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The effect of BMPs on water quality: Optimizing monitoring to reduce uncertainty and maximize scientific value

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Key Restoration Questions

This project is addressing two major research questions:

1. *What are the cumulative effects of watershed restoration activities within a watershed?*

2. *What degree of representative sampling is required to determine levels of pollutant discharge at a county scale?*

Hypotheses to be Tested

1. *An increase in BMP treated area by 0.6% of a watershed area reduces pollutant export by 5%.*

2. *Stream water sampling at seven-hour frequencies using an automated sampler is sufficient to reduce maximum load estimate error rates to 15%.*

3. *The uncertainty of pollutant loads estimated at different sampling frequencies significantly differs with watershed size, land use, area of impervious surface, rainfall, and hydrology.*

Data Used to Test Hypotheses

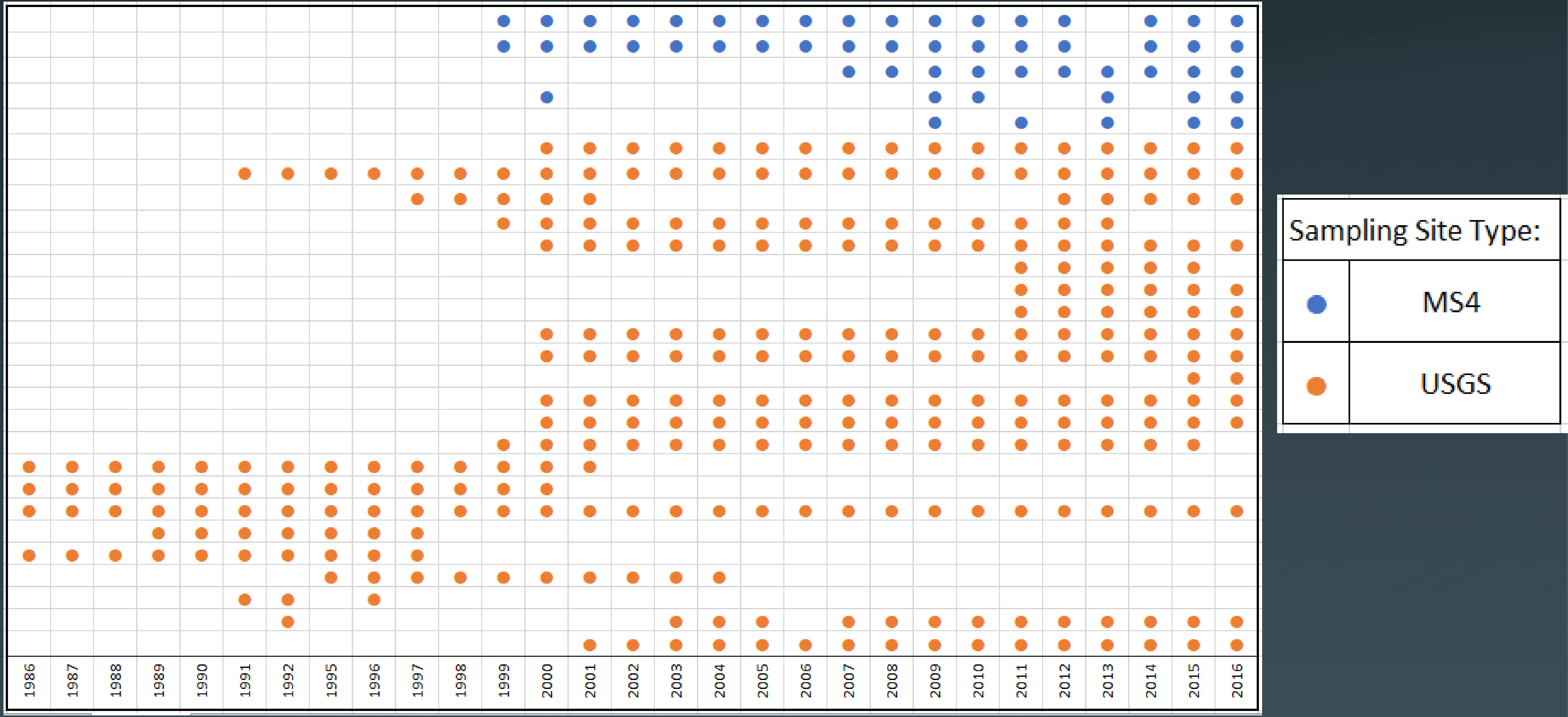
Hypothesis 1:

- MS4 Permittee Water Quality and Hydrological data
- USGS Water Quality and Hydrological data
- StormwaterPrint BMP Geodatabase

Hypothesis 2 and 3:

- Near-continuous Water Quality and Watershed data

Time Series Analysis Not Possible: Lack of Overlap



Do Not Have Range of BMPs in Data

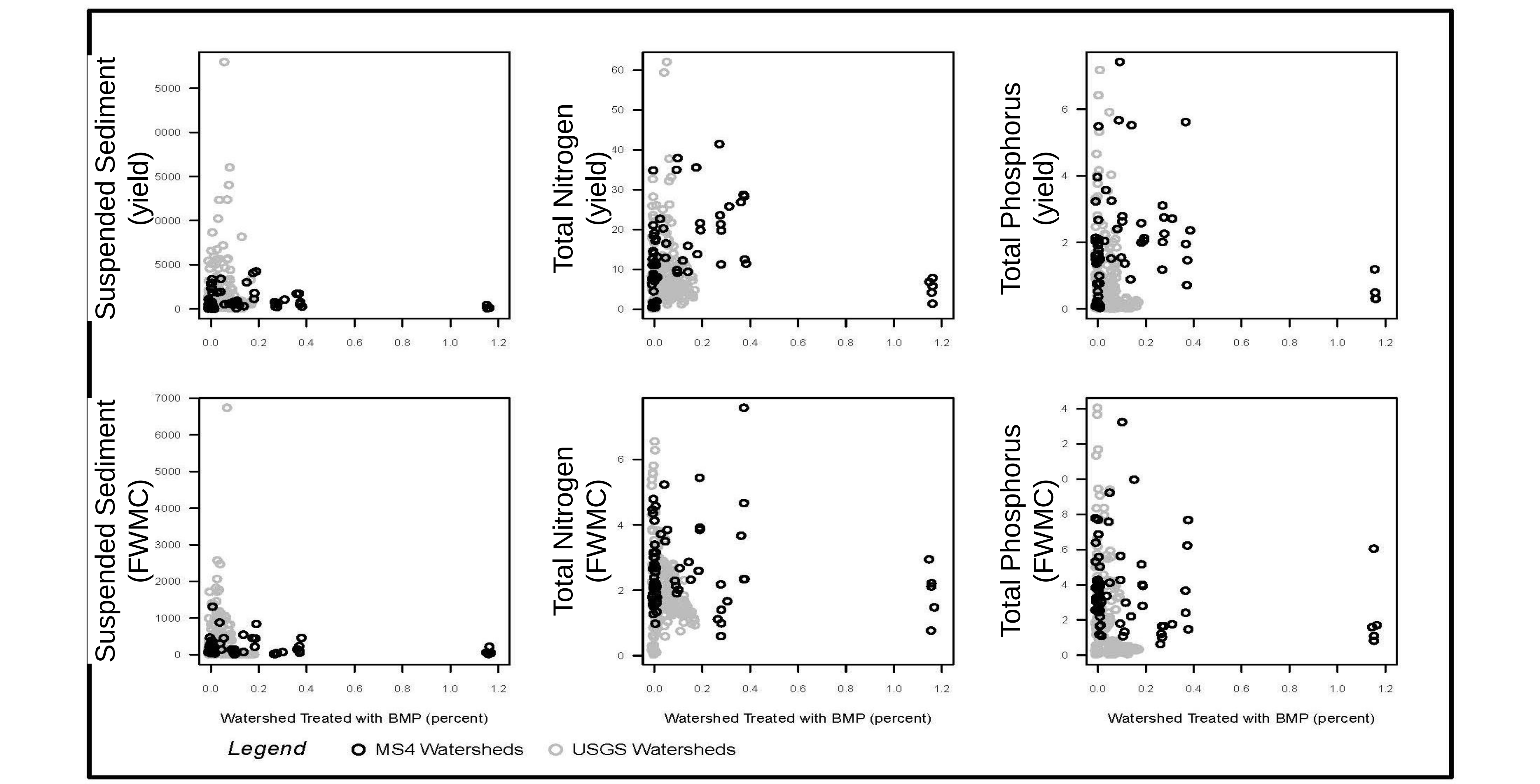
- MS4 watersheds with >30% BMP
- Less BMP area for USGS watersheds
  - Several with 0%
- BMP change within watershed
  - <10% except few MS4 watersheds

Site ID	Watershed Area (acres)	Acres with BMP Treatment Min	Acres with BMP Treatment Max	Acres with BMP Treatment Change	BMP as % of Watershed Min	BMP as % of Watershed Max	BMP as % of Watershed Change
MS4	1,843	--	15	15	--	0.8%	0.8%
	2,280	2	20	18	0.1%	0.9%	0.8%
	406	41	126	84	10.2%	30.9%	20.7%
	156	--	182	182	--	116%	116%
	570	210	215	4	36.9%	37.7%	0.8%
	1,566	--	290	290	--	18.5%	18.5%
USGS	4,095	--	--	0	--	--	0
	88	--	--	0	--	--	0
	1,265	49	176	127	3.9%	13.9%	10.0%
	182,454	3,782	5,490	1,708	2.1%	3.0%	0.9%
	192,523	4,594	6,978	2,384	2.4%	3.6%	1.2%
	198,464	4,909	7,379	2,470	2.5%	3.7%	1.2%
	221	12	17	5	5.6%	7.6%	2.1%
	791	32	61	29	4.1%	7.7%	3.7%
	2,157	127	138	11	5.9%	6.4%	0.5%
	20,863	1,361	2,886	1,524	6.5%	13.8%	7.3%
	3,519	417	624	207	11.9%	17.7%	5.9%
	40,689	1,775	3,864	2,090	4.4%	9.5%	5.1%
	22,395	0	38	37	0.0%	0.2%	0.2%
	62,981	1,433	3,088	1,654	2.3%	4.9%	2.6%
	224,019	1,828	13,707	11,879	0.8%	6.1%	5.3%
	5,959	--	--	0	--	--	0
	1,978	--	--	0	--	--	0
	46,413	972	4,232	3,259	2.1%	9.1%	7.0%
	35,338	173	508	335	0.5%	1.4%	0.9%

Analysis Used to Test Hypothesis 1

- Nested Linear Mixed Effect Regression
- Predict pollutant load from amount of BMPs and impervious surface in a watershed
- Accounting for the variability in loads between each watershed by having the watershed as a factor
- Also applied to pollutant yields and flow-weighted mean concentrations
- Pollutants modeled include sediment, nitrogen, and phosphorus

Little Relationship Between BMPs and Pollutants



Results – Hypothesis 1, MS4 Sites Only

				Significance (p-value)	
Measure of Pollutants	Intercept	%Treated	%Impervious	%Treated	%Impervious
Suspended Sediment					
Load	13.087	-1.327	-3.283	0.0629	0.1020
Yield	7.003	-0.872	-2.742	0.2044	0.1627
FWMC	6.280	-0.453	-4.603	0.1312	<0.0001
Total Nitrogen					
Load	8.390	-0.910	-0.779	0.0430	0.5580
Yield	2.507	-0.745	-0.577	0.0971	0.6681
FWMC	1.401	-0.033	-1.731	0.8320	0.0005
Total Phosphorus					
Load	6.319	-1.751	-0.162	0.0008	0.9143
Yield	0.355	-1.536	0.216	0.0036	0.8874
FWMC	-0.467	-0.430	-2.033	0.0426	0.0005

Results – Hypothesis 1, USGS and MS4 Sites

Measures of Pollutants	Model Coefficients				Significance (p-value)		
	Intercept	%Treated	%Impervious	% Cult.Crops	%Treated	%Impervious	% Cult. Crops
Suspended Sediment							
Load	16.986	-0.854	-10.072	-4.777	0.3600	0.0006	0.0519
Yield	7.170	-0.840	-2.429	-0.362	0.3023	0.1594	0.7935
FWMC	5.432	0.538	-5.770	-0.145	0.5169	0.0129	0.9284
Total Nitrogen							
Load	9.368	-0.717	-0.961	0.545	0.1190	0.6526	0.8328
Yield	1.285	-0.718	1.980	2.934	0.0872	0.0983	0.0075
FWMC	0.184	0.369	0.639	1.888	0.1771	0.4091	0.0114
Total Phosphorus							
Load	6.563	-1.389	-0.361	1.132	0.0456	0.8950	0.7069
Yield	-1.393	-1.115	1.766	3.515	0.0839	0.3126	0.0310
FWMC	-2.518	-0.144	0.659	2.412	0.7794	0.6650	0.1005

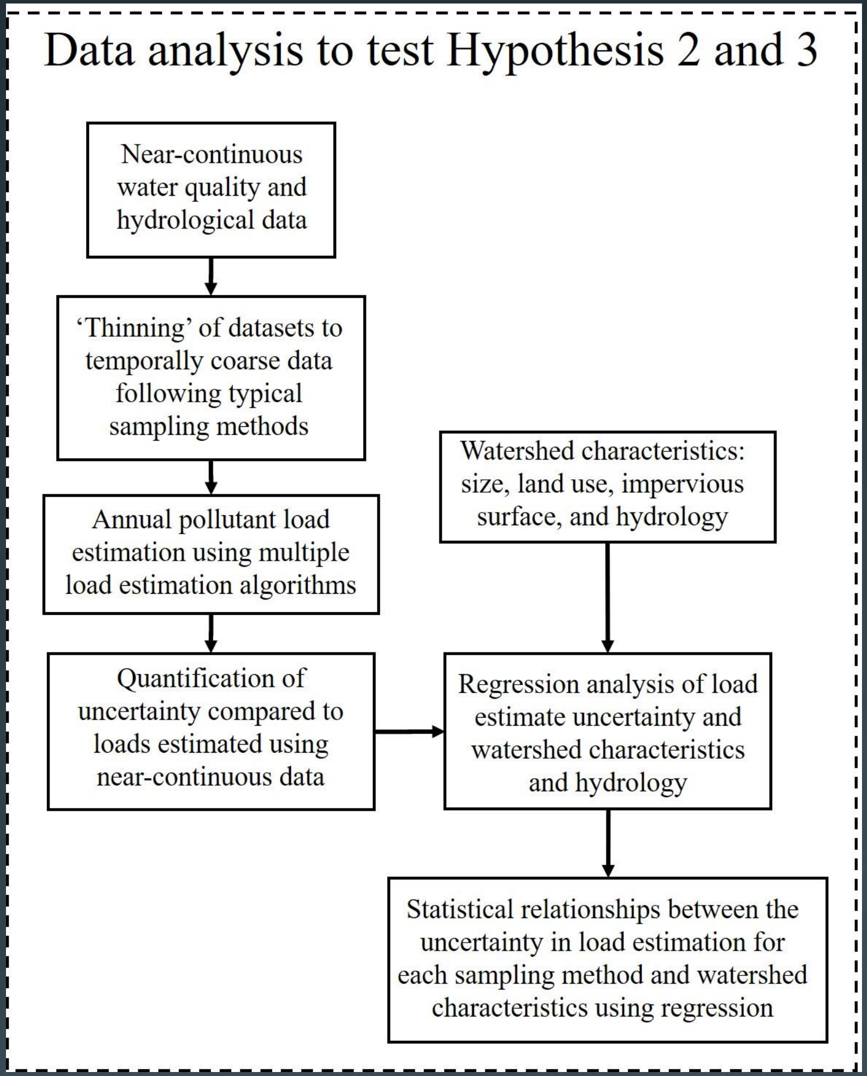
Summing up…

- … based on the data used in the analysis, there is no obvious correlation between BMP implementation and pollutant reduction.

- There may be other confounding variables that were not considered in the analysis.
- There is uncertainty in BMP accounting in each watershed.
- There are limitations of sampling methods that result in large uncertainty in annual pollutant estimates.

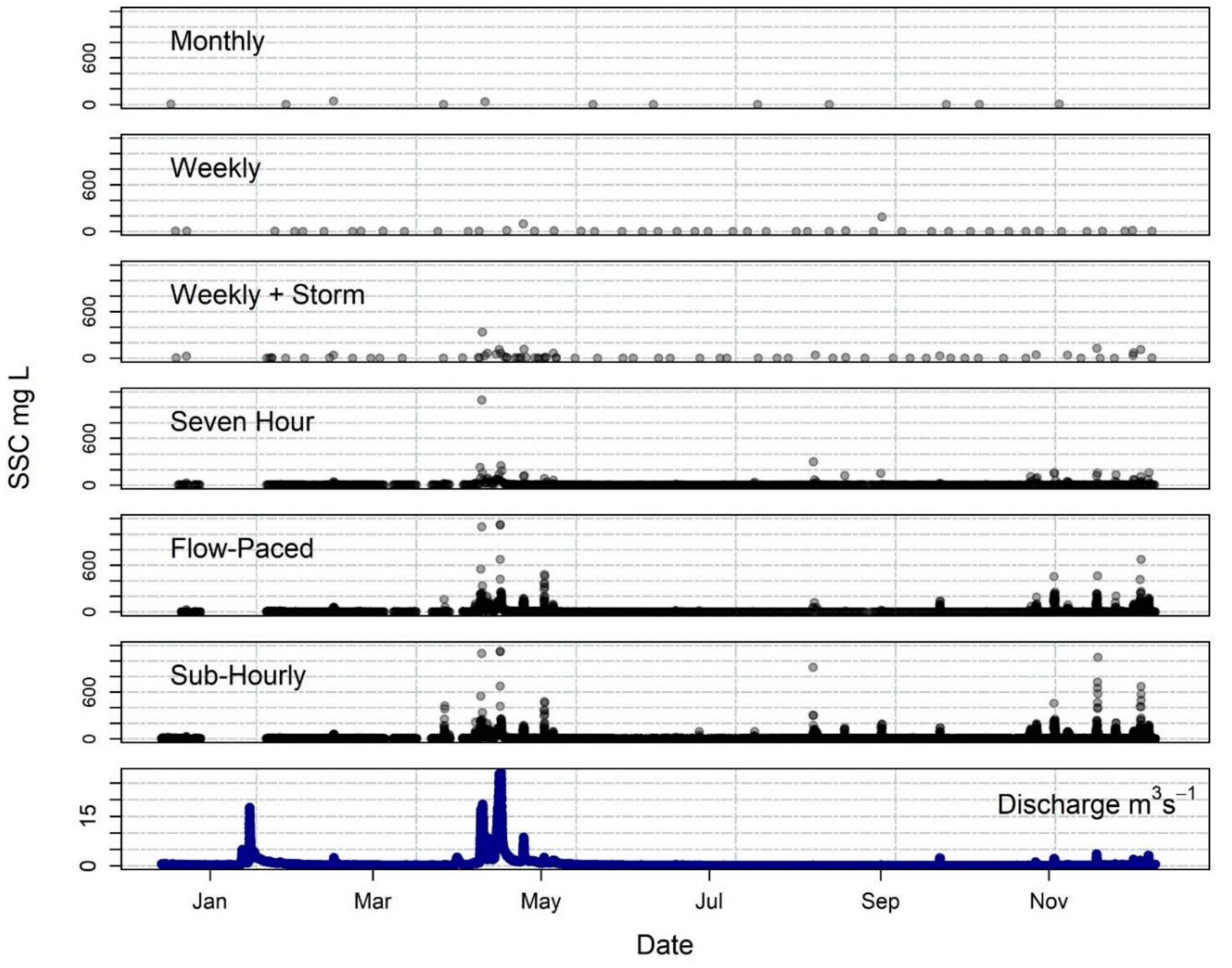
- The second half of the project looks at this sampling uncertainty.

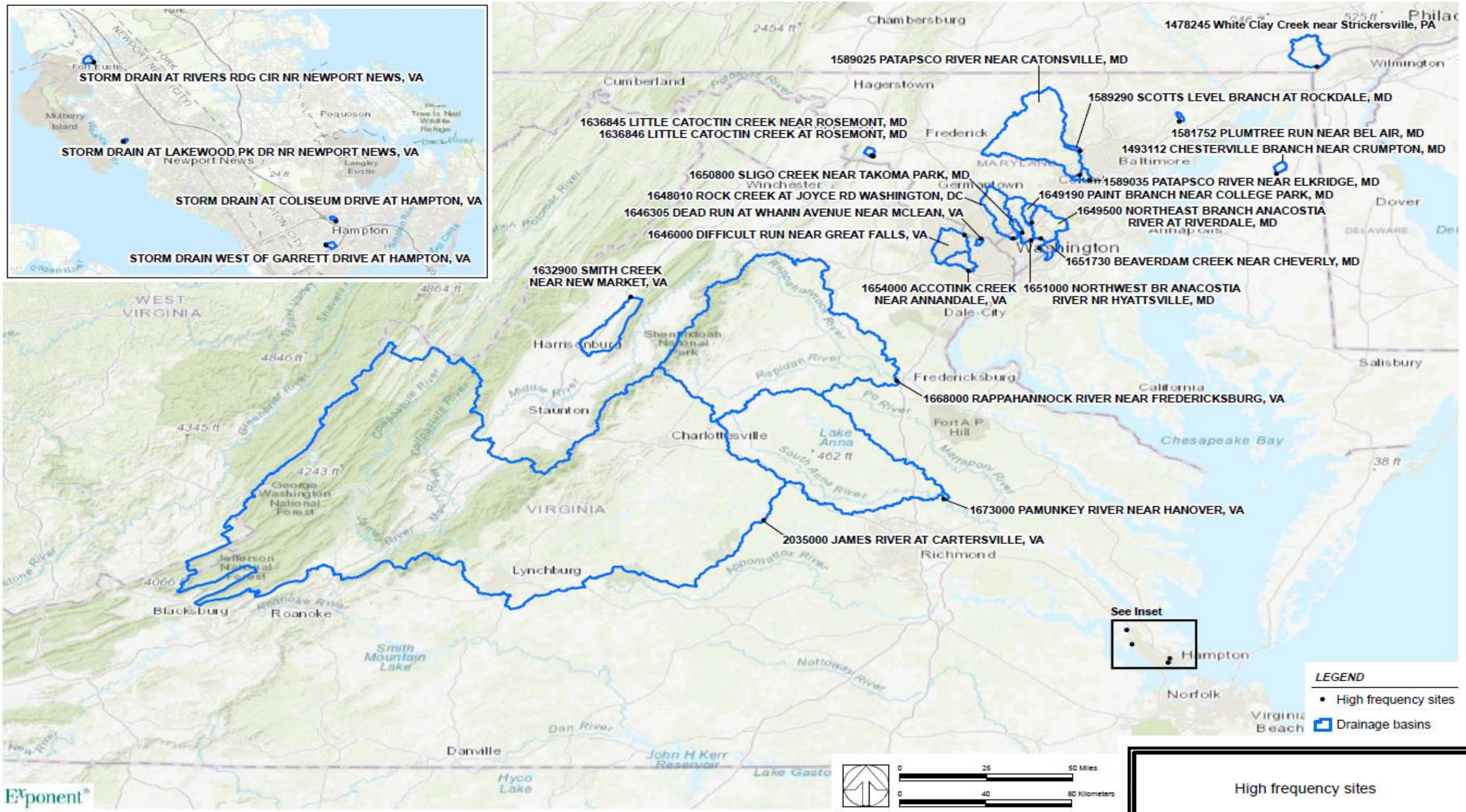
High-frequency USGS data were used to test Hypotheses 2 and 3 about sampling uncertainty



Sampling Method	No. Sample Sets	Description
Monthly	1,000	Sample taken every month (7 am–6.30 pm, M–F)
Weekly	1,000	Sample taken every week (7 am–6.30 pm, M–F)
Weekly + Storm	1,000	Sample taken every week (7 am–6.30 pm, M–F) with a daily sample taken when flow >10th percentile.
Seven-Hour	1,000	Sample taken every 7 hours.
Flow-Paced	600	Sample taken when flow exceeds cumulative threshold (threshold set to yield an average 80 pumps per week and aggregated into weekly composite).
MDE MS4 Permittee Requirements	1,000	Samples taken from 12 storms with monthly samples taken during episodes of extended low flow.

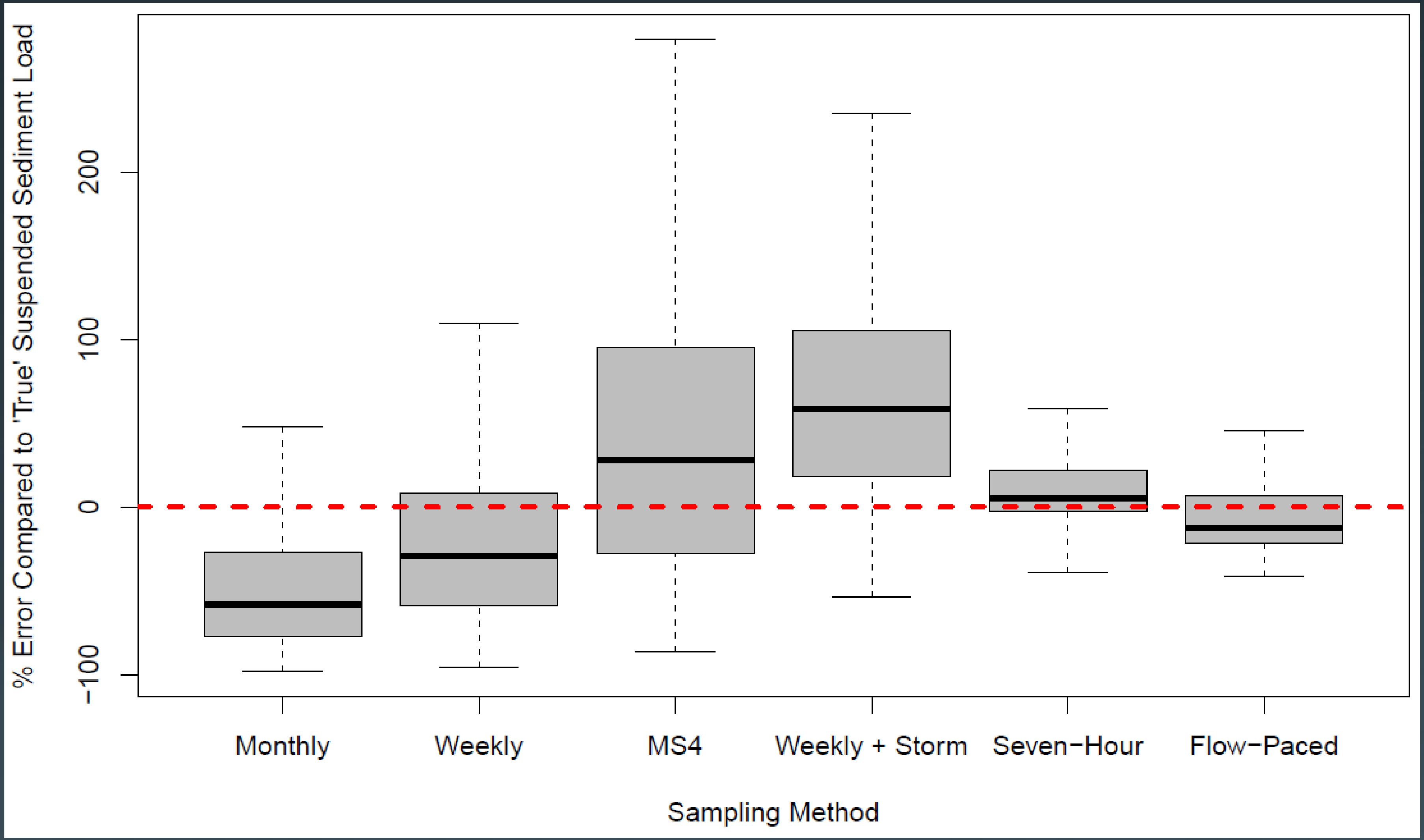
Less sampling reduces amount of information available for annual load computation





High frequency sites

Sampling Error Varies Among Methods and Pollutants



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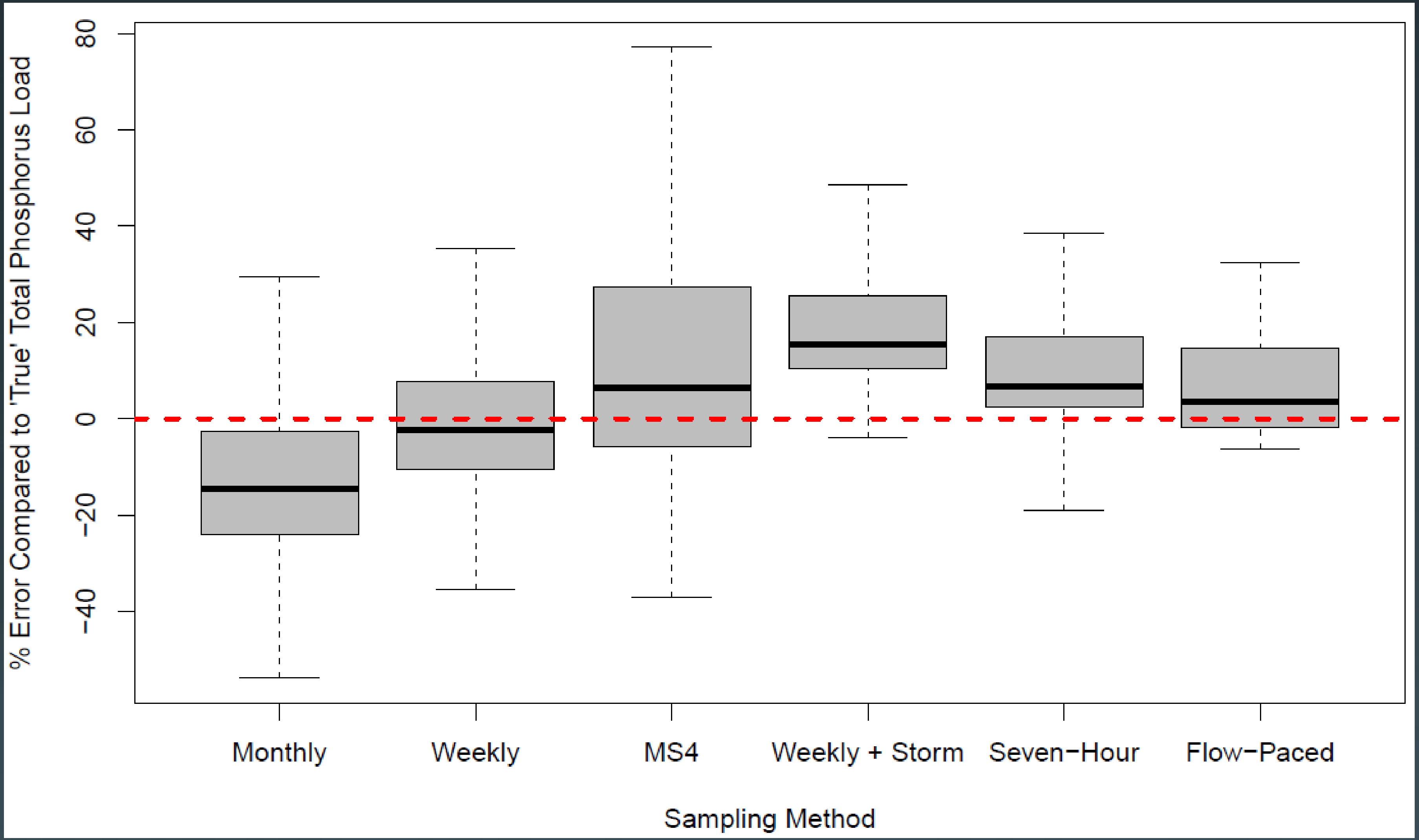

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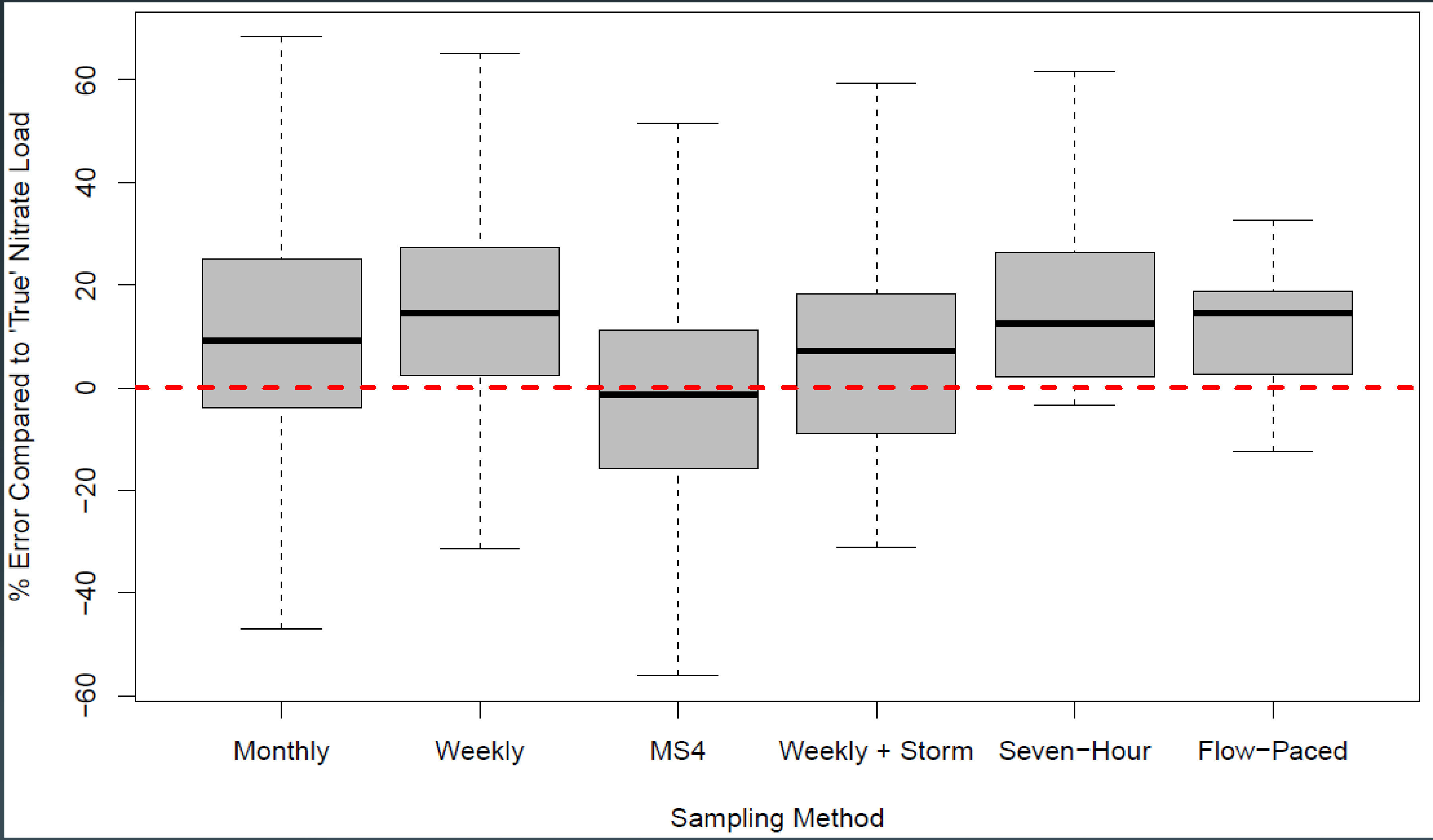


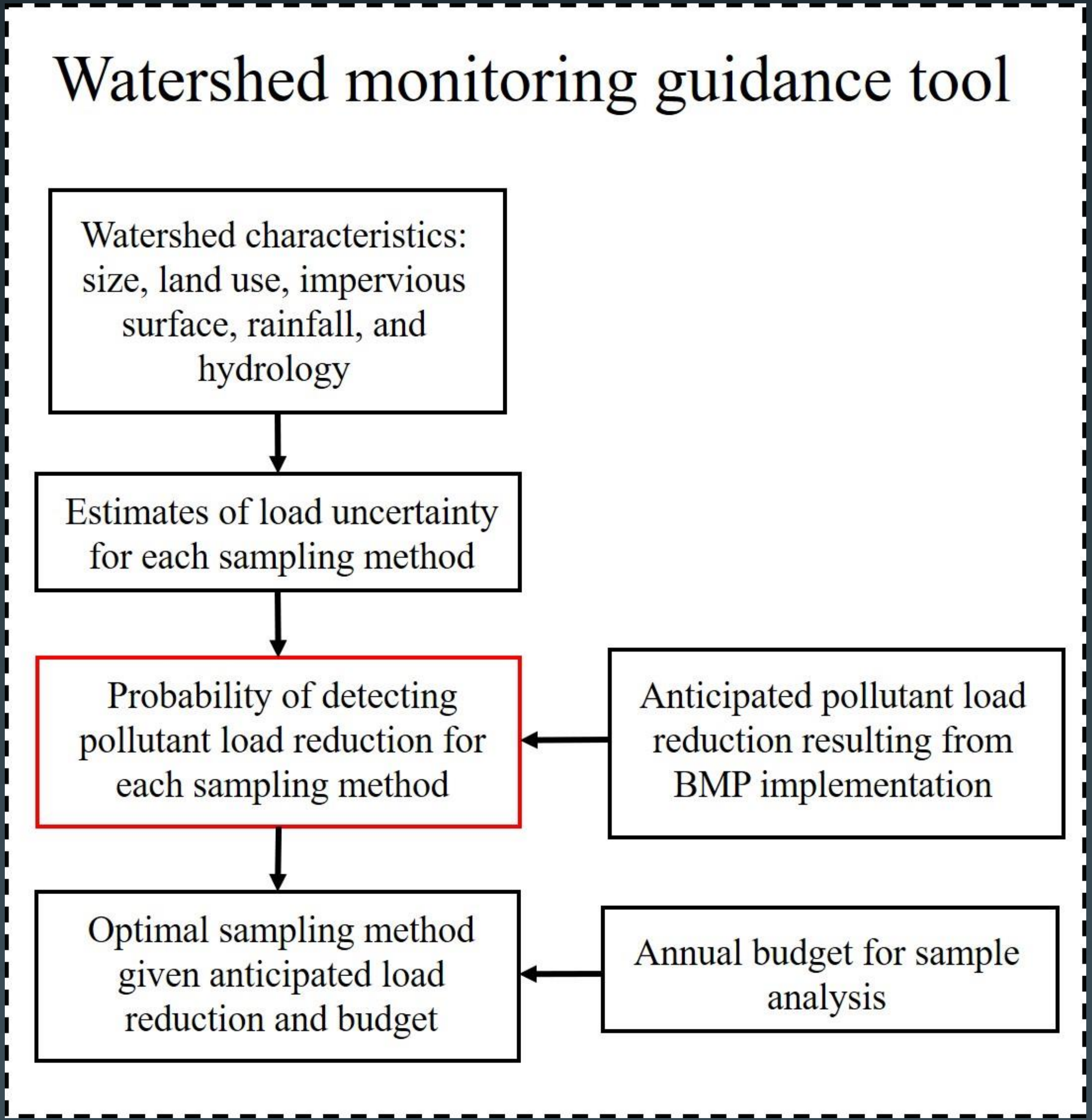
Watershed Characteristics Predict Sampling Error

Table 1. Results of stepwise linear regression models for suspended sediment concentrations

Model Fit	Monthly		Weekly		Weekly+Storm		Seven-Hour		Flow-Paced		MDE MS4	
AIC	-12.19		28.76		125.78		111.72		98.28		77.91	
Adjusted R-squared	62.7%		69.3%		13.0%		35.7%		23.6%		3.5%	
Overall p-value	<0.0001		<0.0001		0.0094		<0.0001		0.0005		0.1168	
Residual standard error (df)	0.1972 (40)		0.3110 (39)		0.9661 (42)		0.8146 (41)		0.7067 (42)		0.5607 (42)	
Model Terms	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
Intercept	0.08140	0.4594	-0.9875	0.0038	-2.265	0.0003	-0.7647	0.0054	1.148	0.1670	-1.115	0.0018
Log Watershed Size	-0.06871	0.0002	-0.1657	<0.0001	--	--	-0.2140	0.0002	--	--	--	--
Log Discharge	--	--	--	--	--	--	--	--	-0.1693	0.0005	--	--
Baseflow Index	--	--	2.253	0.0028	4.499	0.0094	--	--	--	--	1.537	0.1168
Flashiness Index	--	--	0.0203	0.0362	--	--	--	--	--	--	--	--
% Developed Low Intensity	-0.5668	0.0858	--	--	--	--	--	--	--	--	--	--
% Woody Wetlands	-14.30	<0.0001	-18.00	<0.0001	--	--	-16.98	0.0773	--	--	--	--

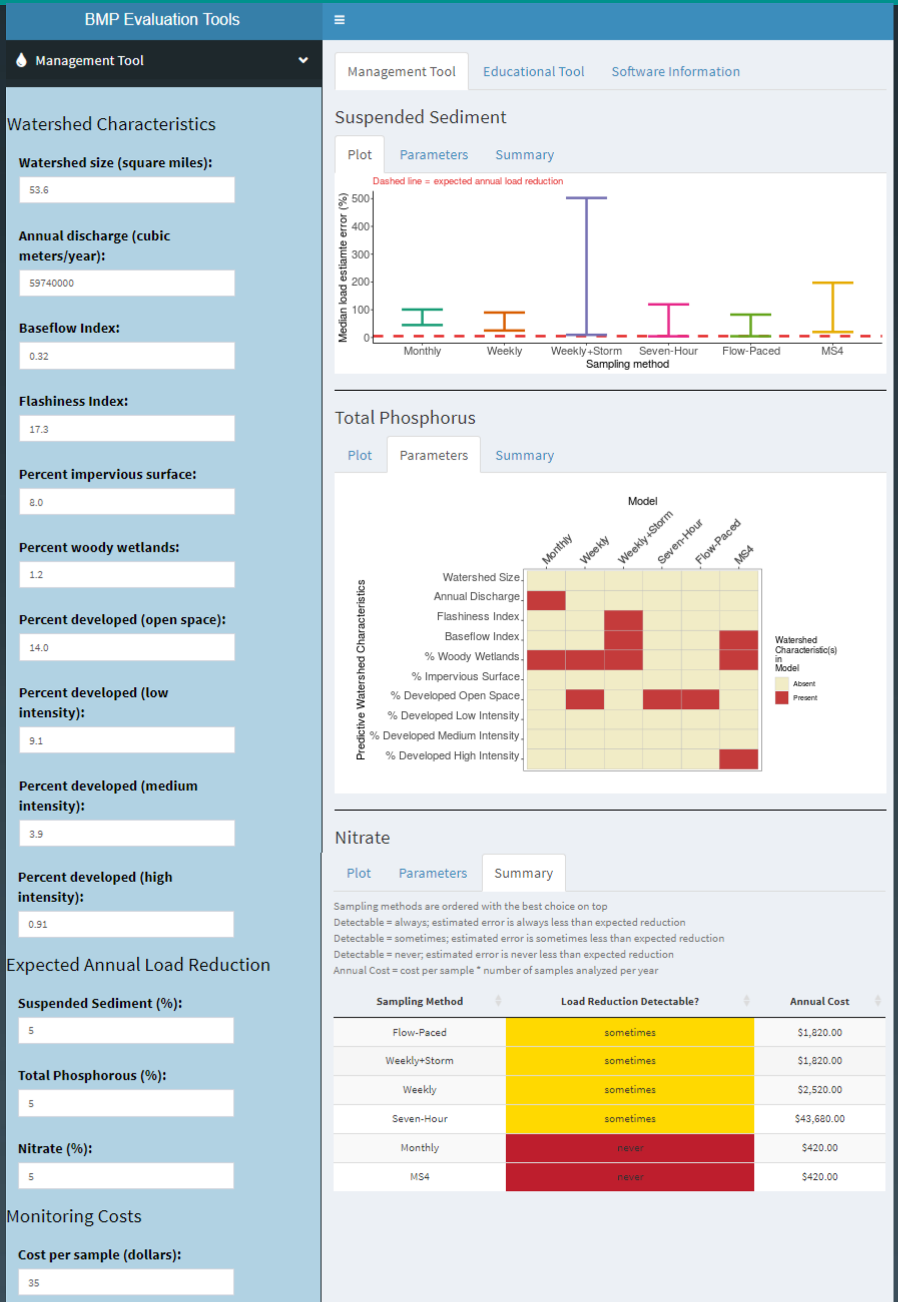
Monitoring guidance tool

- Uses regressions of load estimate error rate for each sampling method and watershed variables.
- Predicts error rate (with 95% confidence interval), using regressions, based on user inputs of those variables.
- Outputs whether sampling method would detect expected load reductions and plots error rate by sampling method.



Inputs of watershed characteristics of proposed monitoring site

Anticipated load reduction from BMP and sample analysis cost



For each pollutant and method, users can see:

- graphical summaries,
- model parameters included,
- monitoring costs,
- summary of likelihood of whether load reduction is detectable

BMP Evaluation Software: Educational Tool

- The educational tool allows users to visualize how sample size influences the uncertainty in annual load estimates from two demonstration datasets in the Chesapeake Bay.

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Exponent, Inc.

Translation Slides by Joshua Thompson, Watershed Protection and Restoration Program, Annapolis, MD

What does this mean for me?

- Re-purposing data for causal analyses is challenging – there are confounding issues of data quality, comparable monitoring methods, and unknown exogenous variables.
- Having large amounts of data from a number of monitoring sites is not equivalent to a BACI monitoring design.
- Accuracy and precision of annual sediment, phosphorus, and nitrogen pollution estimates are not only affected by sampling frequency but also the type of watershed in which sampling methods are applied.
- The right sampling methods need to be applied to make monitoring restoration projects worthwhile.

What does this mean for me?

What do I take from this if I am a practitioner:

- The smaller the pollutant reductions from a project, the larger the investment needed in a high-resolution monitoring program able to detect the expected water quality benefits.
- Using tools such as the decision support tool developed in this project can be beneficial when deciding whether monitoring will be a worthwhile component of a project.

What does this mean for me?

What do I take from this if I am a regulator:

- Temporally coarse monitoring will likely be ineffective at evaluating a restoration program's success. The financial burden of a scientifically weak monitoring program outweighs the benefits of the information gained.
- Evolving from broader regulatory monitoring to hypothesis-driven monitoring, with greater coordination between researchers, practitioners, state, and local agencies, will help maximize the scientific value of monitoring dollars and better audit implementation dollars.

Acknowledgements

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Chesapeake Bay Trust

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A Watershed Partnership

National Fish and Wildlife Foundation

Thank you!

- Questions?
- Comments?
- Suggestions?