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

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>Average instantaneous discharge (\times) average concentration</td>
<td>(\text{Load} = K \left( \sum_{i=1}^{n} \frac{Q_i}{n} \right) \left( \sum_{i=1}^{n} \frac{C_i}{n} \right))</td>
</tr>
<tr>
<td>M2</td>
<td>Average instantaneous flux</td>
<td>(\text{Load} = K \left( \sum_{i=1}^{n} \frac{Q_iC_i}{n} \right))</td>
</tr>
<tr>
<td>M3</td>
<td>Constant concentration before and after sampling</td>
<td>(\text{Load} = K \left( \sum_{i=1}^{n} C_i \bar{Q}_{i,i-1} \right))</td>
</tr>
<tr>
<td>M4</td>
<td>Annual flow volume (\times) average concentration</td>
<td>(\text{Load} = KV \left( \sum_{i=1}^{n} \frac{C_i}{n} \right))</td>
</tr>
<tr>
<td>M5</td>
<td>Annual flow volume (\times) flow weighted mean concentration</td>
<td>(\text{Load} = KV \sum_{i=1}^{n} \frac{Q_iC_i}{\sum_{i=1}^{n} Q_i} )</td>
</tr>
<tr>
<td>M6</td>
<td>Linear interpolation of concentrations (\times) continuous flow rates</td>
<td>(\text{Load} = K \left( \sum_{j=1}^{365} Q_j C_{int}^j \right))</td>
</tr>
</tbody>
</table>

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

![Graphs showing DRP load over time for 1 day and 30 days.]
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
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

<table>
<thead>
<tr>
<th>Desired uncertainty</th>
<th>W1</th>
<th>W2</th>
<th>TD1</th>
<th>TD2</th>
<th>TD3</th>
<th>TD4</th>
</tr>
</thead>
<tbody>
<tr>
<td>±2%</td>
<td>4 h</td>
<td>5 h</td>
<td>4 h</td>
<td>7 h</td>
<td>3 h</td>
<td>3 h</td>
</tr>
<tr>
<td>±5%</td>
<td>9 h</td>
<td>13 h</td>
<td>8 h</td>
<td>16 h</td>
<td>6 h</td>
<td>6 h</td>
</tr>
<tr>
<td>±10%</td>
<td>18 h</td>
<td>1.0 d</td>
<td>17 h</td>
<td>1.1 d</td>
<td>14 h</td>
<td>13 h</td>
</tr>
<tr>
<td>±15%</td>
<td>1.1 d</td>
<td>1.5 d</td>
<td>1.0 d</td>
<td>1.7 d</td>
<td>21 h</td>
<td>18 h</td>
</tr>
<tr>
<td>±25%</td>
<td>1.7 d</td>
<td>2.4 d</td>
<td>1.6 d</td>
<td>2.3 d</td>
<td>1.3 d</td>
<td>1.2 d</td>
</tr>
</tbody>
</table>

* 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.

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

Moatar et al. developed relationships between \(M_{2\%}\) and uncertainty using data from many studies (across nutrients, scales, etc.)
Moatar et al. (2013) Tile DRP
Moatar et al. (2013) Tile NO3-N
Moatar et al. (2013) Watershed DRP
Moatar et al. (2013) Watershed NO3-N

y = -0.0093x^2 + 0.1869x
R^2 = 0.82

y = -0.0203x^2 + 0.1716x
R^2 = 0.79

y = -0.5360x
R^2 = 0.63

y = 0.5006x
R^2 = 0.14

y = 0.9496x
R^2 = 0.59

y = -0.8633x
R^2 = 0.61

y = 1.7295x
R^2 = 0.28

y = 0.9496x
R^2 = 0.59

y = -1.1862x
R^2 = 0.71
Compositing strategies

- Grab sample
- Daily samples composited (2, 3, or 7 d)
- 6 hour samples composited (2, 3, or 7 d)

Sample frequency

- e(%) vs. Sample frequency
  - 1d, 12h, 6hr, 3hr
  - 2d, 3d, 7d
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?