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A Guide for Monitoring Phosphorus

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1. Overview of water-quality monitoring of drainage discharge

Subsurface drainage discharge and surface runoff are pathways for phosphorus (P) loss from subsurface-drained farms. Monitoring P loss is crucial for evaluating the performance of conservation practices in reducing P, which is quantified through the measurement of P load. The P load is the amount of P lost from a farm over a specific time period, usually measured in units of lb/ac. Calculating P load requires information on P concentration and flow rate.

There are three strategies for collecting water samples: (1) flow-proportional sampling, (2) time-proportional sampling, and (3) grab sampling. For the flow- and time-proportional strategies, you can take either discrete or composite samples. A discrete sample is a single sample taken at a given time, whereas a composite sample combines several aliquots, taken at different times, into a single bottle. Generally, compositing is used to reduce the cost because there are fewer samples to analyze. A grab sample, by nature, is discrete.

This bulletin is based on scientific research conducted with a HydroCycle unit to get hourly P concentration in drainage discharge at a monitoring farm. We used the high-resolution data to evaluate the effects of sampling strategies on the P load estimation in drainage discharge.

The sampling strategy affects the outcome of the monitoring project. Therefore, it is important to choose an appropriate sampling strategy based on the project objective. There are two general monitoring objectives: (1) estimating P load, and (2) investigating P movement.

2. Recommended sampling strategy for estimating P load

2.1. Automated sampling for estimating P load

2.1.1. Flow-proportional compositing

For estimating the annual P load, you can use flow-proportional compositing for both drainage discharge and surface runoff. This strategy needs an automated sampler and a flow rate sensor to trigger the sampling (Figure 1). In this method, the sampler takes an aliquot when a certain flow depth has occurred. Flow depth is flow volume divided by drained area (defined as flow depth interval). Then, the sampler pumps the aliquot into a bottle. The decision of the aliquot number depends on the volume of the aliquot, capacity of the bottle, and project budget.

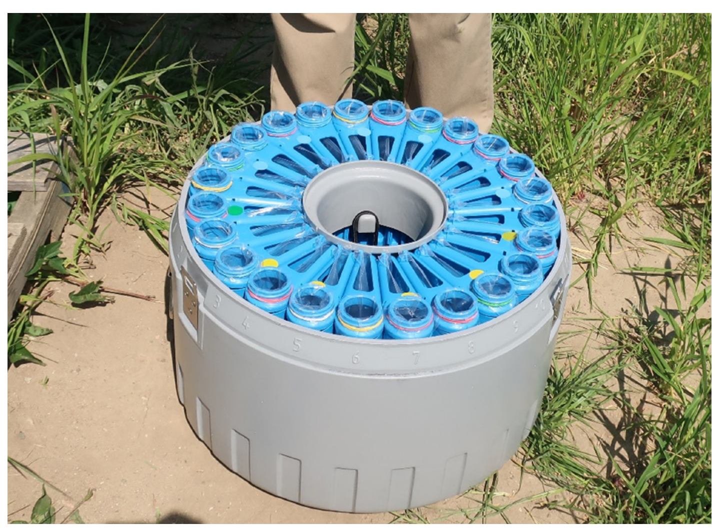

Figure 1- An automated sampler can perform flow-proportional or time-proportional sampling.

In flow-proportional compositing, the number of aliquots per 1-L bottle typically ranges from 4 to 8. At a given flow depth interval, as the number of aliquots per bottle increases, the cost is considerably reduced because there are fewer individual samples to analyze. The number of aliquots per bottle does not have a considerable effect on the accuracy of the P load estimation. Therefore, choose a greater number of aliquots per bottle to reduce analytical cost and still not compromise the accuracy of the P load estimation.

For taking the aliquots from drainage discharge, choose an interval of 1 to 5 mm to get less than about 7% underestimation error of the annual P load. Within that interval range, the shorter the interval, the smaller the error of the P load estimation, but the analysis cost goes up because of the greater number of samples.

In a flow-proportional sampling, more aliquots are taken during event flows and fewer during baseflow (Figure 2). This is because more flow occurs during event flows. The greater number of aliquots during event flows is useful because P concentration varies rapidly during event flows, but fewer samples are taken during baseflow because P concentration does not vary considerably. With the greater number of aliquots during event flows in flow-proportional compositing, the annual P load estimation becomes more accurate than time-proportional compositing (section 2.1.2).

Flow-proportional compositing is limited by the need for a reliable flow rate measurement because the sampling is triggered by the flow rate reading. If the flow rate sensor cannot measure both low and high flows accurately, or the sensor malfunctions during an event flow, the sampling will not be trigged at the designated flow interval and data will be lost.

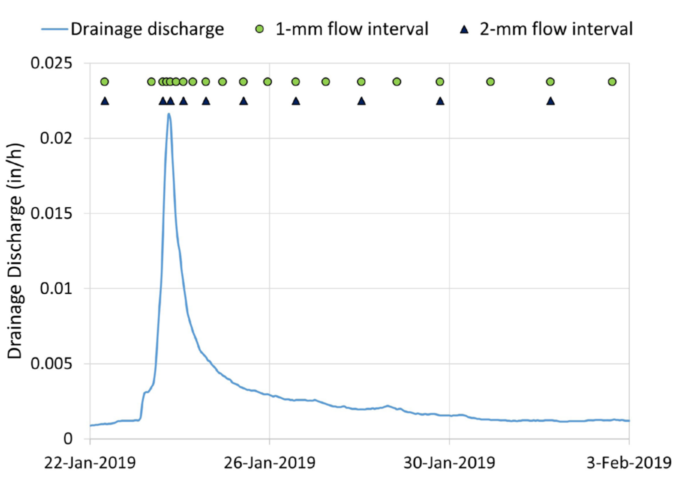

Figure 2- In flow-proportional sampling, more aliquots are taken during event flows and fewer during baseflow.

2.1.2. Time-proportional compositing

For estimating the annual P load, you can use time-proportional compositing for drainage discharge, but it is not ideal for surface runoff. This method requires investment in automated samplers and a flow-measuring device.

In time-proportional compositing, the sampler takes aliquots that are spaced equally over time, and unlike flow-proportional sampling, event flows do not get more aliquots than baseflow. The sampler is programmed to pump a certain number of aliquots into each bottle. Once the bottle is full, the resulting composite sample corresponds to a given time interval.

The sampling time interval should be no longer than 24 hours to minimize the underestimation error of the annual P load. As the sampling interval becomes longer than 24 hours, the underestimation error increases. The underestimation error of the P load can be 13% for 1-day, 20% for 2-day, 28% for 3-day, 43% for 7-day time-proportional compositing.

Even a 24-hour compositing still has less accurate P load estimation than that of the 1–5-mm interval flow-proportional compositing. Time-proportional compositing fails to capture rapid fluctuations in P concentration during event flows.

In time-proportional compositing, the number of aliquots per 1-L bottle typically ranges from 4 to 8. If you make a composite with 4 or more aliquots, the accuracy of the P load estimate remains constant and would not improve.

2.1.3. Time-proportional variable-time compositing

Another accurate strategy is to have one sampler perform both time-proportional 24-hour compositing during baseflow and time-proportional 1–2-hour compositing during event flows. This method works for drainage discharge. For this method, the sampler is programmed to trigger high-resolution sampling during event flows based on the detection of a change in flow rate or water level above a certain threshold.

This strategy can also be performed with two samplers: one for time-proportional 24-hour during baseflow and the other for time-proportional 1–2-hour compositing during event flows.

2.2. Grab sampling for estimating P load

In some cases, there are resource limitations or budgetary constraints that do not allow automated sampling. In this case, you can take daily grab samples during event flows and weekly samples during baseflow (Figure 3).

The limitations of grab sampling are: (1) knowing when event flow has transitions into baseflow to be able to adjust the sampling interval from daily to weekly, (2) determining if an event flow is possible ahead of time to be able to plan for the daily grab sampling, and (3) daily sampling during event flows may not always be possible due to unavailability of personnel. Because of these limitations, grab sampling provides less accurate P load estimation than automated sampling.

A daily grab sampling can underestimate the annual P load by 5% to 19% depending on how close the sampling is to the peak flow. As the sampling interval becomes longer than daily, the underestimation error increases (Figure 4). A 3-day grab sampling can underestimate the annual P load by 24% to 30%, and a 7-day grab sampling by 33% to 46%. Note that these underestimation errors assume daily grab sampling during every day of the event flows and baseflow.

It is challenging to take daily grab samples during every day of the event flows, so longer sampling intervals are sometimes used. The error of a grab sampling strategy that does not cover every day of the event flows can be even greater than those reported in this section. Because of the high error of the grab sampling, it is important to report the uncertainty of the annual P load estimation.

Figure 3- Grab sampling from the subsurface drainage discharge.

3. Recommended sampling strategy for investigating P movement

3.1. Using an in-field automated P lab for investigating P movement

If you want to investigate P movement during event flows in drainage discharge, you need high-frequency time-proportional discrete sampling. The sampling interval depends on site-specific conditions, but generally choose a sampling interval of 1–2 hours to capture the rapid variation in P concentration. This sampling strategy requires an in-field automated P lab to take high-frequency samples. Sampling intervals greater than 1–2 hours will miss the peak P concentration (Figure 4).

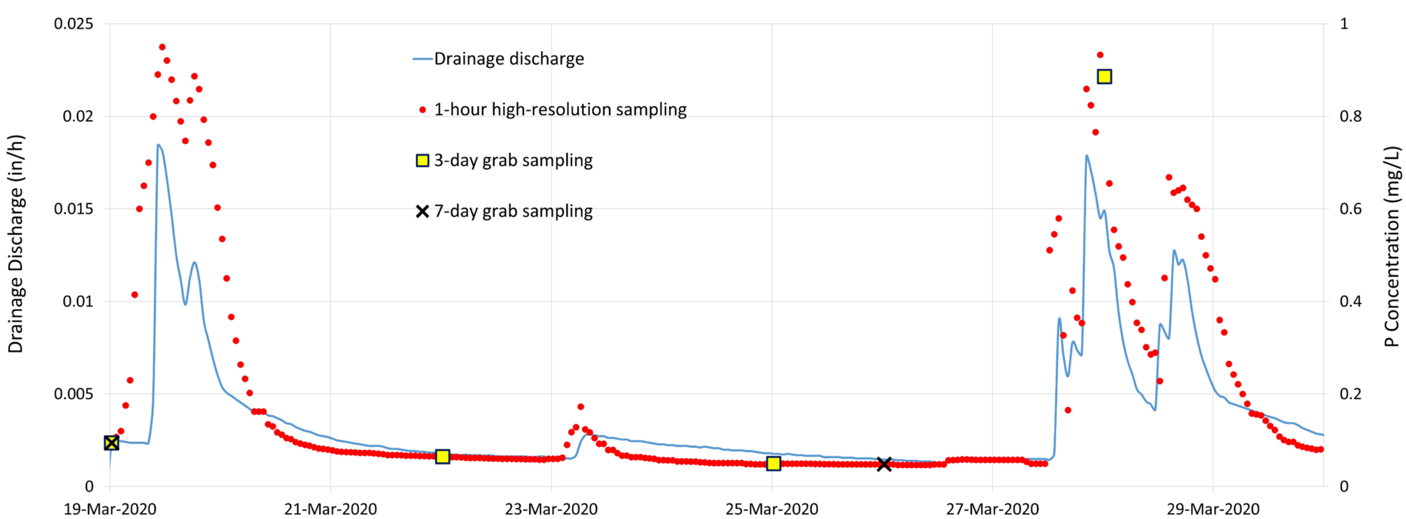

Figure 4- Graph showing the high-resolution hourly P concentration along with different grab sampling strategies. The 3-day and 7-day grab sampling strategies missed several peak P concentrations.

Example investigations in need of high-frequency sampling include hysteresis, flushing, preferential movement of P through macropores, and P loss from manure and timed-release fertilizer. The study of hysteresis identifies if there is a source of P in the proximity of the tile drain pipe. Another example is determining the source of P moving into tile drain pipes.

3.2. Using automated samplers for investigating P movement

In case of using automated samplers to investigate P movement, set one sampler to time-proportional 24-hour compositing to target baseflow. Set the other sampler to high-frequency time-proportional 1–2-hour discrete sampling to target event flows.

4. Summary and recommendations

For estimating the annual P load using flow-proportional compositing, choose a flow depth interval of 1 to 5 mm to take the aliquots. Choose a greater number of aliquots per bottle to reduce analytical cost and still not compromise the accuracy of the P load estimation.

For estimating the annual P load using time-proportional compositing, choose a sampling time interval no longer than 24 hours to minimize the underestimation error of the annual P load. If you make a composite with 4 or more aliquots, the accuracy of the P load estimate remains constant and would not improve.

Another strategy is to use both time-proportional 24-hour compositing during baseflow and time-proportional 1–2-hour compositing during event flows.

For estimating the annual P load using a grab sampling strategy, take daily grab samples during event flows and weekly samples during baseflow. However, daily sampling during every day of the event flow is challenging. Because of the high error of grab sampling, it is important to report the uncertainty of the annual P load estimation.

For investigating P movement, use high-frequency time-proportional 1–2-hour discrete sampling. This sampling strategy requires an in-field automated P lab or an automated sampler.

Overall, if choosing automated sampling, the accuracy of the P load estimation is highest for flow-proportional compositing with 1–5-mm flow depth interval followed by time-proportional 24-hour compositing. However, time-proportional compositing may be more reliable because it does not depend on a flow rate measurement. Grab sampling has the highest error while being the most accessible and affordable option.

Expert Reviewed

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Reference

Dialameh, B., & Ghane, E. (2022). Effect of water sampling strategies on the uncertainty of phosphorus load estimation in subsurface drainage discharge. *Journal of Environmental Quality, 51*, 377–388. https://doi.org/10.1002/jeq2.20339

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