Estimating Phosphorus Loads in Streams Draining Commercial Poultry-Pasture Operations in the Upper Etowah River, Georgia

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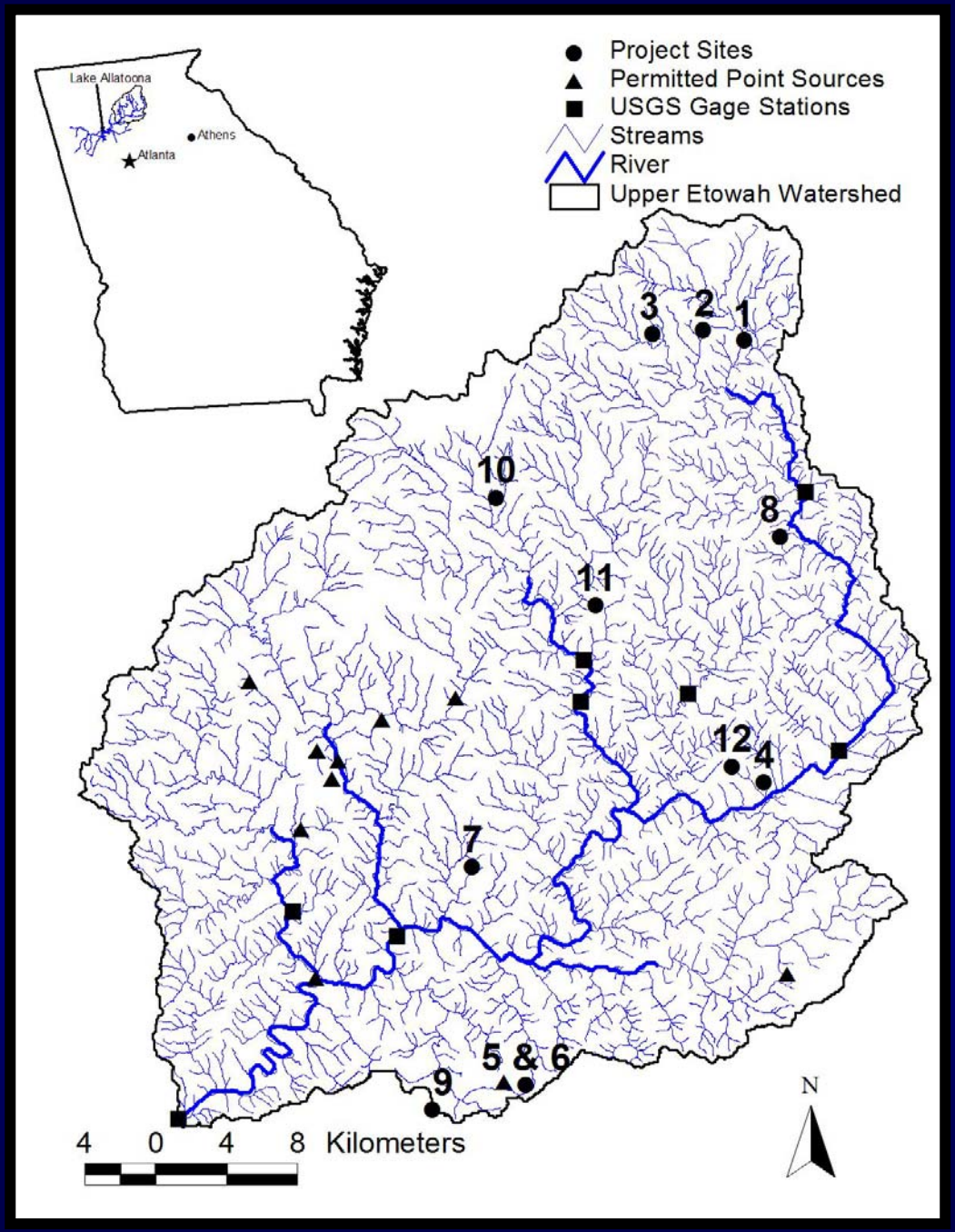
Upper Etowah River Basin In North-Central Georgia



Research Objectives

1) Use literature-established load estimators to estimate loading rates and yields of P

2) Use results of customized autosampler program to validate load estimates from regression estimators

Project Site Characteristics

Land Use + Site No.	Drainage Area (ha)	Pond in Watershed	Buffer Present	Average Mehlich-1 Soil P (mg/kg)	Number of Poultry Houses on Farm	Annual Number of Birds Produced	Annual Tons Cake / Litter Produced	% Cake / % Litter Applied	Number / Type Livestock	Livestock Excluded from Stream Channel
FORS-1	44	Yes	Yes	3	--	--	--	--	--	--
FORS-2	28	No	Yes	3	--	--	--	--	--	--
FORS-3	31	No	Yes	3	--	--	--	--	--	--
AG-4	28	No	No	26	3	--	--	--	-- / Cattle	No
AG-5	3	No	No	186	3	300,000	75 / 250	100 / 100	40 Cows	No
AG-6	2	No	Yes	133	3	300,000	75 / 250	100 / 100	40 Cattle	No
AG-7	10	No	No	34	3	302,500	60 / 150	50 / 25	-- / Horses	Yes
AG-8	7	No	Yes	64	2	--	--	--	None	NA
AG-9	11	Yes	Partial	52	2	156,000	20 / 75	80 / 0	-- / Goats + Horses	Yes
AG-10	19	No	Partial	50	12	1,104,000	750 / 1800	95 / 0	30 Cows	No
AG-11	16	Yes	Partial	97	5	332,500	2 / 20	100 / 100	-- / Cows	No
AG-12	3	No	No	151	2	300,000	22.5 / 114	100 / 0	1 Cow + 48 Sheep	No

TYPICAL SITES

Hydrologic Monitoring

- 18-22 months
- Flow
  - 2-ft H-flume
  - ISCO submerged probe
- Rainfall
  - ISCO rain gage
- 5-minute measurements

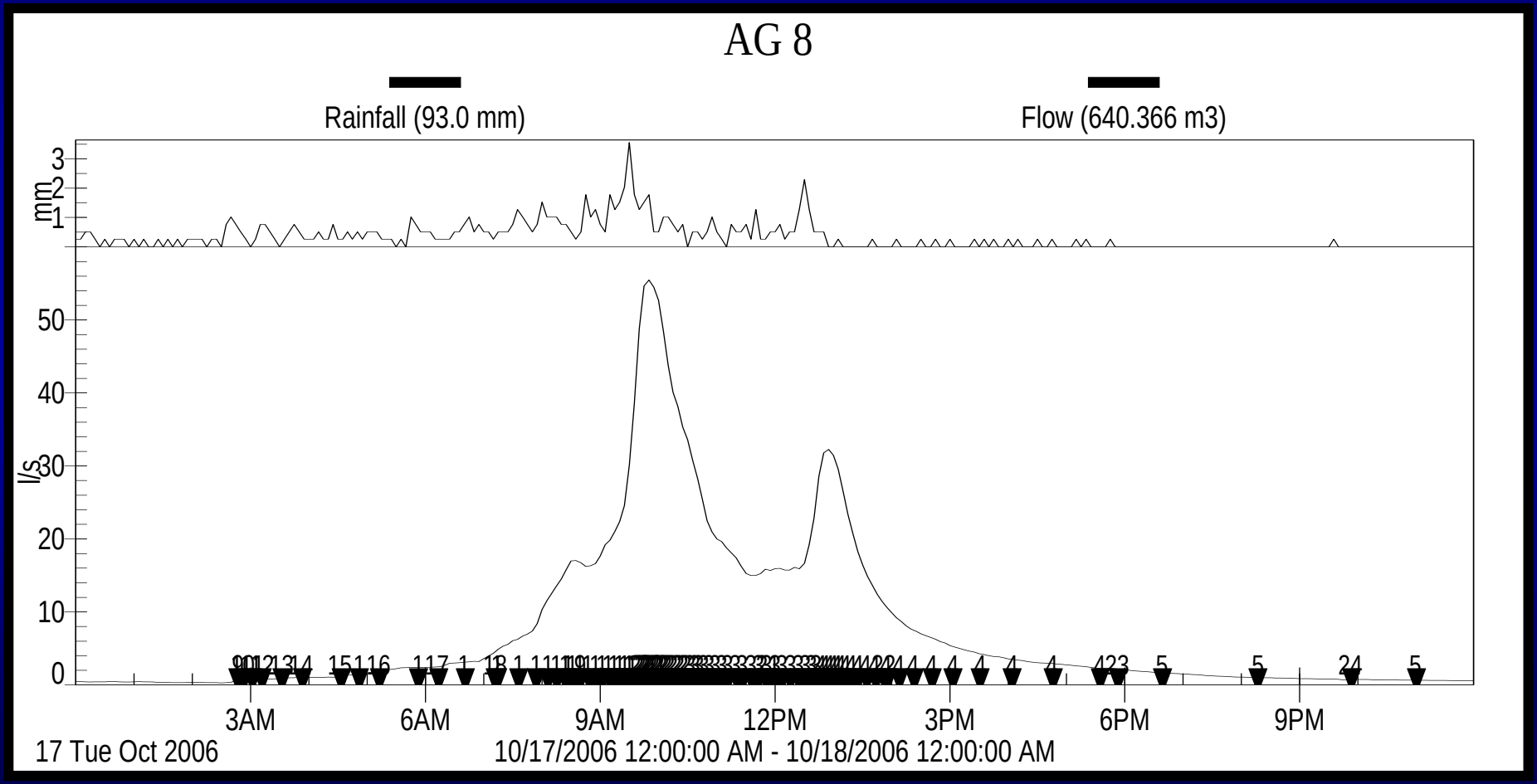
Water Quality Monitoring

- Biweekly grab samples
- Automated storm samples
- Laboratory analyses
  - Total P
  - 0.45-µm filtered P
  - Total suspended solids
  - Turbidity
  - Specific conductivity

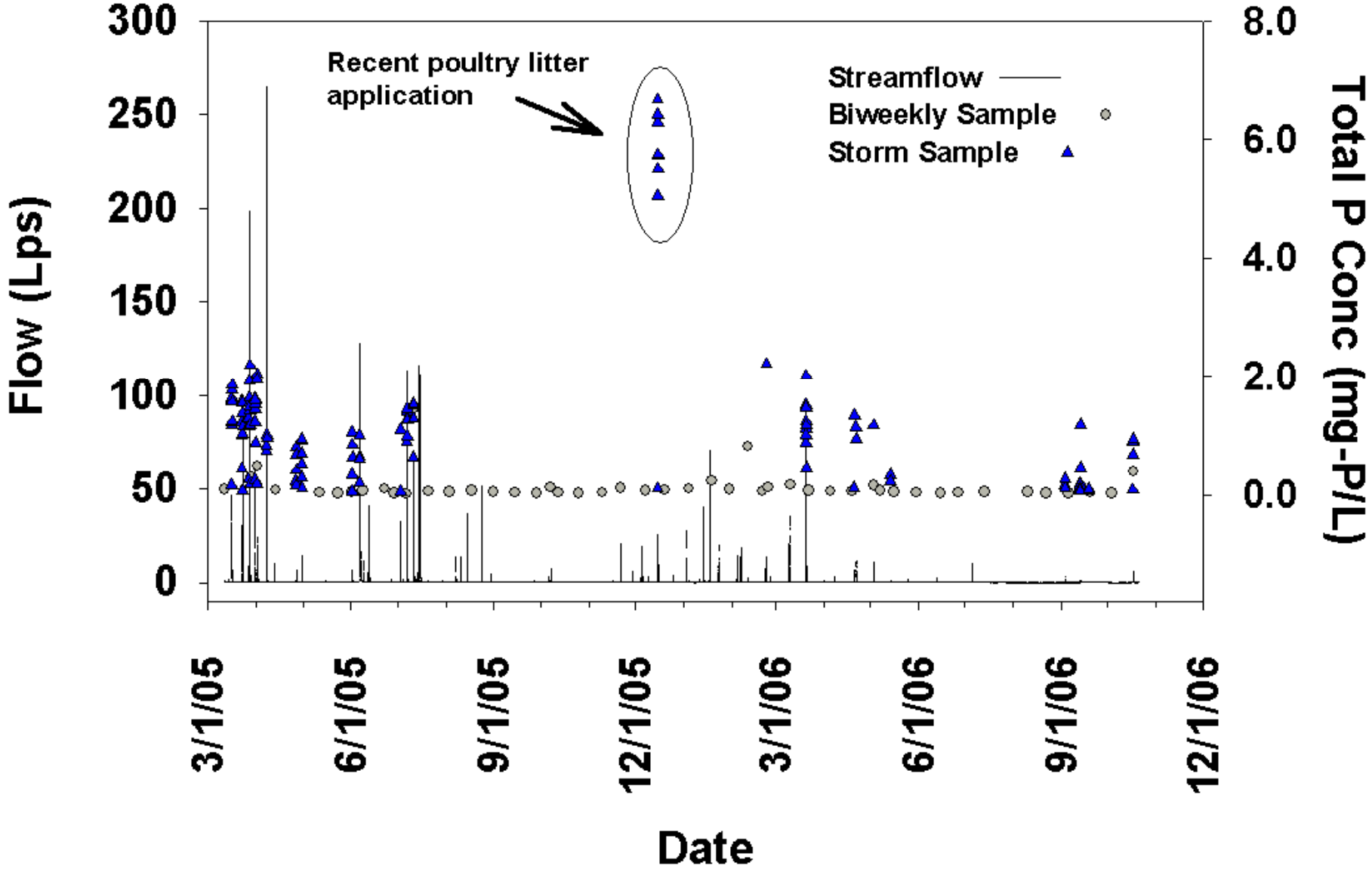
Autosampler Program

1. Program ISCO with two-part program using 24 * 1-L bottles
2. First set of bottles (i.e. 1-6) allocated to composite sample via flow-weighting
3. Second set of bottles (i.e. 7-24) used for discrete samples collected at non-uniform time intervals

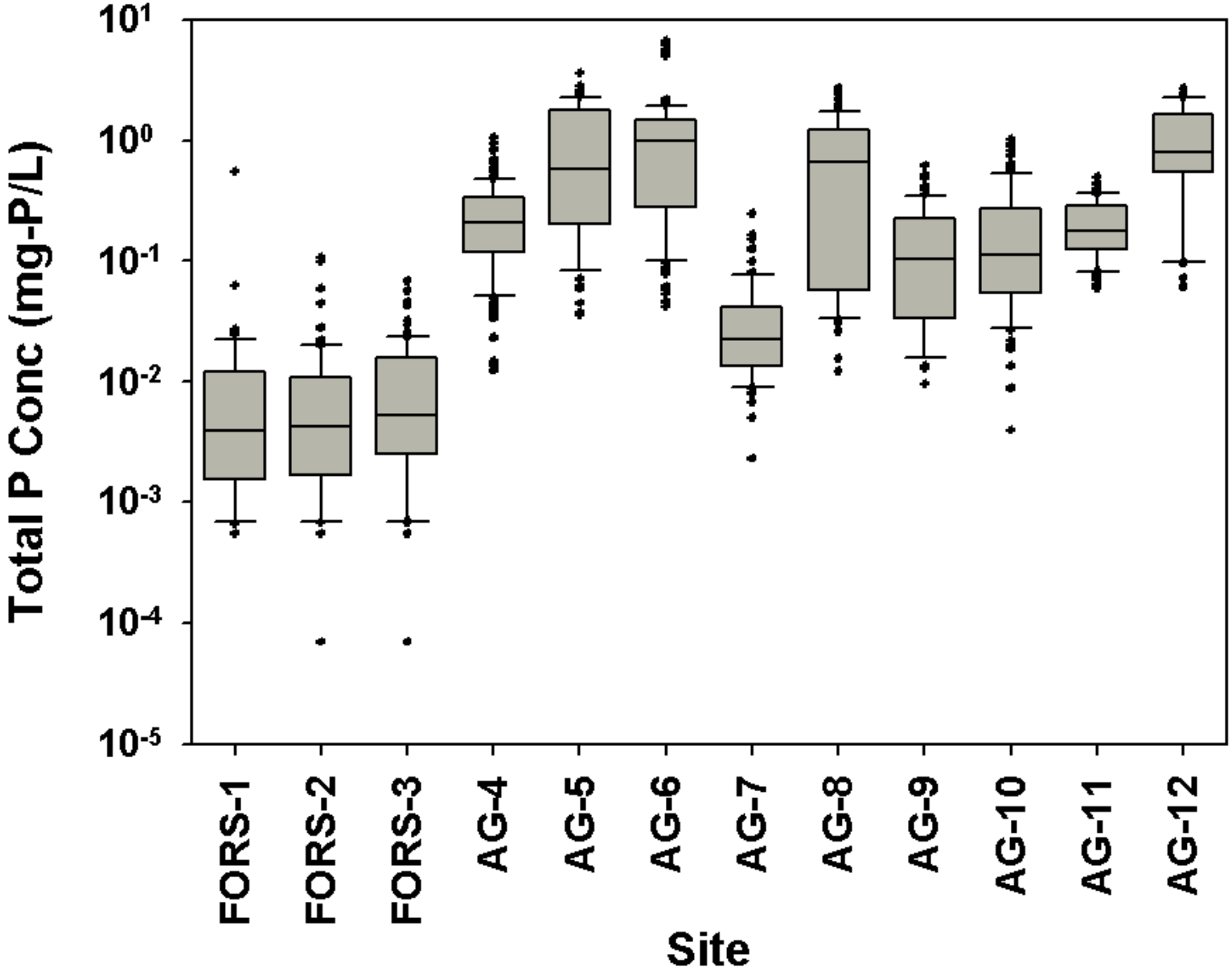
Storm Hydrograph Sampled via 2-part Autosampler Program



Time Series of Site AG-6 Flow + Biweekly and Storm Sample Total P Concentrations



Total P Concentrations in Automated Storm Samples



Load Estimation Background

$$Load\ L = \int Q(t)*C(t)*dt$$

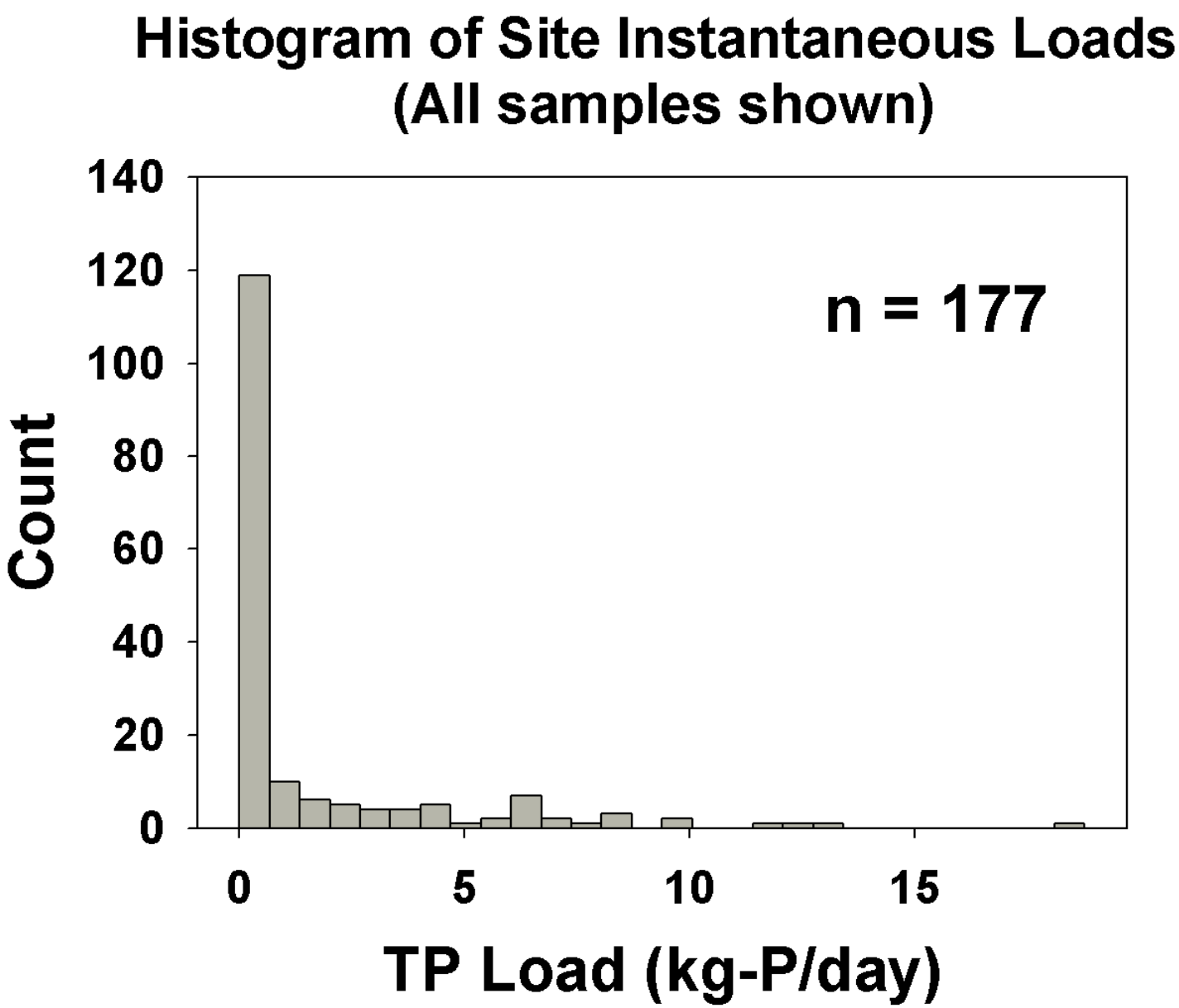
- Mass flux representing advective and dispersive transport processes
- Different “estimator” types
- There is not one “perfect” estimator
- Uncertainty of load estimate only computed for certain estimators

Estimator #1
"Averaging" by geometric mean

1. Calculate (for lognormal distribution):
   a. Geometric mean (TP conc. all samples)
   b. Standard deviation
   c. 95% confidence intervals

2. Average daily load (ADL) =
   Total flow volume * geometric mean

3. Phosphorus yield (Y in kg-P/ha/yr) =
   ADL / drainage area


Histogram of Site Instantaneous Loads
(All samples shown)
n = 177
Count
140
120
100
80
60
40
20
0
0
5
10
15
TP Load (kg-P/day)

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Estimator #2: Flow-duration rating curve (FDRC) (Verhoff et al. 1980)

1. Allocate instantaneous loads (L_{inst}) to equally-spaced flow intervals
2. Compute mean (μ_{int}), standard error (SE), and variance (*V*) of L_{inst} in each flow interval
3. Multiply μ and SE in each interval by % of time flow interval occurred
4. Average daily load (L_{FDRC}) = sum (u * % time) of each flow interval
5. Use *V* of each flow interval to calculate confidence interval of L_{FDRC} assuming Student's "t" distribution

Estimator #3:
Linear regression by least squares

Linear model:

$$Ln\,(L) = B_0 + B_1 * Ln\,(Q) + \varepsilon$$

L and Q	=	observed instantaneous load and associated flow
B_0 and B_1	=	model coefficients
ε	=	residual (model error)

Note: ε is a normal random variable

Estimator #3: Linear regression

- <u>ISSUE</u>: Retransformation of model estimates from "log space" to "real space" introduces prediction bias:

$$L_{exp} = exp(B_o + B_1 * Q)$$

- When variance of ε > 0, mean response of model is underestimated
- Estimating precision "not easy" (Cohn, 1995)

Bias-correction factor #1:

- Quasi-maximum likelihood estimator (QMLE) described by Ferguson (1986) and Cohn et al. (1989)
- Used when ε is normally-distributed
- Model form:

$$L_{qmle} = L_{exp} * \exp(s^2/2)$$

s^2 = standard deviation of model residuals

Bias-correction factor #2:

- "Smearing" estimator presented by Duan (1983) and described by Koch and Smillie (1986)
- Non-parametric (independent of ε distribution)
- Model form:

$$L_{sm} = L_{exp} * (1/n) * (\text{sum } \exp(\varepsilon))$$

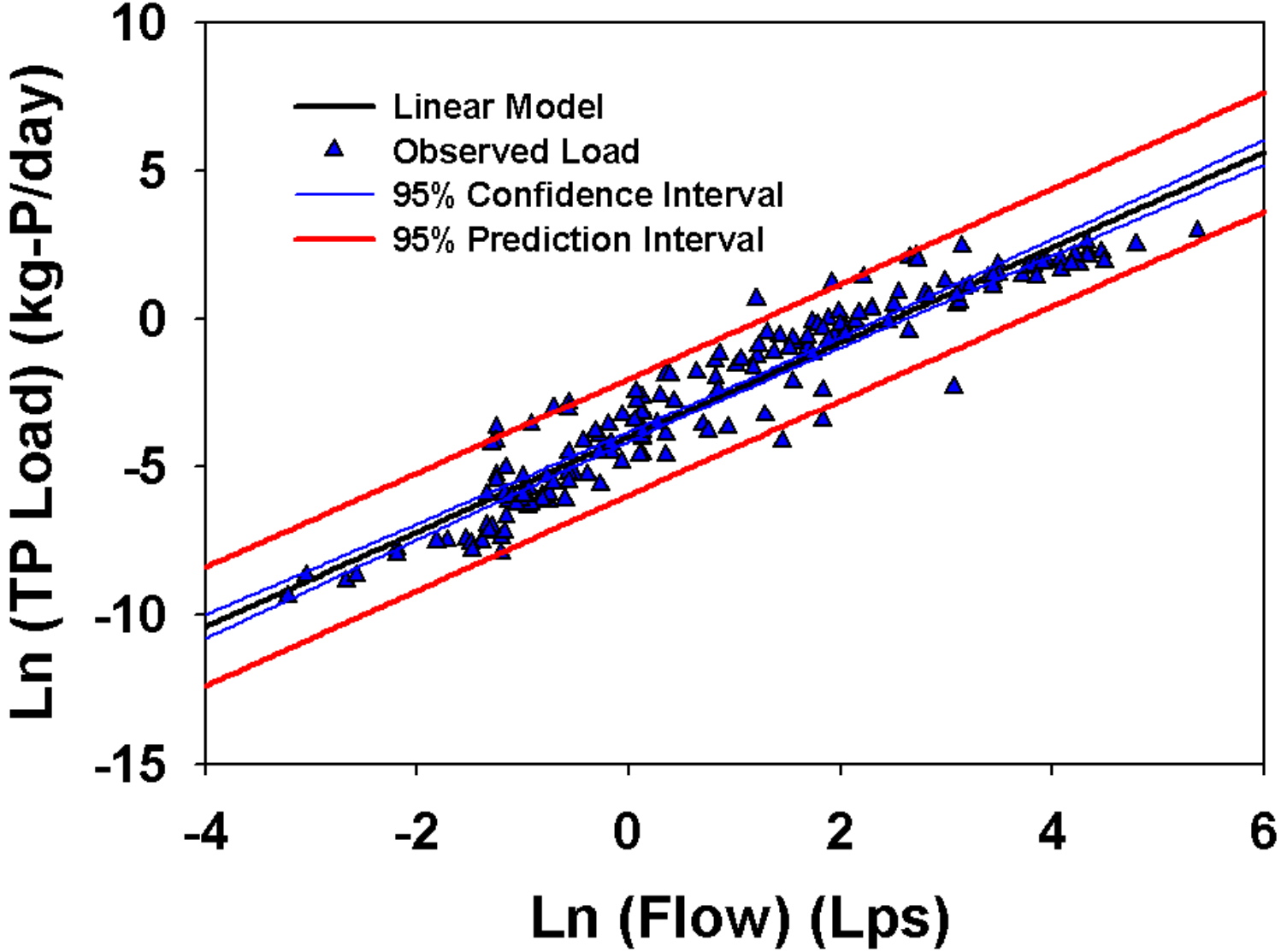
n = number of (Q,L) data pairs used to fit model

Regression Diagnostics

- Statistical tests on residuals
  - Significance (α=0.05) and SE of model coefficients
  - Kolmogorov-Smirnov test (normality)
  - Constant variance test
  - Durbin-Watson (serial correlation)
  - R^2

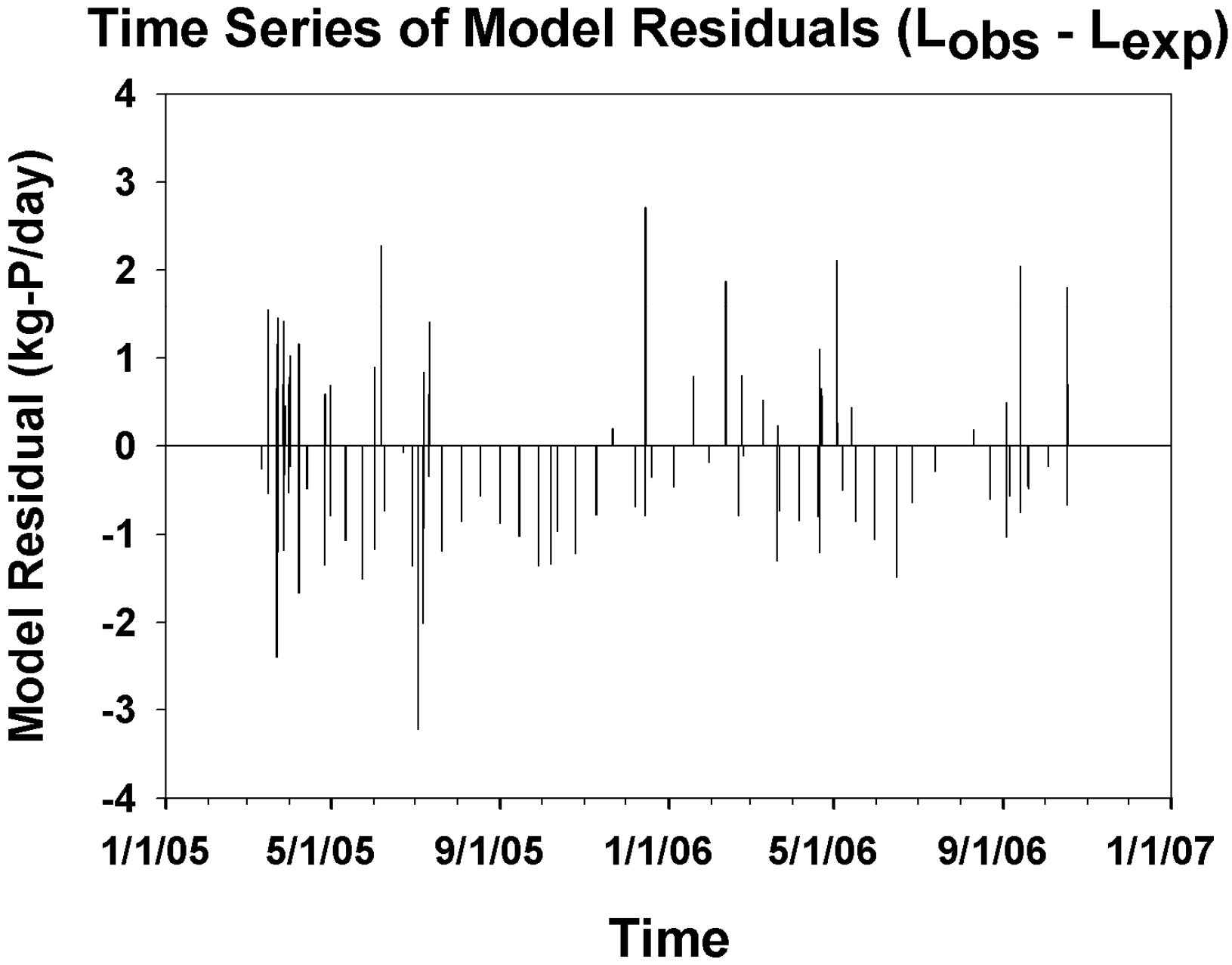
- Residual plots

Least-Squares Regression Model Fit to Site 6 Load vs Flow

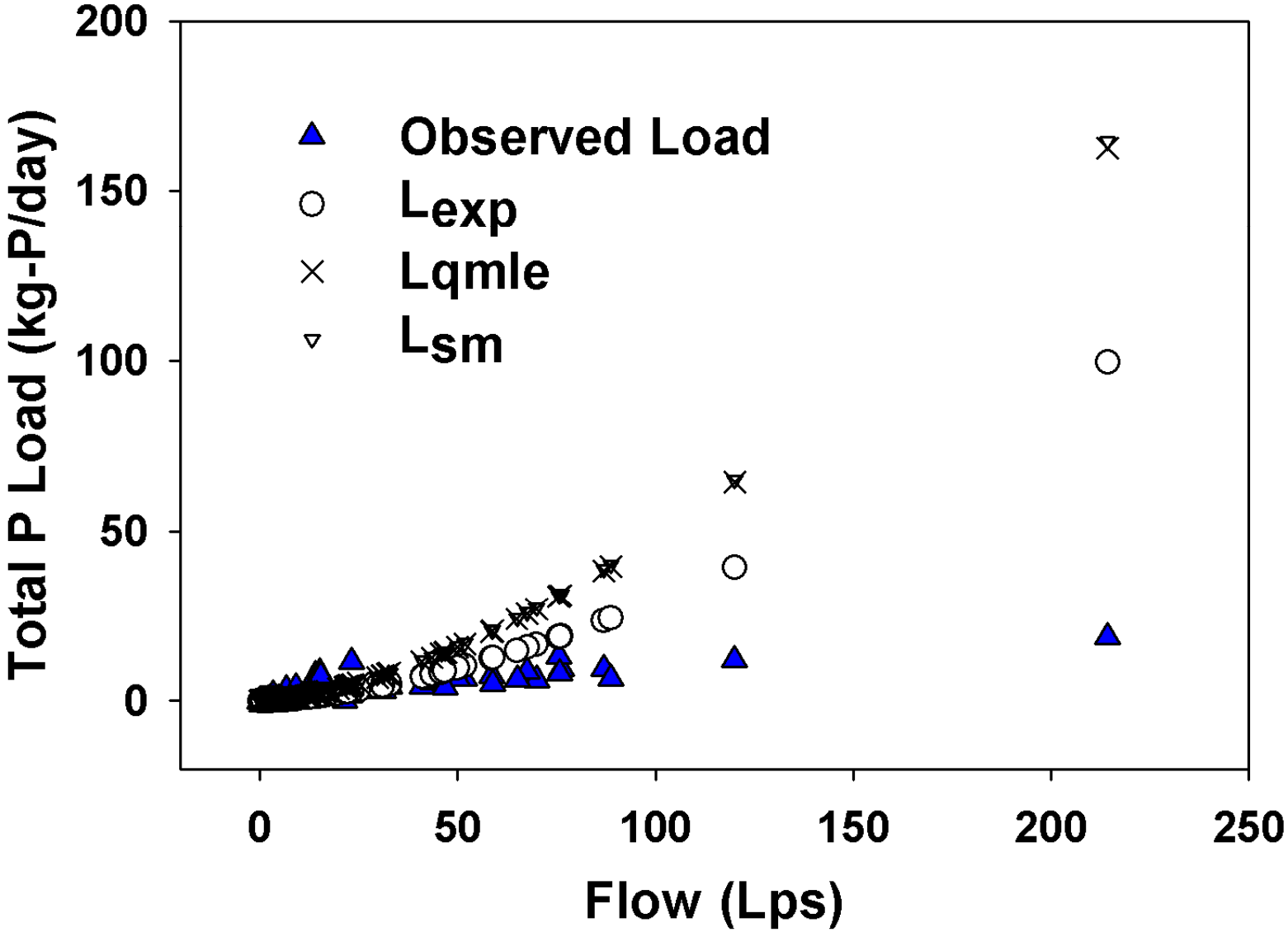


Model Fit Statistics for Site AG-6

Coefficient	Value	SE	P
B	-3.9886	0.0819	<0.0001
B_o	1.6003	0.0388	<0.0001
Test	**Value**	**P-level**	**Pass / Fail**
Kolmogorov-Smirnov	0.0692	0.3596	Pass
Constant Variance	---	0.3290	Pass
Durbin-Watson	*1.0604*	---	*Fail*
R^2	0.9071	---	---


Time Series of Model Residuals (L_{obs} - L_{exp})
Model Residual (kg-P/day)
4
3
2
1
0
-1
-2
-3
-4
1/1/05
5/1/05
9/1/05
1/1/06
5/1/06
9/1/06
1/1/07
Time

Comparison of Observed and Estimated Loads for Site 6 with and without Bias Correction



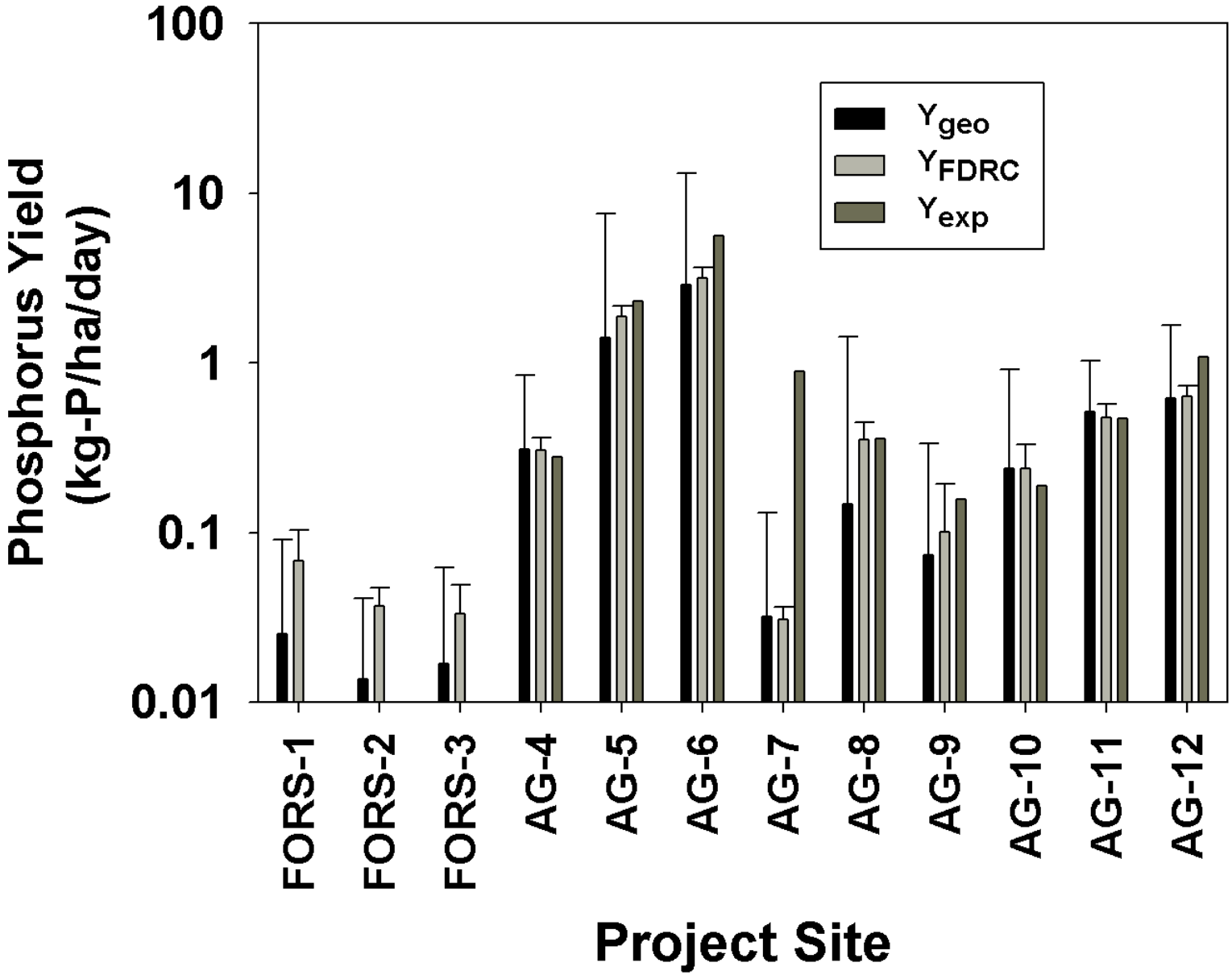
Comparison of Observed vs. Predicted Load using Composite Sample

Time Storm Composite Collected	No. Flow-Weighted Samples Collected	Flow Volume Sampled (L)	Event Mean Conc. (mg-P/L)	Obs. Load (kg-P)	Pred. Load (kg-P)	Percent Difference
1/2/06 08:32 - 1/4/06 11:39	71	371,881	2.10	0.781	0.440	43.6
3/9/06 23:50 - 3/10/06 12:41	14	177,871	2.27	0.404	0.212	47.5
5/3/2006 02:33 - 5/3/06 03:26	9	31,414	0.90	0.028	0.030	-6.12

Diagnostic Statistics

Site	Model Coeff. P-levels	K-S Test	C-V Test	D-W	R^2
AG-4	<0.0001	Pass	*Fail*	*Fail*	0.74
AG-5	<0.0001	Pass	Pass	*Fail*	0.87
AG-6	<0.0001	Pass	Pass	*Fail*	0.91
AG-7	<0.0001	Pass	Pass	*Fail*	0.78
AG-8	<0.0001	Pass	Pass	*Fail*	0.86
AG-9	<0.0001	Pass	*Fail*	*Fail*	0.84
AG-10	<0.0001	Pass	Pass	*Fail*	0.74
AG-11	<0.0001	Pass	*Fail*	*Fail*	0.90
AG-12	<0.0001	Pass	Pass	*Fail*	0.94

Phosphorus Yields from Geometric Mean, FDRC, and Non-Bias Corrected (Lexp) Load Estimators



Comparison of Minimum and Maximum Phosphorus Yields by Estimator

Estimator	Min	Max
Geomean	0.031	2.88
FDRC	0.032	3.17
Lexp	0.36	5.59
Units = kg-P/ha/yr		

Summary

- Substantial variability in P yields across AG sites.
- Variability, in part, due to estimator used
- Results suggest regression estimators offer promise headwater streams
- Customized autosampler program may help validate regression estimates

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