Design of a Flow and Sediment Suspension Sampler

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Abstract

Currently, no widely accepted sampler can accurately collect information regarding the flow rate and sediment composition of stormwater discharge from construction site sediment basins. This lack of accurate monitoring has become a large problem for the Environmental Protection Agency (EPA) and has led to litigation by both environmental and construction organizations, expansive sediment pollution into the nation's water bodies, and costly management practices that are not effective at further stopping this pollution.

The Flow and Sediment Suspension Sampler (FloSSS) is a traversing slot system that autonomously collects samples of discharge leaving a sediment basin. The promising results indicated that this system could potentially solve the EPA's monitoring issues and possibly impact every construction site nationwide. It will allow construction operators to limit expenditure of time and money on complicated management practices, answer environmental groups' concerns about sediment pollution on construction sites, and ensure our waterways remain clean for years to come.

Acknowledgments

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Table of Contents

1. Introduction

The National Pollutant Discharge Elimination System (NPDES) permit program addresses water pollution by regulating point sources that discharge pollutants to waters of the United States. Most NPDES permits are based on allowed discharge of a mass or concentration of contaminant into the receiving water body. In contrast, to secure a NPDES Stormwater Construction Permit, operators must develop a site-specific Stormwater Pollution Prevention Plan (SWPPP) to handle sediment and erosion. A SWPPP describes all the construction site operator's activities and Best Management Practices (BMPs) that will control sediment delivery from the site, and an approved SWPP is seen as the equivalent of meeting an NPDES discharge limit, thus complying with the requirements of the Clean Water Act (United States Environmental Protection Agency [EPA], 2023).

For areas with ten or more acres disturbed at any one time, a SWPPP must include a sediment basin at the site discharge point, which settles sediment and minimizes the amount of sediment that leaves the property. This is just one practice on the United States Environmental Protection Agency (EPA)'s National Menu of Best Management Practices (BMPs) for Stormwater (EPA, 2007). This menu is a collection of many practices the EPA thinks might help protect water bodies from polluted runoff resulting from construction activities. Construction operators must then implement their planned BMPs following EPA or state guidance (Tennessee Department of Environment and Conservation [TDEC], 2012). In urban areas, the current scheme fails to provide protection. This leads to most of the sediment that originates on construction sites depositing into waters, as seen in Figure 1.

Figure 1. Third Creek in Knoxville, TN after heavy storm deposited sediment from nearby construction sites

The lack of accurate sediment discharge monitoring led to litigation by several groups over the faulty implantation of BMPs. Environmental groups, such as the Chesapeake Bay Foundation, have sued for better testing to ensure the practices prevent pollution of water bodies. On the other hand, construction groups, such as the American Farm Bureau Federation and the National Association of Home Builders, have sued due to their belief that costly, time-consuming BMPs should not have to be implemented if the BMPs cannot be proven to work effectively. Federal Courts have upheld that the EPA should implement an effective way to test the discharge leaving the site, but the EPA has not yet been able to do so (Chesapeake Bay Foundation). Having an effective way of measuring sediment discharge from construction sites would allow the EPA to treat construction permits like other NPDES permits, restricting the total sediment discharge rather than controlling site BMPS.

If a Flow and Sediment Suspension Sampler (FloSSS) can be developed to effectively measure total sediment discharge from a construction site, it will be an important step towards moving construction sites more towards a more standard NPDES permitting process— solving an issue that impacts every construction site nationwide. It will allow construction operators to optimize their use of BMPs to meet discharge limits, while answering environmental groups' concerns about the true effectiveness of erosion and sediment control on construction sites.

2. Problem Definition

The most likely approach to measuring storm sediment discharge is to take periodic samples and analyzing them for sediment concentration. This is then combined to time-varying flow information that will indicate what larger mass of water each sample represents, allowing for estimation of the total sediment mass represented by that sample. Currently, no accurate nor effective device can collect information regarding the flow rate and sediment composition of stormwater discharge. The problem addressed by FloSSS's design is to develop a low-cost device that can accurately measure discharge flowrate over time, and that can extract representative samples. The actual measurement of sediment in those samples is being worked on in a parallel project but is not part of this effort. Specific requirements are that the device measure the flow rate and provide a half to two-liter sample that can accurately be measured to reflect the 3-dimensional presence of sediment runoff. The system must also be capable of operating under natural environmental conditions and sample every three minutes during high flow events.

The nature of two-phase flow (solid and liquid) makes simultaneous measurements of sediment and flow rate difficult without misrepresenting the sediment concentration. Sediment is not evenly distributed throughout a flow of water due to differences in densities and flow (Brakensiek et al., 1979). Where appreciable quantities of coarse sediment are in transport, a considerable lateral and vertical concentration gradient can exist throughout any given flow cross-section. Sample concentrations collected from a single point or single stationary vertical traverse of the stream cross-section may vary considerably from the mean.

Even when the pipes are uniform in cross-section, the velocities tend to be higher at midstream. This velocity difference, together with naturally occurring differences in turbulence, can result in a higher transport rate of the coarse sediment fractions at midstream. The ratio of midstream to cross-section concentration can be much greater than unity (Mott & Untener, 2021).

These two factors have caused great difficulty in accurately capturing a representative sample from a sediment basin's discharge pipe. Though many methods have been allowed by the EPA as ways to collect samples from stormwater discharge, they have varying degrees of success, complexity, and cost. The current methods and their shortcomings are as follows.

2.1 Turbidity Monitoring

Turbidity monitoring is the current method used to monitor sediment presence in water, but it is highly unreliable and requires calibration based on the soil types present on site (EPA, 2022b). When not calibrated properly, turbidity monitoring can give vastly different results. Although there are various turbidity meters, there is no standard method for using them, which makes developing a standard benchmark method challenging, especially given the presence of various soil types.

2.2 Weirs and Flumes

Weirs and flumes are commonly used to obtain high-precision flow rate measurements by changing their geometry and the depth of the water flowing through to calculate the flow rate. One important factor that prevents this method from being considered accurate is that it requires a barrier to function properly which will create ponding upstream of the device that causes settling of the sediment of the water.

2.3 Stationary Pump

The EPA recommends using a stationary collection pump placed in one location of the flowing discharge to collect a sized sample from the discharged pipe. This produces an inaccurate sample as the stationary nature of the pump limits the collected sample to only one section of the discharge. Sediment type and size is distributed differently across each section of the flow leaving the stormwater basin, so having only one testing location may under or over represent the actual sediment levels.

3. Success Criteria

The project will be considered successful when it accomplishes the following tasks within a $5,000 budget.

3.1 Autonomously Collect a Representative Sample

The sample needs to represent the correct mass and size distribution of sediment particles and flow rate of the discharge within at least 10% accuracy. The system must collect this sample autonomously.

3.2 Half to Two Liter Sample Size

The collected sample must be within this size range to fit in the downstream device that will analyze the sample.

3.3 Handles Typical Storm Events and Environmental Conditions

Part 2.2.12 of EPA's 2022 CGP indicates that sediment basins must be able to provide storage for the calculated volume of runoff from a 2-year, 24-hour storm or 3,600 cubic feet per acre drained (EPA, 2022a). The system must thus be designed to handle the typical flow rate from an outflow pipe, flow direction, flow speed, weather and temperature conditions, and normal sediment and debris sizes.

3.4 Maximum Three Minute Collection Time

The entire process of the sampler must be performed in under three minutes. This is due to the assumption that the discharge maintains a constant flow and sediment levels for a 3-minute period.

4. Alternatives

From the current methods in Section 2, it was verified that most alternatives did not accurately measure flow rate and collect a representative discharge sample. A common theme was that none of the devices could be autonomously adjusted for varying flow amounts, which led to vastly different results at low flow rates versus high flow rates. A new device would have to be created to alleviate these issues. Inspiration behind FloSSS was first taken from a similar device used in streams, seen in Figure 2.

4.1 Stream Multi-slot Sampler

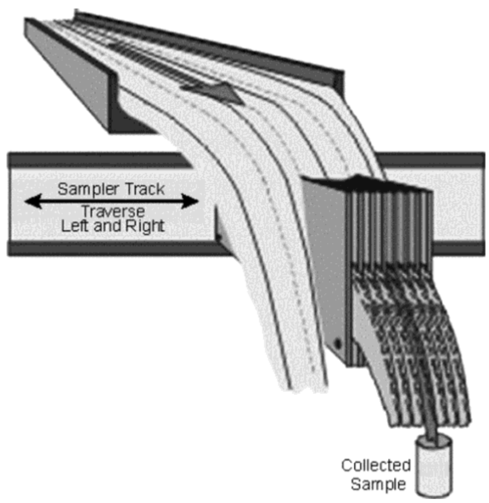

Figure 2. Sampling assembly at a stream channel overfall (Replogle, 2009)

Replogle (2009) developed a traversing, multi-slot system for sampling the sediment load and water flow of stream channel cross-sections. It included multiple long, straight, guarded slots that each collected samples. While the sampling assembly did work with 4% accuracy, this assembly was incredibly large, required a sizeable amount of labor to install, was only tested to work on straight streambanks, and would most likely exceed the allowed budget. However, the theory behind a traversing slot was taken, analyzed, and then adapted in further alternatives.

4.2 Traversing Slot Theory

Inspired by the theory behind the Stream Multi-slot Sampler, the following is a comprehensive justification for the use of a single constant velocity traversing slot to sample discharge from a circular pipe, for the purpose of flowrate measurement and sediment concentration analysis.

The paramount assumption to FloSSS is, that for the entire duration of time that the traversing slot is within the flow, the flow rate and sediment concentration of the discharge remains constant. Additionally, samples taken at intervals no greater than three minutes apart are valid for the use of total sediment discharge over time (calculated by measured flow rate and sediment concentration). Figure 3 acts as a visual representation of the flow from a circular discharge pipe.

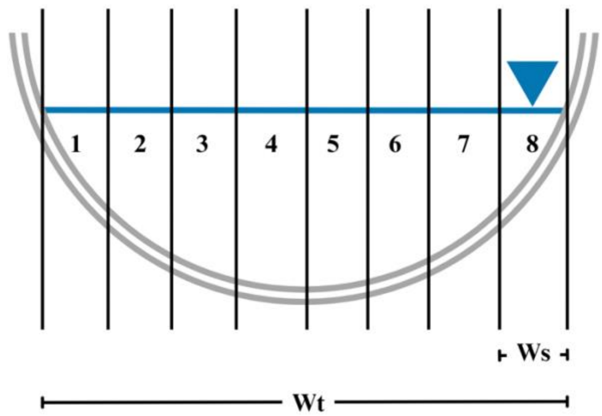

Figure 3. Traversed flow from a circular discharge pipe

To account for the variance in the velocity and sediment profiles within the flow, the slot moves consistently through all sections of the flow. Volumetric Flow Rate, q_i, will be greater in sections of larger cross-sectional area ($q_4 > q_1$). Additionally, sections with less pipe surface perimeter will have increased velocity, and in turn increased flow rate. The result of this is that if flow is sampled from only one cross section, the sample is not representative of the sediment concentration and flow rate.

The traversing slot, with width w_s, moves through the profile. For the example in Figure 3, the total width of the nappe in the pipe, w_t, is divided into 8 sections based on the dimension w_s. If the slot remains in each of the 8 sections for exactly one second, exactly one-eight of total flow it collected, and each of the various flow conditions in the total nappe has been accounted for. In actuality, the traversing slot takes infinite sections of the flow, defines the flow rate based on the sample volume collected, and gets a representative sample by integrating horizontally and vertically.

4.3 Curved Vertical Slot Sampler

Figure 4. Curved vertical slot sampler

Applying the theory, the first generation of FloSSS's traversing slot design, seen in Figure 4, included a telescoping slot that extended vertically through the discharge nappe. This slot boasted an even cross-sectional sample, an effective way to be moved with constant velocity, as well as the ability to collect a sized sample of the flow. Seen in Figure 4, the final generation of traversing the slot was designed around a slot suspended in the flow by two tie rods. To move FloSSS evenly through the profile without interruption, the slot was connected to an external track and carriage system. The curved slot was able to reflect the curved flow of the discharge from the pipe and was able to collect the flow at the range of flow rates.

5. Overview of Design

The design consists of a traversing curved slot sampler placed on a carriage system that can adjust its speed based on a rough measurement of the flow of the discharge, which is calculated based on data obtained from an ultrasonic sensor. The slot will then obtain a cross-sectional slice of the water and sediment profile, which can then be pumped to an external machine that will be able to analyze the sediment concentration in the sample. The pump is not engaged until the slot has fully crossed the nappe and the conveyance system's limit switches are activated. The metering pump will also be used to calculate an accurate flow rate based on the collected volume and travel time across the nappe. The pump is then shut off and the system proceeds to start a new sample. The steps in the sampling cycle are detailed in Figure 5.

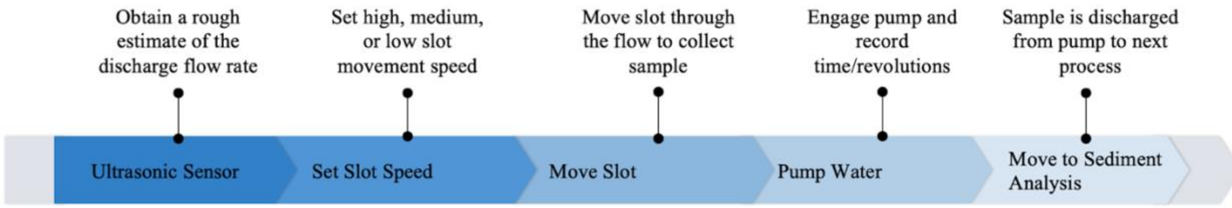

Figure 5. Process flow for sampling sediment and flow rate

6. Prototyping

FloSSS consists of multiple parts to collect a representative sample of the discharge flow. The full system can be seen in Figure 6 and the parts are listed below with details on their use and benefits compared to alternatives.

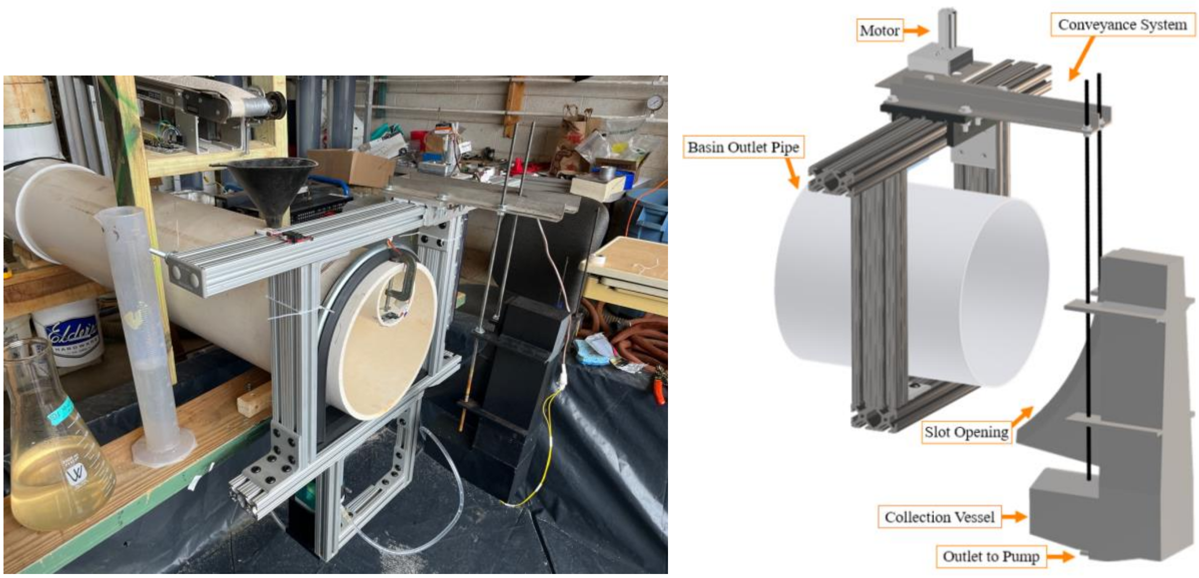

Figure 6. FloSSS system

6.1 Microcontroller and Datalogger System

An Arduino Mega 2560 Rev3 is a microcontroller board based used to allow the system to function autonomously. It controls sensors as inputs and motors or other devices as its outputs. It was selected because of its low-cost, cross-platform compatibility, and ease of programming.

The Arduino connects to an Arduino SD card module which provides external data storage. It stores the required data (such as flow rate and sampling time) in a CSV file which can then be collected by a worker on site.

6.2 Ultrasonic Sensor

The first step in the device's process is to obtain a rough flow rate measurement using an ultrasonic sensor. Being able to increase the speed of the slot during high flow rates and slowing it down during low flow rates enables the team to collect roughly the same volume of water every time. This measurement is sent to the Arduino which analyzes takes the sensor reading, uses the it to assign reading depth to flow rate, and moves the slot speed. If the calculation shows no flow, the system stays in stand-by mode.

The ultrasonic sensor takes up minimal space in the pipe. This is imperative as it allows for minimal installation costs, minimal interference with pipe discharge, and ensures that the sensor will not impede the sediment or flow being released from the discharge pipe. This sensor was chosen as opposed to other options and approaches (such as paddle sensors and flow meters) because it minimizes cross-contamination by not disturbing or being in the flow of the water as this disrupts the sediment and flow rate in the pipe.

6.3 Conveyance System

For the slot to be moved effectively through the nappe, several things were considered. Firstly, the conveyance system must maintain a constant velocity, otherwise the volume of water collected will not be correctly related to the flow rate coming from within the pipe. Second, the structure must withstand the forces resulting from the weight and force of the flowing water.

To achieve such a carriage system, it was necessary to evaluate what forces the slot would be subjected to when moving through the flow profile or the discharge stream. Using the free body diagram, Figure 7, where Ry and Rx represent the force tolerance required by the mounting system, the force of the fluid on the traversing slot can be calculated. The angle of F_{WATER} is estimated on the observed, typical activity on free flow exiting the pipe. All calculations are completed at the highest flow that will be exerted on the system.

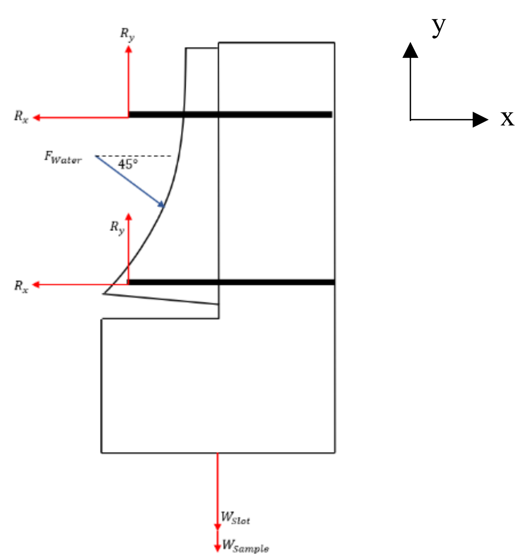

Figure 7. Free body diagram of traversing slot

Note that W_{Slot} is the weight of the slot structure, and W_{Sample} is the weight of a 2-liter sample of water.

To calculate F_{Water}, the conservation of momentum equation was applied (Equation 1).

$$F_{water} = \rho A_{CS} v^2 \tag{1}$$

To calculate the velocity, the flow rate was set to the maximum possible outflow from a properly functioning, standard condition sediment basin (Equation 2).

$$Q_{max} = 0.5 \frac{ft^3}{s} \tag{2}$$

The Brink Width equation, Equation 3, was then used to solve for the cross-sectional area of the flow, A_{CS}. The Brink Width value, B_c, was determined experimentally for a 12-inch diameter pipe at 2% slope, as reported by Blevins (1984).

$$\frac{Q_{max}^2}{g} = \frac{A_{CS}^3}{B_C} \tag{3}$$

$$\frac{(0.5 \frac{ft^3}{s})}{32.2 \frac{ft}{s^2}} = \frac{A_{CS}^3}{0.833 ft} \tag{4}$$

$$A_{CS} = 0.1841\ ft \tag{5}$$

The Continuity Equation, Equation 6, was rearranged to solve for the velocity of the flow, v.

$$Q_{max} = v * A_{CS} \tag{6}$$

$$v = 2.716 \frac{ft}{s} \tag{7}$$

According to the previously stated Conservation of Momentum Equation, Equation 8, the following force of water flow, F_{water}, is calculated.

$$F_{water} = \rho A_{CS} v^2 \tag{8}$$

$$F_{water} = \left(\frac{62.4\ lb_f}{ft^3}\right)(0.1841 ft^2)\left(2.716 \frac{ft}{s}\right) \tag{9}$$

$$F_{water} = 31.2\ lb_f \tag{10}$$

The system must be able to withstand water at a force of 31.2 lb_f at an angle of 45 degrees, the average angle of the nappe. In static motion, the X-Directional forces and Y-Directional forces must equal zero (Equations 9 and 12, respectively), where R_x and R_y are the reaction force in the X and Y direction, respectively. These are all in reference to the Free Body Diagram, Figure 7.

$$\Sigma F_x = 0 \tag{9}$$

$$0 = -R_x + F_{Water}(\cos 45°) \tag{10}$$

$$R_x = 22.06\ lb_f \tag{11}$$

$$\Sigma F_y = 0 \tag{12}$$

$$0 = +F_{Water}(\sin 45°) + R_y - W_{SLOT} - W_{Sample} \tag{13}$$

$$R_y = 27.36\ lb_f \tag{14}$$

The total support requirements for the conveyance system are 22.06 lb_f in the horizontal direction and 27.36 lb_f in the vertical direction.

The final generation of moving the slot was designed around a completely enclosed slot that was suspended in the flow by tie rods. A track and carriage system were constructed, composed of 80/20 aluminum extrusions, cable pulleys powered by a 24 V motor, and mounting plates. Due to their interlocking nature, the carriage moves smoothly and securely across the rail. Limit switches were also installed on the conveyance system's ends, which can alert the Arduino to stop the slot.

6.4 Slot

The length of the slot opening needed to be high enough that it encompassed the whole discharge nappe coming from the pipe, and wide enough to ensure that the collected sample is in between 0.5 L and 2 L. From an in-depth examination of the stormwater regulations from Tennessee and Minnesota (TDEC, 2012; Minnesota Pollution Control Agency [MPCA], 2023), the recommended outlet pipe diameter from a sediment basin is 12 inches, with minimums of 8 inches for corrugated metal pipe and 6 inches for smooth pipe. From this, the length of the slot was chosen to be 12 inches to align with the recommended diameter size. Establishing a length of 12 inches ensured that the slot would always have the potential to collect a sample at extremely high flow sizes.

The width of the slot opening needed to ensure that the collected sample was between 0.5 L and 2 L, while minimizing the edge effect. Edge effect can be defined as the effect that a material's width has on its interaction with the steady flow stream. As seen in Figure 9, thicker widths show more of the fluid deflecting from the object's surface, and slimmer widths cut through the water sharply with little deflection. The deflection seen with thicker widths could cause the sediment and water to not fall properly into the lot, which could lead to an unrepresentative sample. To minimize the deflection, an edge width of 1 mm was selected for the slot's opening walls.

Figure 8. 1 mm versus 5 mm edge effect

6.5 Vessel

The slot was connected in one 3D printed piece to the vessel collects the sample. The vessel can contain up to 2 L (70.4 oz) at a time and can therefore hold the sample until the slot has fully traversed the nappe. The slope of the surfaces within the vessel were chosen to ensure that sediment will not settle or adhere to the slot before pumping. Based on the results of Blom's model of the influence of slope on deposits (2020), a minimum slop of 1/16" per foot or 0.52% for surfaces within the vessel was selected.

6.6 Pump System

A pump needed to be chosen that can quickly pump a sediment-laden water sample without obstructing or leaving residue behind in the tube, while also being able to be self-priming and metering. A peristaltic pump with a flow rate of 1.24 L/min (43 oz/min) and reduction ratio of 1:20 was chosen to fulfill these requirements. $\frac{3}{16}''$ polyethylene tubing was used to connect the pump to the reservoir and the sediment analysis device. This tubing was large enough that sediment easily flows, while being sufficiently small to ensure adequate vacuum suction pressure to fully evacuate the sample from the reservoir.

A peristaltic pump is a positive displacement pump where fluid is fed through tubing by rollers, squeezing the flexible tube against the pump housing. The discharge is fully contained in the tubing, so there are no rotating parts for sediment to obstruct (unlike diaphragm pumps). The arrangement of the rollers and the vacuum created also prevent backflow from occurring, thus ensuring no cross contamination between the samples.

Since peristaltic pumps are a type of metering pump, they also provide an accurate volumetric flow rate. The period from when the slot starts collecting water until the slot stops will give the time component. The peristaltic pump's flow rate and pump time to empty the basin will yield the sample's volume. These values are then used in the volumetric flow rate equation as reported by Mott and Untener (2021) (Equation 15):

$$Q = (V)(t) \tag{15}$$

6.7 Float Switch

The final step of the system is the water level sensor. This sensor was placed in the bottom of the collection vessel and alerts the system when the sample has been fully pumped out. This allows accurate calculation of the pump time, which along with the pump flow rate yields the sample volume.

7. Testing and Results

To assess the accuracy of the system, the team constructed a simulated sediment basin outlet. This was done using the hydrograph generator in the Biosystems Department's hydraulics lab and a 12" sediment basin outlet pipe. The hydrograph generator seen in Figure 9 provides a consistent flow rate via a centrifugal pump, using an in-line needle valve that can vary the flow output of the pipe that correlate with flows achieved from a real sediment basin. Sediment can also be placed into the pipe at a consistent velocity and amount via a hole upstream of the flow. Development and testing of this device was detailed and established by Buchanan, Hurley, D. Yoder, R. Yoder, and Wilkerson (1998).

Figure 9. Hydrograph generator and slot in action

Part 2.2.12 of EPA's 2022 CGP indicates that sediment basins must be able to provide storage for the calculated volume of runoff from a 2-year, 24-hour storm or 3,600 cubic feet per acre drained (EPA, 2022). The system must thus be designed to handle the flow rate from the outflow pipe. Though there is no 'typical flow' number, the parameters can be calculated by using the smallest and largest typical basins' values.

There is no standard minimum and maximum basin size established by the EPA, so a comprehensive examination of various state requirements was conducted. In the entire United States, the smallest drainage area to any one temporary basin is one acre (TDEC, 2003). In Tennessee, the maximum drainage allowed to one temporary basin is fifty acres, but it is highly unrecommended. Ten acres is the maximum recommended. The team decided against fifty acres as the max, due to its lack of recommendation.

The total storage volume provided by sediment basins should be a minimum of 3,600 cubic feet per acre of contributing area. A 2-year, 24-hour storm event should be used to calculate peak flows. The first flush volume at a minimum size of 3,600 cubic feet must be captured and then slowly released over a maximum period of 72 hours with the majority being drained by 24 hours (TDEC, 2012).

Following these requirements, maximum and minimum discharge rates were calculated using Equation 16 (Iowa State University, 2022):

$$Q = \frac{cubic\ feet\ of\ drainage}{(x\ hour)(\frac{60\ \mathrm{min}}{1\ hr})(\frac{60\ \mathrm{sec}}{1\ min})} \tag{16}$$

Using Equation 16, 0.417 cfs was determined for a 10-acre pond with a 24-hour minimum drainage and 36,000 cf storage and 0.139 cfs was determined for a 10-acre pond with a 72-hour minimum drainage and 36,000 cf storage.

To find a theoretical minimum flow rate, the minimum parameters for a sediment basin were used to produce a very low flow rate. Using Equation 16, 0.0417 cfs was determined for a 1-acre pond with a 24-hour minimum drainage and 36,000 cf storage and 0.0139 cfs was determined for a 1-acre pond with a 72-hour minimum drainage and 36,000 cf storage.

Using these values, the mock sediment basin was set to 0.057 and 00.242 cfs for testing. The testing values lied between the calculated values and were moderately low and moderately high flow rates.

7.1 Ultrasonic Sensor

Testing of the ultrasonic sensor was done to measure the accuracy of the ultrasonic sensor when measuring the distance from the sensor to the top of the water. The smaller the distance, the higher the flow rate and vice versa. Each distance was measured for each flow rate ranging from a minimum value to a maximum value. The team performed five trials at each flow rate and acquired very consistent data between the minimum and maximum values.

As seen in Appendix 1, this information was compiled into an Excel spreadsheet and statistically analyzed for error. This showed that the ultrasonic sensor was a reliable device to be used to set the speed for the conveyance system.

7.2 Conveyance System

To effectively control the motor using the Arduino, initial testing was required. Arduino uses a numerical scale of 0 to 255 to control motor speed via a L298N dual H-Bridge motor driver controller. To relate the numerical scale to a specific slot movement velocity, the duration of slot travel across the pipe was recorded. At each Arduino setting, 6 trials were completed (3 tests each rightwards and leftwards across the pipe). As seen in Appendix 2, this information was compiled into an Excel spreadsheet and analyzed for error.

After correlating the motor velocities to the numerical scale, the conveyance system was able to be tested in the water flow. Using the ultrasonic sensor's readings, code was established that correlated the sensor's reading to discharge in the pipe.

7.3 Flow Rate

The hydrograph generator is a device developed to mimic discharge from stormwater scenarios. It is calibrated so that it can put out a known flow rate that will stay consistent and controlled throughout. This known rate was then compared to the rate measured by FloSSS's peristaltic pump because the pump speed is proportional to the flow. By determining the total amount of discharge pumped at a given pumping speed over the time interval that the slot took to collect the sample, the sampler calculated the flow rate of the discharge. The generator's actual flow rate was compared to the sampler's measured volume and was compiled into an Excel spreadsheet and statistically analyzed for error as seen in Appendix 3. It was shown to be consistent and linearly correlated with r-squared value of 0.94 for low speed and 0.96 for high speeds. These results thus prove the premise that the sampler can accurately obtain and provide a controlled volume and correspondingly measure an accurate flow rate.

7.4 Sediment Composition

Two types of dried sediment samples (a silty soil and pure sand) were tested at two different flow rates (a lower flow rate of 0.057 cfs and a higher flow rate of 0.242 cfs). This was done three times for each sediment class using the following procedures with the hydrograph generator.

The needle valve of the hydrograph generator was set to the required flow rate and the tins were tare weighed. Once the water equalized to achieve the target rate, sediment was added upstream via a conveyer belt at a known velocity, taking the sediment from a hopper to a funnel into the discharge pipe. Once the sediment was fully mixed into the discharge, the slot was initiated and started collecting three samples at the set sediment type and flow rate. This was repeated for each sediment class and both flow rates.

After all the samples were pumped into sterile pans, the sediment was allowed to settle for 24 hours. Following the EPA's method for testing solids in water, the pans were then heated in an oven to 105 °C for a minimum of 12 hours or until the water was completely evaporated from the sample. The residue was then cooled and weighed. The weight of the pan was subtracted, and the sediment weight was recorded (EPA, 2001). Seen in Appendix 4, the results were then analyzed for consistency and compared to the input sediment values.

The results showed a sampling variance of 3% for silt at low flow, silt at high flow, and sand at high flow. The sand testing at low flow showed a slightly increased level with 8% variance. Therefore, the results of the sediment samples demonstrated that for the silt at high flow, silt at low flow and sand at high flow met the success criteria of having less than a 10% variance for consistantcy. However, for the sand at low flow did not meet the criteria for success.

When comparing the input and output sediment concentrations in Appendix 4, there is more variance ranging from 6% to 32%. This is likely due to the use of the hydrograph generator for testing. There was visibile settelement of sediement in the discharge pipe before reaching FloSSS which lead to smaller sediment consentrations being collected. Eliminating the settling will have an increased likelihood for success of the testing. In a sediment basin, this settling in the pipe will not be as drastic.

8. Conclusion

There is now a potential way to monitor and test sediment runoff from construction sites nationwide. The sampler will ensure safe measures are being taken to reduce sediment pollution for the environmental agencies, along with saving construction agencies time and money from implementing failing practices. The following criteria were either met or rejected.

8.1 Autonomously Collect a Representative Sample

The system operates completely autonomously upon setup on the discharge pipe. The traversing slot system can calculate an accurate flow rate while ensuring reliability, repeatability, and accuracy with less than 5% error. Meanwhile, the collection of a representative sample of sediment distribution did not fully meet the criteria due to it being consistant below 10% variance but having larger variances in accuracry.

8.2 Half to Two Liter Sample Size

By using the ultrasonic sensor to change the slot speed to align with the flow rate, the samples consistently maintained the required half to two liter sample size.

8.3 Handles Typical Storm Events and Environmental Conditions

The system was tested and designed to handle the typical flow rate from an outflow pipe, flow direction, flow speed, weather and temperature conditions, and normal sediment and debris sizes.

8.4 Maximum Three Minute Collection Time

The entire process of the sampling and collection occurs in a 1-minute period, which was significantly below the required 3-minutes.

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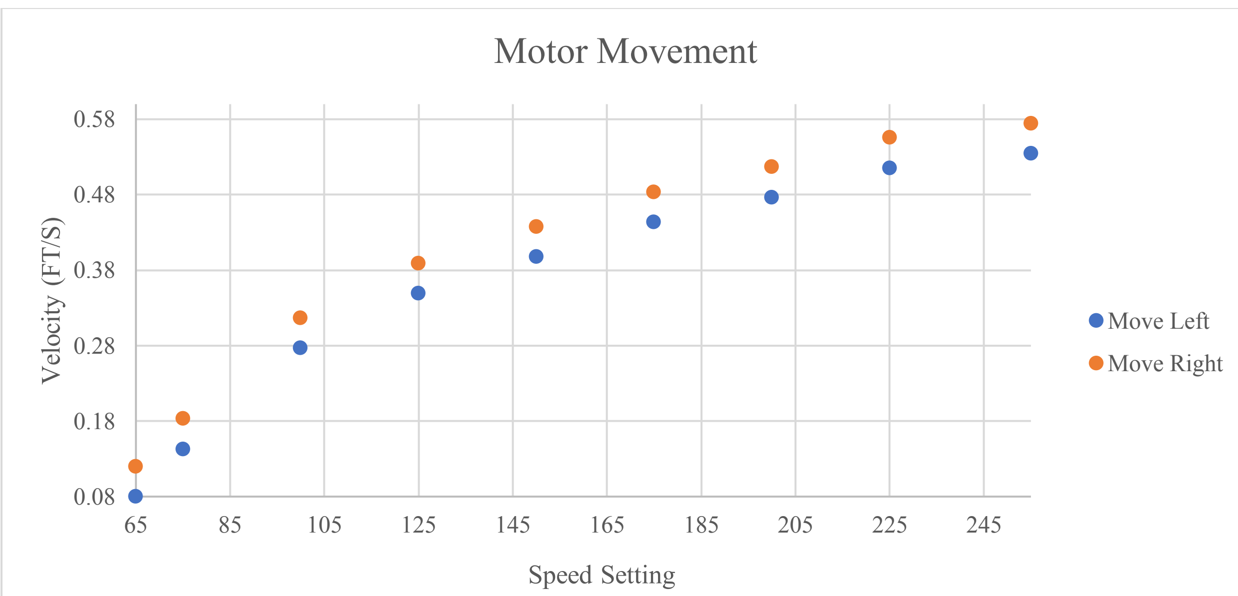
10. Appendixes

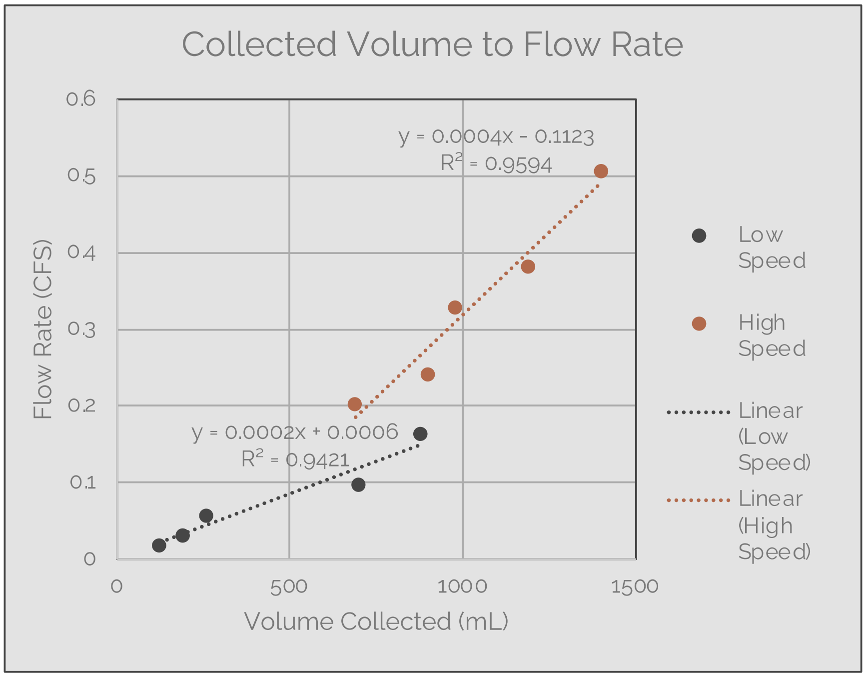
Appendix 1. Ultrasonic Sensor Calibration Results

Ultrasonic Sensor Testing Data (12 Inch PVC)				
Flow Rate (CFS)	**Reading Variance (IN)**	**Mean (IN)**	**Water Height (IN)**	**Flow Breadth (IN)**
0.0097	0.3	6.83	1.17	2.75
0.031	0.3	6.67	1.33	4.00
0.057	0.5	6.57	1.43	5.50
0.098	0.7	6.50	1.50	6.75
0.163	0.6	6.22	1.78	7.00
0.203	0.8	6.06	1.94	8.00
0.242	0.8	5.89	2.11	9.00
0.328	0.7	5.77	2.23	9.50
0.382	0.9	5.59	2.41	9.75
0.506	0.9	5.53	2.47	10.00

Appendix 2. Conveyance System Calibration Results



Appendix 3. Flow Rate Testing Results



Appendix 4. Sediment Testing Results

Sediment Concentration Silt					
Case	Flow Rate of Water (CFS)	Flow Rate of Sediment (g/s)	Sediment Concentration Input (g/ml)	Sediment Concentration Output Avg (g/ml)	Variance
Mid-Low	0.05569	21.44	0.00591	0.00641	6%
Mid-High	0.242	21.44	0.00136	0.00185	22%

Sediment Concentration Sand					
Case	Flow Rate of Water (CFS)	Flow Rate of Sediment (g/s)	Sediment Concentration Input (g/ml)	Sediment Concentration Output Avg (g/ml)	Variance
Mid-Low	0.05569	24.82	0.00685	0.00590	11%
Mid-High	0.242	24.82	0.00362	0.00230	32%

Final Silt Testing (Low Flow)		
Sample ID	Concentration (g/ml)	Variance
FLF 1.6	0.00615	3%
FLF 1.7	0.00654	
FLF 1.8	0.00654	

Final Silt Testing (High Flow)		
Sample ID	Concentration (g/ml)	Variance
FHF 1.9	0.00178	3%
FHF 1.10	0.00189	
FHF 1.11	0.00189	

Final Sand Testing (Low Flow)		
Sample ID	Concentration (g/ml)	Variance
FLF 1.0	0.00538	8%
FLF 1.1	0.00615	
FLF 1.2	0.00615	

Final Sand Testing (High Flow)		
Sample ID	Concentration (g/ml)	Variance
FHF 1.3	0.00233	3%
FHF 1.4	0.00222	
FHF 1.5	0.00233	