Experimental work on improving the efficiency of storm networks using a new galley design filter bucket.

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Abstract. Storm networks, as with all urban infrastructure elements, are important to life in society. One of the most important problems facing such networks is the clogging of pipes due to sediment inlet into the sewage systems, which can cause flooding during heavy rain. This study aims to improve the efficiency of storm networks by using a new filter. In this study, a model of a network of pipes was built up to simulate rain flow over a street of two lanes. The first lane contained a filter and the second lane contained a manhole. The percentage of sediment passing from the manhole to the filter was calculated and compared in terms of the effects of several variables, such as the intensity of rainfall and the street slope. The results showed that the passing ratio from the filter to manhole was 0.28 at a low rain intensity of 30 mm/hr and 0.13 at a high rain intensity of 58 mm/hr. The passing ratio from filter to manhole was 0.21 and 0.12 for small and big lengths of filter, respectively, while the passing ratio at small and big bed slopes was 26 and 13, respectively.

Keywords: Filter; Manhole; Storm networks; Sediments

1. Introduction

Storm networks as a part of urban infrastructure are important elements of life in society [1]. In the construction of streets, highways, and similar projects, the road system is generally first marked out, and the streets cleared and graded [2]. Storm water is a major cause of urban flooding, however, and the important problems facing storm networks include clogging of pipes by waste and soil, which lead to flooding during heavy rain [3]. The quality of storm water can also vary significantly depending on the surrounding land use (commercial, agricultural, or urban area) [4].

Many studies have been carried out to improve the efficiency of storm networks involving rainfall simulation: [5] examined a filter without moving parts placed on angled iron supports attached to the walls of a storm sewer inlet to filter debris, trash, and sediment transported by storm water runoff, where, previously, storm water runoff had flowed without filtration into the storm sewer. Maintenance operations to remove such debris are costly and usually result in the flushing of the system to the receiving stream or lake, making the operation not only expensive but also a contributor to the non-point source pollution problems that affect streams, rivers, and lakes. [6] further created a street curb drain filter comprised of U-shaped brackets attached to the inside wall of a street curb drain, adjacent to the inlet. A horizontal retaining bar was then attached to the outer ends of the brackets, and the lower edge of a horizontally elongated flexible net attached to the retaining bar. The upper edge of the net was connected to the interior ceiling of the drain with eye bolts and S-hooks, and a horizontally elongated debris basin supported within the brackets. A filter media pack was positioned inside the basin, adjacent to the perforated outer wall of the basin. Water flowing from the street into the drain was thus directed through the filter. When runoff was relatively light, debris flowing into the drain was collected inside the basin when runoff was relatively heavy or when the basin was clogged, debris bypassing the basin was filtered by the net. Many other researchers have also worked on the development of storm water networks [7], [8], [9], [10], and [11]. There are several different types of rainfall simulators, each with its own applications, benefits, and shortcomings. In the 0.5m² simulator developed in [12], he majority of experiments utilised a simulator with an upper Perspex plate of 1 x 0.5 m, which contained 627 drop formers in 19 rows of 33, and could thus produce intensities ranging from 7.74 to 28.57 mmh⁻¹ with temporal coefficients.
of variation for intensities ranging from 5.04 to 11.55 %. The experimental results there led to the recognition of various philosophical and practical problems associated with the realistic simulation of rain, which must addressed in future research. One of the early simulators of this type, developed by [13], was a nozzle type simulator suitable for both large- and small-scale studies of the erosion, infiltration, and runoff processes. The simulator closely approximated the kinetic energy of natural rainfall at intensities greater than 25 $mmh^{-1}$. Rainfall intensities ranging from 3.5 to 185 $mmh^{-1}$ can thus be produced, with measured uniformity coefficients ranging from 80.2 to 83.7%. [14] developed a rainfall simulator for a 2.2$m^2$ plot that achieved 85–96 $mmh^{-1}$ with a mean uniformity coefficient of 60 %; the emphasis was placed on reproducibility rather than uniformity in that case, however. Test results for the Portable Wind and Rainfall Simulator (PWRS) are generally very satisfactory, especially considering the physical constraints that must be taken into account to reach the desired portability, and the analysis presented in this study suggests very good reproducibility of wind and rain conditions.

Many researchers have tried to improve the rain network using different systems with good efficiency and low cost. The implementation of a new system thus generally improves the rain network, and the objective of this study is thus to enhance efficiency of storm networks by introducing and using a new filter.

2. Methodology
The simulation models used here attempt to explain the system by including rainfall and the filter used to capture the sediments. The models are divided into two categories: experimental work and dimensional analysis.

2.1. Experimental work
The laboratory storm network and filter model consisted of several separate parts attached to form a complete system. The laboratory model scale to prototype scale was 1:4, and the reasons for choosing these dimensions for the laboratory model were that this best represents the dimensions of most streets. The first part was a steel frame that carries the rain pipe network, as well as carrying the “street”, the gravel filter, and all other model segments. Each part of the frame had a thickness of 1.5 mm. The dimensions of the structure were 4.1*2.2*2 m, as shown in figure 1.

Figure 1. Shape of structure with nozzles
The second part was the rainfall system, which was built based on the rain system used in Italy [15], which consists of two plastic pipes, each with a diameter of 0.5 inches and a length of 4.1 m. Each pipe was installed on the upper side of the structural frame, and they faced each other at a distance of 2.2 m. Each pipe had 12 nozzles with spacing’s of 33 cm between them. The directions of nozzle openings were set by the angle between the top of the nozzle and the horizontal axis. The first angle was 48° and the second one 54°. The droplets were then dropped from a height of about 3 m, as shown in figure 2. The system also contained valves to control the effluent water based on intensity of rainfall. Water was supplied to the system by a water tank of 500 litre capacity.

The third part, the gravel filter, was installed on one side of the two-sided street model. The other side contained a single manhole to drain surface runoff from the simulated rainfall. The gravel filter dimensions were 10 cm width and 5 cm depth with varied lengths, as shown in figure 3. The gravel particle sizes were 1.25 mm to 2.5 mm, and the gravel was placed inside a filter container without compaction.

Several variables are studied by dimensional analysis, requiring several steps to be taken in each case. The bed slope in each experiment was stabilised using JK, and the rainfall intensity was fixed. The amount of sediment on the ground was set to a diameter of 0.2 mm, and the selected rainfall intensity run for a fixed period 15 minutes. After the end of each run, the weights of the passing sediments for both the manhole and the filter systems were calculated through the use of sieves.

Figure 2. Inclination of the nozzle

Figure 3. Gravel filter
2.2. Dimensional Analysis

Dimensional analysis is a powerful tool for formulating problems. One of the useful applications of dimensional analysis is that the space needed to describe and analyse certain physical phenomena can be reduced by integrating variables into dimensionless groups such that the number of resulting groups is less than the number of variables. In general, Buckingham’s theorem [16] is used to solve the physical mechanisms of system operation. The required parameters are classified in terms of mass (M), length (L), and time (T). The affected variables can be categorised as follows: Variables that characterise the fluid include the density of water (\( \rho \)). Variables that characterize the flow include rainfall intensity (I), duration of that intensity (T), and bed slope (\( S_0 \)). Variables that characterise the filter include the length of the filter (\( L_f \)), the diameter of the gravel filter (\( D_f \)), the diameter of the sediments (\( D_s \)), and the mass of sediments (\( M_s \)). Variables that characterise the mass of sediments include the mass of sediments passing through the filter (\( M_f \)), and the mass of sediments passing through the manhole (\( M_g \)). The function of all variables can be written as

\[
f(M_g, M_f, M_s, I, T, D_s, D_f, S_0, L_f, \rho) = 0 \quad (1)
\]

and after calculation, the relationship will be

\[
\therefore \frac{M_f}{M_g} = f \left( S_0 \cdot \frac{I \cdot T}{L_f}, \frac{D_s}{D_f}, \frac{\rho \cdot L_f^3}{M_g} \right) \quad (2)
\]

Based on this dimensional analysis, three variables, rainfall intensity, the bed slope, and length of the filter, were considered in this study in order to determine their effect on the efficiency of the filter. In all, 45 experiments were carried out for this purpose.

3. Results and Discussion

3.1. Experimental data and equation of efficiency

After completing the experimental work as shown in table 1, the study has 45 results for the passing ratios from filter to manhole (\( M_f/M_g \)). The equation was formed from 85% of the experimental data.
Table 1. The used data in experiments.

| Run | Bed slope | Rainfall intensity | Length of filter | Passing ratio(Mf/Mg) |
|-----|-----------|-------------------|------------------|---------------------|
| 1   | 1         | 30                | 200              | 0.389               |
| 2   | 1.5       | 30                | 200              | 0.31                |
| 3   | 2         | 30                | 200              | 0.282               |
| 4   | 2.5       | 30                | 200              | 0.244               |
| 5   | 3         | 30                | 200              | 0.237               |
| 6   | 1         | 37                | 200              | 0.306               |
| 7   | 1.5       | 37                | 200              | 0.256               |
| 8   | 2         | 37                | 200              | 0.197               |
| 9   | 2.5       | 37                | 200              | 0.176               |
| 10  | 3         | 37                | 200              | 0.165               |
| 11  | 1         | 44                | 200              | 0.263               |
| 12  | 1.5       | 44                | 200              | 0.207               |
| 13  | 2         | 44                | 200              | 0.166               |
| 14  | 2.5       | 44                | 200              | 0.151               |
| 15  | 3         | 44                | 200              | 0.136               |
| 16  | 1         | 51                | 200              | 0.236               |
| 17  | 1.5       | 51                | 200              | 0.182               |
| 18  | 2         | 51                | 200              | 0.152               |
| 19  | 2.5       | 51                | 200              | 0.126               |
| 20  | 3         | 51                | 200              | 0.113               |
| 21  | 1         | 58                | 200              | 0.205               |
| 22  | 1.5       | 58                | 200              | 0.161               |
| 23  | 2         | 58                | 200              | 0.137               |
| 24  | 2.5       | 58                | 200              | 0.113               |
| 25  | 3         | 58                | 200              | 0.106               |
| 26  | 1         | 44                | 100              | 0.342               |
| 27  | 1.5       | 44                | 100              | 0.278               |
| 28  | 2         | 44                | 100              | 0.214               |
| 29  | 2.5       | 44                | 100              | 0.191               |
| 30  | 3         | 44                | 100              | 0.169               |
| 31  | 1         | 44                | 150              | 0.316               |
| 32  | 1.5       | 44                | 150              | 0.247               |
| 33  | 2         | 44                | 150              | 0.185               |
| 34  | 2.5       | 44                | 150              | 0.168               |
| 35  | 3         | 44                | 150              | 0.152               |
| 36  | 1         | 44                | 250              | 0.229               |
| 37  | 1.5       | 44                | 250              | 0.169               |
| 38  | 2         | 44                | 250              | 0.142               |
| 39  | 2.5       | 44                | 250              | 0.13                |
| 40  | 3         | 44                | 250              | 0.121               |
| 41  | 1         | 44                | 300              | 0.177               |
| 42  | 1.5       | 44                | 300              | 0.145               |
| 43  | 2         | 44                | 300              | 0.13                |
| 44  | 2.5       | 44                | 300              | 0.12                |
| 45  | 3         | 44                | 300              | 0.113               |
The coefficient of determination \( R^2 \) for the equation was 0.93. To verify the predictions of the equation, the 15\% of the experimental data not used in its creation was utilised. The maximum passing from the equation was 0.37, while the experimental value was equal to 0.389; the results of the equation thus showed good agreement with the experimental results.

\[
P = 841^s \frac{D_s}{L_f} + 621^s \left( \frac{I^*T}{L_f} \right)^3 + \frac{87.5^s D_s}{S} \cdot 0.208 - 0.03^s S - 9530^s \frac{I^*T}{D_s} \tag{3}
\]

where \( P \) is passing ratio from filter to manhole, \( S \) is the bed slope, \( L_f \) is filter length in mm, \( I \) is rainfall intensity in m\( \text{m} \text{h}^{-1} \), \( T=0.25 \text{ hr} \), and \( D_s=0.2 \text{ mm} \)

3.2. Effect of intensity on passing ratio from filter to manhole
Changes in rainfall intensity affected the passing ratio from filter to manhole. Overall, increasing the rainfall intensity decreased the passing ratio. The reason for this is that increasing rainfall intensity increases the velocity of water on the bed, and the amount of sediments transported is thus greater, in agreement with [17]. The decrease in the passing ratio from filter to manhole between intensities of 30 to 37 m\( \text{m} \text{h}^{-1} \) was large compared with other intensities. In bed slope 3 the passing ratio was 0.237 for intensity 30 m\( \text{m} \text{h}^{-1} \), and 0.165 for intensity 37 m\( \text{m} \text{h}^{-1} \), creating a difference between passing ratios of 0.072. The decrease in the passing ratio between intensities 51 and 58 m\( \text{m} \text{h}^{-1} \) was lower compared with the smaller intensities difference, being 0.012. As the amount of sediments entering the filter is larger in this case, the quantity of sediment caught is big in both cases. Figure (5) shows the effect of intensity on passing ratio (\( Mf/Mg \)).

![Figure 5](image.png)

**Figure 5.** Relationship between bed slope and the passing ratio from filter to manhole.

3.3. Effect of bed slope passing ratio from filter to manhole
The bed slope is one of the most important things affecting transmission and velocity of both runoff and sediments. Twenty-five runs were conducted to determine the effect of bed slope on the passing ratio from filter to manhole. For every bed slope, five rainfall intensities were used, namely 30, 37, 44, 51,
and 58 $m/mh^{-1}$. The results indicate that the increase in bed slope decreases the passing ratio from filter to manhole. The change in passing ratio from filter to manhole with bed slope is not uniform, however, and the rate of decrease in passing ratio between the first bed slope 1 and the second bed slope 1.5 is great than between other bed slopes, as shown in figure (6). The reason for the irregular change in passing ratio with change of slope is that the velocity of runoff is unstable, and the velocity of the transmission of sediments depend on the velocity of the runoff.

![Figure 6. Relationship between the passing ratio from filter to manhole and $(I*T)/L_f$](image)

### 3.4. Effect of filter length on the passing ratio from filter to manhole

Changes in filter length affect the passing ratio from filter to manhole. Five sizes of filter length were used: 100, 150, 200, 250, and 300mm, and for each filter length, the run was done with an intensity of rainfall of 44 $m/mh^{-1}$. Increases in the length of filter decreased the passing ratio. It was observed at bed slope 1 the passing ratio was 0.34 at filter length 100mm, and 0.17 for length filter 300mm. At bed slope 3, the passing ratio at filter length 100mm was 0.16, with 0.11 for length filter 300mm. The change in passing ratio for the smaller filter length is greater than for the larger filter length, as the cause of the change in passing ratio with increased length of filter is the increase in surface area of filter to catch the sediments, as shown in figure 6.
Figure 7. Relationship between the bed slope and the passing ratio from filter to manhole

Figure 8. Comparison between results for predicted and experimental data
4. Conclusions
In this study, the aim was to increase the efficiency of storm networks by using a new filter to prevent the entry of soil and impurities into the rain network systems, thus reducing flooding during rainfall storm events. The removal efficiency of the new filter was tested under different values of the rainfall intensity, bed slope, and filter length. The results showed that the passing ratio from filter to manhole was 0.28 for low rainfall intensity of 30 mm$h^{-1}$ and 0.13 for high rainfall intensity of 58 mm$h^{-1}$, while the passing ratio at small and big bed slopes were 26 and 13, respectively. The passing ratio from filter to manhole was also found to be 0.21 for a short filter and 0.12 for a long filter. The results from this study can be extended to other regions with the same conditions.

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