

Tracking Nutrient Delivery from Upland Watersheds to Coastal Waters

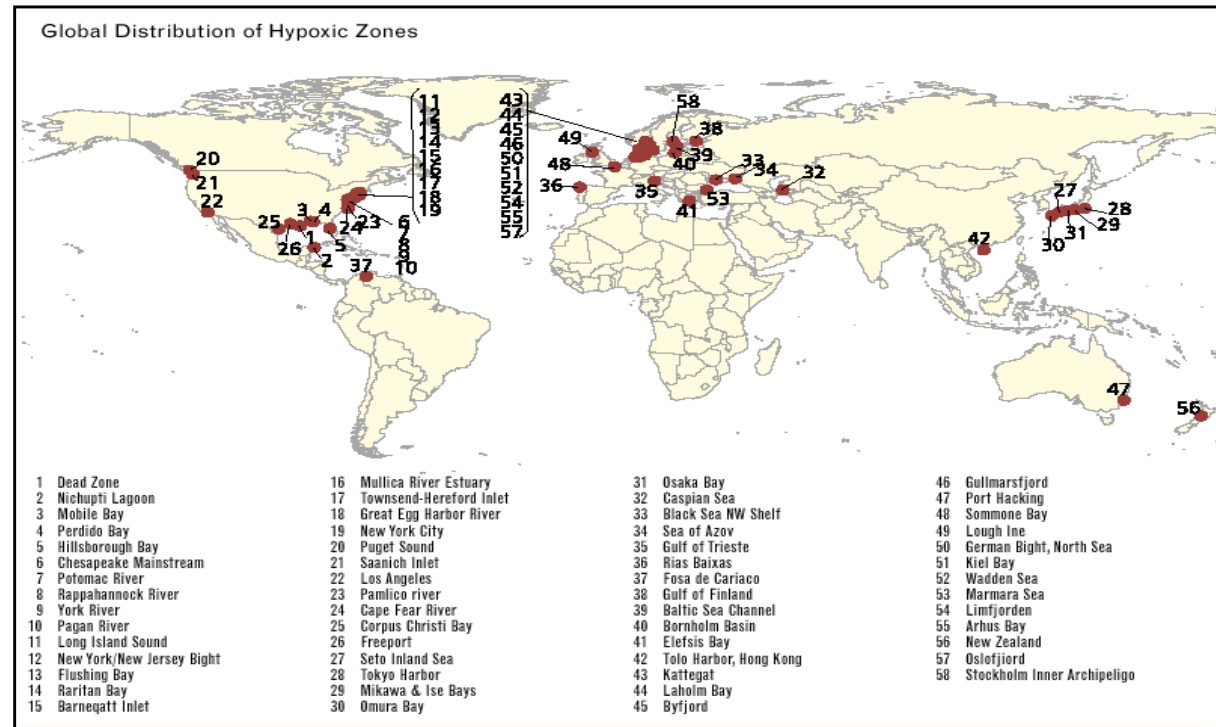


**USDA-CSREES 2009
National Water
Conference**

**St. Louis, Missouri
February 8-12, 2009**

Richard B. Alexander
U.S. Geological Survey
Reston, VA

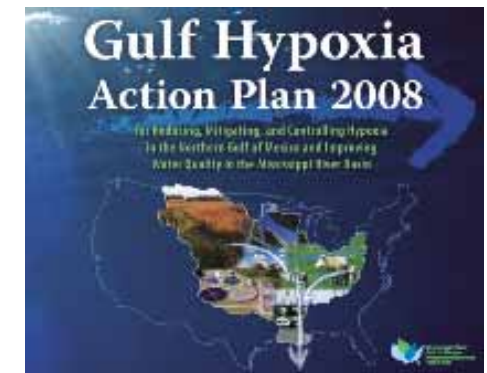
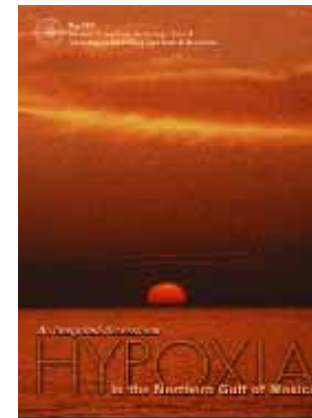
Stressed estuarine trophic conditions related to elevated nutrients globally



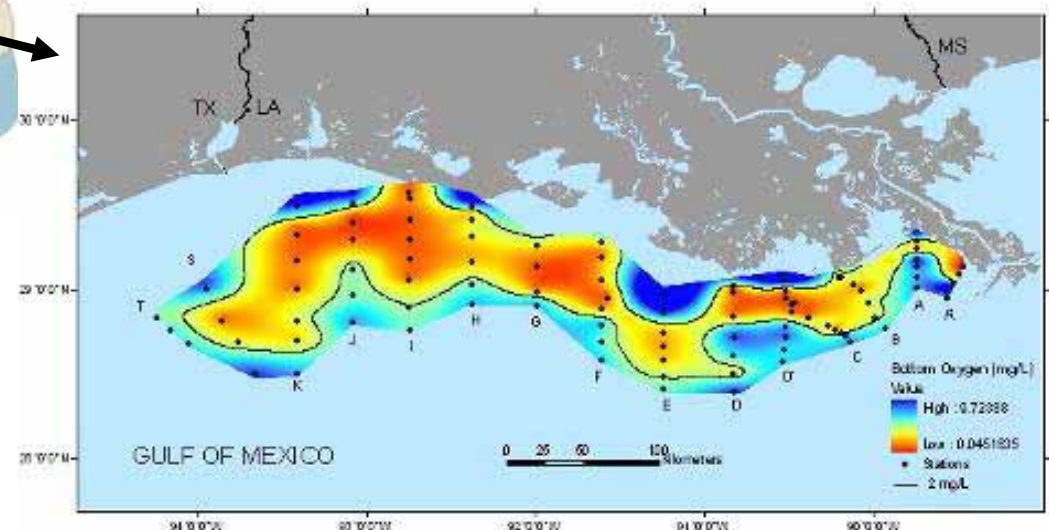
From Burke et al. 2000



Elevated nutrients in riverine loads have contributed to seasonal occurrence of hypoxia in the northern Gulf of Mexico



Hypoxic zone in July 2007
~8,000 km² (about the size of the state of Mass.; 3rd largest since 1985)



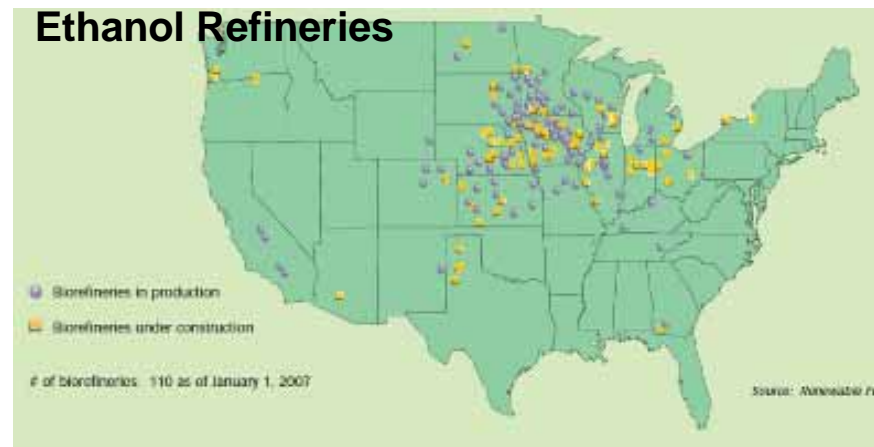
Challenges and Progress in Tracking Nutrient Sources through Monitoring, Research, and Modeling



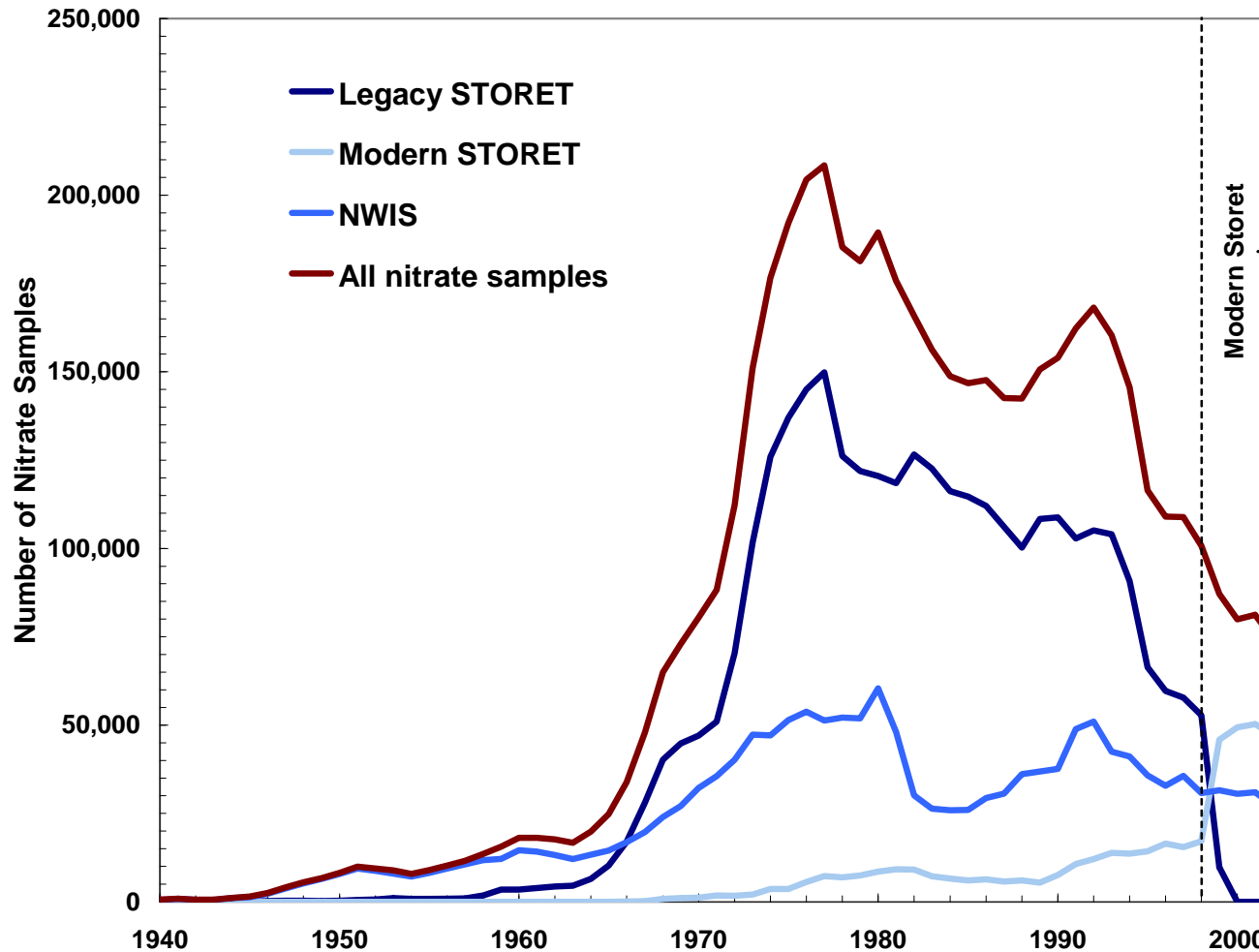
Mississippi/Atchafalaya
River Basin



Ethanol Refineries



Monitoring records of nitrate-nitrogen for U.S. Streams have declined since 1970s



- Streamflow collected at few water-quality sites (e.g., In SE US streams, <25% of sites co-located)!

- Nutrient mass flux cannot be calculated without flow data

- Flow and flux required to track sources and assess processes in models

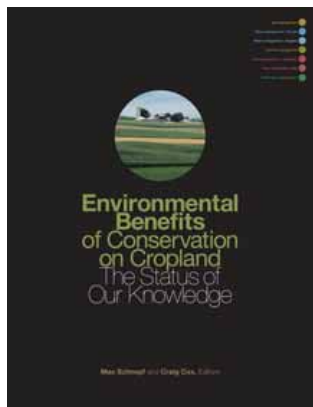
Progress in Assessing Field- and Catchment-Scale Measurements

USDA CEAP

Assessment of Agricultural Conservation Effects



J. Soil Water Conserv.,
v. 63, Dec 2008



Literature Review of
Effects of Conservation
Practices

SWCS, Schnepf and Cox
(eds.) 2006

USGS NAWQA

Sources and Fate of Nutrients and Pesticides in Water and Biota

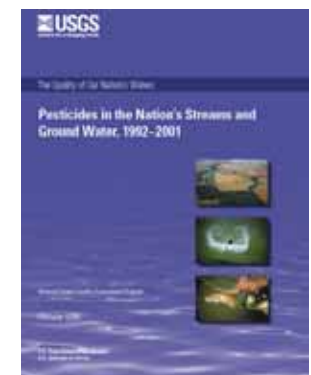


J. Environ. Qual., v. 37,
May/June 2008



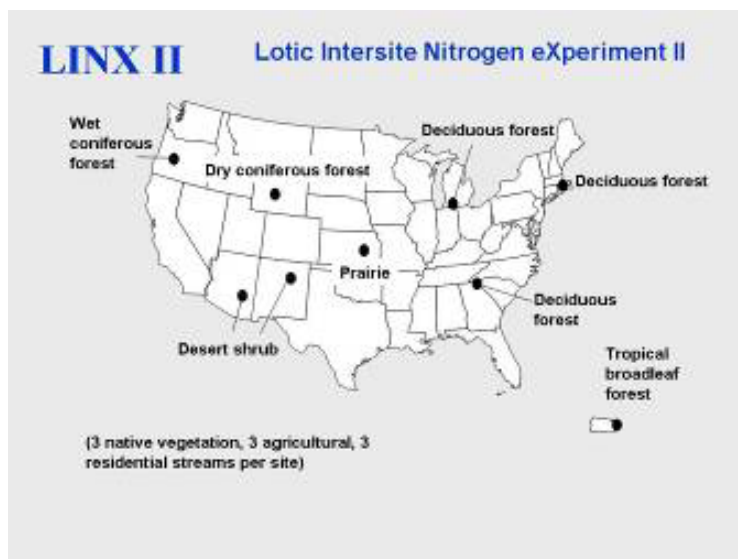
Synthesis of NAWQA
Pesticide Studies

Gilliom et al. 2006



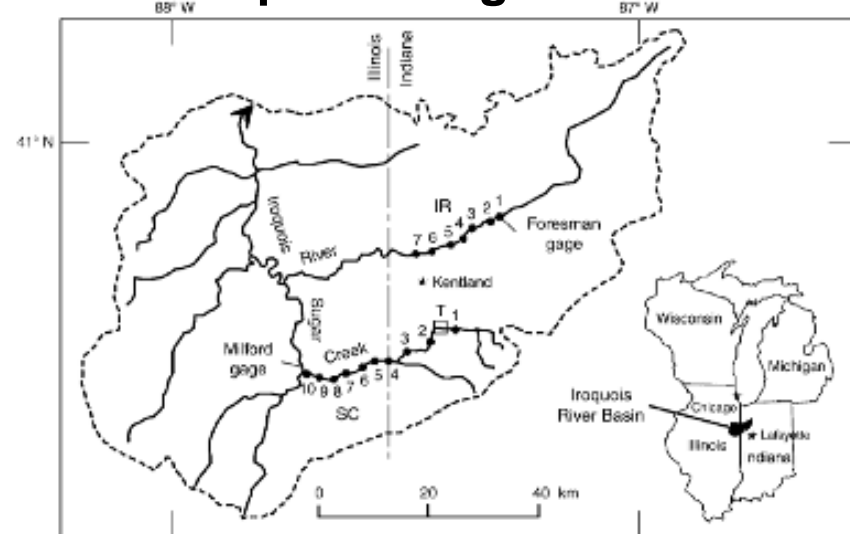
Progress in Assessing Field- and Catchment-Scale Measurements

Reach-Scale Studies of Nitrogen Loss via Stream Denitrification



Mulholland et al. *Nature*, 2008, v. 452, 202-205

USGS Iroquois / Sugar Creek Studies



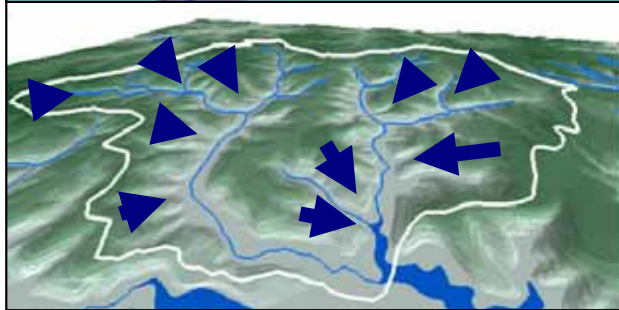
Smith et al. *Ecol. Apps*, 2006, v. 16, 2191-2207

See related modeling syntheses: *Biogeochemistry* special issue (*in press*) (8 articles now available in “Online First”)

Challenges in “Scaling Up” to Large Watersheds using Models



- Limited knowledge of rate-controlling variables across a wide range of environmental conditions



- Poor geospatial data descriptions of certain environmental conditions that limit model applications

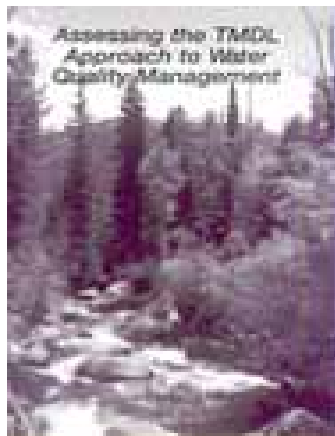


Progress in Applications of Large Watershed Models

Parsimony vs. Complexity Debate

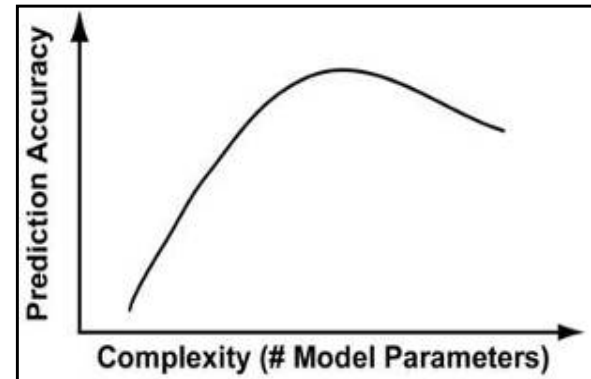
A New Modeling Paradigm

- Increasing recognition of the value of evaluating parsimonious models, using parameter estimation (e.g., PEST) in models (e.g., MODFLOW-2000, SWAT, SPARROW)



NRC study (2001) recommends use of parsimonious models for TMDLs

Model Complexity \neq Accuracy

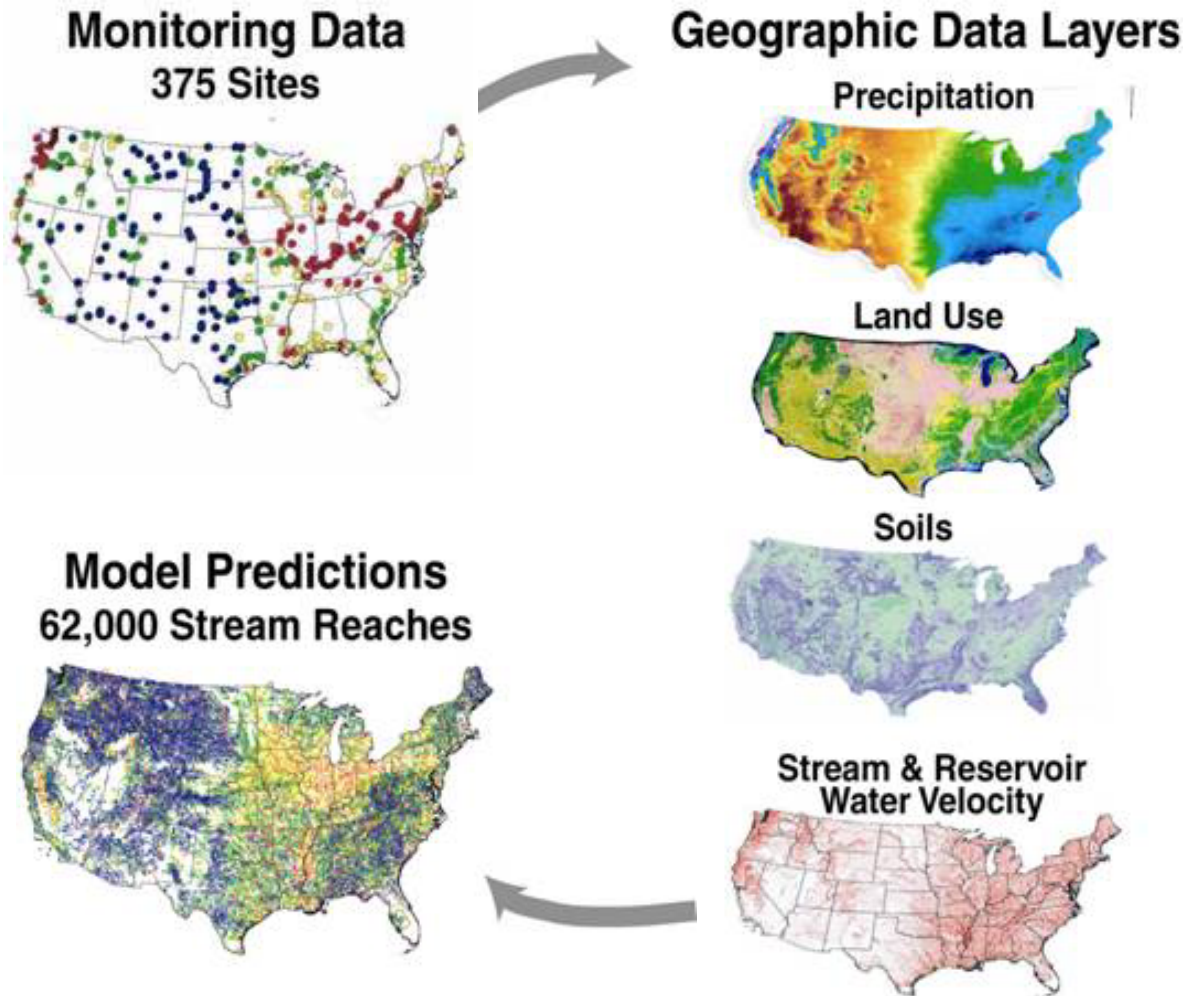


Hypothetical illustration of relation of model accuracy to complexity (after Schwarz et al., 2006)

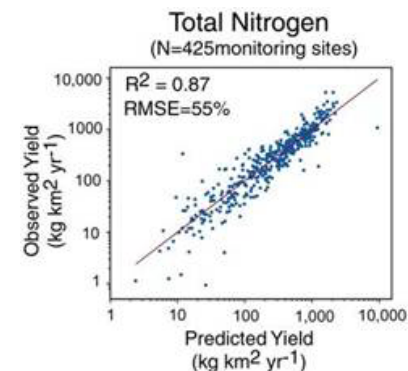
- Insight from estimating model parameters and uncertainties:
 - How much model complexity and process interpretation is supported by the data?
 - More transparent reporting of model limitations and prediction uncertainties

SPARROW Water-Quality Model

SPATIALLY Referenced REGRESSION ON WATERSHED ATTRIBUTES (Smith et al., 1997)



- Stream nutrient loads explained by geospatial data on nutrient sources and transport factors
- Uses mechanistic and statistical features to improve model interpretability and prediction accuracy:
 - Non-linear structure
 - Mass-balance constraints
 - Non-conservative transport
 - Land / water separation of processes and sources
 - **Parameter estimation using non-linear regression**



SPARROW Model Predictions and Uses

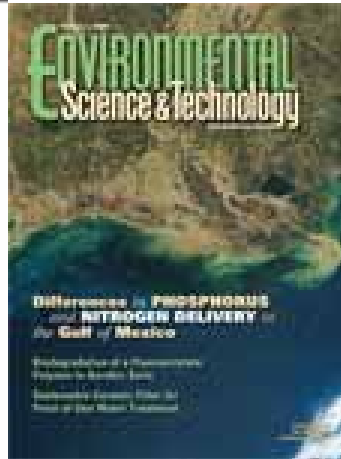
- Predicts mean annual loads, yields, and concentrations (*and uncertainties*) in unmonitored stream reaches
- Apportions stream loads to major nutrient sources and upstream watersheds
- Assesses the effects of hydrological and biogeochemical processes on nutrient transport and fate in watersheds
- Simulates stream water-quality response to future changes in land use and climate
- Informs network monitoring and use of watershed management simulation models

SPARROW Study of Nutrient Sources in the Mississippi River Basin (Feb. 2008)

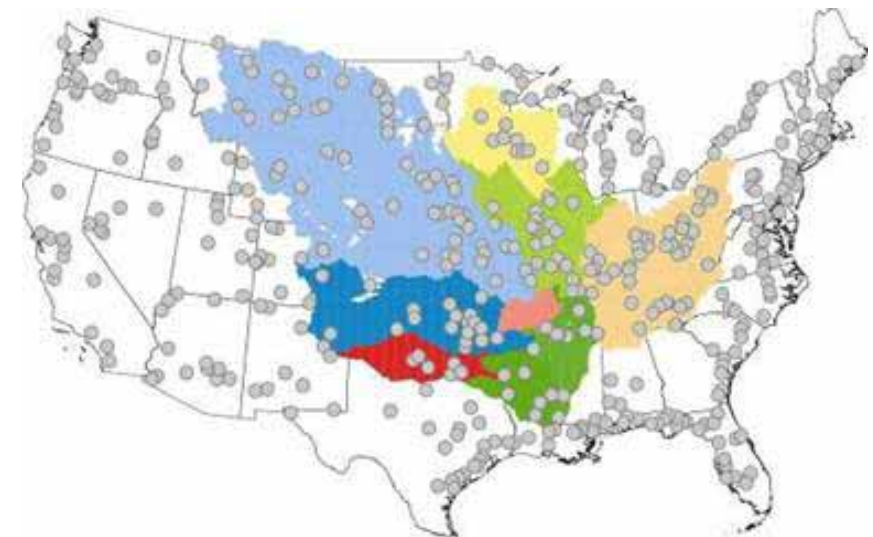
Differences in Phosphorus and Nitrogen Delivery to The Gulf of Mexico from the Mississippi River Basin

RICHARD B. ALEXANDER,^{*,†}
RICHARD A. SMITH,[†]
GREGORY E. SCHWARZ,[†]
ELIZABETH W. BOYER,[†]
JACQUELINE V. NOLAN,[†] AND
JOHN W. BRAKEBILL[§]

National Water Quality Assessment Program, U.S. Geological Survey, 413 National Center, Reston, Virginia 20192, Department of Environmental Science, Policy, and Management, University of California, Berkeley, California 94720, Maryland-Delaware State Science Center, and U.S. Geological Survey, Baltimore, Maryland 21228



Mississippi and Atchafalaya River Basins (MARB)



FAQ and other supporting information:
http://water.usgs.gov/nawqa/sparrow/gulf_findings

Statistically significant sources and transport features

NUTRIENT SOURCES#

- Urban and population-related sources
- Atmospheric N deposition
- Cultivated crops:
 - Farm fertilizer sales for corn, soybeans, cotton, wheat, other crops
 - N₂ fixation – cultivated lands
 - Recoverable manure applied
- Non-recoverable animal manure
 - Unconfined wastes excreted on pasture and rangelands
 - Confined operation losses
- Natural background and residual sources (lands in forest, barren, shrub)

LAND-TO-WATER DELIVERY

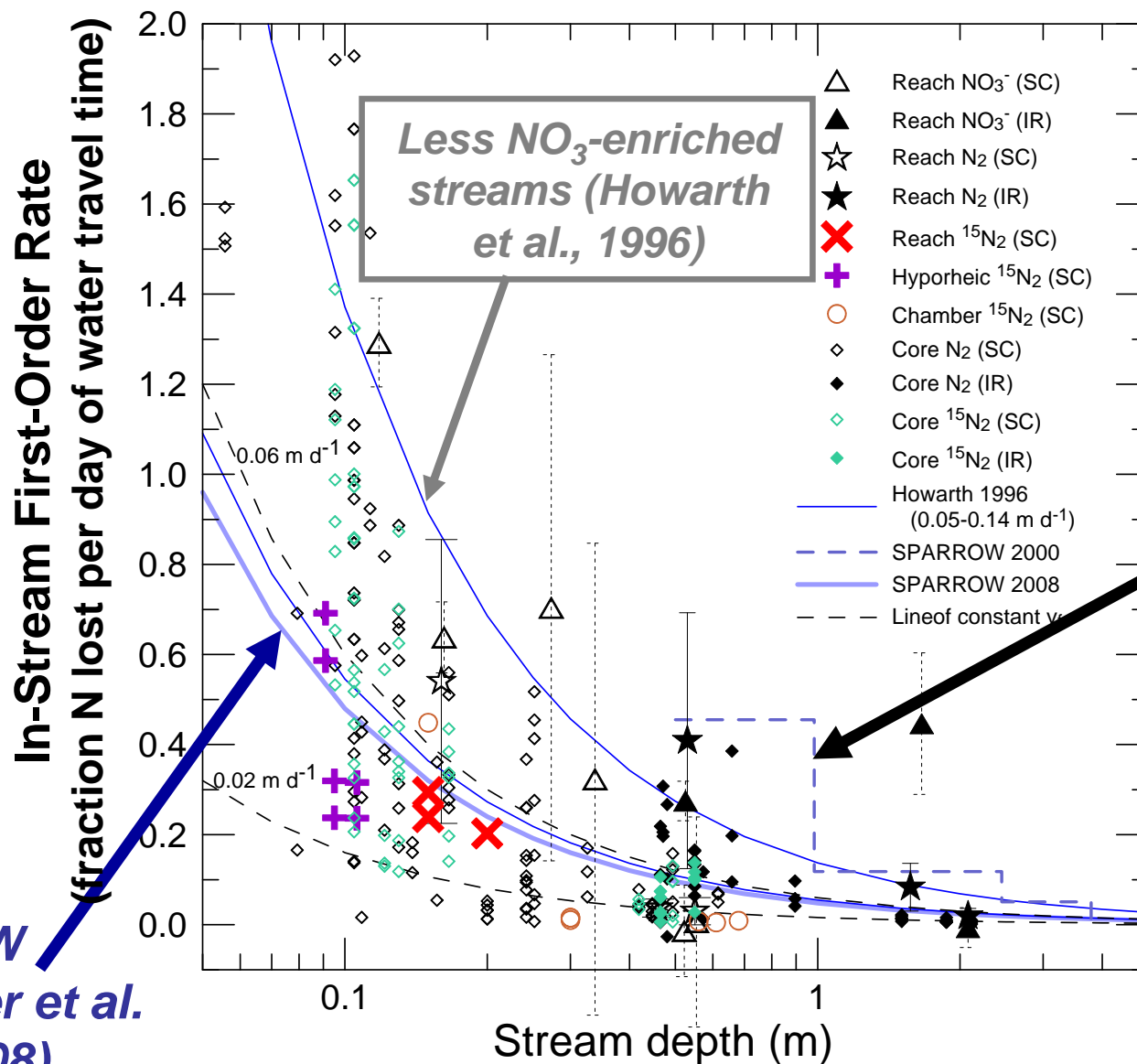
- Climate (precipitation, temperature)
- Soils (permeability)
- Topography/subsurface (slope, specific catchment area)
- Artificial drainage (tiles, ditches)

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)

Spatially located by 1-km DEM and 30-m NLCD land cover

SPARROW and literature denitrification-related nitrogen loss rates decline with stream size



SPARROW
(Alexander et al.,
ES&T, 2008)

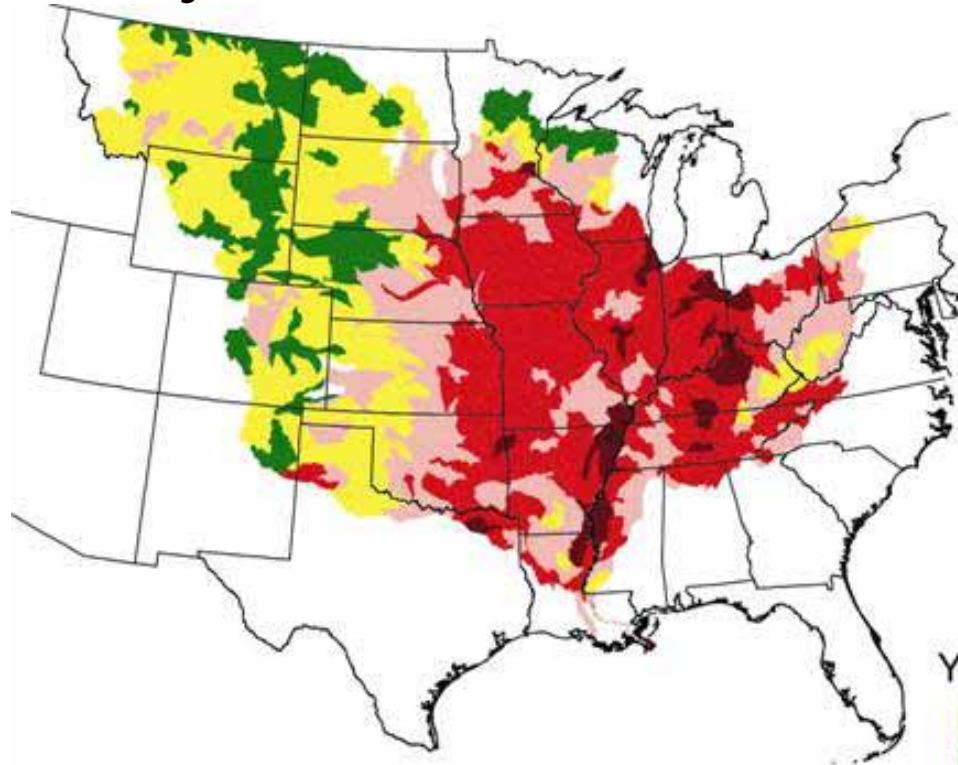
SPARROW
(Alexander et al.,
Nature, 2000)

Point-estimates from Iroquois R. & Sugar Creek, Indiana (Böhlke et al. in press)

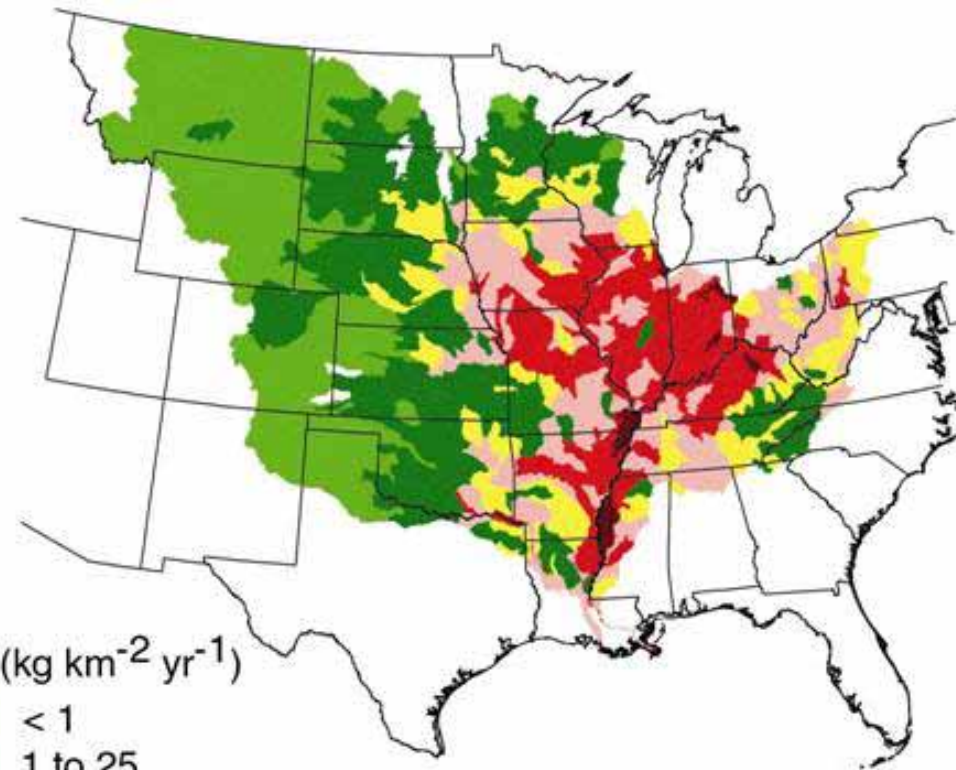
Delivery of nutrients locally to the outlet of inland watersheds and regionally to the Gulf of Mexico

Phosphorous originates from the incremental areas of watersheds*

Delivery to Outlet of Inland Watersheds



Delivery to Gulf of Mexico



Yield ($\text{kg km}^{-2} \text{ yr}^{-1}$)

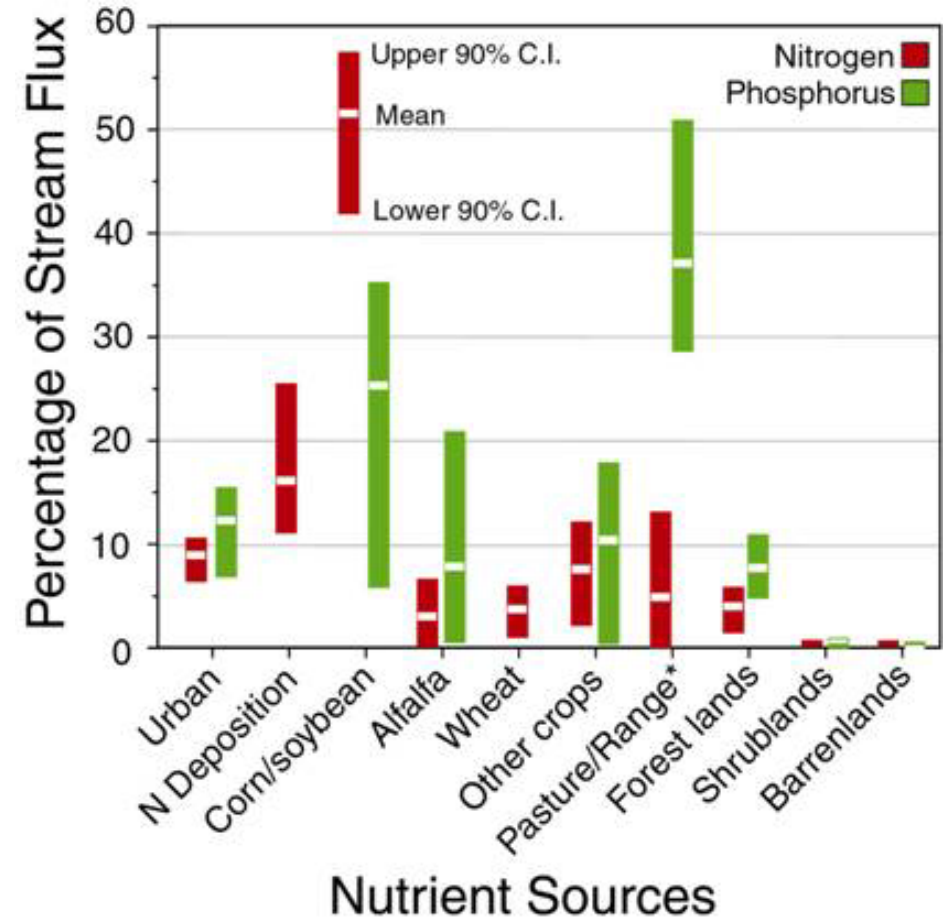


*Watersheds defined for 813 8-digit hydrologic units

After Alexander et al., 2008, *Environ. Sci. Technol.*, v 42

Upstream sources contributing to the nutrient load delivered to the Gulf of Mexico

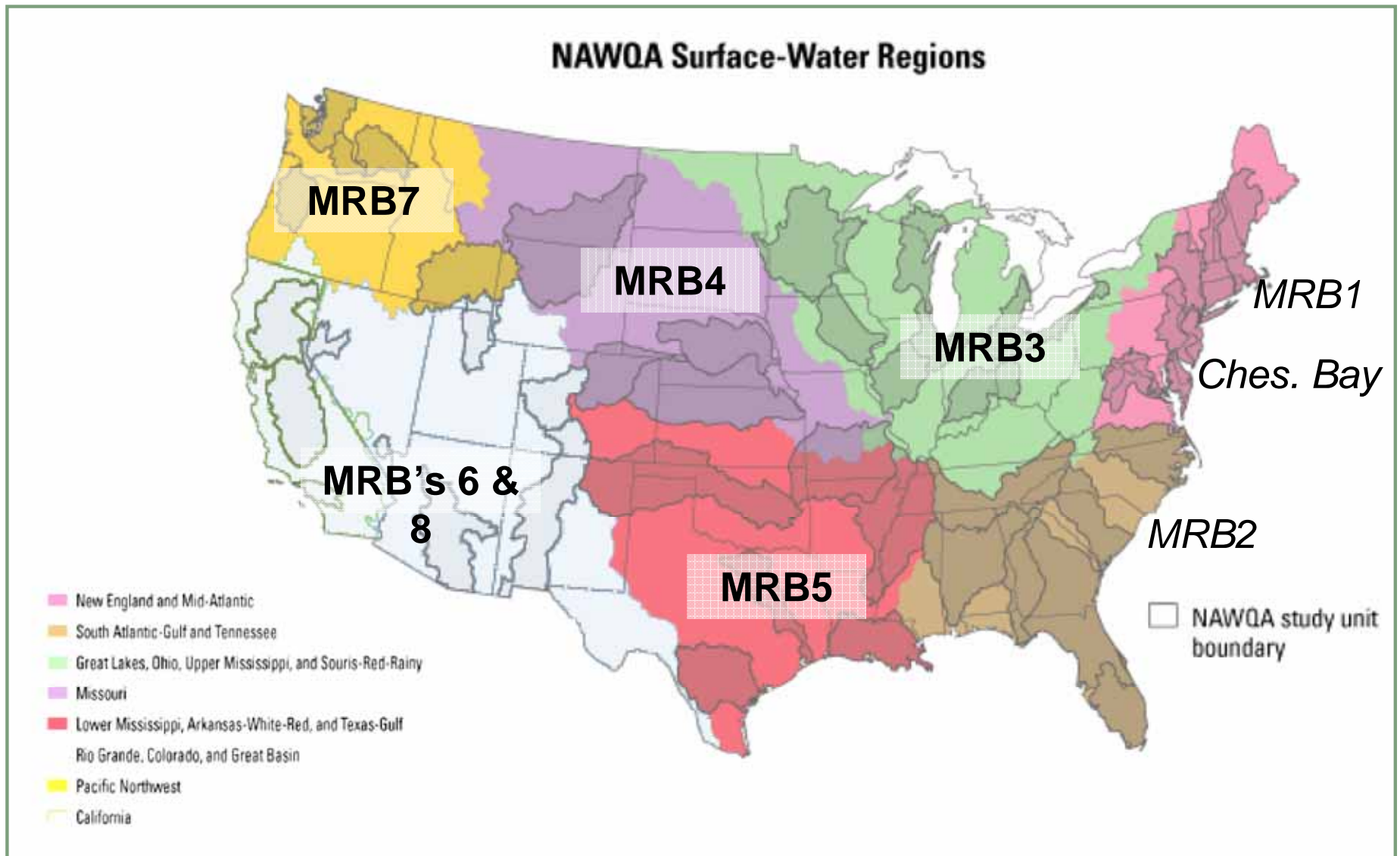
Mississippi/Atchafalaya River Basin



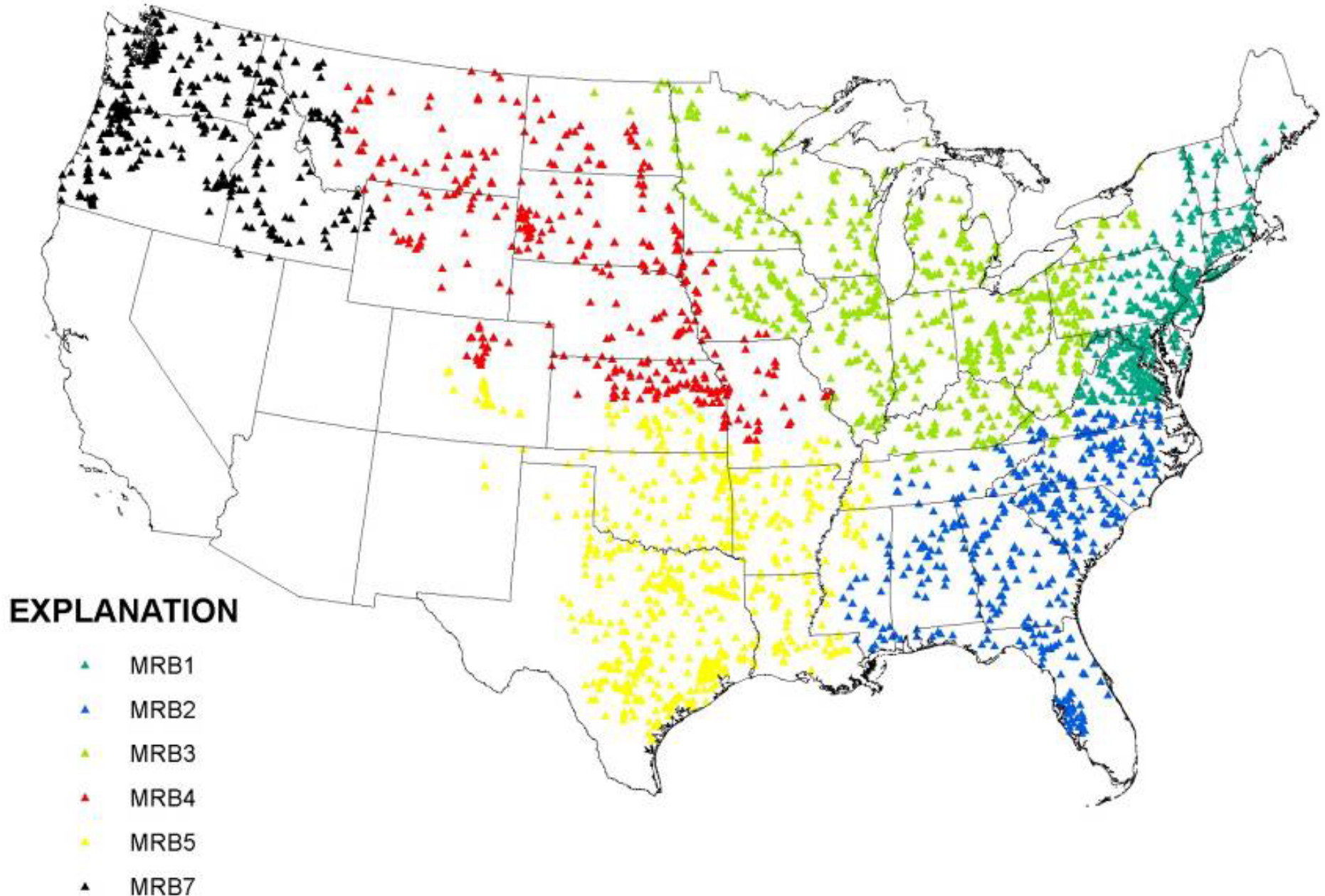
*Non-recoverable animal manure

Steps Towards Improving Information from SPARROW and Other Watershed Models

USGS Regional SPARROW Modeling

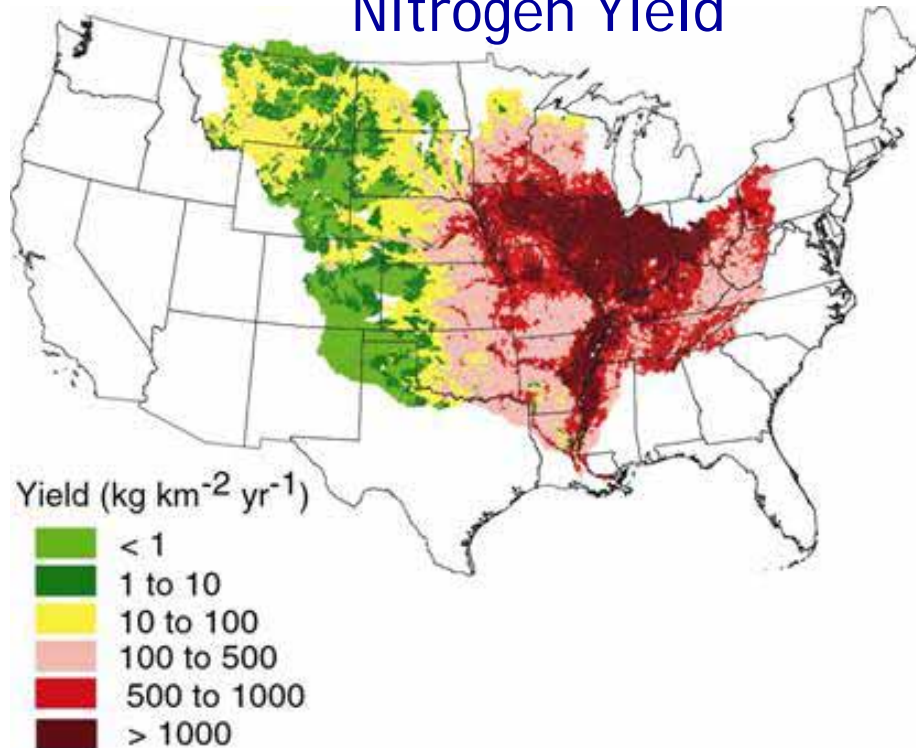


USGS SPARROW Stream Monitoring Sites (~3,000 sites for 2002 base year)

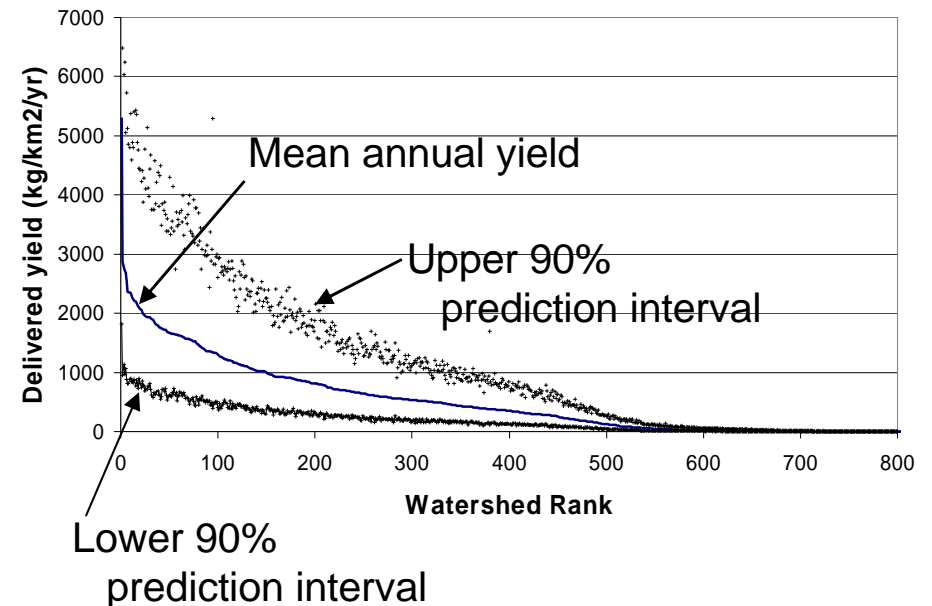


Uncertainties in SPARROW predictions of nitrogen delivery to the Gulf of Mexico from inland watersheds

Mean Annual Delivered Nitrogen Yield



Rank-ordered predictions of delivered yield to the Gulf of Mexico for 813 watersheds in the Mississippi R. Basin*

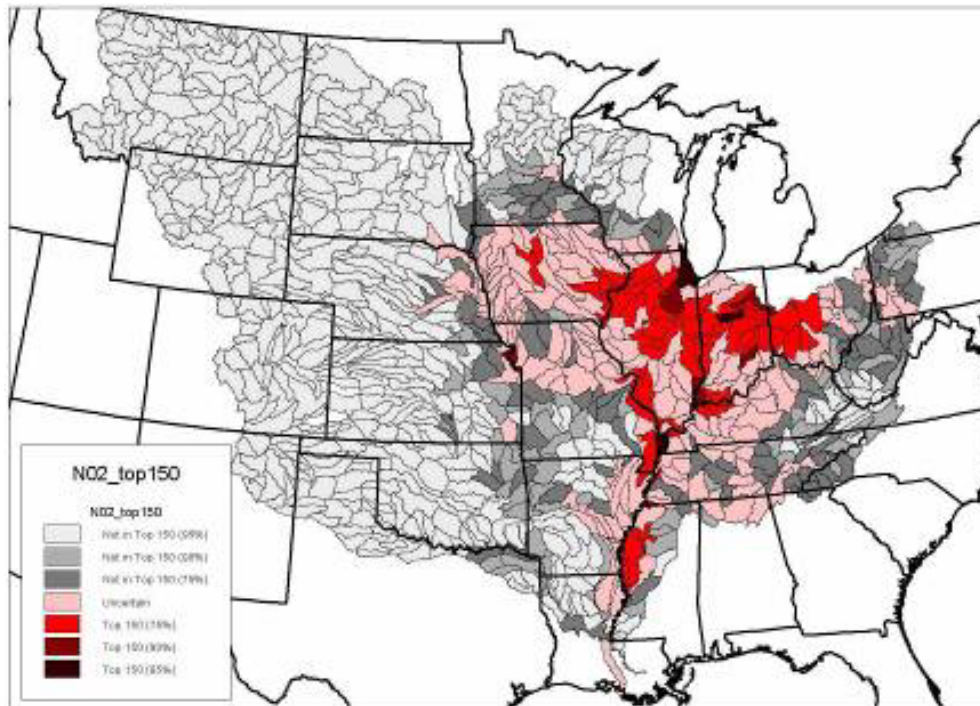


After Alexander et al., 2008, *Environ. Sci. Technol.*, v 42

*Watersheds defined for eight-digit hydrologic units

Use of SPARROW to rank inland watersheds having the highest nutrient delivery to the Gulf of Mexico

Probability that a watershed is among the “top” 150 watersheds that deliver the highest nitrogen loads to the Gulf

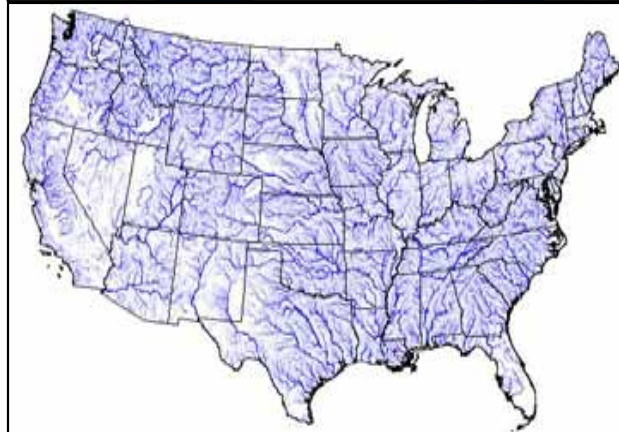
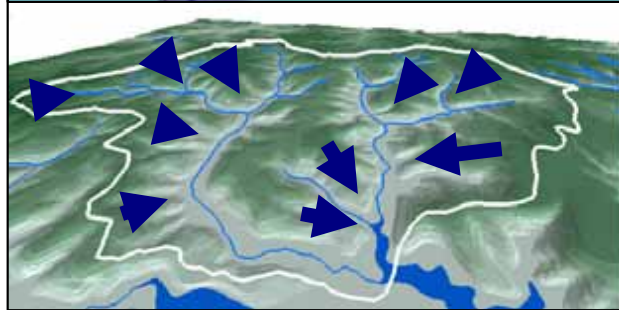


Number of 813 watersheds “in” or “not in” the top 150 watersheds contributing nitrogen to the Gulf

<i>Confidence level</i>	<i>“in” top 150</i>	<i>“not in” top 150</i>
95%	4	444
90%	11	513
75%	61	600

Robertson et al., JAWRA, in press

Opportunities for improved tracking of nutrients by integrating models and field observations across broad spatial scales



- **Using field measurements to inform calibration of watershed models**
 - Mechanistic models
 - SPARROW (e.g., Alexander et al. *JAWRA*, 2007)
- **Linking field/catchment-scale mechanistic model predictions to watershed models**
 - APEX linkages to SWAT (e.g., CEAP)
 - Catchment-scale model linkages to SPARROW aquatic transport and delivery components
- **Using statistical models to inform calibration and uncertainties of watershed models**
 - SPARROW use by SWAT HUMUS
 - Regressions and dynamic modeling of denitrification (Alexander et al. *Biogeochem.*, *in press*)
 - Multi-level statistical modeling: synthesis of MANAGE data; P runoff effects of farm management practices (Reckhow et al., *JAWRA*, *in press*)

Tracking Nutrient Delivery: Concluding Remarks

- **Evidence of excellent progress in research and modeling for tracking nutrients from catchments to coastal waters**
- **Opportunities for expanding watershed model capabilities, accuracy, and management utility:**
 - Greater transparency in model calibrations and reported results
 - Hybrid models, especially integration of synthesis modeling of field/stream measurements with watershed models
 - Improved maintenance of monitoring and geospatial data for describing environmental conditions:
- **Continue research to quantify temporal lags in nutrients and land-use legacy effects; need to evaluate and communicate the implications for model predictions and management**