivers	1292.5	1057.3	244.2	3600.7	0.5	0.4	0.1	1.3
Aransas River	403.6	345.9	83.3	1050.5	0.6	0.5	0.1	1.6
Nueces River/Corpus Christi Bay	336.7	277.5	64.2	1053.5	0.1	0.1	0.0	0.2
Upper Laguna Madre	202.3	165.9	39.8	496.3	0.1	0.1	0.0	0.3
Lower Laguna Madre	256.4	211.4	47.1	741.9	0.2	0.2	0.0	0.7

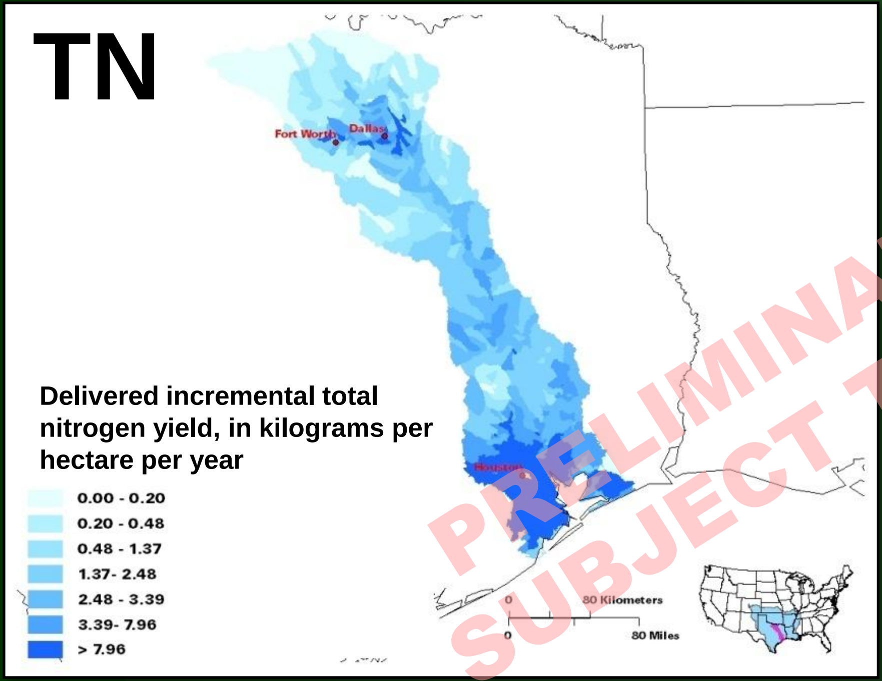
Delivered Incremental Yields Maps by Estuary

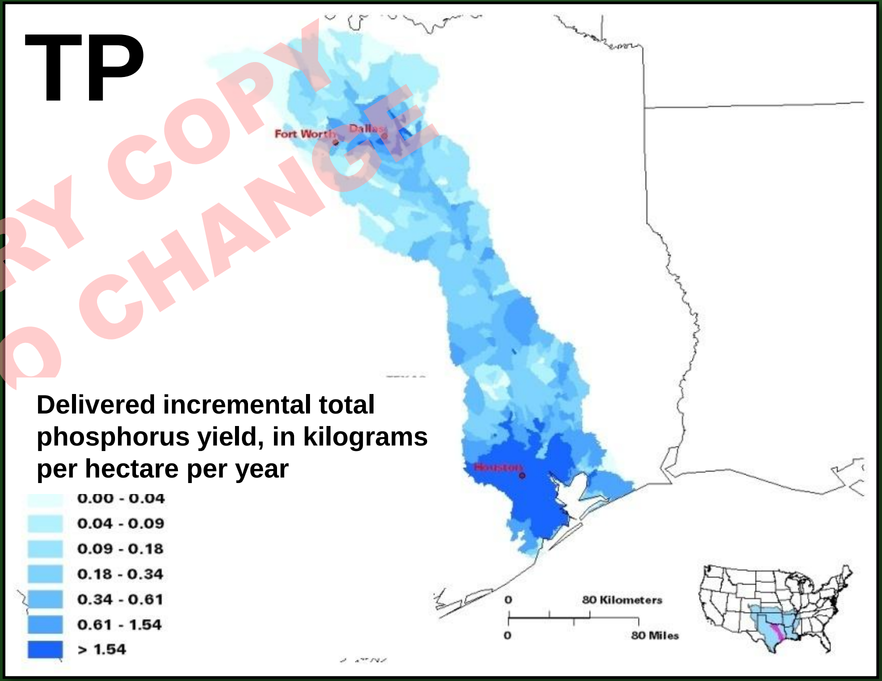




Neches and Sabine Rivers estuary

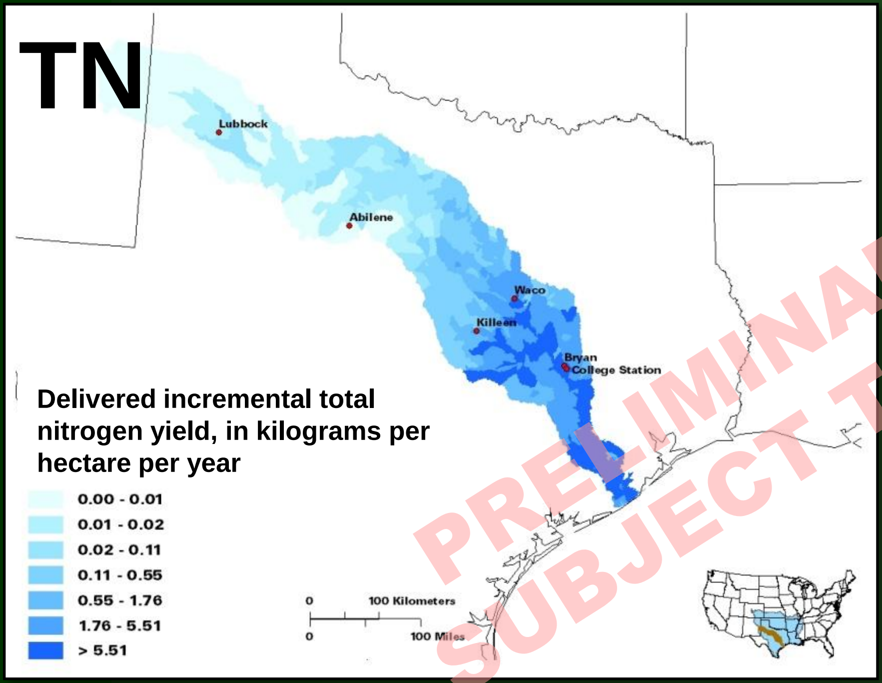
Delivered Incremental Yields Maps by Estuary

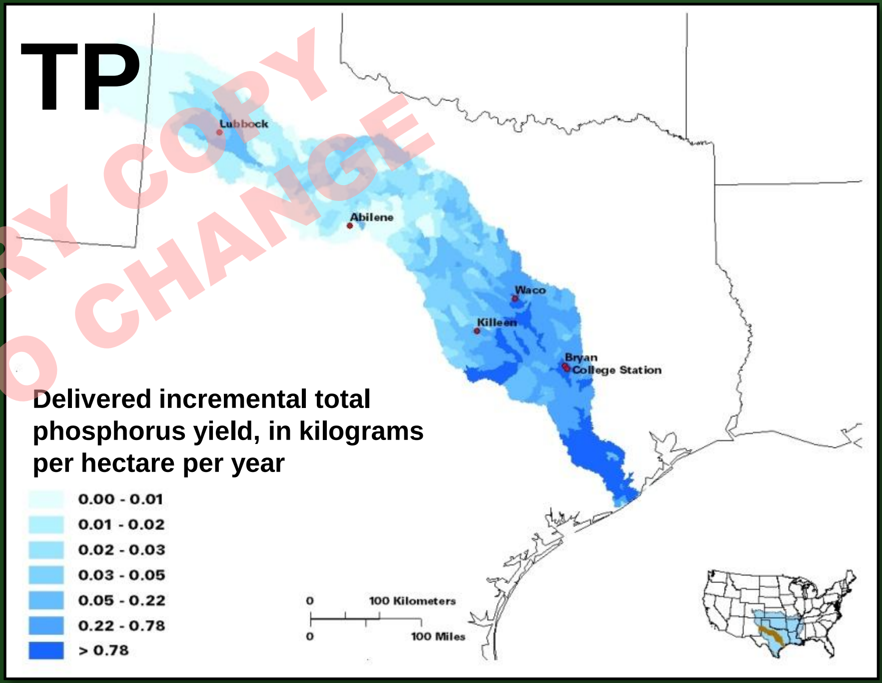




Trinity River/Galveston Bay estuary

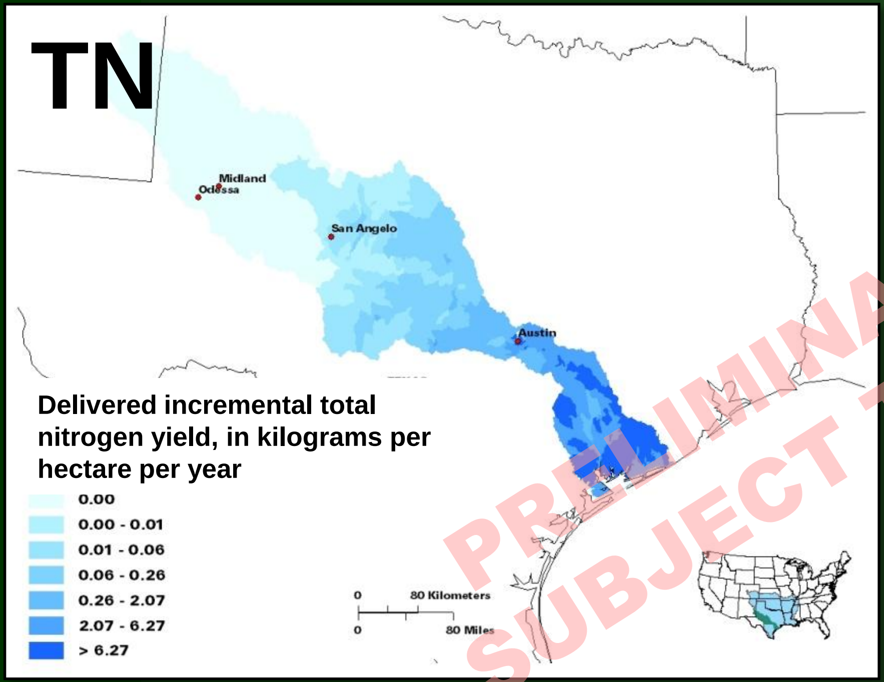
Delivered Incremental Yields Maps by Estuary

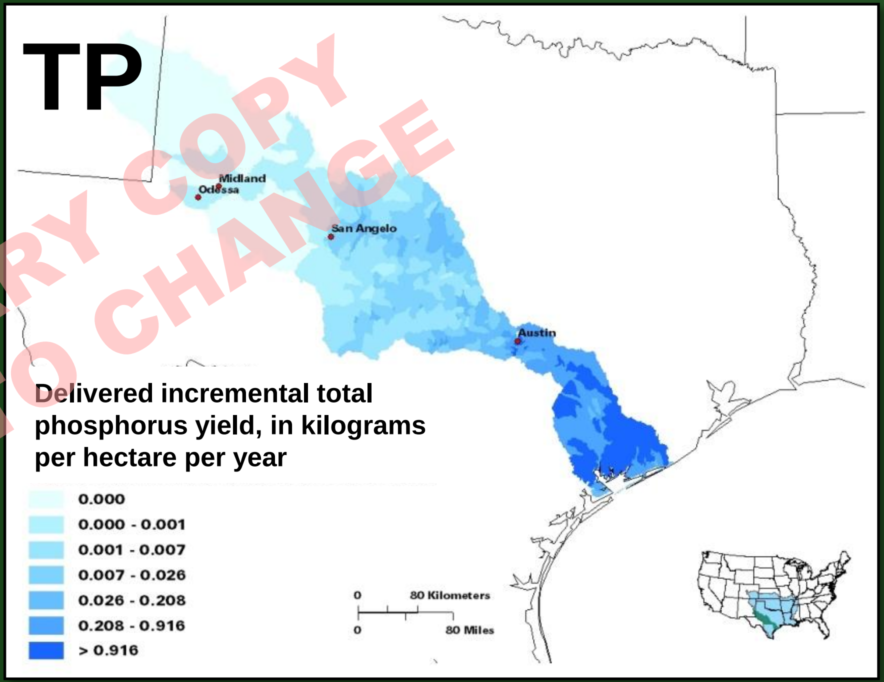




Brazos River estuary

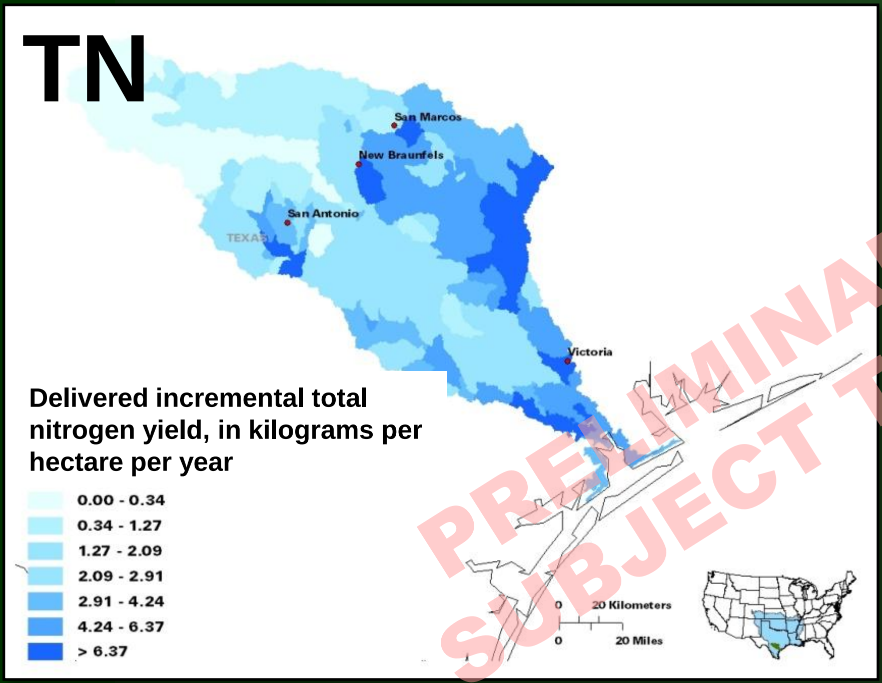
Delivered Incremental Yields Maps by Estuary

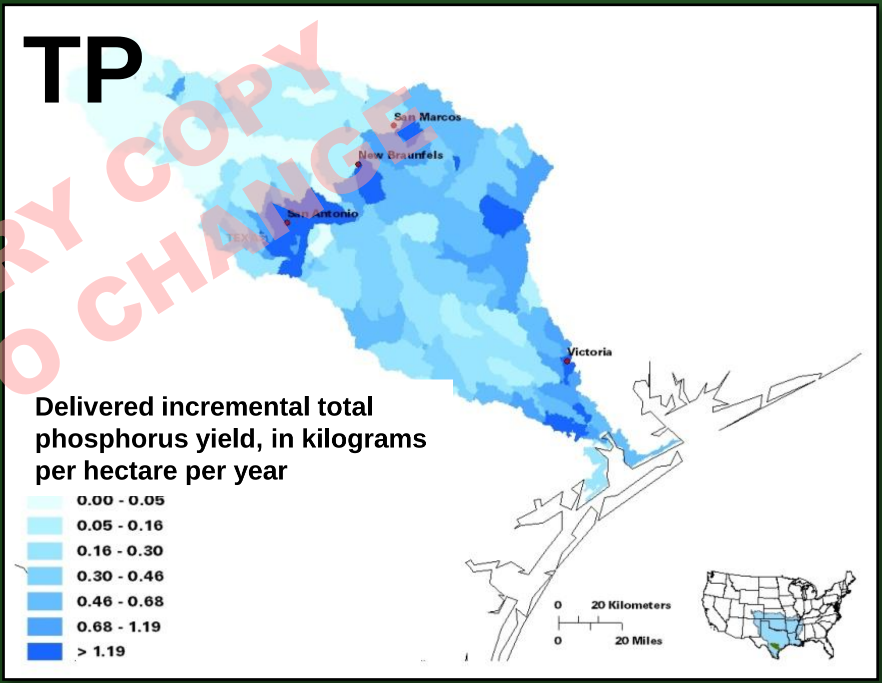




Colorado River/Matagorda Bay estuary

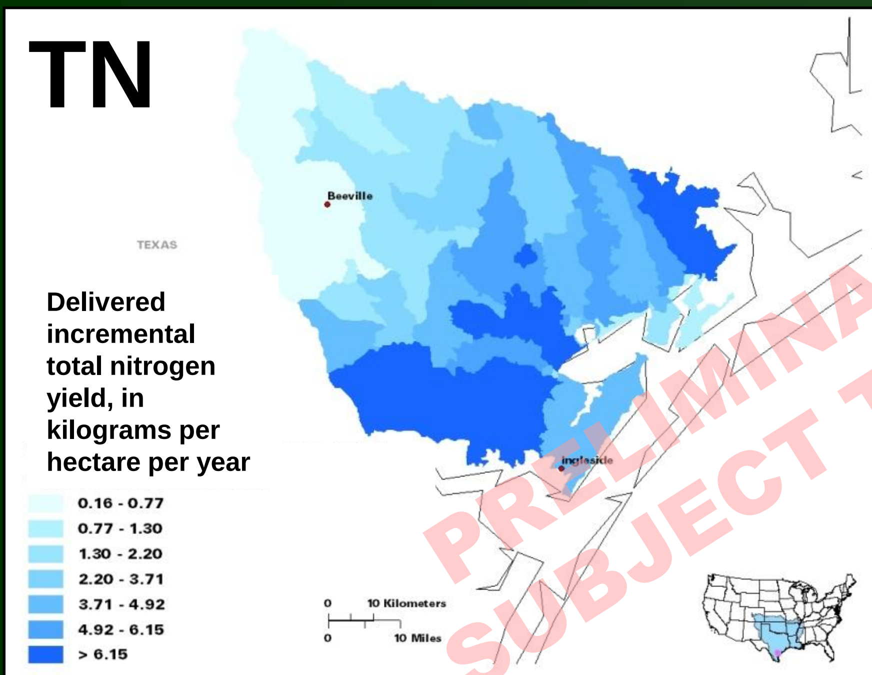
Delivered Incremental Yields Maps by Estuary

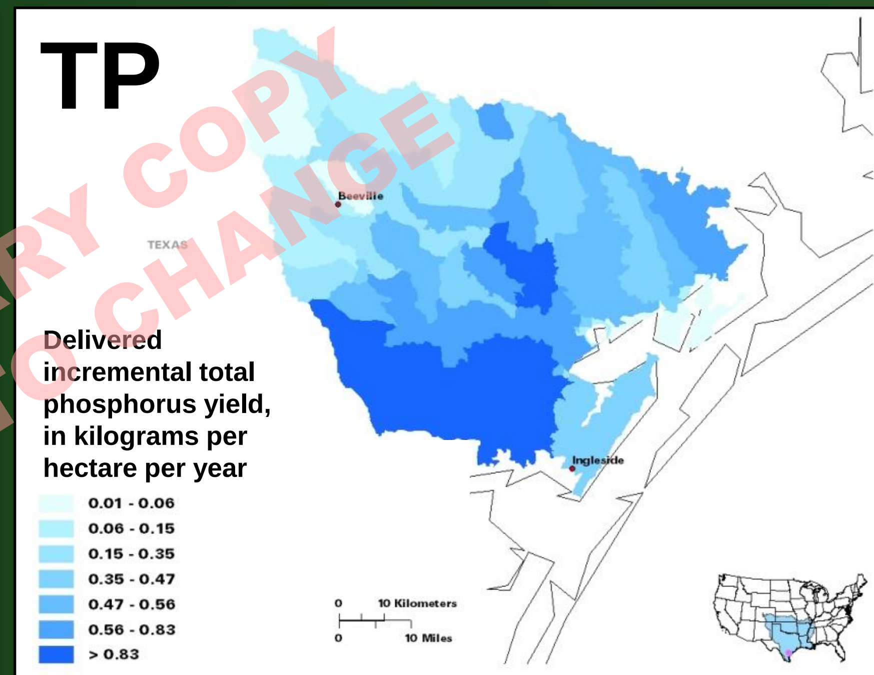




San Antonio and Guadalupe Rivers estuary

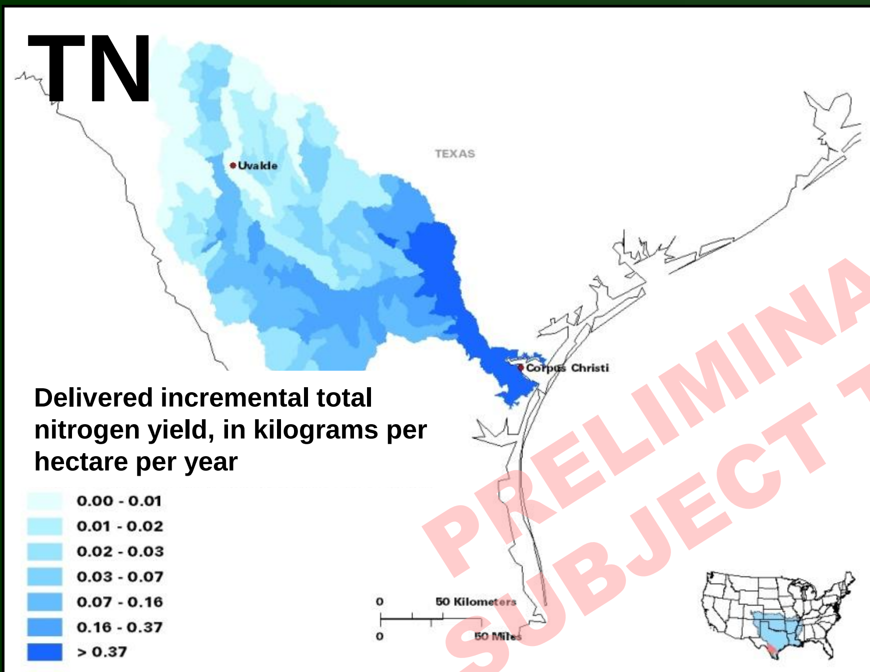
Delivered Incremental Yields Maps by Estuary

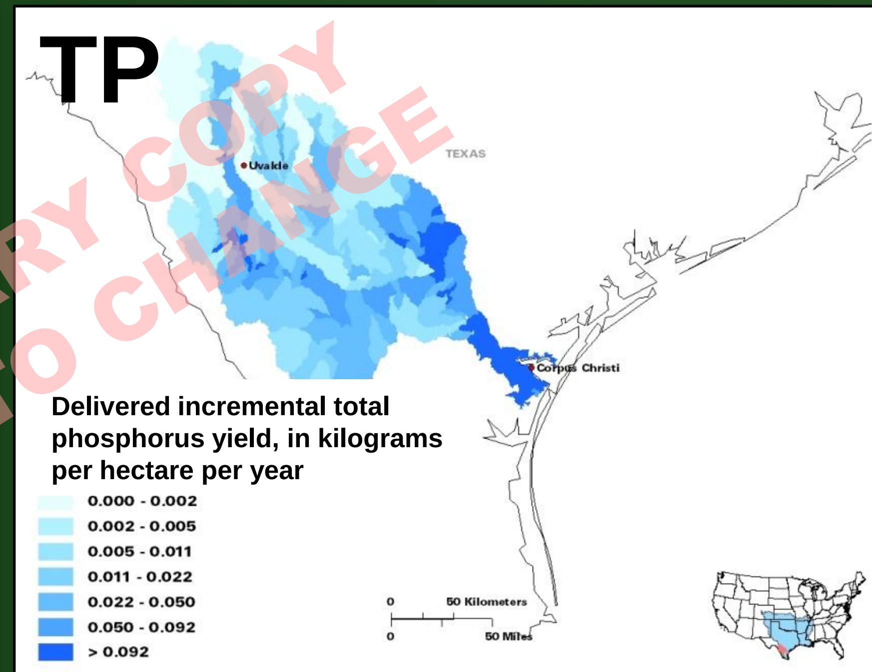




Aransas River estuary

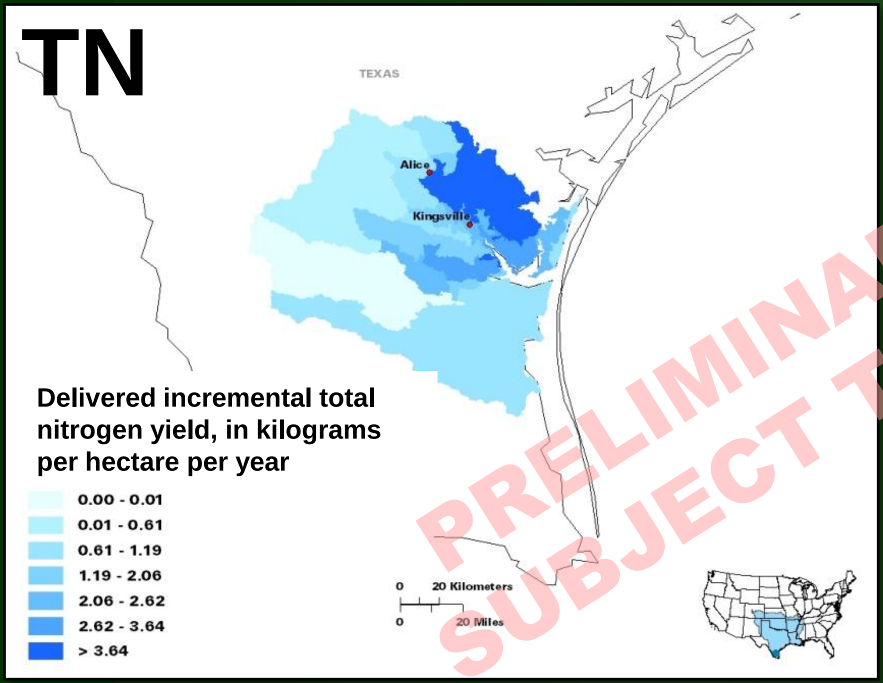
Delivered Incremental Yields Maps by Estuary

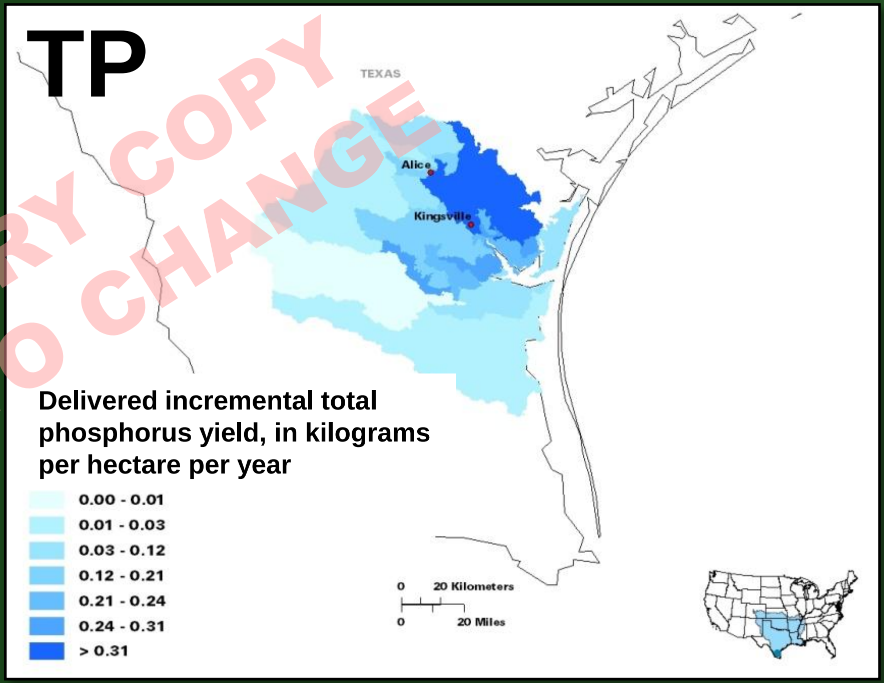




Nueces River/Corpus Christi Bay estuary

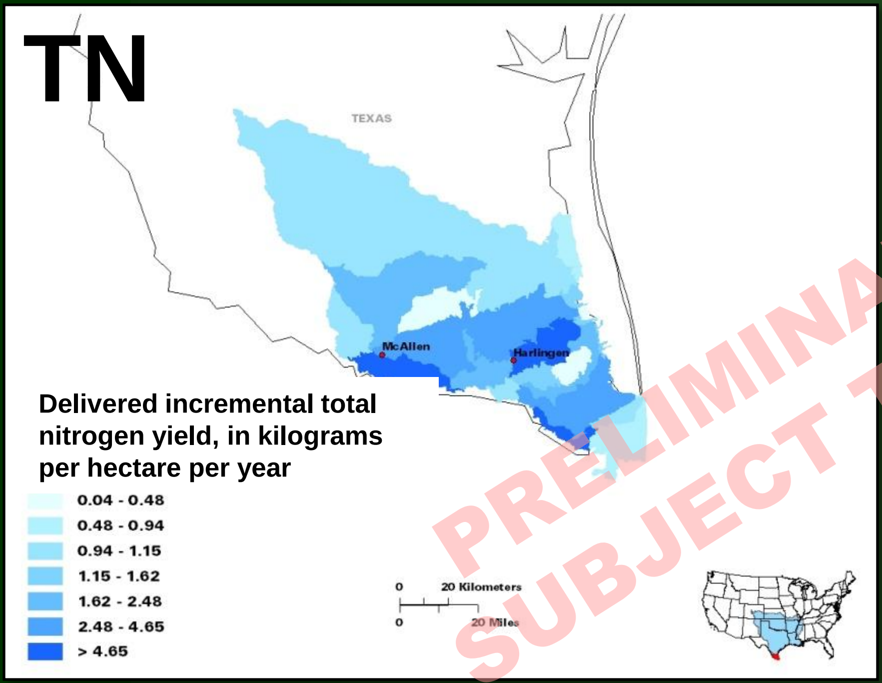
Delivered Incremental Yields Maps by Estuary

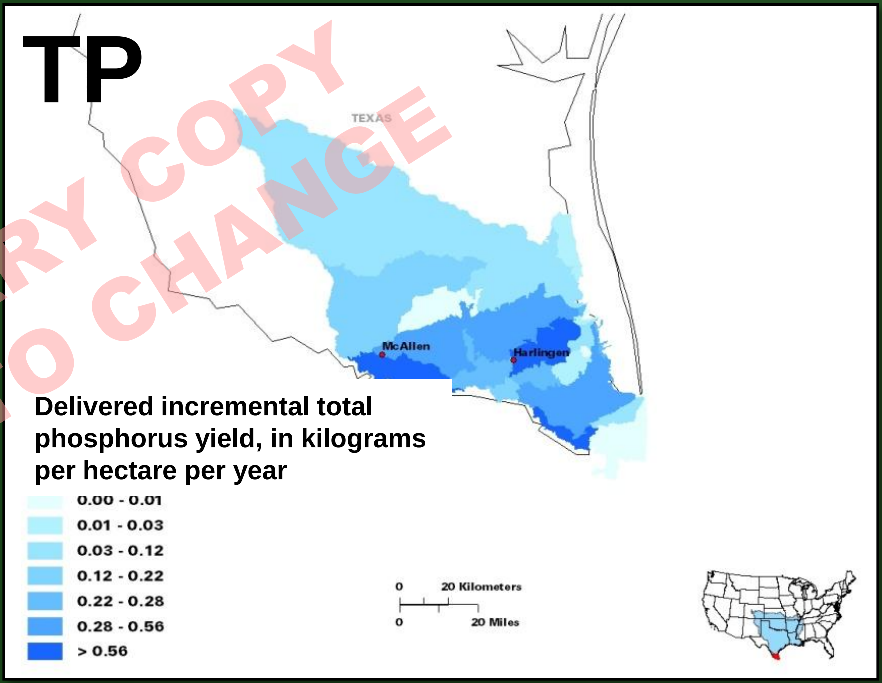




Upper Laguna Madre estuary

Delivered Incremental Yields Maps by Estuary



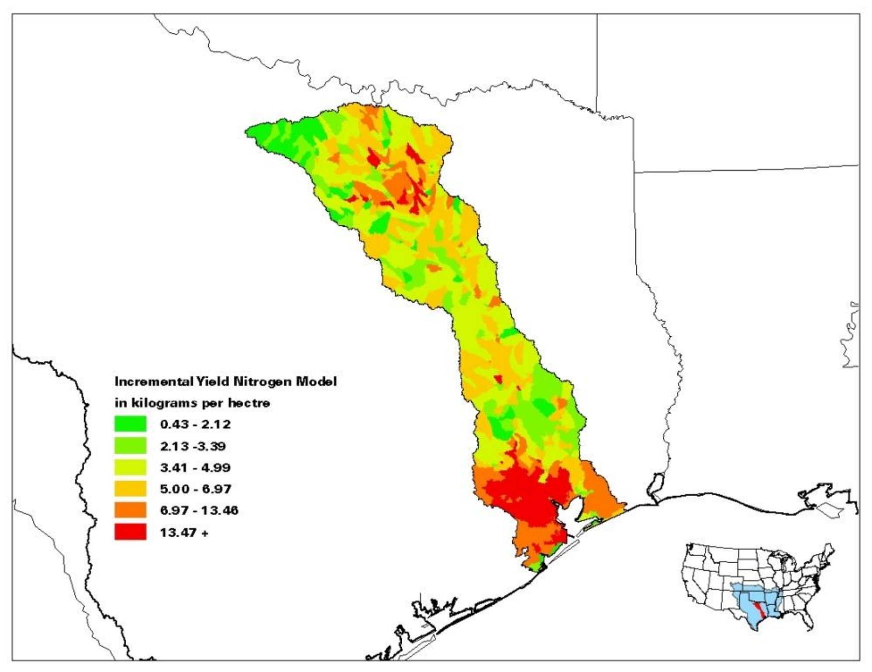


Lower Laguna Madre estuary

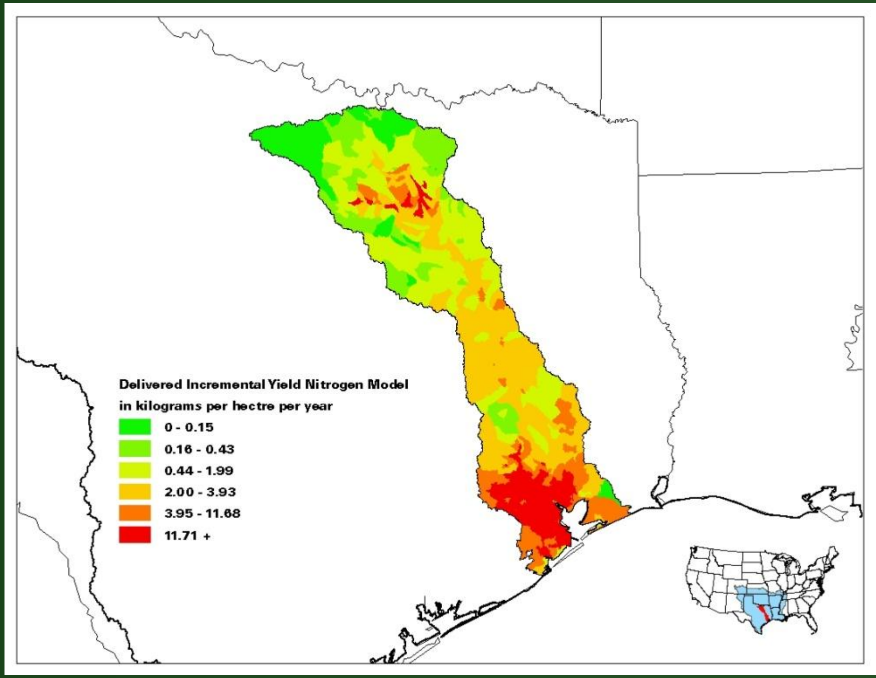
Other watershed-specific examples …

Yield plots

Catchment yield

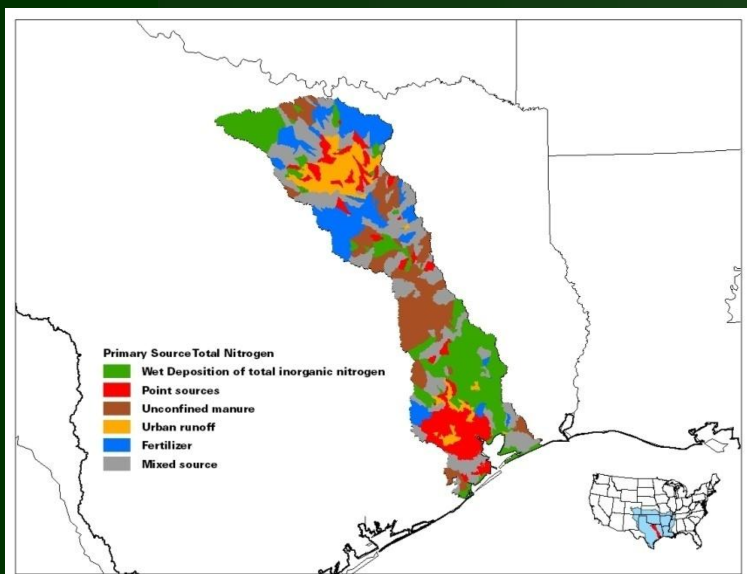


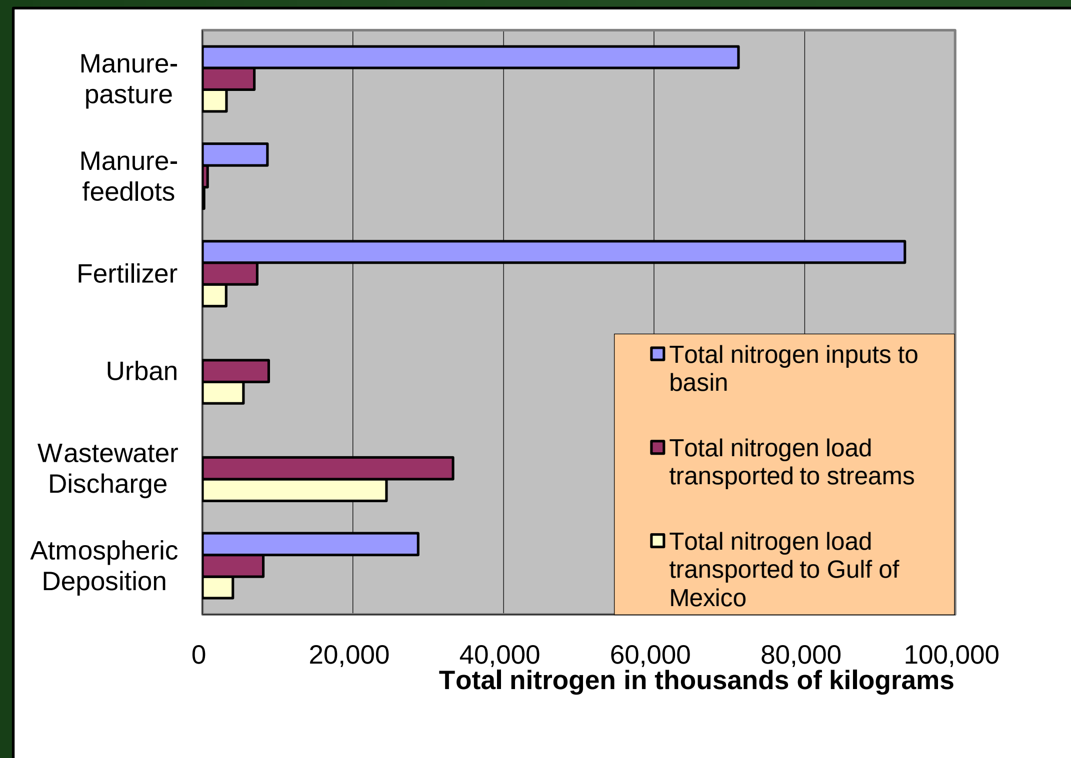
Catchment yield delivered to estuary



Other watershed-specific examples …

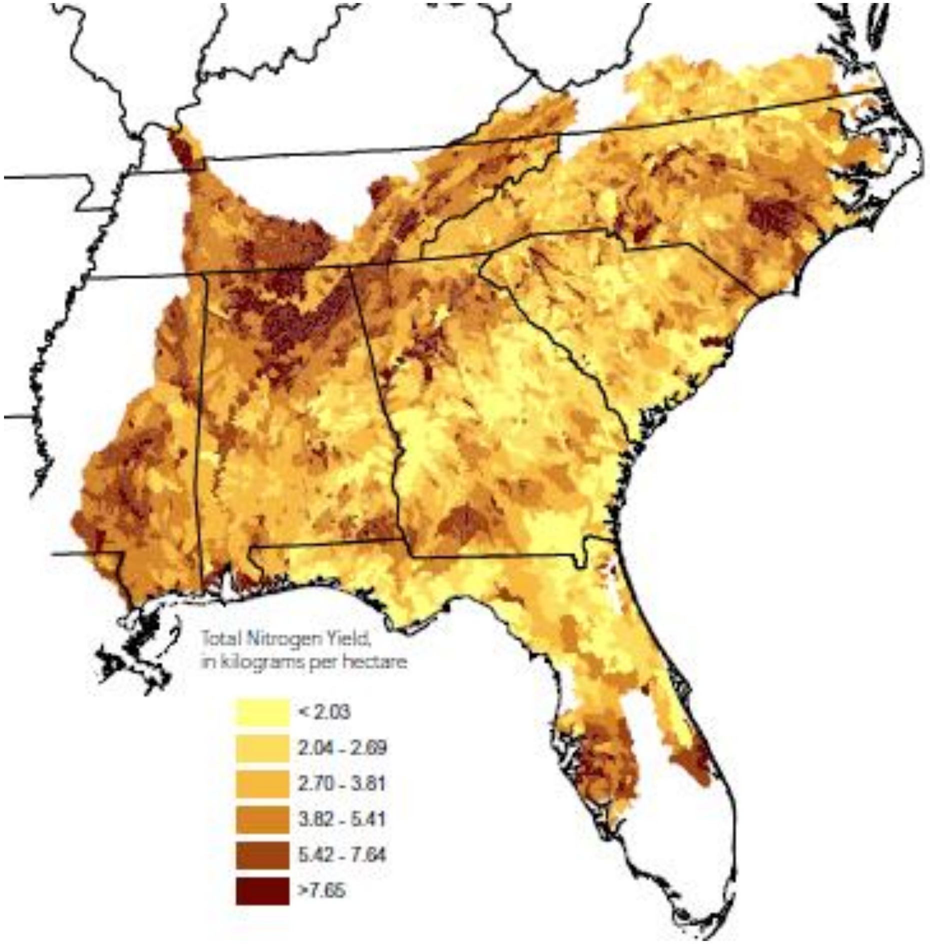
Source plots and bar charts





USGS

How have regional SPARROW model results been used throughout the southeast?



Total Nitrogen Regional Model

Available online at

http://water.usgs.gov/nawqa/pubs/nitrogen_loads

HYDROLOGICAL PROCESSES
Hydrol. Process. (2009)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/hyp.7323

Spatial analysis of instream nitrogen loads and factors controlling nitrogen delivery to streams in the southeastern United States using spatially referenced regression on watershed attributes (SPARROW) and regional classification frameworks†

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[1] *U.S. Geological Survey, Nashville, TN, USA*
[2] *U.S. Geological Survey, Raleigh, NC, USA*

Abstract:

Understanding how nitrogen transport across the landscape varies with landscape characteristics is important for developing sound nitrogen management policies. We used a spatially referenced regression analysis (SPARROW) to examine landscape characteristics influencing delivery of nitrogen from sources in a watershed to stream channels. Modelled landscape delivery ratio varies widely (by a factor of 4) among watersheds in the southeastern United States—higher in the western part (Tennessee, Alabama, and Mississippi) than in the eastern part, and the average value for the region is lower compared to other parts of the nation. When we model landscape delivery ratio as a continuous function of local-scale landscape characteristics, we estimate a spatial pattern that varies as a function of soil and climate characteristics but exhibits spatial structure in residuals (observed load minus predicted load). The spatial pattern of modelled landscape delivery ratio and the spatial pattern of residuals coincide spatially with Level III ecoregions and also with hydrologic landscape regions. Subsequent incorporation into the model of these frameworks as regional scale variables improves estimation of landscape delivery ratio, evidenced by reduced spatial bias in residuals, and suggests that cross-scale processes affect nitrogen attenuation on the landscape. The model-fitted coefficient values are logically consistent with the hypothesis that broad-scale classifications of hydrologic response help to explain differential rates of nitrogen attenuation, controlling for local-scale landscape characteristics. Negative model coefficients for hydrologic landscape regions where the primary flow path is shallow ground water suggest that a lower fraction of nitrogen mass will be delivered to streams; this relation is reversed for regions where the primary flow path is overland flow. Published in 2009 by John Wiley & Sons, Ltd.

Additional Supporting information may be found in the online version of this article.

KEY WORDS nutrients; total nitrogen; spatially referenced regression; watershed models; landscape attenuation

Received 24 November 2008; Accepted 10 March 2009

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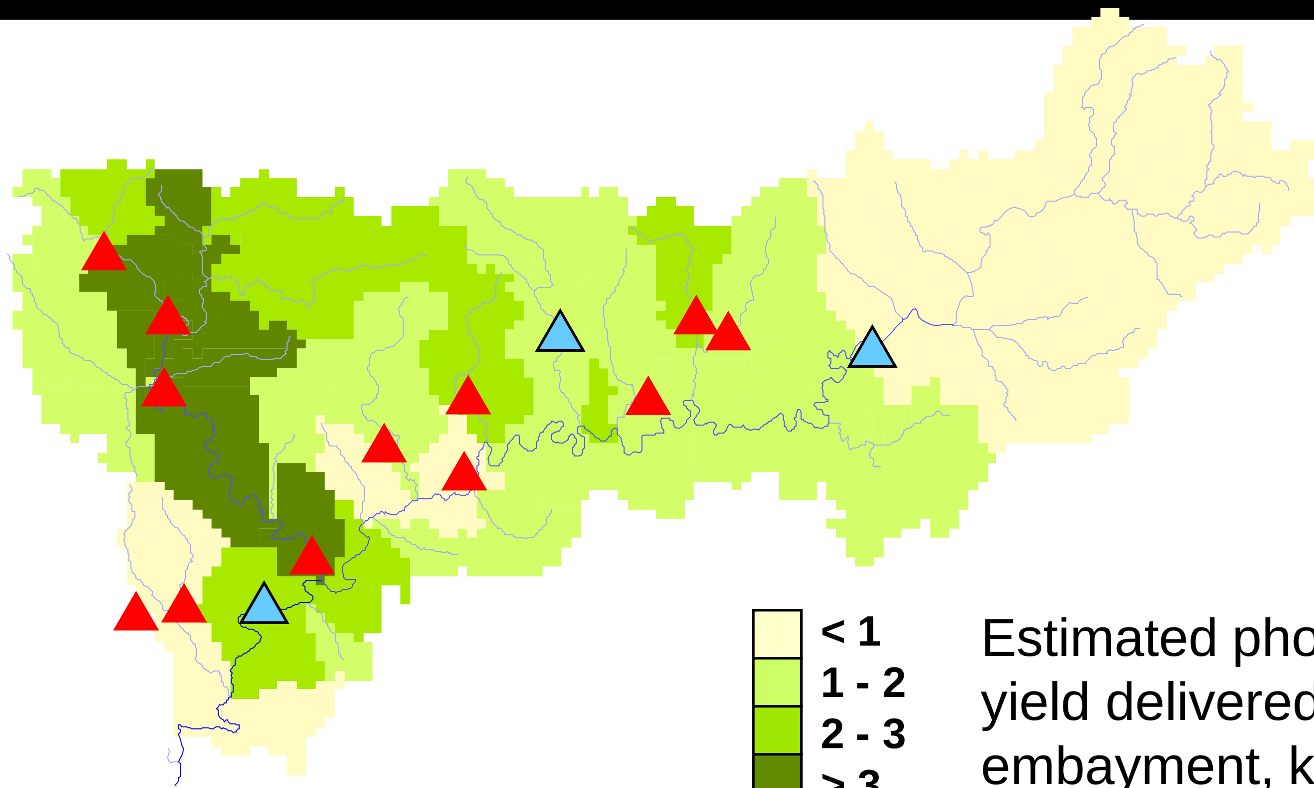
Validation of watershed models for Beaver Creek – Clinch River

Tennessee Division of Water Pollution Control

	HSPF (LSPC)	A-W model (GWLF)	SPARROW southeast region
Total Nitrogen, kg/yr	285,000	170,000	312,000

Additional monitoring to verify SPARROW model findings



< 1
1 - 2
2 - 3
> 3

Estimated phosphorus yield delivered to Elk River embayment, kg/ha/yr

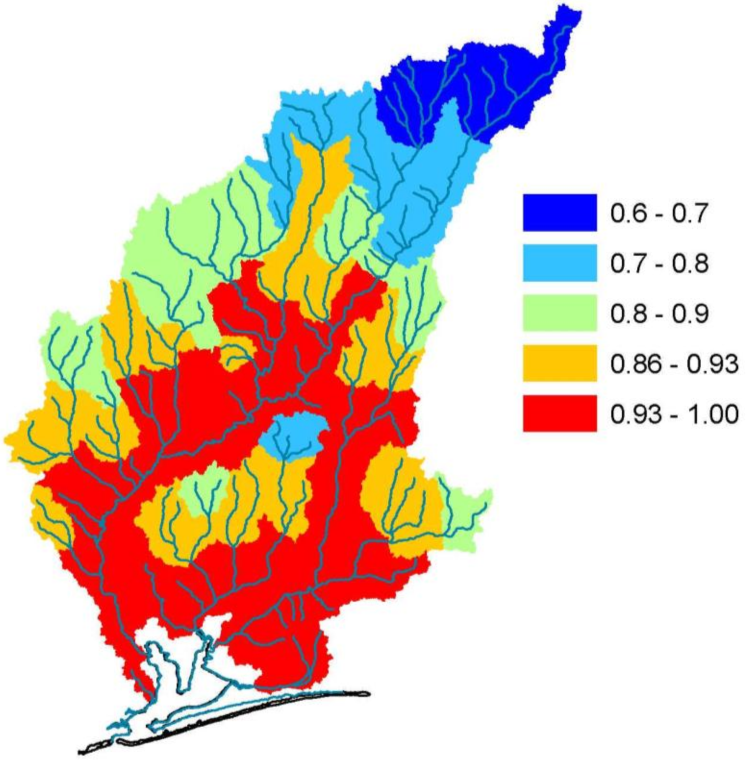
Historic sampling site (used in regional model)

Sampling site added in 2006

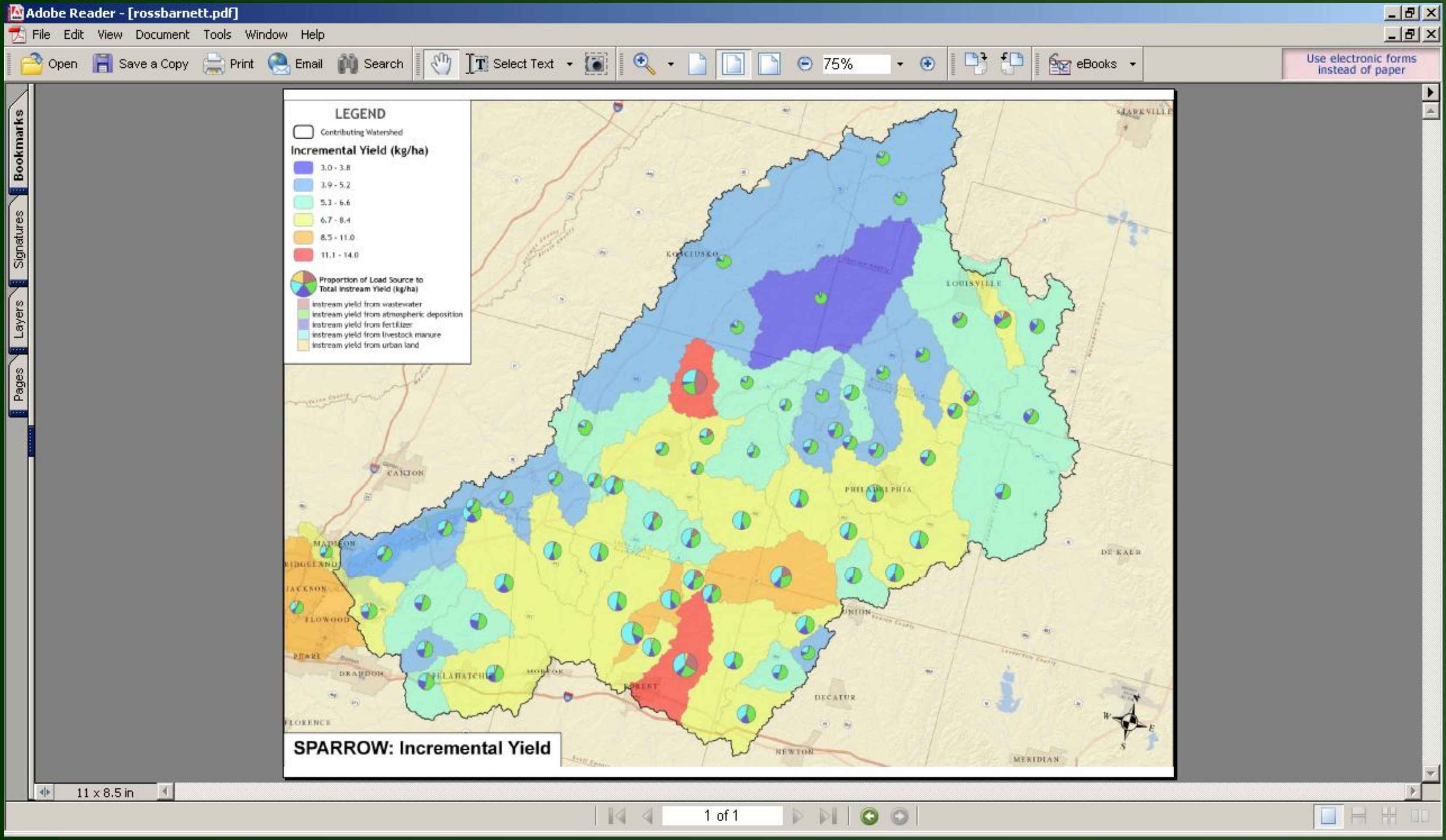
Calculate instream load and concentration to match a desired delivery rate to target – Florida streams

U.S. EPA Gulf Ecology Division – Richard Greene, Jim Hagy
greene.rick@epa.gov, hagy.jim@epa.gov,

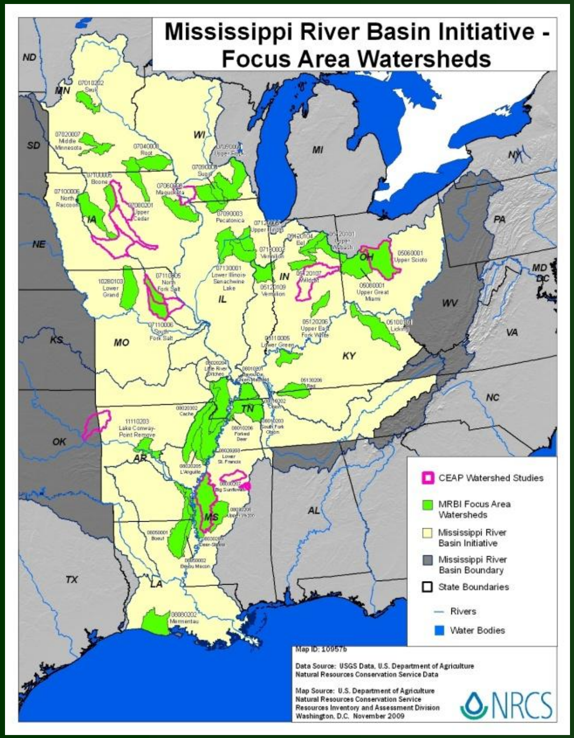
Uses SPARROW estimates of fraction of nitrogen delivered to Pensacola Bay

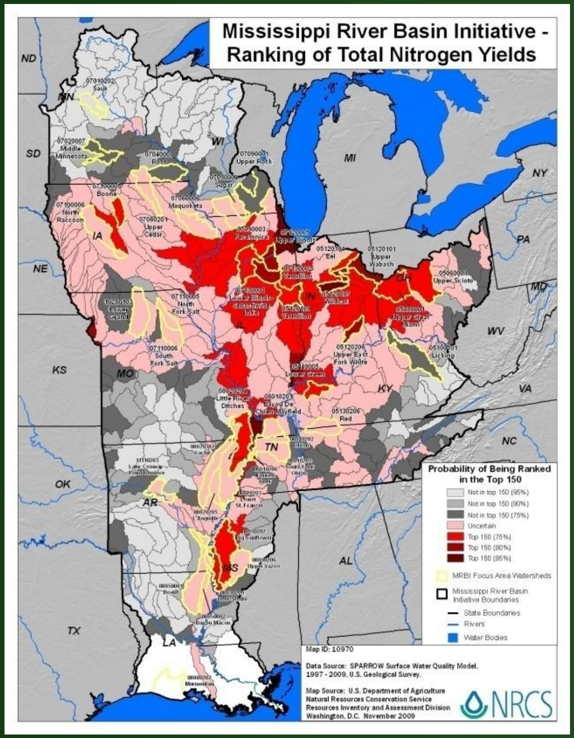


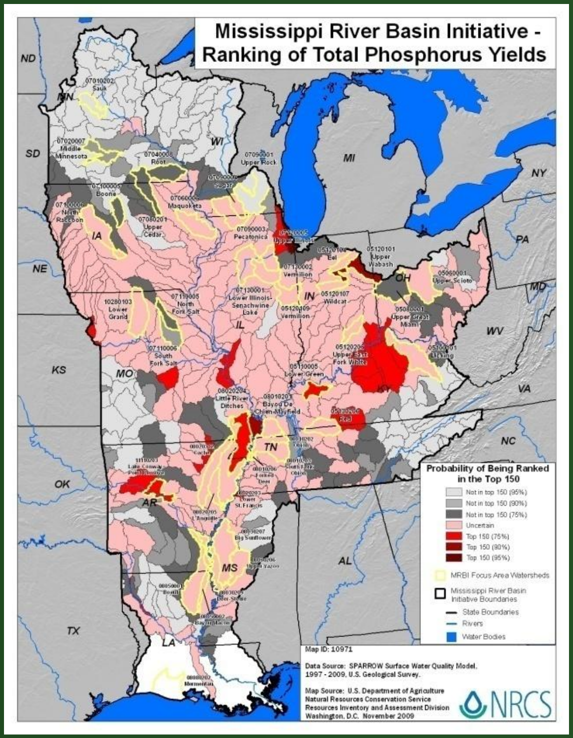
Ross Barnett Reservoir - Mississippi



Mississippi River Basin Healthy Watersheds Initiative – 41 Focus Watersheds selected

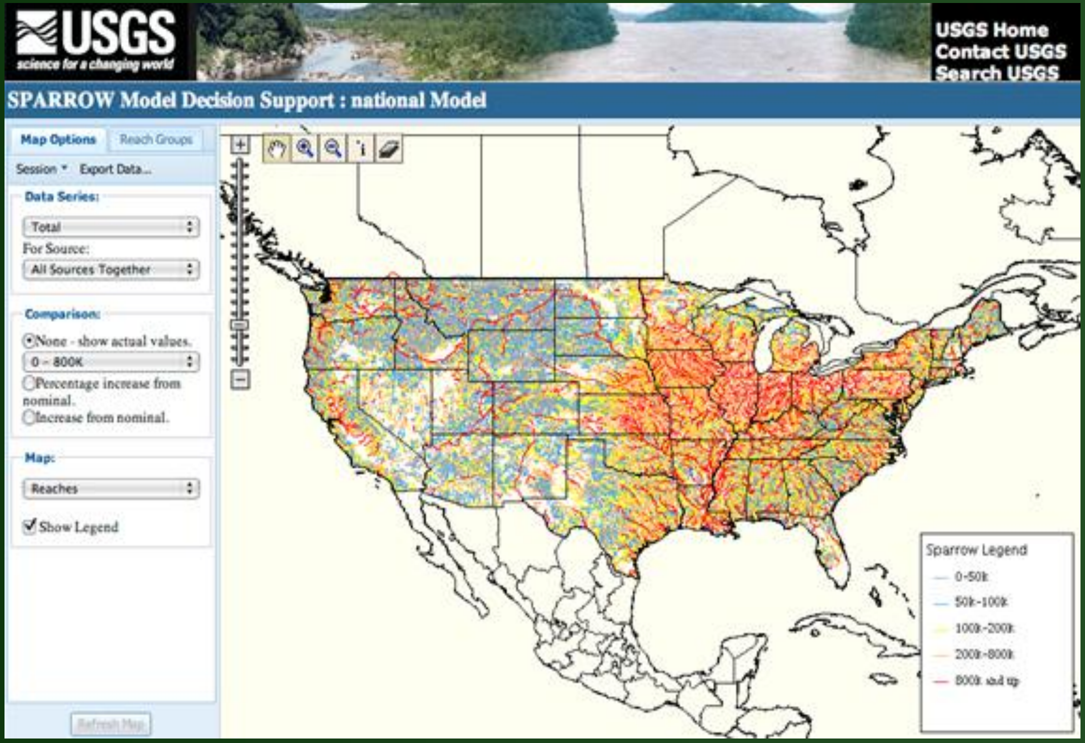






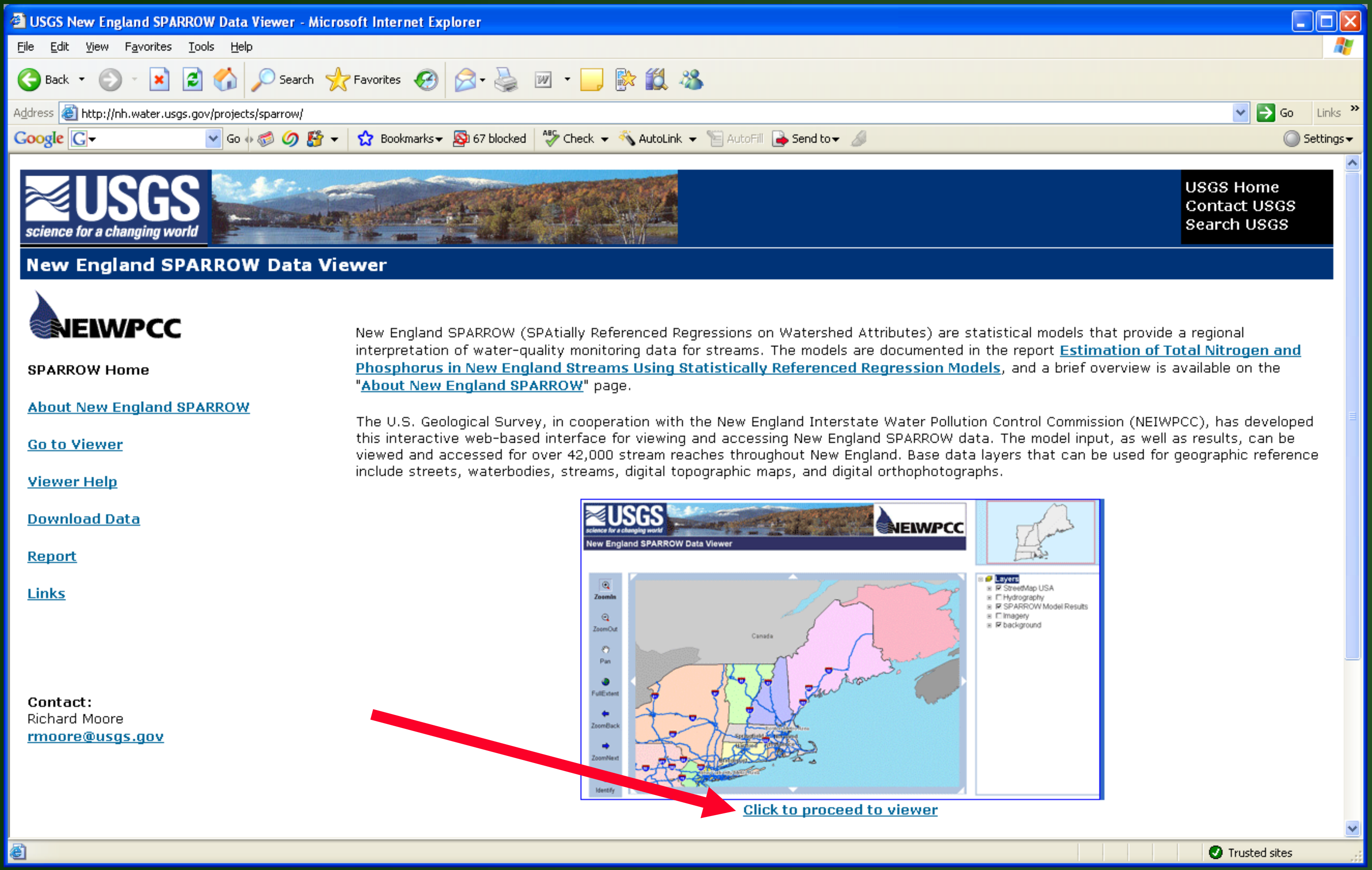
Nutrient Models—Decision Support Tools

Modeling decision support tools is being developed to enable managers to evaluate management scenarios and the associated environmental response and also incorporate economic aspects into the scenarios.

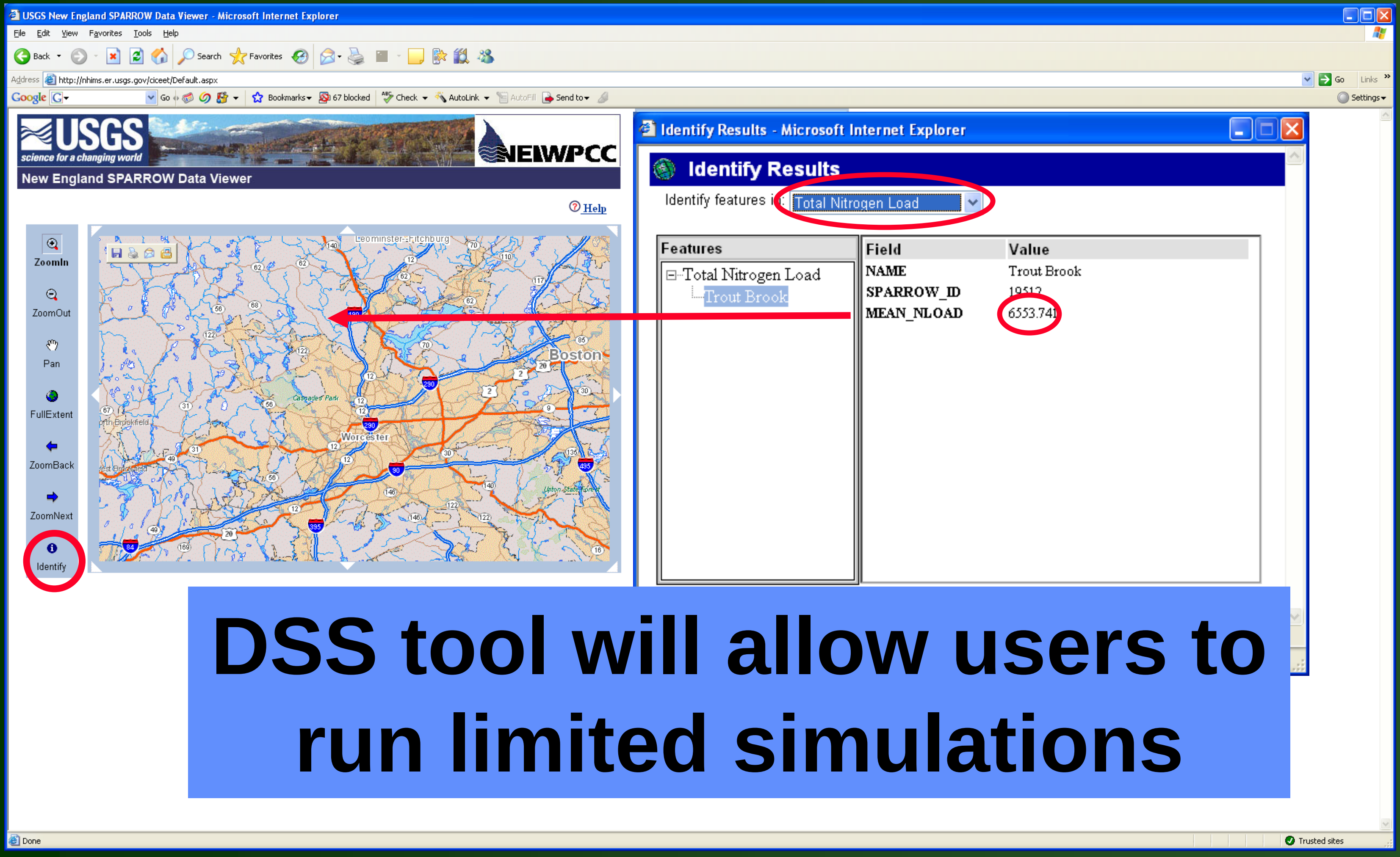


USGS

Decision Support Tool – available in 2011



Decision Support Tool …



DSS tool will allow users to run limited simulations

Next phase starting in FY2010

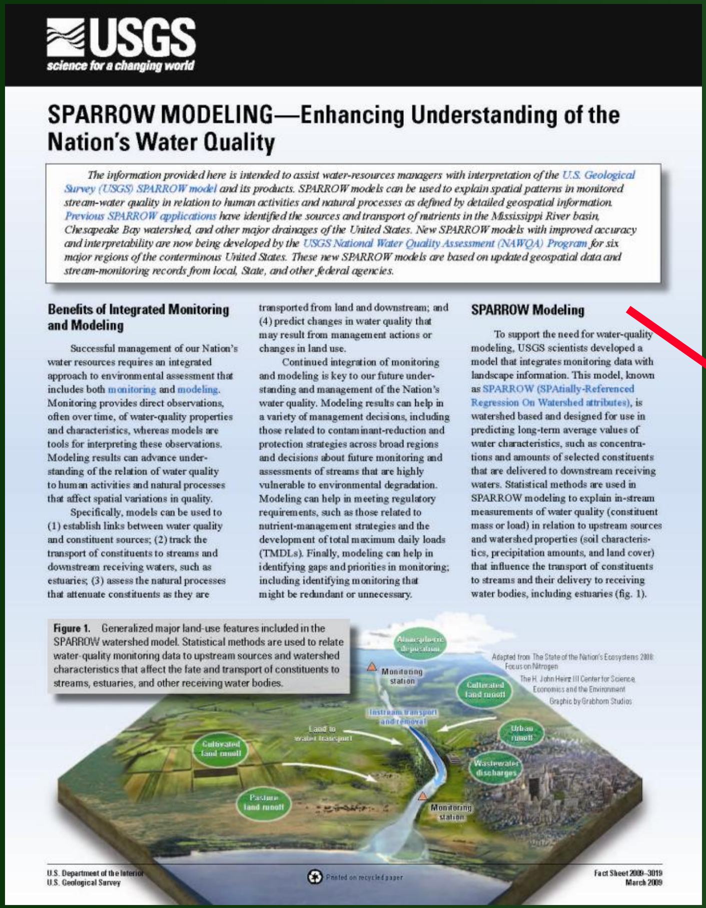
Upgrade to National Hydrography Dataset models begins in 2010

Why?

- **Will be able to add more load sites (about 50-100 more for MRB5)**
- **Better "plumbing"**

SPARROW Fact Sheet

- **For more information about model concepts:**



USGS
science for a changing world

SPARROW MODELING—Enhancing Understanding of the Nation's Water Quality

The information provided here is intended to assist water-resources managers with interpretation of the U.S. Geological Survey (USGS) SPARROW model and its products. SPARROW models can be used to explain spatial patterns in monitored stream-water quality in relation to human activities and natural processes as defined by detailed geospatial information. Previous SPARROW applications have identified the sources and transport of nutrients in the Mississippi River basin, Chesapeake Bay watershed, and other major drainages of the United States. New SPARROW models with improved accuracy and interpretability are now being developed by the USGS National Water Quality Assessment (NAWQA) Program for six major regions of the conterminous United States. These new SPARROW models are based on updated geospatial data and stream-monitoring records from local, State, and other federal agencies.

Benefits of Integrated Monitoring and Modeling

Successful management of our Nation's water resources requires an integrated approach to environmental assessment that includes both monitoring and modeling. Monitoring provides direct observations, often over time, of water-quality properties and characteristics, whereas models are tools for interpreting these observations. Modeling results can advance understanding of the relation of water quality to human activities and natural processes that affect spatial variations in quality.

Specifically, models can be used to (1) establish links between water quality and constituent sources; (2) track the transport of constituents to streams and downstream receiving waters, such as estuaries; (3) assess the natural processes that attenuate constituents as they are transported from land and downstream; and (4) predict changes in water quality that may result from management actions or changes in land use.

Continued integration of monitoring and modeling is key to our future understanding and management of the Nation's water quality. Modeling results can help in a variety of management decisions, including those related to contaminant-reduction and protection strategies across broad regions and decisions about future monitoring and assessments of streams that are highly vulnerable to environmental degradation. Modeling can help in meeting regulatory requirements, such as those related to nutrient-management strategies and the development of total maximum daily loads (TMDLs). Finally, modeling can help in identifying gaps and priorities in monitoring; including identifying monitoring that might be redundant or unnecessary.

SPARROW Modeling

To support the need for water-quality modeling, USGS scientists developed a model that integrates monitoring data with landscape information. This model, known as SPARROW (SPAtially-Referenced Regression On Watershed attributes), is watershed based and designed for use in predicting long-term average values of water characteristics, such as concentrations and amounts of selected constituents that are delivered to downstream receiving waters. Statistical methods are used in SPARROW modeling to explain in-stream measurements of water quality (constituent mass or load) in relation to upstream sources and watershed properties (soil characteristics, precipitation amounts, and land cover) that influence the transport of constituents to streams and their delivery to receiving water bodies, including estuaries (fig. 1).

Figure 1. Generalized major land-use features included in the SPARROW watershed model. Statistical methods are used to relate water-quality monitoring data to upstream sources and watershed characteristics that affect the fate and transport of constituents to streams, estuaries, and other receiving water bodies.

Adapted from The State of the Nation's Ecosystems 2008: Focus on Nitrogen
The H. John Heinz III Center for Science, Economics and the Environment
Graphic by Grabhorn Studios

Monitoring station
Cultivated land runoff
Land to water transport
Urban runoff
Wastewater discharges
Pasture land runoff
Monitoring station

U.S. Department of the Interior
U.S. Geological Survey
Printed on recycled paper
Fact Sheet 2009–3019
March 2009

SPARROW home page:
http://water.usgs.gov/nawqa/sparrow/

SPARROW fact sheet:
http://pubs.usgs.gov/fs/2009/3019/

Questions?

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