Estimating Nutrient Sources, Transport, and Fate in the Mississippi and Atchafalaya River Basins (MARB) Using the SPARROW Model

USEPA Science Advisory Board and Hypoxia Advisory Panel

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U.S. Geological Survey

Outline

- Overview of key features of SPARROW
- Strengths and limitations of the model
- Previous and current SPARROW studies and activities in the MARB
- Regional applications of SPARROW (New England, Chesapeake Bay)

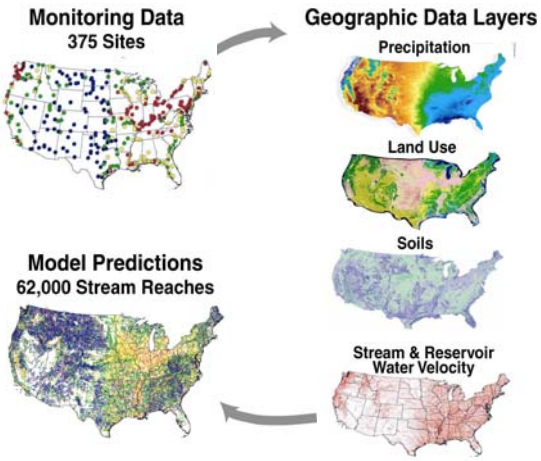
SPARROW Modeling Objectives

- Predict fluxes, yields, concentrations (*and uncertainties*) in unmonitored stream reaches
- Quantify principle sources and processes that explain spatial variations in water-quality conditions
- Track the origin and fate of contaminants from upstream watersheds to downstream receiving waters
- Simulate effects of changes in land-use, sources, climate on downstream water quality
- Inform network monitoring and use of watershed management models

SPARROW Water-Quality Model

SPAtially Referenced Regression on Watershed Attributes

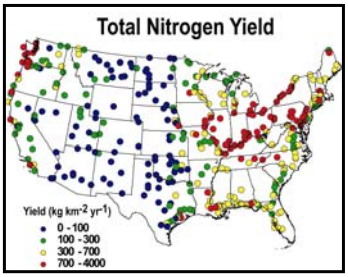
http://water.usgs.gov/nawqa/sparrow; Smith et al. 1997

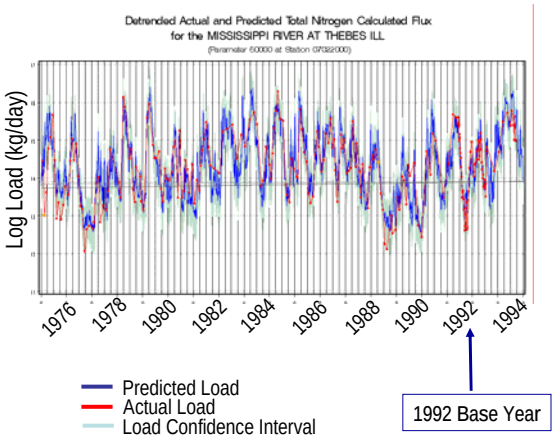


- **Hybrid statistical / mechanistic process structure; mass-balance constraints**
- **Data-driven model specification and complexity**
- **Spatially explicit; separates land and water processes using one-dimensional transport flow paths**
- **Physically interpretable coefficients; model supports hypothesis testing and uncertainty analysis**
- **Predictions reflect long-term, steady state conditions, based on mean-annual total nitrogen flux; denitrification and long-term storage are dominant removal processes**

Estimation of mean-annual nutrient load at stream monitoring sites

Mean-annual TN load for 1992 base year (detrended; flow-adjusted 1970-2001)





SPARROW's Reach-Scale Mass Balance

Reach network relates watershed data to monitored loads

$$LOAD_i = \left\{ \sum_{j \in J(i)} \left[\sum_{n=1}^{N} S_{n,j} \beta_n \exp(-\alpha' Z_j) \right] \prod_m \exp(-\delta_m^s T_{i,j,m}) \prod_l 1/(1+\lambda^r q_{i,j,l}^{-1}) \right\} \exp(\varepsilon_i)$$

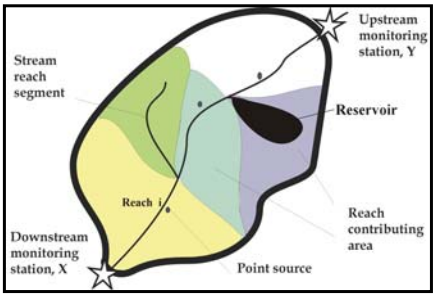
Monitored Stream Load

Sources

Land-to-water transport

Aquatic transport

Error



SPARROW Predictions at Reach and Watershed Scales

- Flux, yield, concentration (total and incremental drainage)
- Source contributions to streams (total and incremental drainage)
- Nutrient removal in streams and reservoirs
- Flux and yield (total and by source) delivered downstream
- Uncertainty measures (e.g., 95% CI)

SPARROW Model Documentation

USGS

The SPARROW Surface Water-Quality Model: Theory, Application, and User Documentation

By G.E. Schwarz, A.B. Hoos, R.B. Alexander, and R.A. Smith

U.S. Geological Survey Techniques and Methods Book 6, Section B, Chapter 3, 2006

- Theoretical and practical discussion of SPARROW methodology and applications
- User's guide
- Downloadable software
- Periodic training classes

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

Summary of SPARROW Features

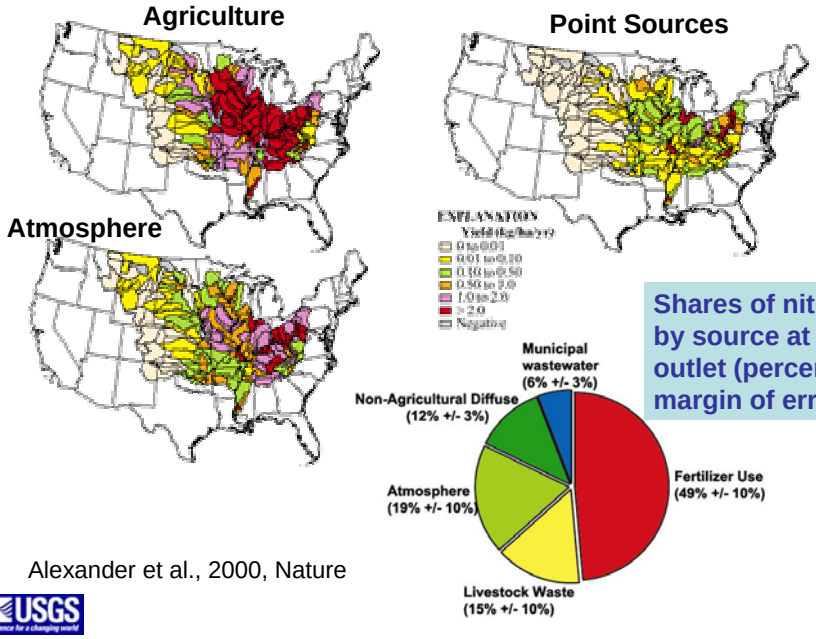
- Spatially explicit infrastructure
  - Land / water connectivity through DEM and reach network
  - Quantification of aquatic nutrient removal, the types and geography of nutrient source contributions to streams, and downstream delivery
- Mass-balance, nonlinear structure
  - Enhanced interpretability
  - Supports model verification of coefficients and predictions via comparisons with literature rates
- Steady state conditions
  - Reflects long-term nutrient supply and removal processes
- Statistical estimation of mechanistic processes in a parsimonious model structure
  - Data-driven evaluation of process hypotheses
  - Insight into the level of complexity supported by the data
  - Uncertainty quantification for parameters and predictions

SPARROW Limitations

- Data-intensive requirements for monitoring and watershed data
- Intra- and inter-year variability and dynamics in nutrient flux not explicitly modeled
- No chemical speciation
- Temporal lags in flux not modeled
- Management practices not explicit

Previous MARB studies

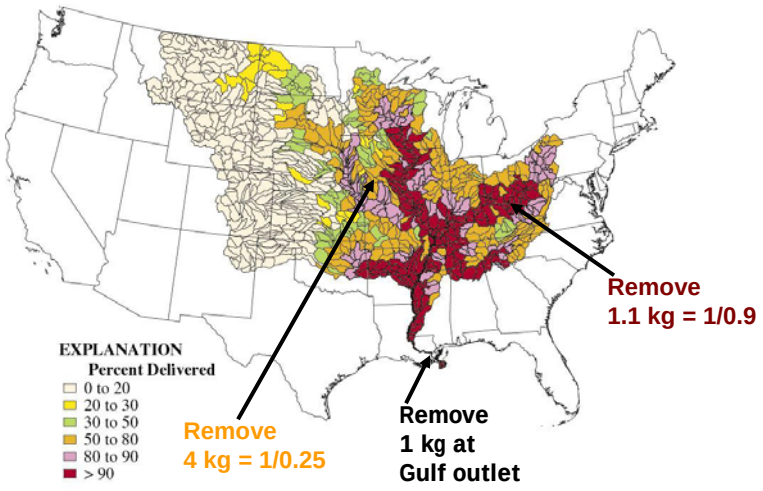
Sources of Nitrogen Delivered to Gulf of Mexico



Shares of nitrogen by source at Miss. R. outlet (percent and margin of error)

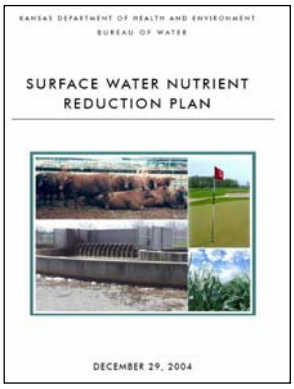
Alexander et al., 2000, Nature

Percentage of Total Nitrogen in Streams Delivered to the Gulf of Mexico

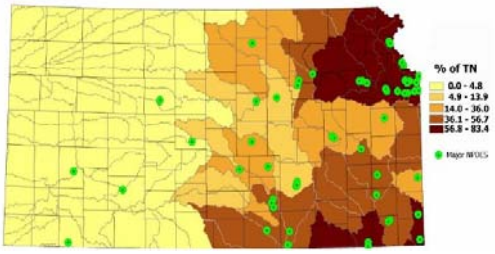


Alexander et al. 2000, *Nature*, v. 403

Use of SPARROW model results in the Kansas Nutrient Reduction Plan



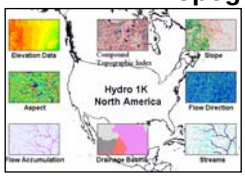
Nitrogen Delivery to the Gulf of Mexico from Kansas Watersheds

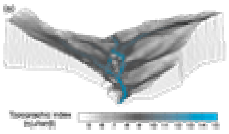


Current MARB studies and USGS activities

Recent Advances in the National Model

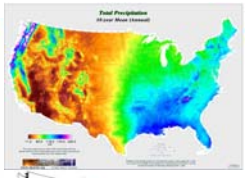
Topography

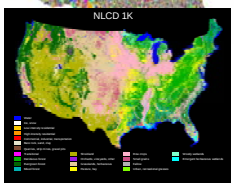




Climate

Watersheds





Land Use

Artificial Drainage

- **Model structure:** Specification, stream flux estimation, documentation
- **Data infrastructure:** Climate, 1-km DEM, cropping and drainage systems, 30-m NLCD land use
- **Result:**
  - Added complexity
  - Model accuracy improved by 25% to 30%

SPARROW Sources and Transport Features

NUTRIENT SOURCES (1992)

- Population
- Atmospheric N deposition
- Farm fertilizer sales; expenditures; crop acreage and application rates (corn, soybeans, cotton, wheat, other crops)
- Livestock wastes
- Land area (forest, barren, shrub, grass)

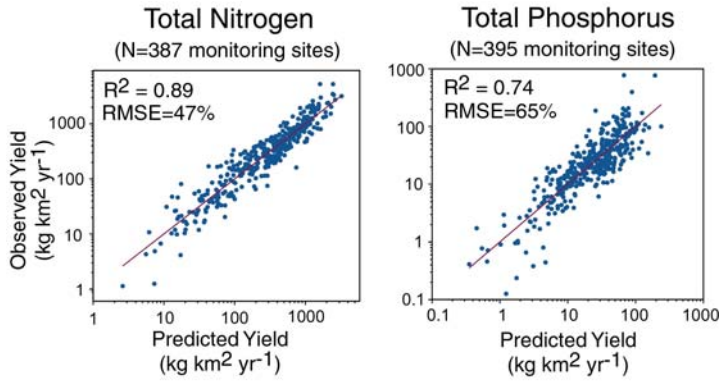
LAND-TO-WATER DELIVERY

- Climate (precipitation, temperature)
- Soils (permeability, porosity)
- Topography/subsurface (slope, specific catchment area, depth-to-water)
- Artificial drainage

AQUATIC ATTENUATION

- Streams (water travel time, water flow and depth)
- Reservoirs (areal hydraulic load, water temperature)

SPARROW Nutrient Models
Observed vs. Predicted Yield



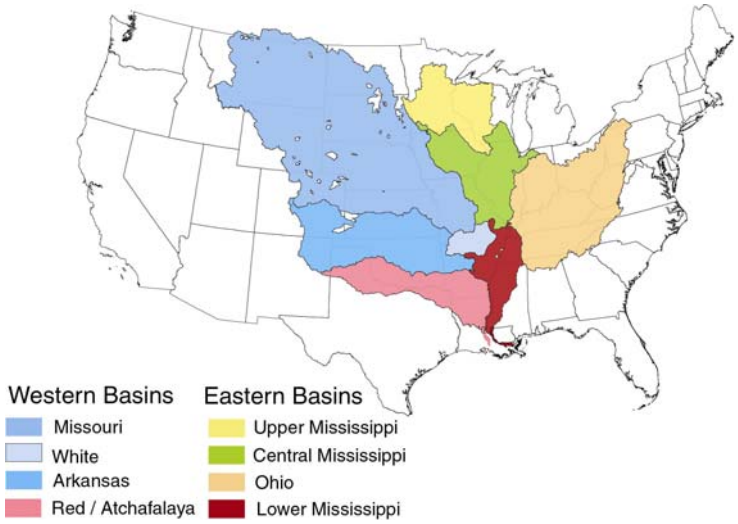
21 model coefficients:

- 11 sources
- 8 landscape transport
- continuous stream and reservoir decay

20 model coefficients:

- 10 sources
- 7 landscape transport
- continuous stream and reservoir decay w/ temp.

SPARROW Application to 25,000 Watersheds in Major Basins of the MARB



Key Topics of Investigation

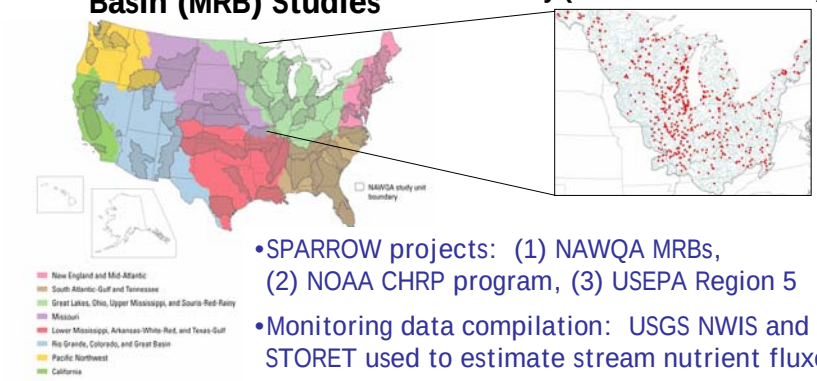
Nitrogen and Phosphorus Sources and Transport

- The types and geography of N and P source contributions to streams:
  - -Evaluate structural differences—livestock wastes vs. crop-related sources; differences among major crops
- Climatic vs. source influences on spatial variability in nutrient flux
- Artificial drainage effects on stream flux
- N and P removal in streams and reservoirs; effects of removal rates on nutrient delivery to Gulf from inland watersheds

USGS SPARROW National / Regional Modeling
National Water Quality Assessment Program

NAWQA Major River Basin (MRB) Studies

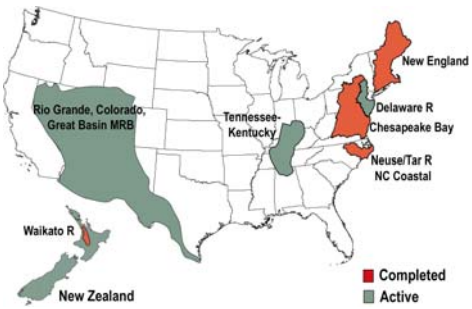
Great Lakes, Ohio, Upper Miss., Red-Rainy (Robertson and others, USGS)



- SPARROW projects: (1) NAWQA MRBs, (2) NOAA CHRP program, (3) USEPA Region 5
- Monitoring data compilation: USGS NWIS and USEPA STORET used to estimate stream nutrient fluxes
- Compilation of municipal wastewater effluent loads and watershed and nonpoint-source annual data
- MRB and MARB models completed by Fall 2008
- SPARROW temporal models; nutrient species models

Regional Applications of SPARROW

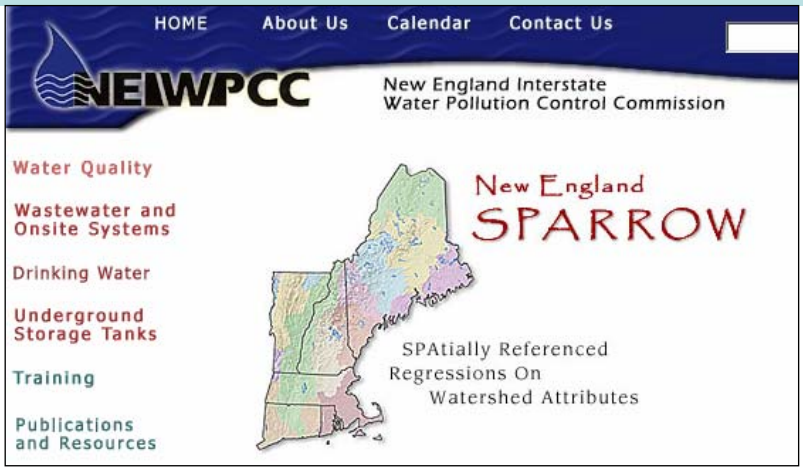
USGS Regional SPARROW Projects



Objectives:

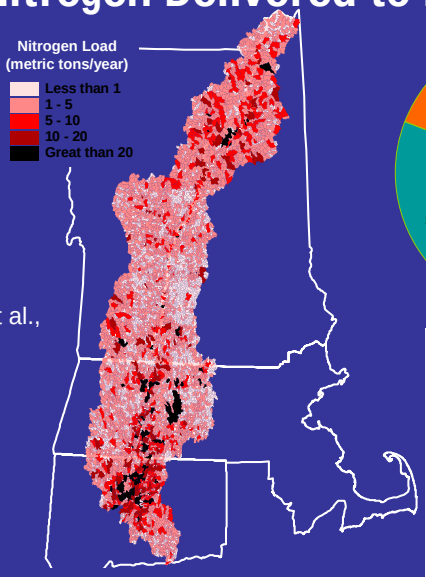
- Quantify source shares and loadings in streams and delivery to estuaries
- Management:
  - Target monitoring and nutrient controls
  - Refine management models
  - Quantify nonpoint sources (TMDLs)

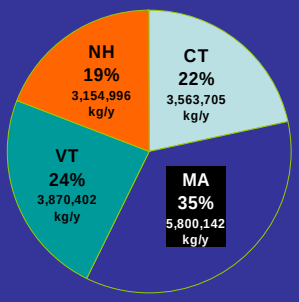
Use of SPARROW model by New England Water Management Agencies



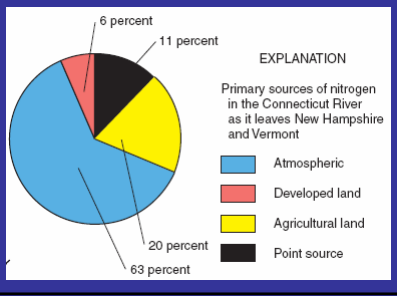
http://www.neiwpcc.org/Index.htm?ne_sparrow.htm

Connecticut River Basin: State Contributions of Nitrogen Delivered to Long Island Sound





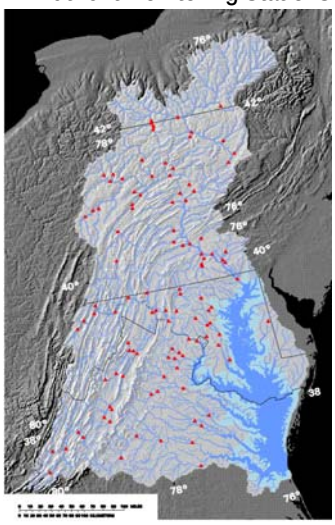
Moore et al., 2004



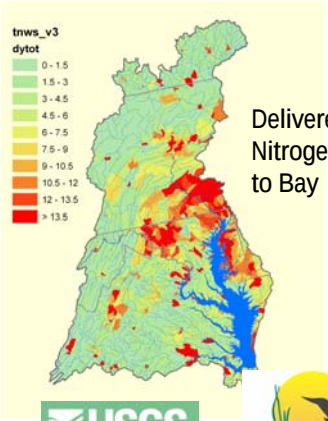
http://pubs.usgs.gov/sir/2004/5012/

Chesapeake Bay SPARROW

77 Nutrient Monitoring Stations



Management goals call for 20-30% reductions in the current nutrient loadings to the Bay by 2010

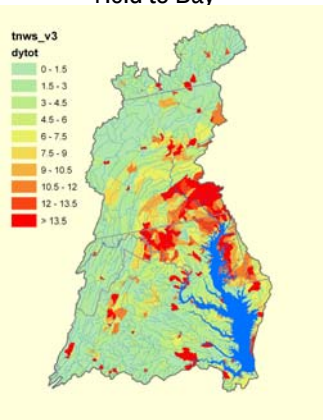


Delivered Total Nitrogen Yield to Bay

Chesapeake Bay Program
A Watershed Partnership

Chesapeake Bay SPARROW

Delivered Total Nitrogen Yield to Bay



- Watershed targeting with local govt. tributary strategy teams
- Scenario assessments:
  - Source characterization (types, geography)
  - Evaluations of downstream effect of source reductions
- Inform HSPF watershed simulation model:
  - Predictions of land-use yields
  - In-stream decay and delivery rates

http://md.water.usgs.gov/gis/chesbay/SPARROW.htm

Questions?

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

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