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

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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


- 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

$LOAD_i = \sum_{j \in T} \sum_{m=1}^N S_{n,j} \exp(-\alpha Z_{j,m}) \prod_{w} \exp(-\delta_{w,j,m}) \prod_{j} 1/(1 + Z_{j,m} T_{j,m}) \exp(\varepsilon_i)$
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

- 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

Agriculture

Point Sources

Atmosphere

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

Alexander et al., 2000, Nature
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

- **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)

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**SPARROW Nutrient Models Observed vs. Predicted Yield**

**Total Nitrogen**
- \( R^2 = 0.89 \)
- RMSE=47%

**Total Phosphorus**
- \( R^2 = 0.74 \)
- RMSE=65%

**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.neiwpc.org/index.htm?ne_sparrow.htm
Connecticut River Basin: State Contributions of Nitrogen Delivered to Long Island Sound

Moore et al., 2004


Chesapeake Bay SPARROW

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

Delivered Total Nitrogen Yield to Bay

77 Nutrient Monitoring Stations
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

Delivered Total Nitrogen Yield to Bay

Questions?

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