

TECHNICAL NOTES

A device to collect passive, flow-weighted water samples from surface runoff

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Assigned to Associate Editor Kevin Mumford.

Funding information

USDA; National Institute of Food and Agriculture, Grant/Award Number: 2018-67019-27851; Virginia Agricultural Experiment Station and the Hatch Program of the USDA National Institute of Food and Agriculture, Grant/Award Number: 1026126

Abstract

Obtaining water quality samples from surface runoff is essential for understanding erosion and pollutant transport processes. Existing water sampling devices are expensive, require installation of extensive infrastructure or power supplies, or have limited ability to collect flow-weighted samples. We created an inexpensive, nonpowered, flow-weighted water sampling device that can be incorporated into runoff quantification systems like the Upwelling Bernoulli Tube (UBeTube). Our device, called the Holey Sampler, consists of a standpipe with holes drilled at specific heights. Water enters the standpipe in proportion to the water flow rate through the UBeTube and is routed to an external collection bottle. We built and tested two versions of the Holey Sampler that sampled water at an approximate ratio of 1:250 of the runoff rate. The Standard Opening Holey Sampler (Standard-OHS) configuration was made with 1.6-mm-diam. holes, whereas the Miniature Opening Holey Sampler (Mini-OHS) configuration was designed to prevent oversampling at low outflows but required drill bit of smaller diameter (0.8-mm). Laboratory and numerical experiments demonstrated that both configurations obtained accurate flow-weighted runoff samples when incorporated into the UBeTube. Flow rates in the Mini-OHS were better correlated with runoff rates under constant-flow ($R^2 = .992$ vs. $.965$ for the Standard-OHS) and variable-flow conditions ($R^2 = .996$ vs. $.954$ for the Standard-OHS). Further modification of the Holey Sampler could also allow flow-weighted sampling of other runoff quantification devices like flumes and weirs.

1 | INTRODUCTION

Surface runoff, also called overland flow, is a main cause of erosion and a contributor to nutrient, pesticide, and other contaminant losses from agricultural fields (Dosskey et al., 2007; Hladik et al., 2017; Radolinski et al., 2019; Udawatta et al.,

2002). Understanding and modeling these processes requires the ability to accurately sample and quantify runoff. However, few solutions are available to collect water samples from runoff plots or similar through-flow installations. In addition, existing approaches tend to be complex and expensive, often suffering from extensive maintenance requirements, and have limited ability to sample different sized events.

Water sampling typically takes one of two approaches: sequential (interval) sampling and proportional sampling. In sequential sampling, fixed volumes of water are collected at

Abbreviations: Mini-OHS, Miniature Opening Holey Sampler; PVC, polyvinyl chloride; Standard-OHS, Standard Opening Holey Sampler; UBeTube, Upwelling Bernoulli Tube.

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regular intervals or under specified conditions (e.g., a threshold pressure head), using devices such as automated water samplers (Inamdar et al., 2011; Yazdi et al., 2021). These samplers are effective but expensive, which means they can quickly become cost prohibitive when attempting to sample multiple plots or locations (Pinson et al., 2004). They also require a power source, limiting their ability to be deployed remotely, though solar panels can be effectively used in some instances (Burcham et al., 1998; Cullum et al., 1992). Zhan et al. (2021) created a sequential sampler that uses an automated flushing mechanism to prevent sediment clogging. However, the mechanism can result in sample contamination and does not allow for continuous sampling. More important, all sequential sampling approaches tend to be of limited use for studies that examine flow controls on transport processes (Frame et al., 2021) or calculate pollutant loads (Kirchner et al., 2004), since the sample volume in these systems does not change with runoff discharge.

Proportional (i.e., flow-weighted) samplers, by contrast, are designed so that the amount of water collected is related to runoff quantity. This sampling protocol is particularly useful for environmental monitoring studies, since, for example, it can be used to calculate pollutant loads (Bonta, 2002; Budai et al., 2020; Pinson et al., 2004). A variety of flow-weighted sampling approaches exist, depending in part on the type of runoff measurement system being used. For example, in storage-based measurements, all or part of the water produced via surface runoff is collected in storage containers. The most basic installations collect and store all water in large containers until time of sampling (Radolinski et al., 2019). However, these systems only function well for small plots, as the storage volumes can quickly become excessive (e.g., 0.01 m of surface runoff from a 50-m² plot translates to 0.5 m³ of water). Related systems, including Coshocton wheels and flow dividers, are typically designed to only collect a portion of the runoff (Bonta, 2002; Geib, 1933; Pinson et al., 2004). Having multiple, nested sampling containers can ensure that all runoff is sampled (Bonilla et al., 2006), though such designs can make it challenging to also quantify runoff rates, and they can be quite expensive. At the same time, flow divider systems can fail to sample small runoff events (Carter & Parsons, 1967), and the systems can become clogged with sediment. Other flow-weighted samplers rely on pumping units and control units (Budai et al., 2020), which can provide accurate samples but also may require extensive maintenance and a continuous power supply.

Through-flow measurements typically measure runoff without storing it. Example installations include tipping buckets (Nehls et al., 2011), flumes (Hernandez-Santana et al., 2013), and flow meters installed on collection pipes (Stewart, Moreno, et al., 2015). Tipping buckets can be fitted with a sampler that collects a portion of each tip to one side (Zhao et al., 2001). Nevertheless, tipping buck-

Core Ideas

- Surface runoff samples are needed to quantify pollutant transport processes.
- We developed an inexpensive, passive flow-weighted sampling system for runoff.
- We tested versions with standard- and miniature-sized sampling holes.
- Both configurations collected flow-weighted samples during constant and variable flow.
- Sampler may be adapted to other runoff quantification systems.

ets can lose water due to evaporation and splashing and may be unable to sample small runoff events that do not generate enough water to tip the bucket (Habib et al., 2001; Nehls et al., 2011). Water samples can be collected from flumes and similar channel-based installations using multipipe samplers built from sampling tubes welded at different heights onto a metal rod (Pathak, 1991). Each pipe leads to a separate sample bottle, which allows for collection of flow-weighted samples in proportion to the water height in the channel. Such systems require large changes in the height of water in the channel to provide proper flow-weighting, as each pipe has a vertical separation of 50–80 mm from the others. Flumes can also be expensive to install and maintain and can be impractical for studies involving multiple runoff plots, as often needed for replicated experimental work.

The Upwelling Bernoulli Tube (UBeTube) was developed as an inexpensive and accurate device to measure plot-scale runoff across a range of flow conditions (Stewart, Liu, et al., 2015). The instrument consists of a vertical pipe with a double trapezoidal weir cut into the side. Water enters laterally from a pipe below the tube and passes through the weir (Ries et al., 2020). Water height in the UBeTube is recorded using a pressure transducer and is used to calculate volumetric water flow (Q) through the slot using Torricelli's equation. The original version was designed to accurately measure flows from 0.05 up to 300 L min⁻¹, and the weir geometry can be altered to accurately measure a wide range of discharge rates (Ries et al., 2020; Stewart, Liu, et al., 2015). However, as currently designed, the system does not have the ability to collect water samples.

Our goal in this study was to develop an inexpensive, rugged, and flow-weighted runoff sampling device that can be incorporated into runoff quantification systems such as the UBeTube. The sampler consists of a polyvinyl chloride (PVC) standpipe with drilled holes at preset heights. The sampler is placed inside of the UBeTube and relies on the same

theory of water flow as the UBeTube (i.e., Torricelli's equation). The sampler is easy to construct and provides a flow-weighted composite sample using a single collection bottle. In this article, we discuss the design and validation of the sampler and demonstrate its ability to collect representative samples under low- to moderate-flow conditions (i.e., 0.01–116 L min⁻¹).

2 | MATERIALS AND METHODS

2.1 | Design

The Holey Sampler is designed to be used in conjunction with a through-flow runoff measurement device such as the UBeTube. The basic sampler configuration consists of a vertically aligned standpipe with a series of drilled holes that are sized and positioned to ensure a flow-weighted sample is collected. Once inside of the sampler, water then flows into a collection bottle or other receptacle that is placed outside of the UBeTube, where it can be easily accessed (Figure 1).

For a given water height in the UBeTube (h), the flow rate entering the Holey Sampler (Q_{Sampler}) can be modeled using a modified version of Torricelli's equation:

$$Q_{\text{Sampler}} = \sum_{i=1}^N \pi c_i n_i r_i^2 \sqrt{2g(h - z_i)}, \quad h > z_i \quad (1)$$

where i indexes the vertical locations where holes are located (with the lowest elevation hole set as 1), c is a calibration coefficient that accounts for the roughness of the drilled holes, n is the number of holes at that position, r is the radius of each individual hole at that position, g is the force of gravity, h is the height of water in the UBeTube, and z is the height of the holes.

Equation 1 can be used for any combination of hole numbers, sizes, and vertical positions. However, only certain combinations will allow the Holey Sampler to collect a flow-weighted sample that remains approximately proportional to outflow. We used a custom R script to model flow rates in the Holey Sampler, Q_{Sampler} , for different sample hole configurations. The script also modeled outflow from the UBeTube, Q_{Outflow} , based on the design presented in Stewart, Liu, et al. (2015) and assuming a calibration coefficient of $c = 0.95$.

We used linear regression to compare Q_{Sampler} vs. Q_{Outflow} . The slope of the regression line was used to assess proportionality between the two quantities, and R^2 was calculated to assess the linearity of the relationship. Based on this analysis, we selected two different hole configurations, each with approximate sampling ratios of 1:250 (sampler flow rate to runoff rate). The Standard Opening Holey Sampler (Standard-OHS) configuration used hole diameters available in standard drill bit sets, from 1.6 to 6.4 mm (Table 1). The

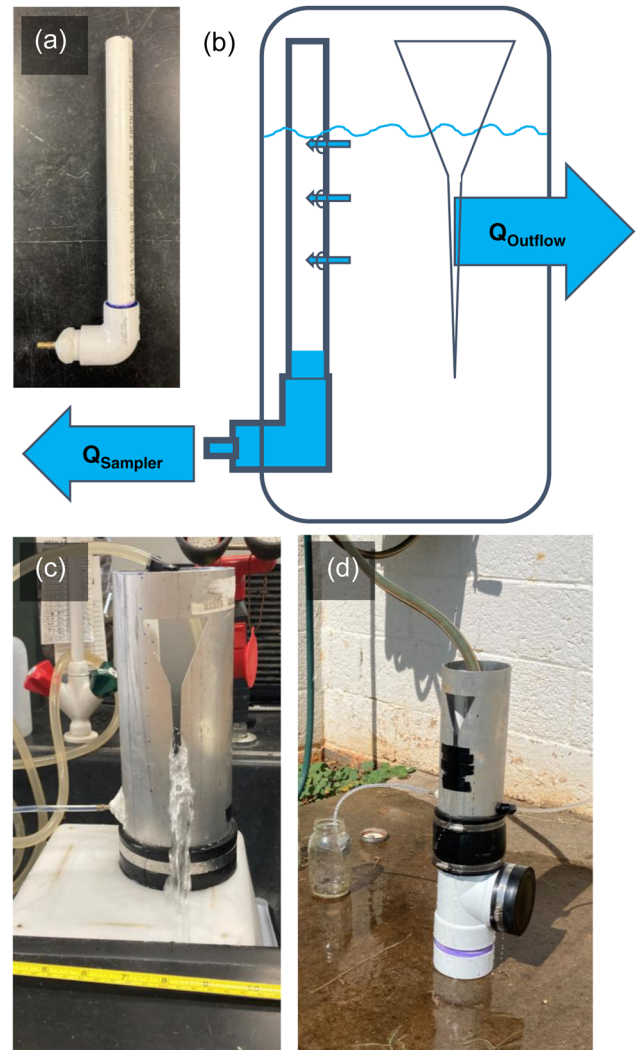


FIGURE 1 (a) Holey Sampler prototype; (b) schematic of the Holey Sampler installed in an Upwelling Bernoulli Tube (UBeTube) with water entering the sampler (Q_{Sampler}) at a rate proportional to the UBeTube outflow (Q_{Outflow}); (c) prototype Holey Sampler installed in an UBeTube during a constant-flow test; and (d) constant-flow sampler test with covered UBeTube slot to simulate higher outflow rates. In Panels c and d, the sampler can be seen in the top left corner of the UBeTube slot along with the sealed polyvinyl chloride (PVC) plug, barb, and tubing protruding from the left side of the UBeTube

TABLE 1 Height, number, and diameter of holes used in Standard Opening Holey Sampler (Standard-OHS)

Height	No. of Holes	Diameter
mm		mm
0	1	1.6
110	1	1.6
130	2	1.6
140	2	1.6
160	1	1.6

Note. Hole heights are in relation to the bottom of the Upwelling Bernoulli Tube (UBeTube) slot.

TABLE 2 Height, number, and diameter of holes used in Miniature Opening Holey Sampler (Mini-OHS)

Height	No. of Holes	Diameter
mm		mm
5	1	0.8
40	1	0.8
70	1	1.6
115	1	1.6
130	1	2.4
155	1	2.4

Note. Hole heights are in relation to the bottom of the Upwelling Bernoulli Tube (UBeTube) slot.

Miniature Opening Holey Sampler (Mini-OHS) configuration included holes that were made with a special-ordered 0.8-mm drill bit (Table 2).

2.2 | Prototype and laboratory testing

To test Equation 1, we constructed prototypes of both the Standard-OHS and Mini-OHS using 200-mm-tall standpipe made from 12.7-mm-o.d. (1/2-inch-o.d.) Schedule 40 PVC pipe. The standpipe was glued into a 12.7-mm-i.d. PVC elbow (Figure 1a), which was mounted to a 22.5-mm-diam. machined hole in the side of a UBeTube with a 12.7-mm PVC plug (Figure 1b). The PVC plug was tapped, and a 4.8-mm brass hose barb was screwed into place. The PVC plug and elbow were sealed and secured to the UBeTube with JB Waterweld Epoxy Putty (JB Weld). An example of the full installation is shown in Figure 1c.

We next calculated the c coefficient using a single 1.6-mm hole in the Standard-OHS. Only one hole was used to isolate this parameter and eliminate possible variation resulting from other holes. A constant flow of water was applied to the UBeTube (Figure 1c). Once the water level in the UBeTube stabilized, the water height was determined using a measuring tape, and a sample was collected for 1 min. The sample volume was used to calculate Q_{Sampler} at the given water height. This process was repeated three times for each water height. Three water heights were tested, corresponding to Q_{Outflow} values of 2.59, 9.70, and 17.3 L min⁻¹. The measured Q_{Sampler} rates were compared to the modeled Q_{Sampler} values (i.e., Equation 1) using least-squares regression and fixing the y -intercept to 0, and the c value was adjusted until the residuals between the modeled and measured values were minimized.

After the c coefficient had been estimated, we used this value for all holes and both sampler configurations. We then

performed two additional laboratory tests to ensure that (a) the model accurately predicted Q_{Sampler} at various flow rates, and (b) Q_{Sampler} had a linear relationship with Q_{Outflow} . The first test used constant flow and was similar to the test used to calculate the c coefficient. Water was first applied to the UBeTube, starting at a low flow rate, until the water level stabilized. The sampler tube was placed in a sample bottle and water was collected for 1 min. The collected volume was used to calculate the measured Q_{Sampler} . This process was conducted in the Standard-OHS configuration for 18 water levels, ranging from 25 to 155 mm (expected Q_{Outflow} rates of 1.86 to 107 L min⁻¹ and expected Q_{Sampler} rates of 0.05–0.44 L min⁻¹), and in the Mini-OHS configuration for 13 water heights ranging from 15 to 158 mm (expected Q_{Outflow} rates of 0.77–116 L min⁻¹ and expected Q_{Sampler} rates of 0.01–0.44 L min⁻¹). Three samples were collected at each water level. To test the samplers at flow rates beyond the capacity of our faucet (~40 L min⁻¹), the slot of the UBeTube was partially sealed with tape, so the water could reach the same height in the UBeTube that it would under higher outflow rates (Figure 1d).

We also tested the Holey Sampler under variable flow conditions. In this test, a constant flow of water was applied to the UBeTube and the initial water height was measured. A sample bottle was placed under the sampler tubing. After 30 s of sampling, the faucet flow rate was increased without removing the sample bottle, and the new water height in the UBeTube was measured. After 30 s of additional sampling, the flow rate was increased again. The sample collection continued for 30 s more, and the final water height in the UBeTube was measured. Changes in water height varied, with height increments between 7.5 and 50 mm used in different tests. The expected Q_{Sampler} for each 90-s period was calculated as a mean of modeled flow rates for the three different heights, and measured Q_{Sampler} was calculated using the volume of water collected during the 90-s period. For the Standard-OHS, the variable-flow test was conducted at 11 different mean water levels ranging from 48 to 127 mm (translating to expected Q_{Outflow} rates of 6.26–52.3 L min⁻¹ and expected Q_{Sampler} rates of 0.07–0.19 L min⁻¹), and the variable-flow test was conducted for the Mini-OHS at 11 different mean water levels ranging from 43 to 146 mm (corresponding to expected Q_{Outflow} rates of 5.07–85.7 L min⁻¹ and expected Q_{Sampler} rates of 0.03–0.34 L min⁻¹).

Measured Q_{Sampler} values were compared to corresponding modeled Q_{Sampler} values by calculating RMSE. Linear regression was used to compare measured Q_{Sampler} and the corresponding modeled Q_{Outflow} values to discern the consistency of flow-weighting (i.e., proportionality) across the range of tested water levels.

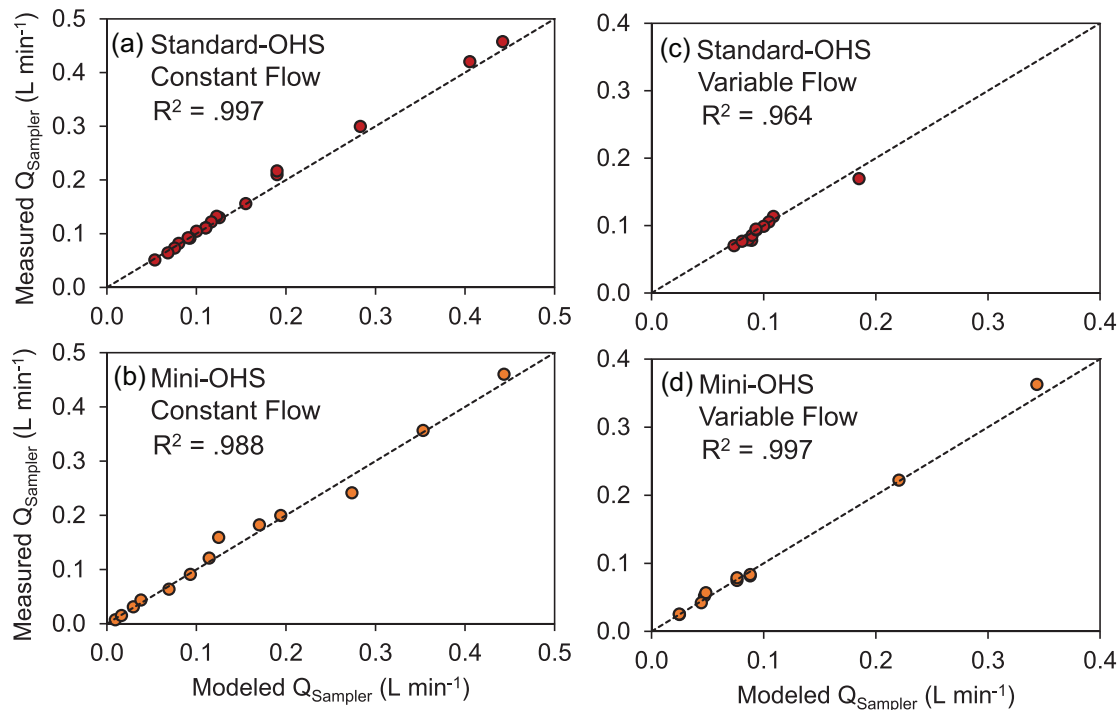


FIGURE 2 Measured vs. modeled values of flow rate entering the sampler (Q_{Sampler}) during the constant-flow test for the (a) Standard Opening Holey Sampler (Standard-OHS) and (b) Miniature Opening Holey Sampler (Mini-OHS), and during the variable-flow tests for the (c) Standard-OHS and (d) Mini-OHS. Dashed black lines show 1:1 relationships

3 | RESULTS AND DISCUSSION

3.1 | Calibration coefficient (c)

During the calibration test, which consisted of four repeated tests done for three different water heights, measured Q_{Sampler} was $72 \pm 3\%$ (mean \pm standard deviation) of modeled Q_{Sampler} . Therefore, we used $c = 0.72$ as the constant in Equation 1 for all holes. We note that this coefficient value was much smaller than that of the UBeTube ($c = 0.95$). This discrepancy is likely due to the small size of the sampler holes relative to the slot in the UBeTube, and also because drilled holes in the PVC Holey Sampler had rougher edges than the machined slot in the aluminum UBeTube. We also note that we only tested a single 1.6-mm-diam. hole, and so users should consider performing a similar calibration if using other sampler materials or hole sizes.

3.2 | Sampler accuracy

A major goal of the laboratory tests was to verify that the model could accurately predict Q_{Sampler} over a broad range of water heights. The constant-flow test showed that the model was able to accurately estimate Q_{Sampler} of the Standard-OHS ($R^2 = .997$, slope = 1.05; Figure 2a). Based on 18 tested water

heights, the RMSE was 0.011 L min^{-1} between measured Q_{Sampler} and modeled Q_{Sampler} . The model also accurately estimated Q_{Sampler} of the Mini-OHS during the constant-flow test ($R^2 = .988$, slope = 1.01; Figure 2b). The RMSE was 0.015 L min^{-1} between measured Q_{Sampler} and modeled Q_{Sampler} . Therefore, the model accurately predicted Q_{Sampler} over a range of water heights for both sampler configurations, which means the model can be used to determine ideal hole placement for samplers in other runoff quantification systems with various flow ranges. This result also indicates that our decision to use a constant c value for all holes did not induce much error.

Runoff rates typically vary during storms, so it was also important to determine if the Holey Sampler could obtain accurate flow-weighted samples under different flow conditions. During the variable-flow test, the model was able to accurately estimate measured Q_{Sampler} of the Standard-OHS ($R^2 = .964$, slope = 0.91; Figure 2c), with an RMSE of 0.006 L min^{-1} . The model was also able to accurately predict Q_{Sampler} of the Mini-OHS during the variable-flow test ($R^2 = .997$, slope = 1.06; Figure 2d). The RMSE between measured Q_{Sampler} and modeled Q_{Sampler} was 0.007 L min^{-1} for this test. The RMSE values were lower for both hole configurations in the variable flow compared with constant flow tests. This discrepancy may have reflected the smaller range of water flows tested in the variable flow test; for example,

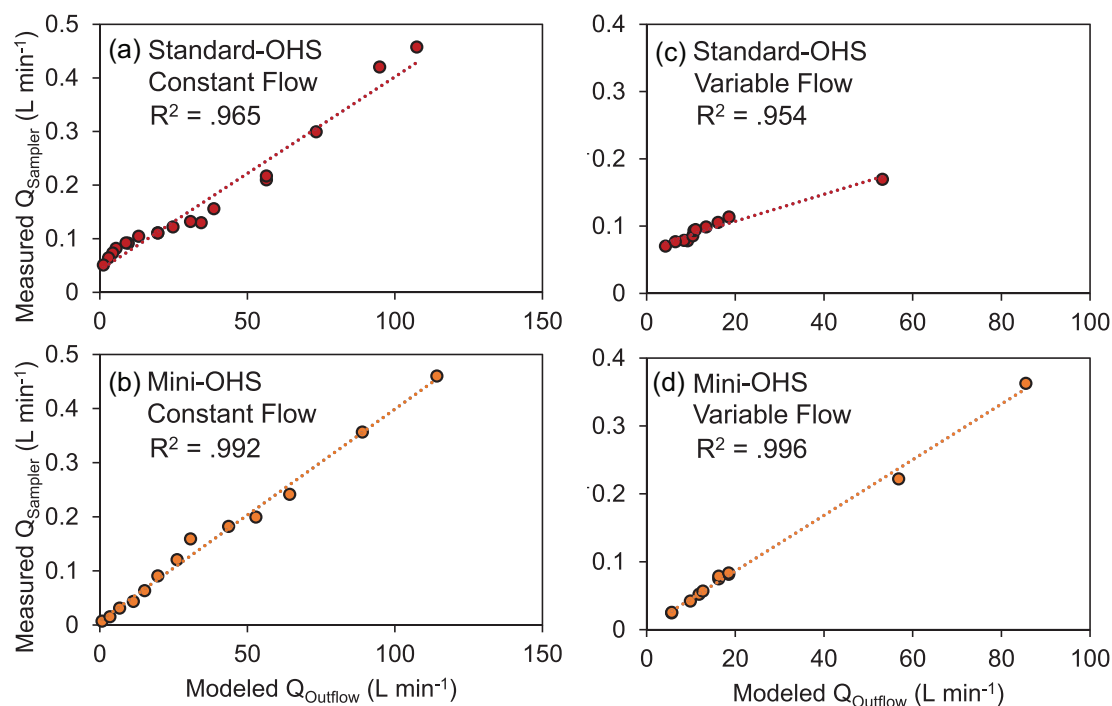


FIGURE 3 Measured vs. modeled values of flow rate entering the sampler (Q_{Sampler}) during the constant-flow test for the (a) Standard Opening Holey Sampler (Standard-OHS) and (b) Miniature Opening Holey Sampler (Mini-OHS), and during the variable-flow tests for the (c) Standard-OHS and (d) Mini-OHS. Dotted lines show linear regression relationships. Q_{Outflow} , modeled outflow through the Upwelling Bernoulli Tube (UBeTube)

the variable flow test for the Standard-OHS had a maximum flow rate of 0.18 L min⁻¹ (Figure 2c), less than half of the maximum flow rate in the constant-flow test (Figure 2a). Because we collected measurements at three water heights in the variable-rate test, it was not possible to seal the UBeTube slot to achieve the higher water heights that were attained in the constant-flow tests.

We also note that our analysis assumed that water height in the UBeTube changed instantaneously during a change in flow. In reality, it took 1–2 s for the water to rise and equilibrate after a change in flow. These lags had minimal effects on the overall sampling performance under these controlled laboratory conditions. Nonetheless, it is possible that more rapid or inconsistent fluctuations under field conditions may induce additional errors that would need to be quantified and understood.

3.3 | Flow linearity and proportionality

The second goal of the laboratory tests was to test the linearity of the relationship between measured Q_{Sampler} and modeled Q_{Outflow} across different water heights. The constant-flow test confirmed that measured Q_{Sampler} values were linearly related to modeled Q_{Outflow} rates. The Standard-OHS had an R^2 value of .965 (Figure 3a), indicating that this sampler collected flow

with a near constant proportionality to the UBeTube outflow under steady-state conditions. However, these test results also revealed that that sampler oversampled at low flow rates (i.e., Q_{Outflow} between 0 and 20 L min⁻¹), and undersampled at moderate flows (i.e., Q_{Outflow} between 20 and 75 L min⁻¹). The Mini-OHS had an R^2 value of .992 (Figure 3b), indicating more consistent proportionality to the UBeTube outflow. The smaller hole size of the Mini-OHS prevented oversampling at low flows (Q_{Outflow} of 0–10 L min⁻¹), and also allowed for decreased hole spacing, which helped to prevent undersampling at moderate flows (i.e., $20 \leq Q_{\text{Outflow}} \leq 75$ L min⁻¹).

The relationship between measured Q_{Sampler} and modeled Q_{Outflow} values remained linear for both samplers under variable-flow conditions ($R^2 = .954$ for the Standard-OHS and .996 for the Mini-OHS; Figure 3c,d). The tendency of the Standard-OHS to oversample at low flows was also evident in the low flow test. For example, the lowest measured Q_{Sampler} rate was 0.07 L min⁻¹, which was only 60 times less than the modeled Q_{Outflow} rate of 4.3 L min⁻¹ (Figure 3c). The Mini-OHS design had a more consistent ratio of approximately 1:240 (sampler to outflow rate) throughout the variable flow test, even at the lowest measured flows (Figure 3d). This proportionality was very close to the designed ratio of 1:250, indicating that the Mini-OHS performed as expected.

3.4 | Other design considerations

Our analysis did not consider any effects of sampler design and construction on the ability of the sampler to collect different analytes. For example, we constructed our prototype systems using PVC parts. This material was selected because it is affordable, easy to work with, and maintains its structural integrity under many conditions. However, there are different types of this material, including the unplasticized (i.e., rigid) PVC that we used in this test, along with plasticized PVC that tends to be more flexible. Rigid PVC is characterized by relatively low reactivity and smooth surfaces that limit chemical binding (Teuten et al., 2007; Wang & Wang, 2018), though the negative charge associated with chlorine groups can attract positively charged molecules (Guo et al., 2018). Users may therefore consider alternate materials when analyzing cationic compounds. The sampler design may also need to be modified when sediment is expected, for example by including larger holes that would allow collection of suspended sediment samples without clogging, or by placing mesh screens or other filters on the sampler pipe to reduce the chance of blockage (Osorno et al., 2018). Filter materials may be particularly important in the case of the Mini-OHS, due to the small diameter holes used in that configuration.

4 | CONCLUSION

In this study, we designed and evaluated a low-cost, passive, flow-weighted sampler for collecting water from runoff collectors such as the UBeTube. We verified the sampler performance with two configurations, including one using larger holes (Standard-OHS), and one using several smaller-sized holes (Mini-OHS). The performance of both samplers was well-described using theory (Equation 1) when they were tested under constant- and variable-flow conditions. Additionally, both configurations collected flow-weighted samples from the UBeTube, with a proportionality of approximately 1:250 between the two flow rates. The Mini-OHS had a stronger linear relationship between measured Q_{Sampler} and modeled Q_{Outflow} because the smaller hole size prevented oversampling at low Q_{Outflow} . However, the smaller (0.8-mm-diam.) holes may be more likely to clog, particularly in sediment-rich waters, meaning that users may wish to consider using filter materials when using this design.

Different hole sizes and placements could also be used to modify the proportion of outflow captured by the sampler. As an example, we created, but did not test, a sampler that was capable of a nearly linear relationship between Q_{Sampler} and Q_{Outflow} with a proportionality of 1:57 (Appendix A). This device could be constructed using holes that all have diameter ≥ 1.6 mm. This design would reduce the likelihood

of clogging but would also require larger sample collection vessels than the Holey Sampler versions tested in this study. Finally, the Holey Sampler device should be adaptable to other systems that measure runoff based on water height (e.g., weirs, flumes), with appropriate adjustments to hole size and placement to match expected flow conditions.

ACKNOWLEDGMENTS

Funding for this work was provided by the USDA National Institute of Food and Agriculture (Grant 2018-67019-27851), and by the Virginia Agricultural Experiment Station and the Hatch Program of the USDA National Institute of Food and Agriculture (1026126).

AUTHOR CONTRIBUTIONS

Jacob O. Maris: Formal analysis; Investigation; Validation; Visualization; Writing – original draft. Ryan D. Stewart: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

- Bonilla, C. A., Kroll, D. G., Norman, J. M., Yoder, D. C., Molling, C. C., Miller, P. S., Panuska, J. C., Topel, J. B., Wakeman, P. L., & Karthikeyan, K. (2006). Instrumentation for measuring runoff, sediment, and chemical losses from agricultural fields. *Journal of Environmental Quality*, 35(1), 216–223. <https://doi.org/10.2134/jeq2005.0130>
- Bonta, J. (2002). Modification and performance of the Coshocton wheel with the modified drop-box weir. *Journal of Soil and Water Conservation*, 57(6), 364–372.
- Budai, P., Kardos, M. K., Knolmár, M., Szemán, G., Turczel, J., & Clement, A. (2020). Development of an autonomous flow-proportional water sampler for the estimation of pollutant loads in urban runoff. *Environmental Monitoring and Assessment*, 192(9), 1–16. <https://doi.org/10.1007/s10661-020-08536-3>
- Burcham, T., Wren, D., Wooten, J., & Varco, J. (1998). Distributed data acquisition system for runoff monitoring and automated water sampler control. *Applied Engineering in Agriculture*, 14(6), 597–597. <https://doi.org/10.13031/2013.19427>
- Carter, C., & Parsons, D. (1967). Field tests on the Coshocton-type wheel runoff sampler. *Transactions of the ASAE*, 10(1), 133–135.
- Cullum, R., Schreiber, J., Smith, S., & Grissinger, E. (1992). Shallow groundwater and surface runoff instrumentation for small watersheds. *Applied Engineering in Agriculture*, 8(4), 449–453. <https://doi.org/10.13031/2013.26091>
- Dosskey, M., Hoagland, K., & Brandle, J. (2007). Change in filter strip performance over ten years. *Journal of Soil and Water Conservation*, 62(1), 21–32.

- Frame, S. T., Pearsons, K. A., Elkin, K. R., Saporito, L. S., Preisendanz, H. E., Karsten, H. D., & Tooker, J. F. (2021). Assessing surface and subsurface transport of neonicotinoid insecticides from no-till crop fields. *Journal of Environmental Quality*, 50(2), 476–484. <https://doi.org/10.1002/jeq2.20185>
- Geib, H. (1933). A new type of installation for measuring soil and water losses from control plots. *Agronomy Journal*, 25(7), 429–440. <https://doi.org/10.2134/agronj1933.00021962002500070001x>
- Guo, X., Pang, J., Chen, S., & Jia, H. (2018). Sorption properties of tylosin on four different microplastics. *Chemosphere*, 209, 240–245. <https://doi.org/10.1016/j.chemosphere.2018.06.100>
- Habib, E., Krajewski, W. F., & Kruger, A. (2001). Sampling errors of tipping-bucket rain gauge measurements. *Journal of Hydrologic Engineering*, 6(2), 159–166. [https://doi.org/10.1061/\(ASCE\)1084-0699\(2001\)6:2\(159\)](https://doi.org/10.1061/(ASCE)1084-0699(2001)6:2(159))
- Hernandez-Santana, V., Zhou, X., Helmers, M. J., Asbjornsen, H., Kolka, R., & Tomer, M. (2013). Native prairie filter strips reduce runoff from hillslopes under annual row-crop systems in Iowa, USA. *Journal of Hydrology*, 477, 94–103. <https://doi.org/10.1016/j.jhydrol.2012.11.013>
- Hladik, M. L., Bradbury, S., Schulte, L. A., Helmers, M., Witte, C., Kolpin, D. W., Garrett, J. D., & Harris, M. (2017). Neonicotinoid insecticide removal by prairie strips in row-cropped watersheds with historical seed coating use. *Agriculture, Ecosystems & Environment*, 241, 160–167.
- Inamdar, S., Singh, S., Dutta, S., Levia, D., Mitchell, M., Scott, D., Bais, H., & McHale, P. (2011). Fluorescence characteristics and sources of dissolved organic matter for stream water during storm events in a forested mid-Atlantic watershed. *Journal of Geophysical Research: Biogeosciences*, 116(G3). <https://doi.org/10.1029/2011JG001735>
- Kirchner, J. W., Feng, X., Neal, C., & Robson, A. J. (2004). The fine structure of water-quality dynamics: The (high-frequency) wave of the future. *Hydrological Processes*, 18(7), 1353–1359. <https://doi.org/10.1002/hyp.5537>
- Nehls, T., Rim, Y. N., & Wessolek, G. (2011). Technical note on measuring run-off dynamics from pavements using a new device: The weighable tipping bucket. *Hydrology and Earth System Sciences*, 15(5), 1379–1386. <https://doi.org/10.5194/hess-15-1379-2011>
- Osorno, T. C., Devlin, J., & Firdous, R. (2018). An in-well point velocity probe for the rapid determination of groundwater velocity at the centimeter-scale. *Journal of Hydrology*, 557, 539–546. <https://doi.org/10.1016/j.jhydrol.2017.12.033>
- Pathak, P. (1991). Runoff sampler for small agricultural watersheds. *Agricultural Water Management*, 19(2), 105–115. [https://doi.org/10.1016/0378-3774\(91\)90002-Z](https://doi.org/10.1016/0378-3774(91)90002-Z)
- Pinson, W. T., Yoder, D. C., Buchanan, J. R., Wright, W. C., & Wilkerson, J. B. (2004). Design and evaluation of an improved flow divider for sampling runoff plots. *Applied Engineering in Agriculture*, 20(4), 433. <https://doi.org/10.13031/2013.16489>
- Radolinski, J., Wu, J., Xia, K., Hession, W. C., & Stewart, R. D. (2019). Plants mediate precipitation-driven transport of a neonicotinoid pesticide. *Chemosphere*, 222, 445–452. <https://doi.org/10.1016/j.chemosphere.2019.01.150>
- Ries, F., Kirn, L., & Weiler, M. (2020). Runoff reaction from extreme rainfall events on natural hillslopes: A data set from 132 large-scale sprinkling experiments in south-western Germany. *Earth System Science Data*, 12(1), 245–255. <https://doi.org/10.5194/essd-12-245-2020>
- Stewart, R., Liu, Z., Rupp, D., Higgins, C., & Selker, J. (2015). A new instrument to measure plot-scale runoff. *Geoscientific Instrumentation, Methods and Data Systems*, 4, 57–64. <https://doi.org/10.5194/gi-4-57-2015>
- Stewart, R., Moreno, D. S., & Selker, J. S. (2015). Quantification and scaling of infiltration and percolation from a constructed wetland. *Journal of Hydrologic Engineering*, 20(10), 04015007. [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0001164](https://doi.org/10.1061/(ASCE)HE.1943-5584.0001164)
- Teuten, E. L., Rowland, S. J., Galloway, T. S., & Thompson, R. C. (2007). Potential for plastics to transport hydrophobic contaminants. *Environmental Science & Technology*, 41(22), 7759–7764.
- Udawatta, R. P., Krstansky, J. J., Henderson, G. S., & Garrett, H. E. (2002). Agroforestry practices, runoff, and nutrient loss. *Journal of Environmental Quality*, 31(4), 1214–1225. <https://doi.org/10.2134/jeq2002.1214>
- Wang, W., & Wang, J. (2018). Comparative evaluation of sorption kinetics and isotherms of pyrene onto microplastics. *Chemosphere*, 193, 567–573. <https://doi.org/10.1016/j.chemosphere.2017.11.078>
- Yazdi, M. N., Sample, D. J., Scott, D., Wang, X., & Ketabchy, M. (2021). The effects of land use characteristics on urban stormwater quality and watershed pollutant loads. *Science of the Total Environment*, 773, 145358. <https://doi.org/10.1016/j.scitotenv.2021.145358>
- Zhan, X., Zhao, J., Zhu-Barker, X., Shui, J., Liu, B., & Guo, M. (2021). An instrument with constant volume approach for in-situ measurement of surface runoff and suspended sediment concentration. *Water Resources Research*, 57(2), e2020WR028210. <https://doi.org/10.1029/2020WR028210>
- Zhao, S. L., Dorsey, E., Gupta, S. C., Moncrief, J. F., & Huggins, D. R. (2001). Automated water sampling and flow measuring devices for runoff and subsurface drainage. *Journal of Soil and Water Conservation*, 56(4), 299–306.

How to cite this article: Maris, J. O., & Stewart, R. D. (2022). A device to collect passive, flow-weighted water samples from surface runoff. *Vadose Zone Journal*, 21, e20226. <https://doi.org/10.1002/vzj2.20226>

APPENDIX 1: High-flow Holey Sampler configuration

A third Holey Sampler configuration was designed, but not tested (Table A1). This configuration was meant to achieve a nearly linear relationship between Q_{Sampler} and Q_{Outflow} without using the smaller, specially ordered 0.8-mm drill bit (Figure A1). While this configuration lowers the likelihood of clogging due to small holes, the sampling ratio is higher than that of the Standard-OHS and Mini-OHS (i.e., 1:57 compared with approximately 1:250). Using this configuration would necessitate a larger sample collection vessel or smaller runoff contributing area than when using the Standard-OHS and Mini-OHS. However, the larger sample volume could be beneficial if users intend to perform multiple analyses on each sample and storage space is not limited. This design also provides a further example of how the Holey Sampler can be modified so that it can be applied in a variety of experimental designs and under different environmental conditions.

TABLE A1 Height, number, and diameter of holes to create a high-flow Holey Sampler configuration. Hole heights are in relation to the bottom of the Upwelling Bernoulli Tube (UBeTube) slot

Height	No. of holes	Diameter
mm		mm
10	1	1.6
40	1	1.6
50	1	1.6
70	2	1.6
100	2	2.4
125	2	3.2
145	2	3.2
155	1	3.2
160	1	2.4

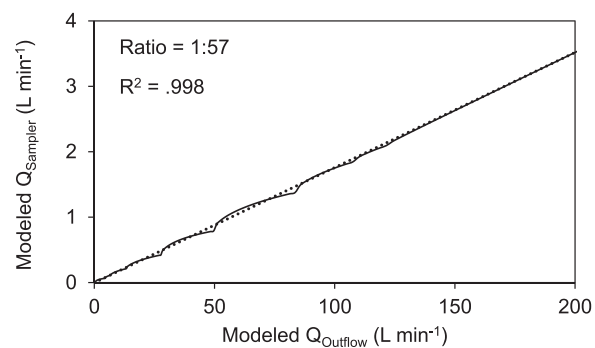


FIGURE A1 Modeled relationship between sampler flow (Q_{Sampler}) and Upwelling Bernoulli Tube (UBeTube) outflow (Q_{Outflow}) for the high-flow Holey Sampler configuration