science for a changing world

Developing a Kentucky SPARROW Model

In Cooperation with the Kentucky Division of Water

USGS Hydrologic Workshop II

November 1, 2005

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

What is SPARROW?

- SPAtially Referenced Regression On Watershed attributes
- Predicts flux (M/T), yield (M/A/T), and concentration of total nitrogen and phosphorus at unmonitored locations
- Steady-state, mass-balance formulation
- Statistically-based and run using the SAS software
- Calibrated with data from water quality monitoring networks

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How can SPARROW be used?

- Concentration and flux for unmonitored stream reaches
- Landscape and aquatic controls on flux
- Source areas and mass contributions
- Source-water protection and TMDL assessments
- Design of monitoring networks

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Where has SPARROW been used?

- USGS national model (6,057,000 km^2)
- New Zealand national model
- Long Island Sound
- New England (Connecticut to Maine)
- Chesapeake Bay
- Coastal Carolina
- Delaware River Basin
- Ecoregion 71 (Alabama,Kentucky,Tennessee)
- New Zealand – Waikato River (14,000 km^2)

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Kentucky SPARROW Model

- Takes advantage of existing spatial information including
  - Soils
  - Hydrography
  - Land-use
  - Ag census
  - Atmospheric deposition
  - Precipitation and temperature
- Base model using Eco-region 71 model constructed by USGS Tennessee Water Science Center – lowest error of any SPARROW model (~19% for TN), and the national model

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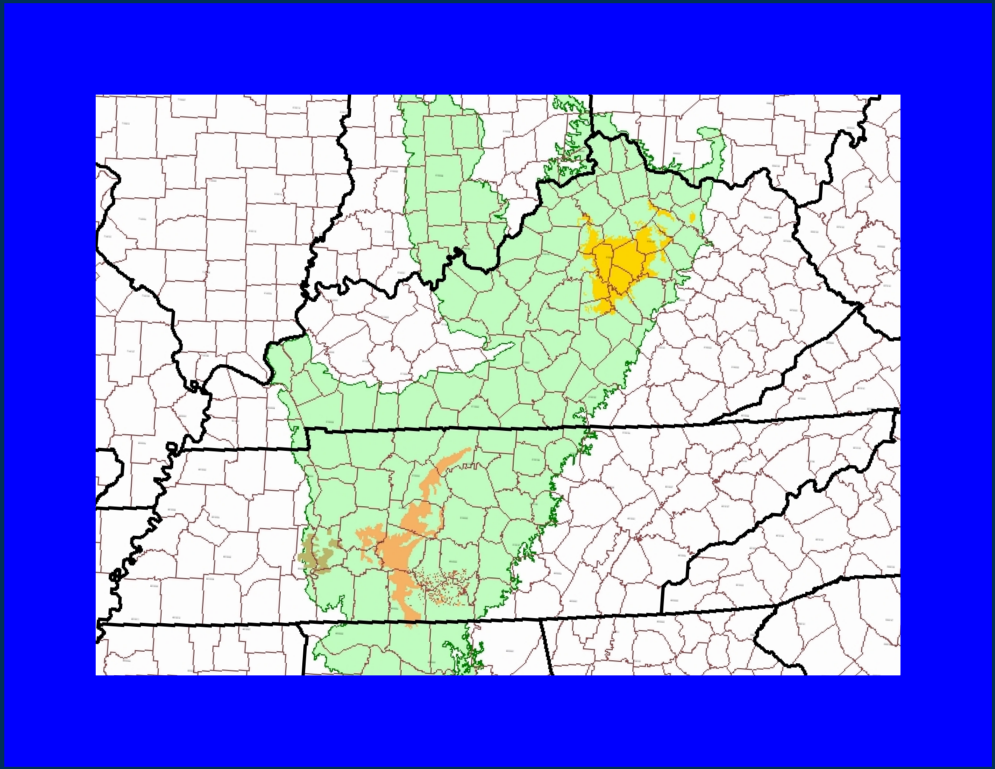
Kentucky SPARROW Model

- Eco-region 71 Model extends from northern Alabama to southern Indiana and Ohio
- Total nitrogen and phosphorus models for Kentucky have been extracted from the Eco-region 71 model and then updated



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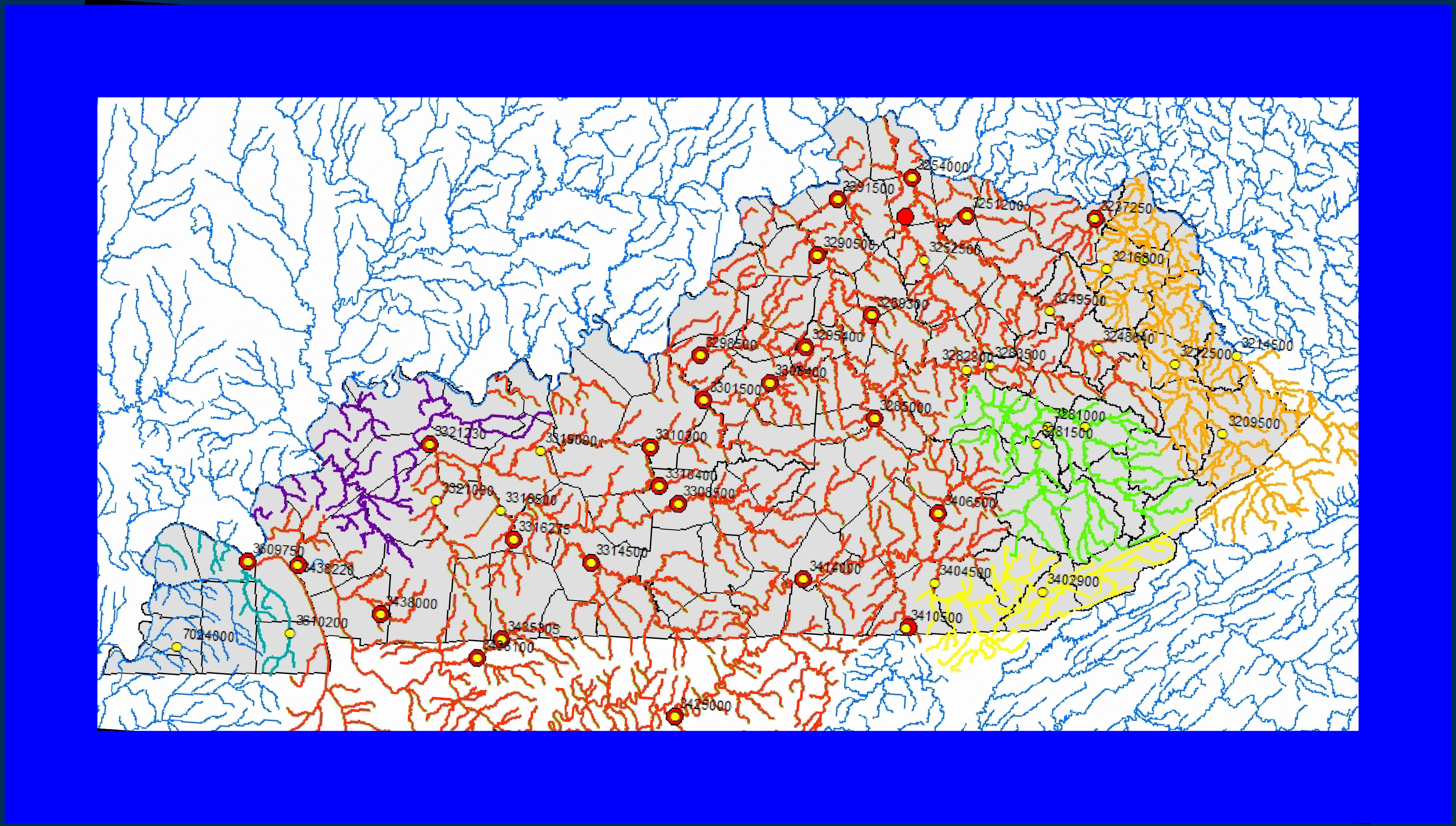
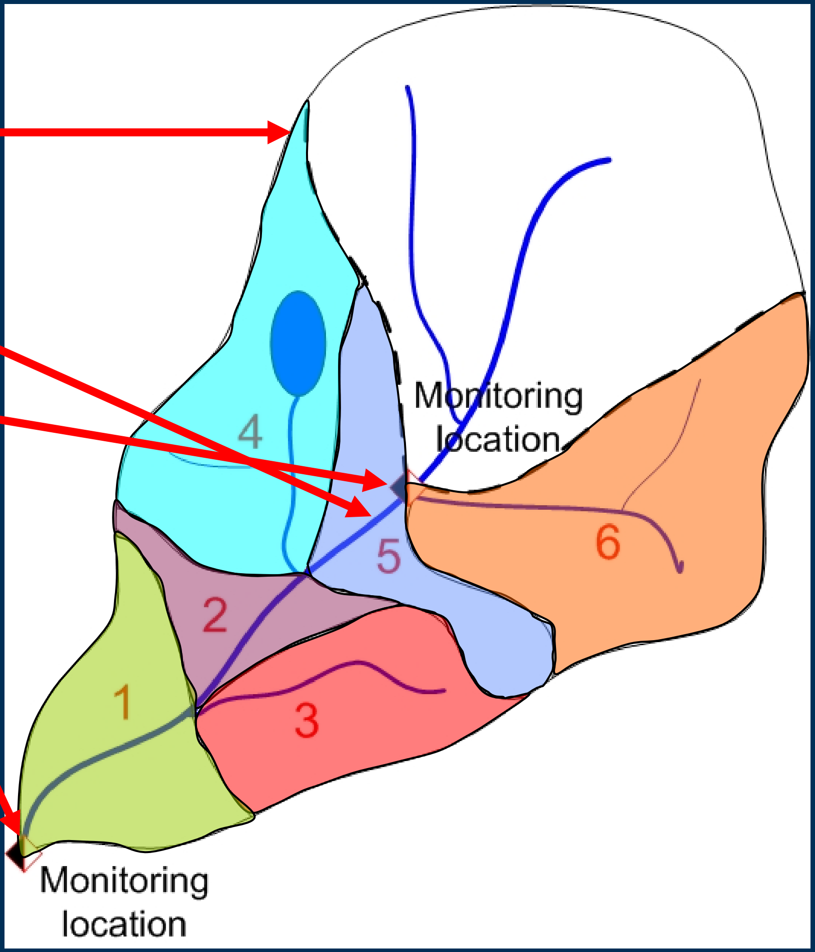
Kentucky SPARROW coverage



SPARROW Model Framework

- Spatial reference frame is a **stream network**
- Fundamental spatial element is a **stream reach**
- Dependent Variable – "measured" flux at monitored locations



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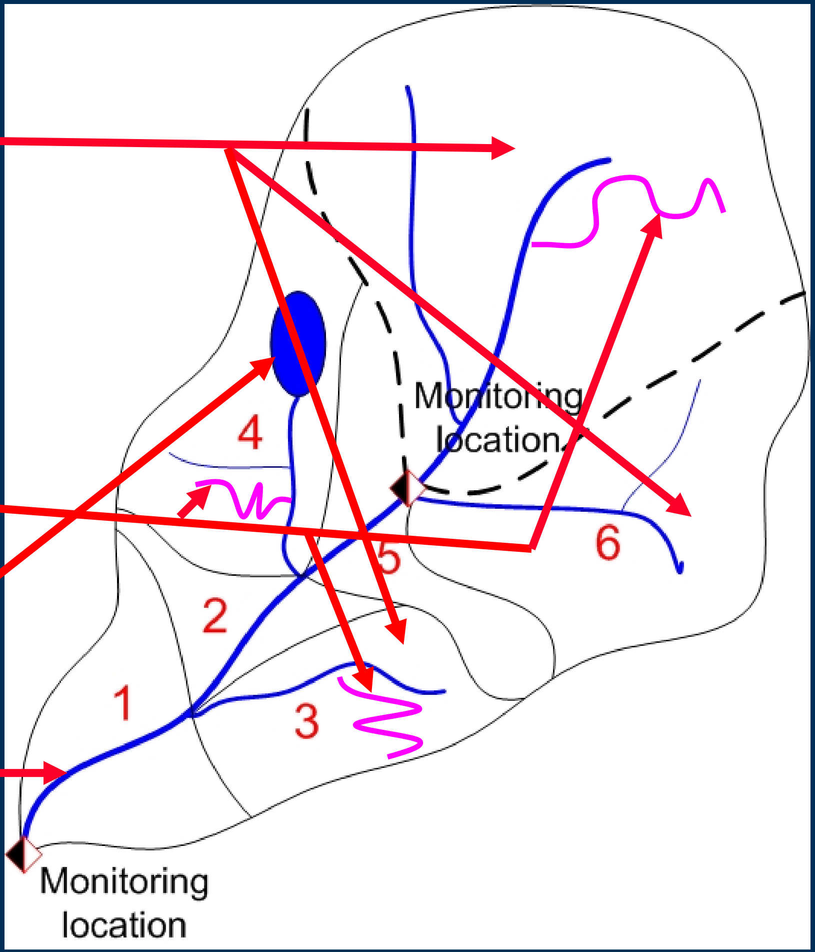
SPARROW Model

Independent Variables

- Sources
  - Fertilizers
  - Atmospheric
  - Wastewater discharges
  - Urban runoff, etc.
- Land-water transport
  - Temperature
  - Precipitation
  - Soil permeability, etc
- In-stream transport
  - Decay
  - Reservoir retention



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Conceptual SPARROW equation

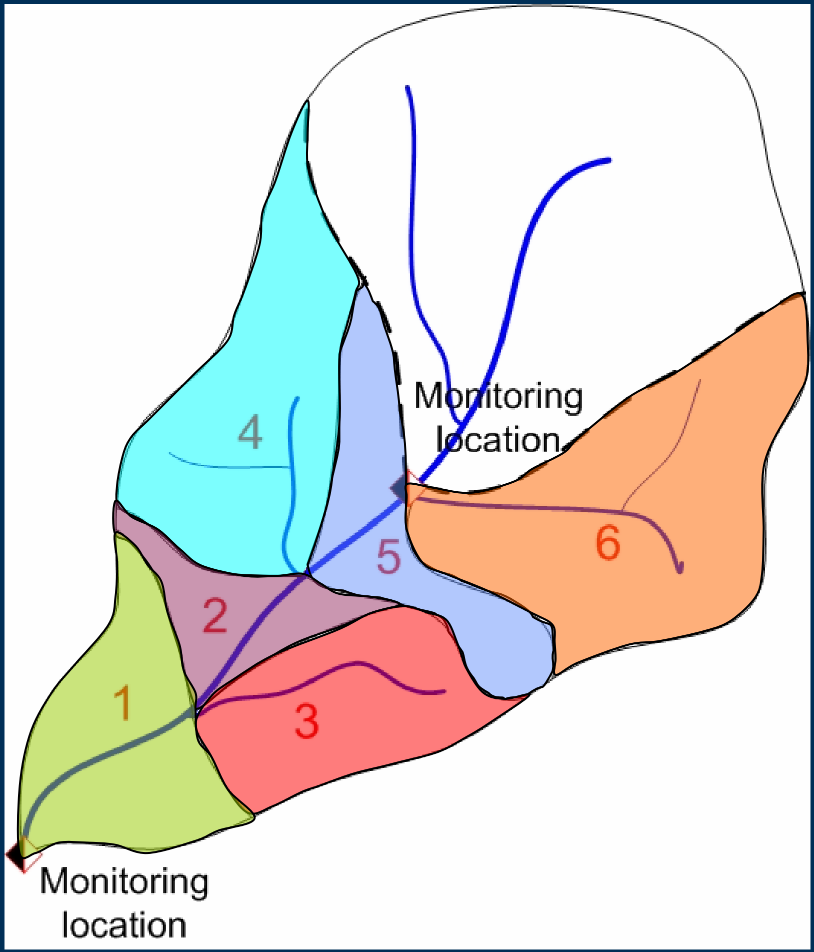
$\text{Load*}_{down} = \text{Load}_{up} + \text{Load}_{inc}$

where

Load_{up} = load calculated at the upstream monitoring location

Load_{inc} = load generated within the catchments between the upstream and downstream monitoring sites

*Measured flux if reach includes a monitoring site



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Governing SPARROW equation

$$LOAD_i = \left\{ \sum_{j \in J(i)} \left[\sum_{n=1}^{N} S_{n,j} \beta_n e^{(\alpha' Z_j)} \right] e^{(-\delta' T_{i,j})} \right\} e^{(\varepsilon_i)}$$

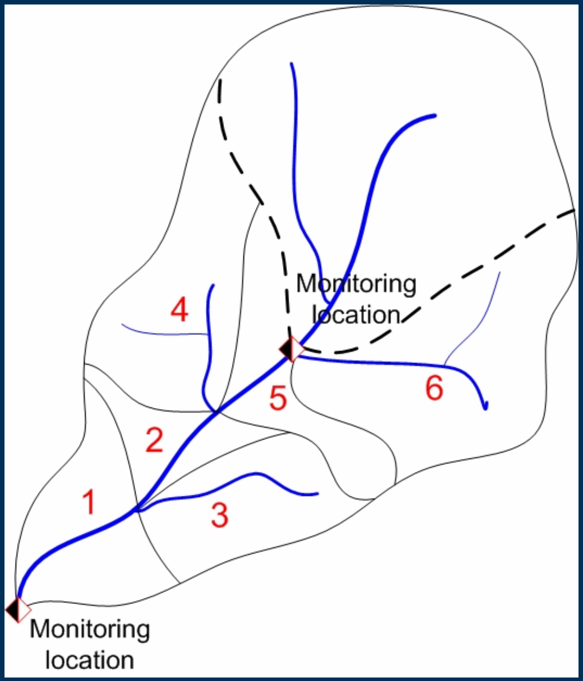
Stream Load

Sources

Land-to-water delivery

In-stream Decay

Error

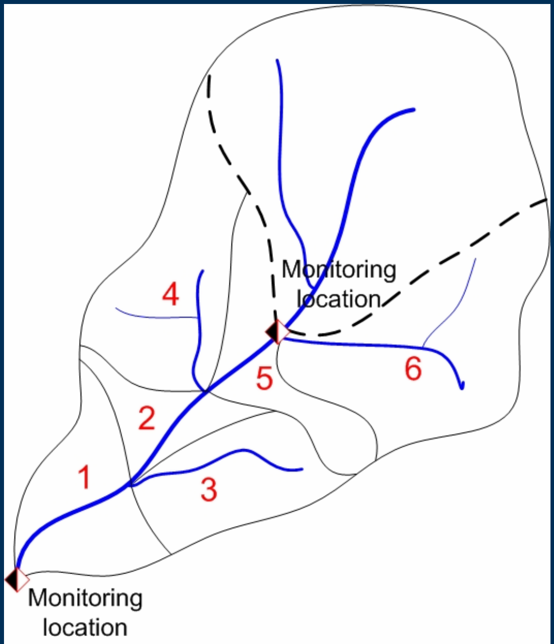


Typical watershed with two subbasins. The lower subbasin has six reaches.

Simple example of the SPARROW equation

$$LOAD_i = \left\{ \sum_{j \in J(i)} \left[\sum_{n=1}^{N} S_{n,j} \beta_n e^{(\alpha' Z_j)} \right] e^{(-\delta' T_{i,j})} \right\} e^{(\varepsilon_i)}$$

N = 3 (sources)
j = 6 (reaches)



Assume there are 3 nitrogen sources (N)
a = atmospheric, b = fertilizer, c = wastewater discharge

$J_i = a + b + c$

$LOAD_1 = J_1 + J_2 + J_3 + J_4 + J_5 + J_6 + LOAD_{US}$
$LOAD_2 = J_2 + J_3 + J_4 + J_5 + J_6 + LOAD_{US}$
$LOAD_3 = J_3$
$LOAD_4 = J_4$
$LOAD_5 = J_5 + J_6 + LOAD_{US}$
$LOAD_6 = J_6$

Nonlinear least-squares is used to solve the system of equations such that the SSE for the loads at the monitored locations are minimized.

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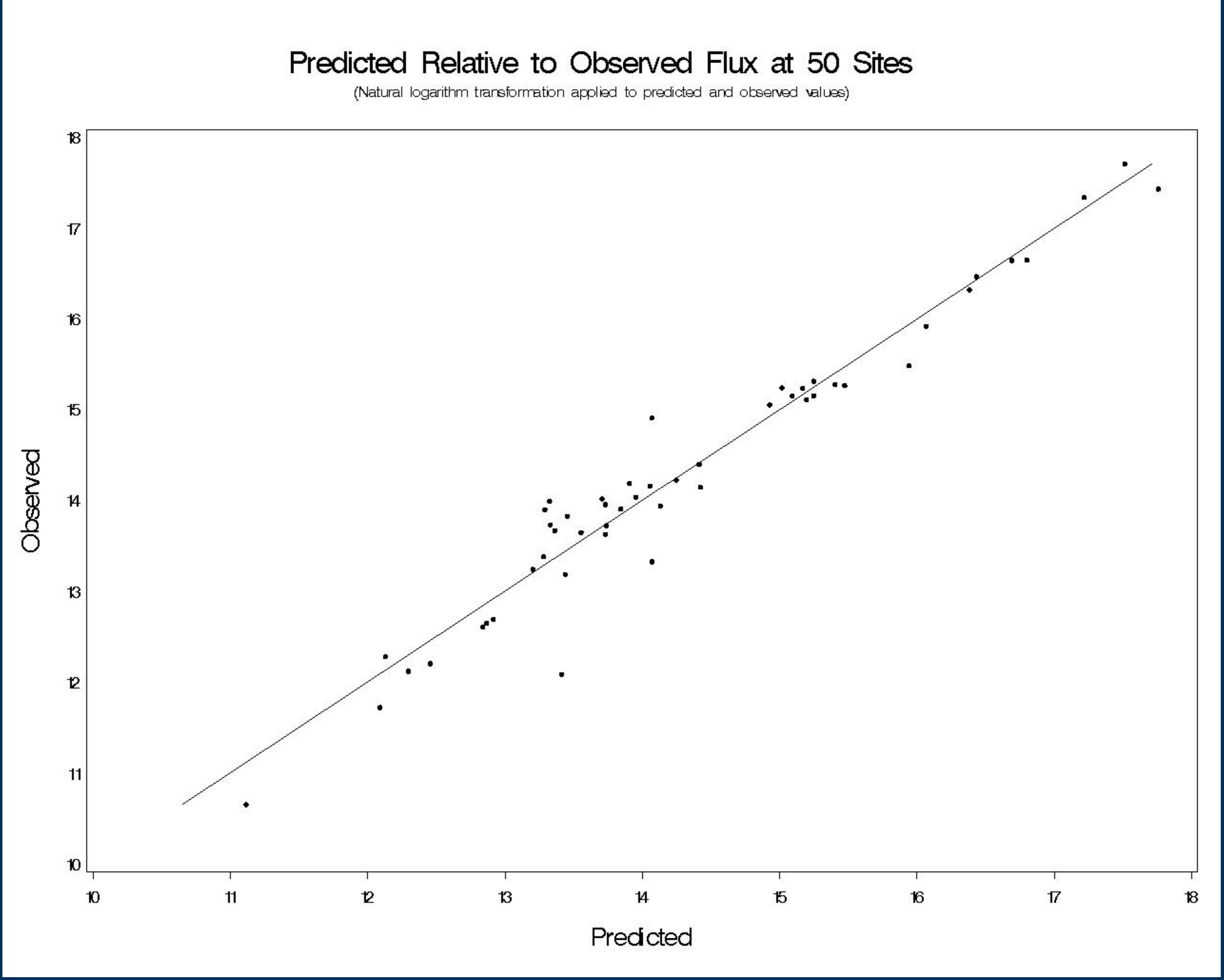
SPARROW results

SPARROW Model Non-linear Least Squares Results

N Obs	DF Model	DF Error	SSE	MSE	RMSE	R-Square	Adj R-Sq	Yld R-Sq
50	7	43	5.8744481	0.1366151	0.3696148	0.9491896	0.9420998	0.7371567

Parameter	Estimate	Std Err	t Value	Pr > |t|	VIF (NC)
BPOINT	1.3159641	0.5382649	2.4448262	0.0186649	1.5458954
BATMDEP	0.5530432	0.1235455	4.4764333	0.0000551	4.0244331
BWASTE	0.1939751	0.0561722	3.4532205	0.0012563	4.4953442
BUPLOAD	1	.	.	.	.
BTEMP	-0.024809	0.101001	-0.245635	0.8071335	2.5299936
BRCHDECAY1	0	.	.	.	.
BRCHDECAY2	-0.421167	0.1744118	-2.414785	0.0200707	5.3333296
BRCHDECAY3	-0.067933	0.0553445	-1.227457	0.2263285	1.7400588
BRESDECAY	12.450581	6.4611149	1.9270019	0.0606037	1.3646631



Predicted Relative to Observed Flux at 50 Sites
(Natural logarithm transformation applied to predicted and observed values)
Observed
Predicted
10
11
12
13
14
15
16
17
18

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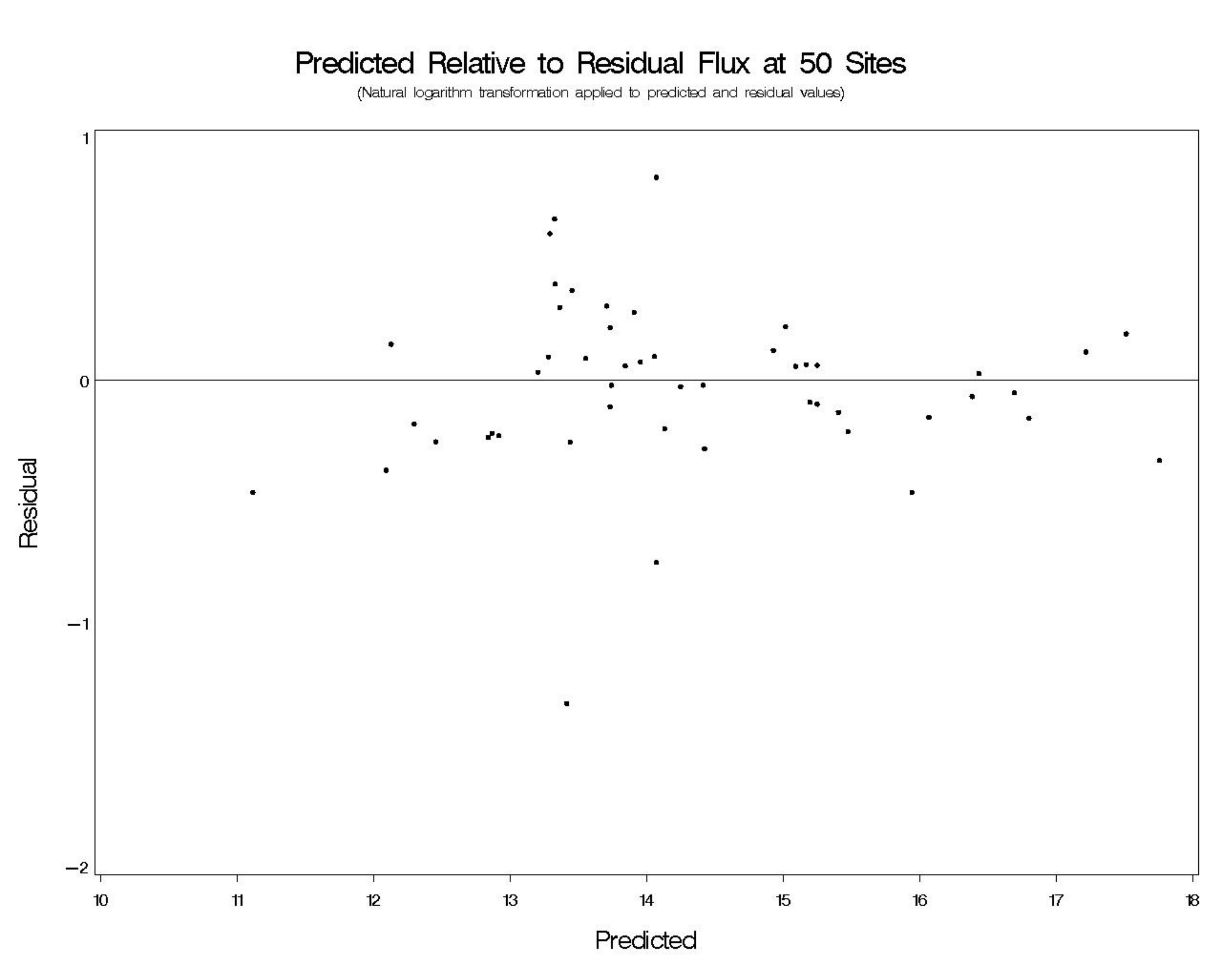
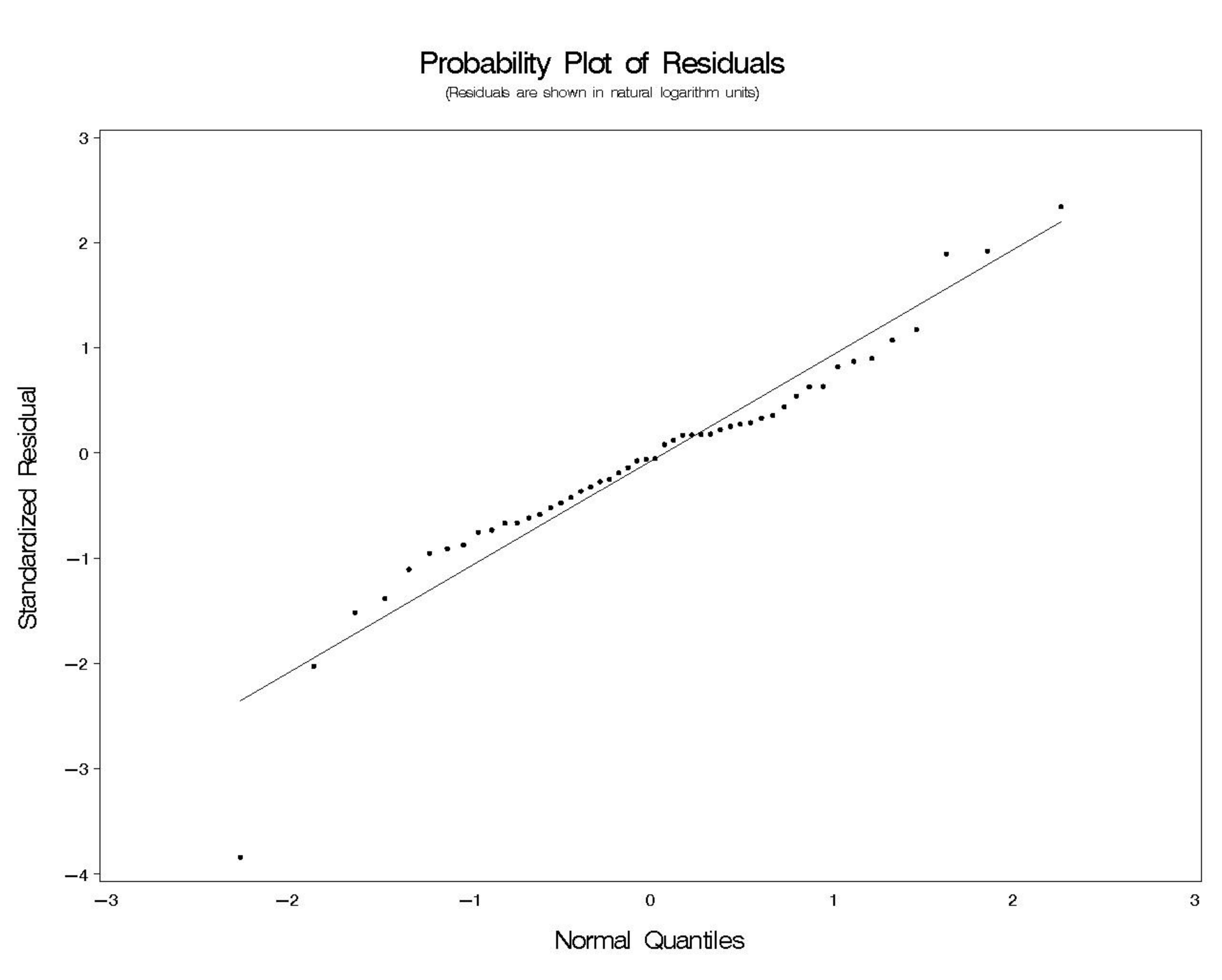
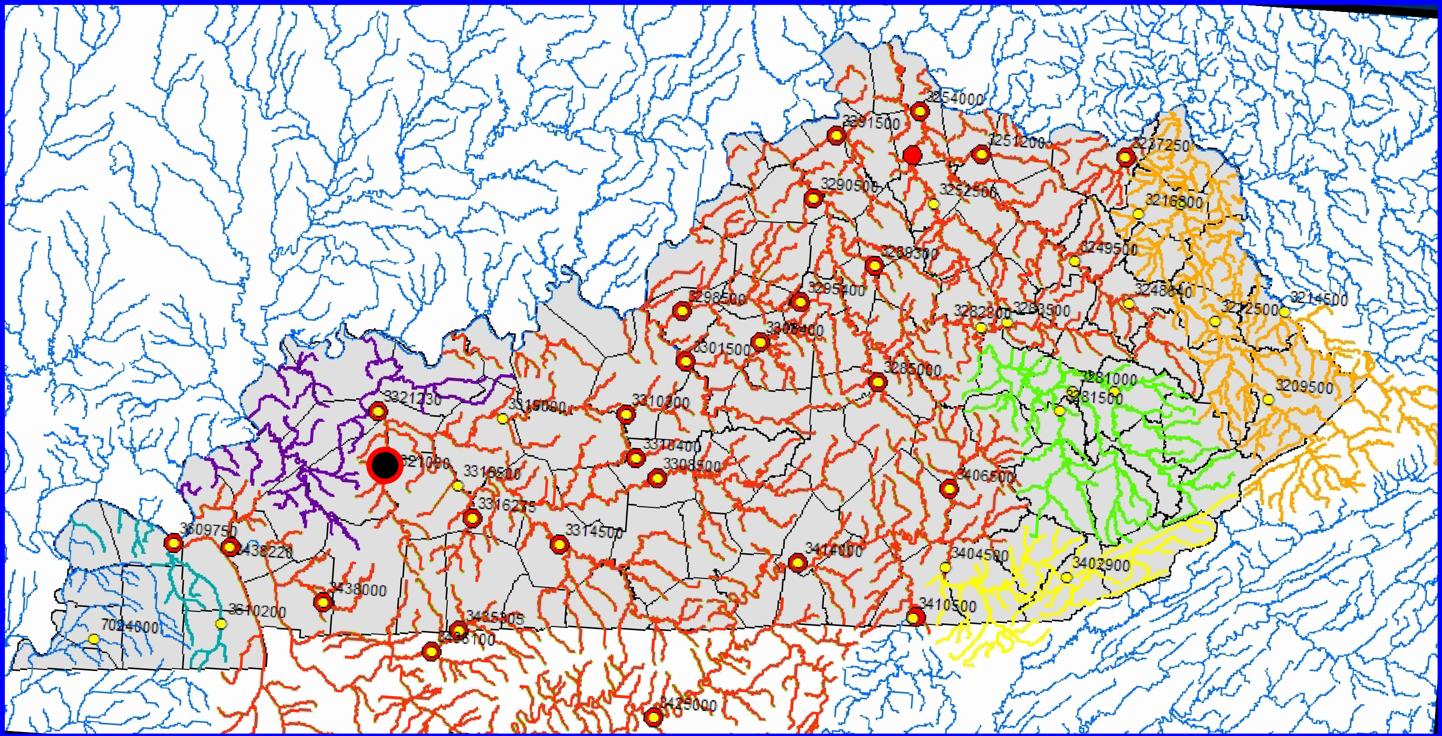

Predicted Relative to Residual Flux at 50 Sites
(Natural logarithm transformation applied to predicted and residual values)
Residual
1
0
−1
−2
10
11
12
13
14
15
16
17
18
Predicted


Probability Plot of Residuals
(Residuals are shown in natural logarithm units)
Standardized Residual
Normal Quantiles
3
2
1
0
−1
−2
−3
−4
−3
−2
−1
0
1
2
3

Sites with high error



What next?

- Refinement
  - Where are the errors
  - Cause of the errors
  - Addition of other explanatory variables
- Removal of the Tennessee River
- Report and publish

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Questions?