Uncertainty in phosphorus loads from tile-drained landscapes

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The need for uncertainty analysis

Who is utilizing the data we collect?

Producers
Watershed groups
General public

Other scientists
State & local agencies
University extension

Policymakers
Resource managers

Uncertainty in nutrient loads

Discharge measurement
Sample frequency
Sample contamination

Sample preservation
Sample storage
Laboratory analysis

Method to calculate load
Calculation errors

$$Load = K\left(\sum_{j=1}^{n} Q_j C_j\right)$$

Objectives

- ✓ Quantify uncertainty in annual DRP load from tile-drained fields and headwater watersheds resulting from infrequent sampling and load calculation method
- ✓ Compare uncertainty estimates from tile-drained landscapes to naturally drained landscapes
- ✓ Examine the impact of three compositing strategies on load estimates

6 tile-drained study sites

2 headwater watersheds
(279 and 389 ha)

4 agricultural fields
(8 to 14 ha)

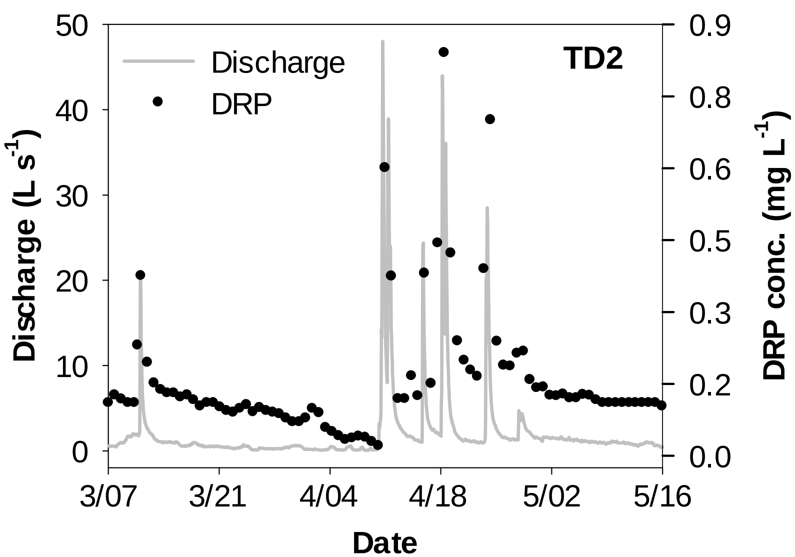
10 to 30 minute discharge
measurement

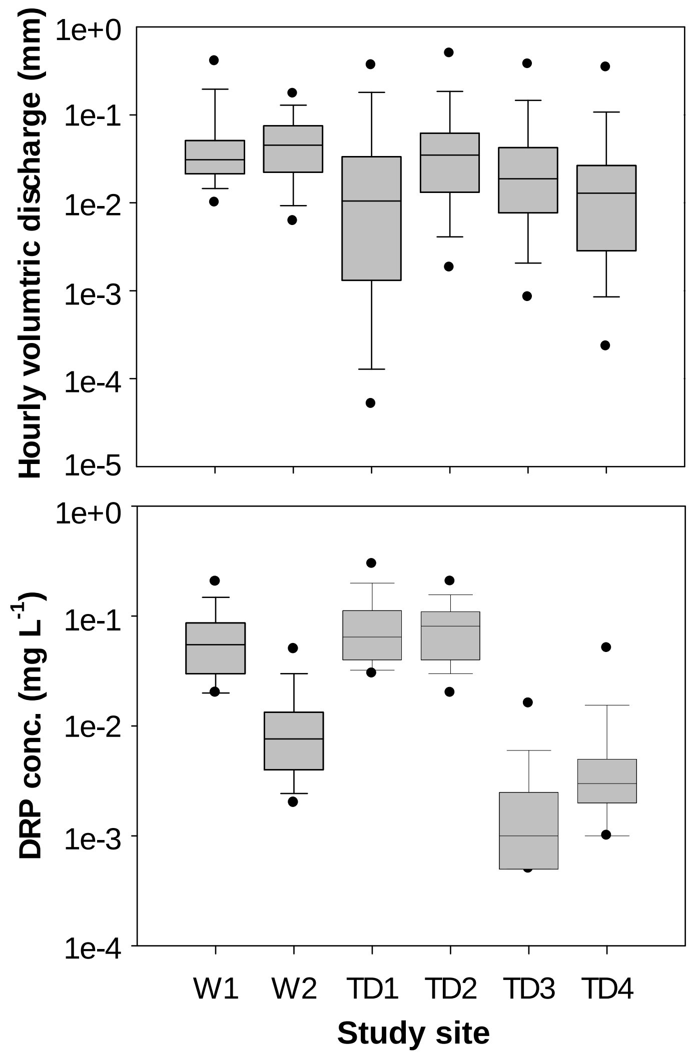
2 hour to 1 day sampling
frequency for DRP

Discharge and DRP concentration

DRP concentration increased with discharge, but weak concentration-discharge relationships were observed for all sites ($R^2 < 0.10$)

DRP concentration ranged from 0.001 to 1.69 mg L^{-1}





Calculating reference loads and uncertainty

Reference DRP load

$$Load_{ref} = K\left(\sum_{j=1}^{n} Q_j C_j^{int}\right)$$

Q_j = hourly discharge
C_j^{int} = hourly DRP concentration derived from linear interpolation between two consecutive samples
K = conversion factor to adjust for units

Uncertainty

$$e = \left(\frac{Load_{est} - Load_{ref}}{Load_{ref}}\right) \times 100$$

e = percent uncertainty
$Load_{est}$ = estimated DRP load based on a specific subsampled dataset
$Load_{ref}$ = reference DRP load

Load estimation algorithms

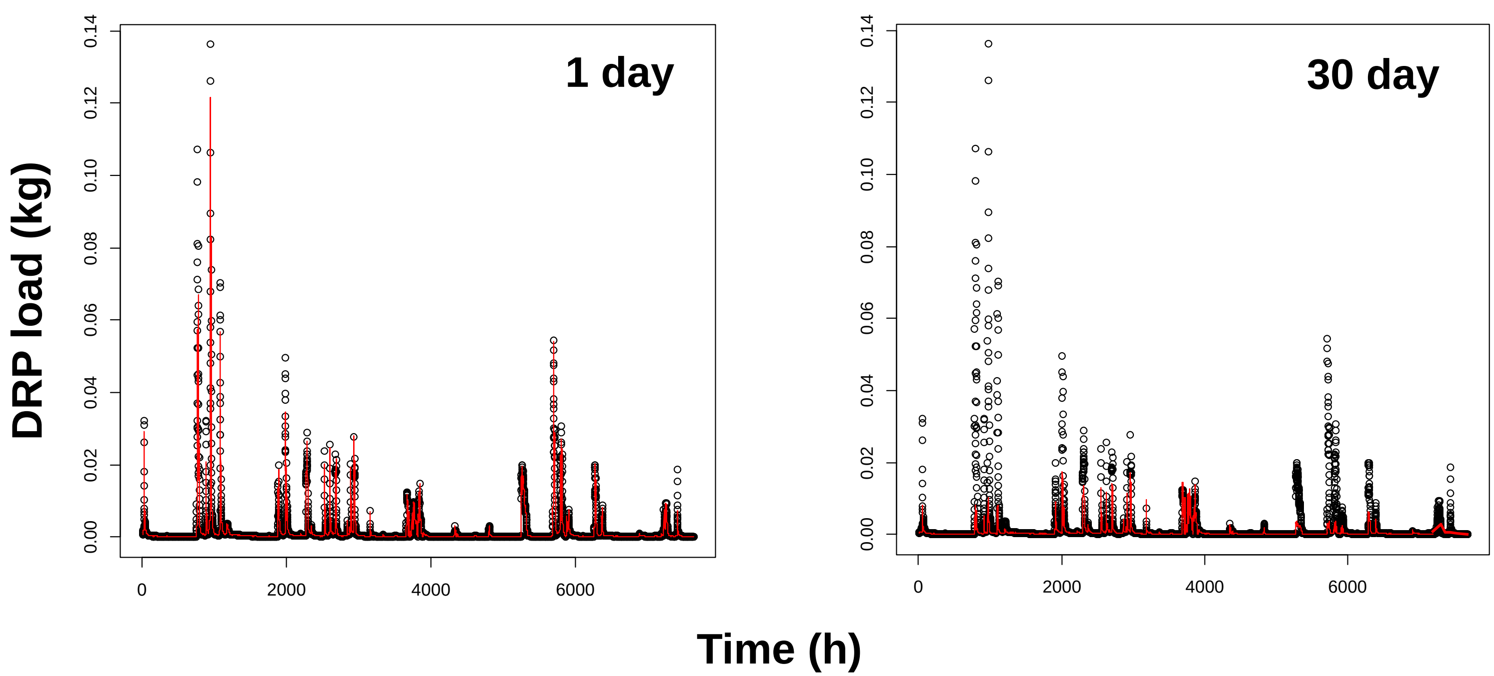
6 load estimation algorithms were tested

Method	Description	Equation
M1	Average instantaneous discharge × average concentration	$Load = K\left(\sum_{i=1}^{n}\frac{Q_i}{n}\right)\left(\sum_{i=1}^{n}\frac{C_i}{n}\right)$
M2	Average instantaneous flux	$Load = K\left(\sum_{i=1}^{n}\frac{Q_iC_i}{n}\right)$
M3	Constant concentration before and after sampling	$Load = K\left(\sum_{i=1}^{n}C_i\overline{Q_{i,i-1}}\right)$
M4	Annual flow volume × average concentration	$Load = KV\left(\sum_{i=1}^{n}\frac{C_i}{n}\right)$
M5	Annual flow volume × flow weighted mean concentration	$Load = KV\frac{\sum_{i=1}^{n}Q_iC_i}{\sum_{i=1}^{n}Q_i}$
M6	Linear interpolation of concentrations × continuous flow rates	$Load = K\left(\sum_{j=1}^{365}Q_jC_j^{int}\right)$

K = conversion factor to adjust for units and intervals of sampling.
C_i = concentration measured at the day and time of the ith sample.
Q_i = flow rate measured at the day and time of the ith sample.
Q_j = continuous flow rate.
V = annual cumulative flow volume (continuous data).
$Q_{i,\, i-1}$ = average flow rate between the ith and $(i-1)$th samples (continuous data).
C_{int} = linearly interpolated concentration value between samples.
n = number of samples.

Sampling scenarios

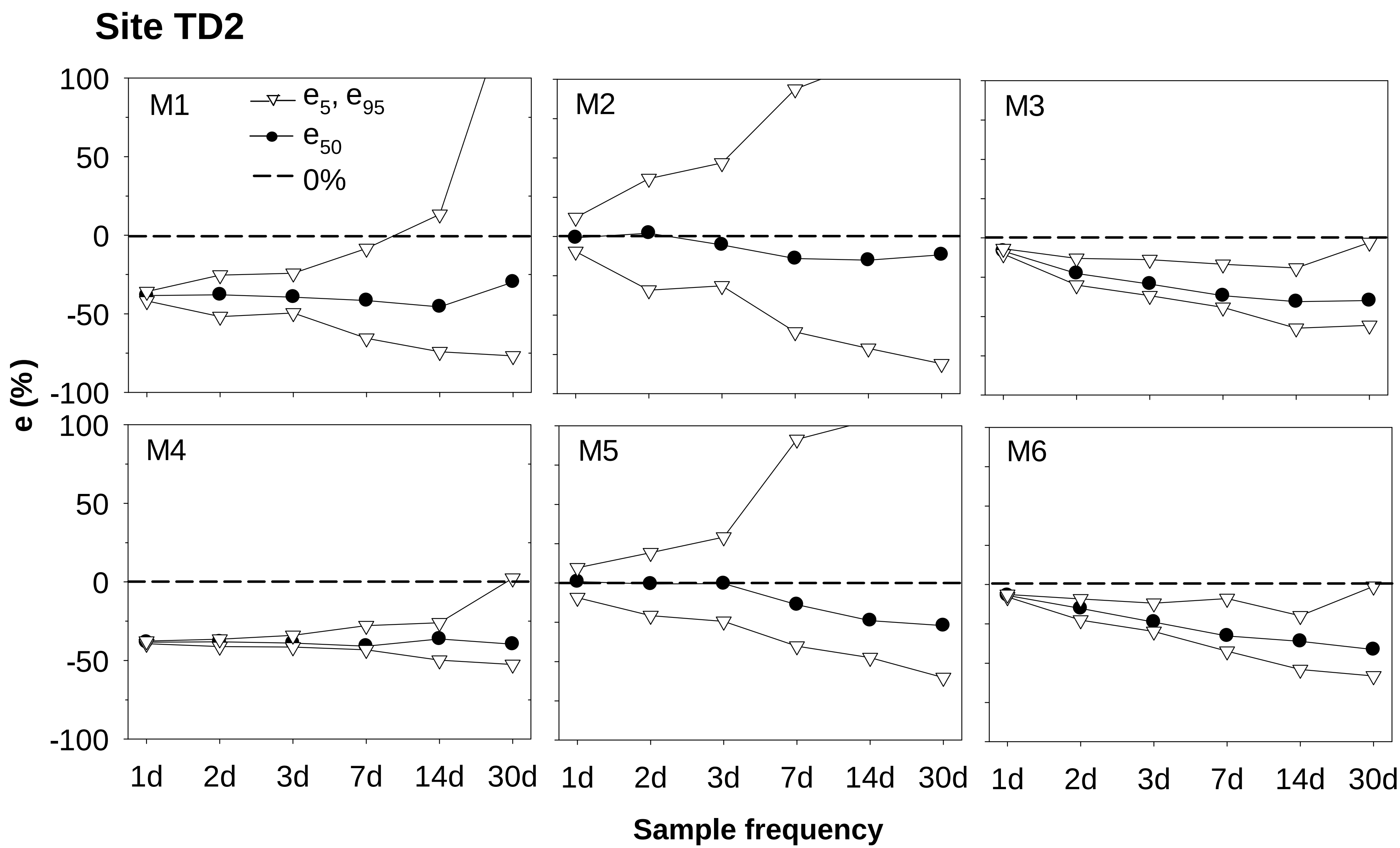
Monte Carlo simulation was used to randomly select a start date and time during the first 2 weeks of the reference dataset and subsample the reference discharge and DRP concentration datasets according to the specified frequency (1-30 days) and load estimation algorithm



Sampling scenarios

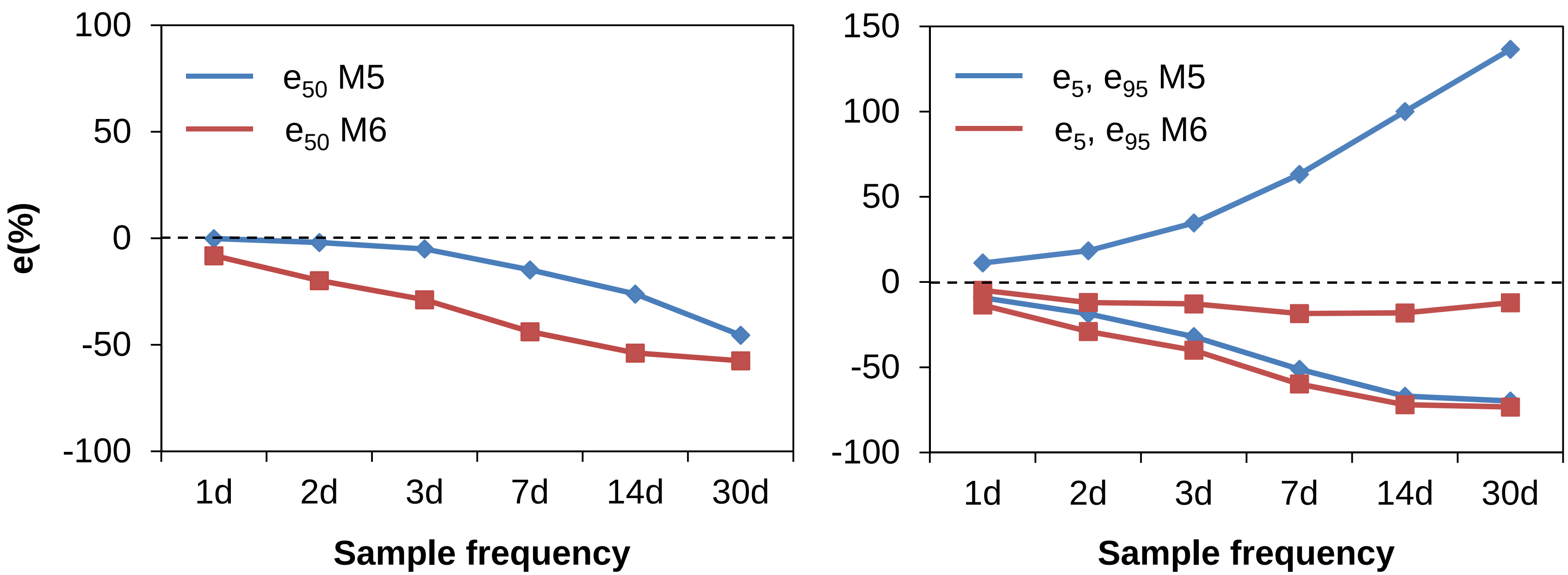
3 compositing strategies were also tested:

1. Hourly samples (3, 6, or 12 h) were composited into a 1 d sample
2. Daily samples were composited every 2, 3, or 7 d
3. Hourly samples (6 h) were composited every 2, 3, or 7 d


Site TD2
M1
M2
M3
M4
M5
M6
e5, e95
e50
0%
e (%)
100
50
0
-50
-100
1d
2d
3d
7d
14d
30d
Sample frequency

Comparing M5 and M6

Average uncertainty



Using FWMC (M5) results in less biased results
Using linear interpolation (M6) results in better precision

Selecting a sampling strategy

Continuous discharge measurements are a must

Uncertainty increases as sample frequency decreases regardless of load estimation algorithm

For monitoring programs evaluating relative changes in load (e.g., % change due to a change in management practice), precision is important

- Linear interpolation of concentrations (M6) offers a good balance between accuracy and precision in tile-drained landscapes

Selecting a sampling strategy

	Study sites					
	W1	W2	TD1	TD2	TD3	TD4
Desired uncertainty						
±2%	4 h	5 h	4 h	7 h	3 h	3 h
±5%	9 h	13 h	8 h	16 h	6 h	6 h
±10%	18 h	1.0 d	17 h	1.1 d	14 h	13 h
±15%	1.1 d	1.5 d	1.0 d	1.7 d	21 h	18 h
±25%	1.7 d	2.4 d	1.6 d	2.3 d	1.3 d	1.2 d

* Using M6 to calculate load

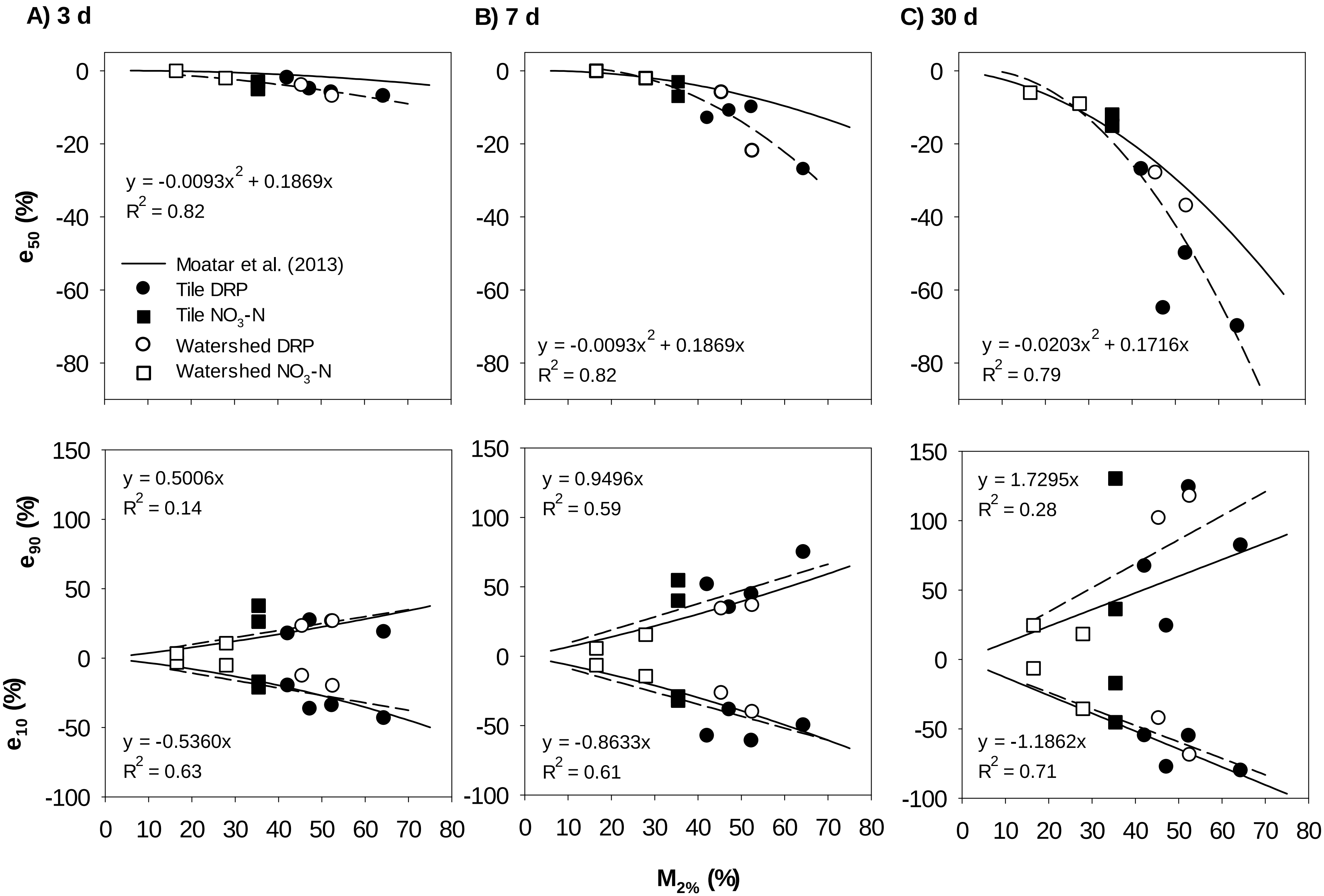
To be within ±10% of the reference annual DRP load, grab samples would need to be collected every 13 to 26 hours (336 to 673 samples/yr) at these sites

Comparing uncertainty across studies

The load duration index ($M_{2\%}$) was proposed by Moatar et al. (2013) as a predictor of uncertainty in annual nutrient load

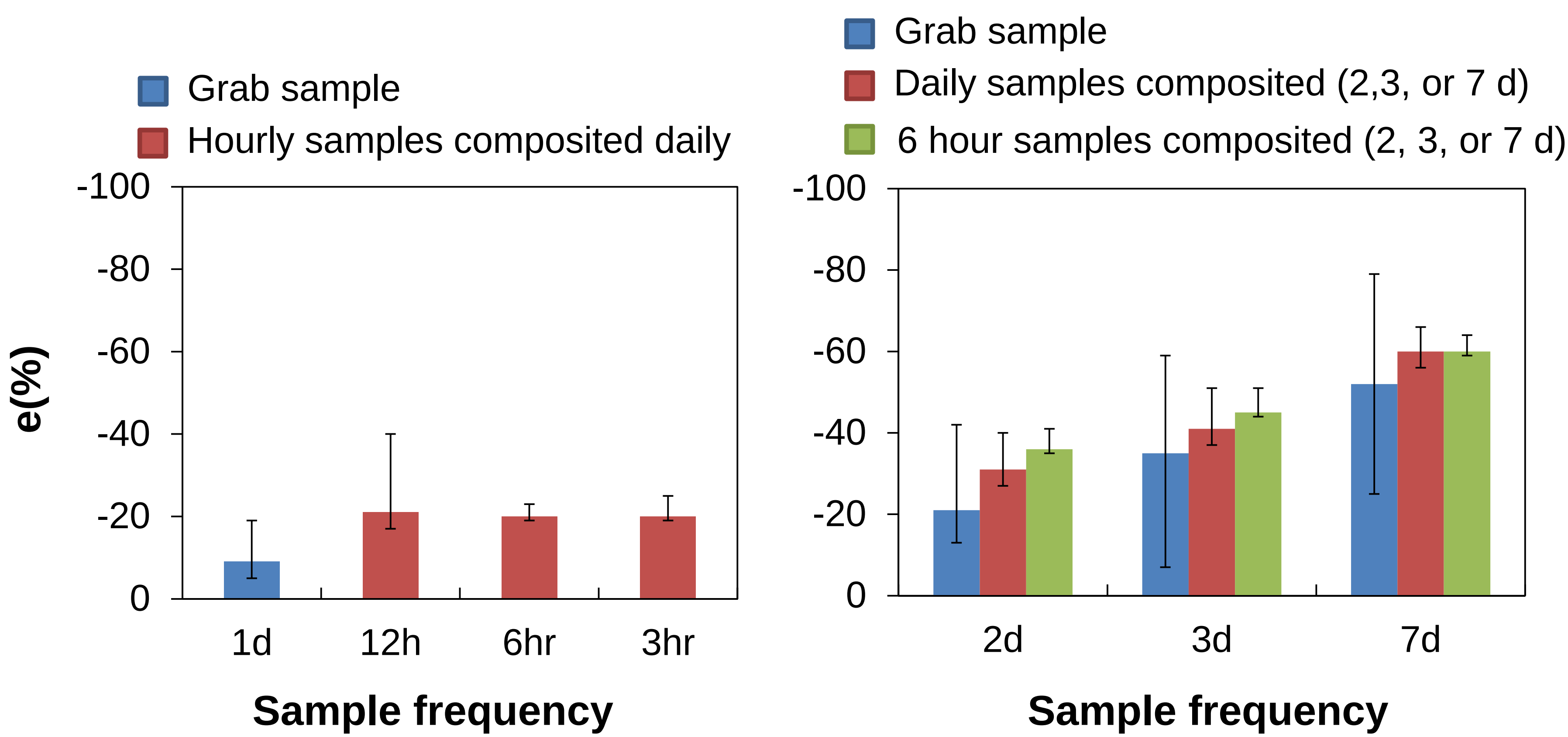
$M_{2\%}$ = percentage of annual load that occurs during the highest flow rates (top 2%)

Moatar et al. developed relationships between $M_{2\%}$ and uncertainty using data from many studies (across nutrients, scales, etc.)



A) 3 d
B) 7 d
C) 30 d
y = -0.0093x^2 + 0.1869x
R^2 = 0.82
Moatar et al. (2013)
Tile DRP
Tile NO3-N
Watershed DRP
Watershed NO3-N
y = -0.0093x^2 + 0.1869x
R^2 = 0.82
y = -0.0203x^2 + 0.1716x
R^2 = 0.79
e50 (%)
e90 (%)
e10 (%)
y = 0.5006x
R^2 = 0.14
y = -0.5360x
R^2 = 0.63
y = 0.9496x
R^2 = 0.59
y = -0.8633x
R^2 = 0.61
y = 1.7295x
R^2 = 0.28
y = -1.1862x
R^2 = 0.71
M2% (%)

Compositing strategies



Conclusions

The frequency of sampling, the algorithm used to estimate load, and sample compositing introduce varying levels of uncertainty

For tile-drained landscapes –

- ✓ To be within ±10% of reference DRP loads samples should be collected every 13 to 26 h
- ✓ Continuous discharge measurements and linear interpolation of DRP concentration yielded the best balance between accuracy and precision
- ✓ Compositing samples generally decreases accuracy, but increases precision of annual DRP load estimates

It is important to include estimates of uncertainty along with annual nutrient loads to effectively communicate results to users of the data

Uncertainty and alternatives to minimize uncertainty should be considered a priority in project design, implementation, and reporting

Questions?