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Utilization of berm technology for reducing sediment loads from construction sites

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ABSTRACT

Post-developed catchments can generate significant amounts of pollutants that degrade environmental quality; however, the development or construction phase can already be a major source of pollutant loads. One of the major advancements in construction technology is the use of berms for erosion, sediment control, and improvement of water quality. This study mainly focused on developing design guidelines for utilizing berms in construction sites. Different types of filter media, sizing, and facility configurations were also evaluated to optimize the design of berms. Generally, woodchips and sawdust media were advantageous as compared with bottom ash and Roche volcanic in terms of pollutant removal. Based on the result of column tests, 4.75 mm woodchips and bottom ash were selected as the filter media for the pilot-scale facilities due to their high pollutant removal performance and low clogging potential. For all configurations of the pilot-scale facility, satisfactory results were obtained in terms of water quality improvement and runoff rate reduction. The guidelines developed in this inquiry can serve as a baseline for developing facilities of the same type.

Keywords: Berm; Bottom ash; Construction site runoff; Filter media; Roche volcanic; Sawdust; Woodchip

1. Introduction

Urban areas are considered as one of the major contributors of pollutants in natural streams. Post-development conditions generate greater amounts of pollutants that can be detrimental to the environment. Moreover, land use and land-use changes enhance the build-up and wash-off processes as a result of catchment development [1]. Urban stormwater runoff contains a variety of pollutants such as sediments, organics, nutrients, and heavy metals. According to a study conducted by Hwang et al. [2] sediments and particulates accumulated on roadsides may contain 100 times higher heavy metal concentration as compared with background conditions. Nutrients and organics in urban stormwater were mostly sourced from lawn fertilizers, pet wastes, and atmospheric deposition. Recent studies also relate vehicular emissions to the presence of phosphorus in stormwater. Engine oils containing zinc dialkyl-dithiophosphate were observed to be potential contributors to phosphorus in the environment [3,4].

Post-developed catchments can generate significant amounts of pollutants that degrade environmental quality; however, the development or construction phase can already be a major source of pollutant loads. Despite its small coverage area, construction sites have high pollution potential as a result of activities that cause soil erosion and exposed soil surfaces [5]. One of the major advancements in construction technology is the use of berms for erosion, sediment control, and improvement of water quality. Berms reduce surface runoff and detain water to promote sediment removal through settling and filtration. Despite its effectiveness as a pretreatment technology for water quality improvement, several factors must be taken into consideration to optimize the efficiency of berms. This study mainly

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focused on developing design guidelines for utilizing berms in construction sites. Different types of filter media, sizing, and facility configurations were also evaluated to optimize the design of berms.

2. Materials and methods

2.1. Column testing

The schematic layout of the eight columns and the experimental set up utilized for testing are exhibited in Fig. 1. The acryl columns have a base diameter of 9 cm and a height of 23.5 cm. The columns were designed based on the standard sizing of low impact development (LID) technologies with facility surface areas approximately equivalent to 1% of the theoretical catchment area. Pretreatment facilities with SA/CA ratios ranging from 1% to 2% were proven to be sufficient for pollutant reduction by means of filtration and infiltration functions [6]. The columns were filled with filter media up to a height of 15 cm from the base. Filter media were selected based on the availability, adsorption and filtration capability, and economic considerations for potential application on LID facilities. The characteristics of filter media used in the column tests are listed in Table 1.

2.2. Design of pilot-scale facility and berm configuration

Fig. 2 exhibits the four cases of pilot-scale experimental conditions developed to analyze the optimum media placement and configurations. The facility was divided into three distinct zones, namely: primary sedimentation zone, media zone, and secondary sedimentation zone. Two outflow ports were installed in the facility to monitor the pollutant removal efficiency at each section. The filter media used in the pilot facilities were based on the results of the column tests. The media were arranged and packed at different configurations to determine the facility design that can effectively improve water quality. Similar to the column experiments, the acryl was designed based on standard sizing of LID facilities (1%).

2.3. Preparation of synthetic stormwater, sampling, and analyses

The sediments collected from a construction site were used for making the synthetic stormwater runoff. Synthetic runoff was prepared by mixing water and sediments passing through sieve # 100. The turbidity of the synthetic runoff was set to have concentrations >60 NTU, which was based on the actual turbidity of the construction site runoff treated using coagulation, flocculation, and sedimentation mechanisms. Each test run was conducted for 60 min. The first samples were collected as soon as the outflow started and succeeding samples were obtained at 15-min intervals. The flow rates used for the column tests were 4.5×10^{-6}, 6.2×10^{-6}, and 1.02×10^{-5} m^3/s, which represented 85%, 90%, and 98% of rainfall that occurred in Cheonan City, respectively. For the pilot facility, a flow rate of 3.17×10^{-5} m^3/s was used, corresponding to 87% of the total rainfall in Cheonan City. The rainfall data utilized in the analyses only covered the events in the year 2017, since historical rainfall patterns

Table 1
Filter media characteristics

Case	Material	Size, mm
A	Woodchip	9.5
B	Woodchip	4.75
C	Sawdust	2
D	Woodchip	38.1
E	Bottom ash	9.5
F	Bottom ash	4.75
G	Bottom ash	2
H	Roche volcanic	9.5

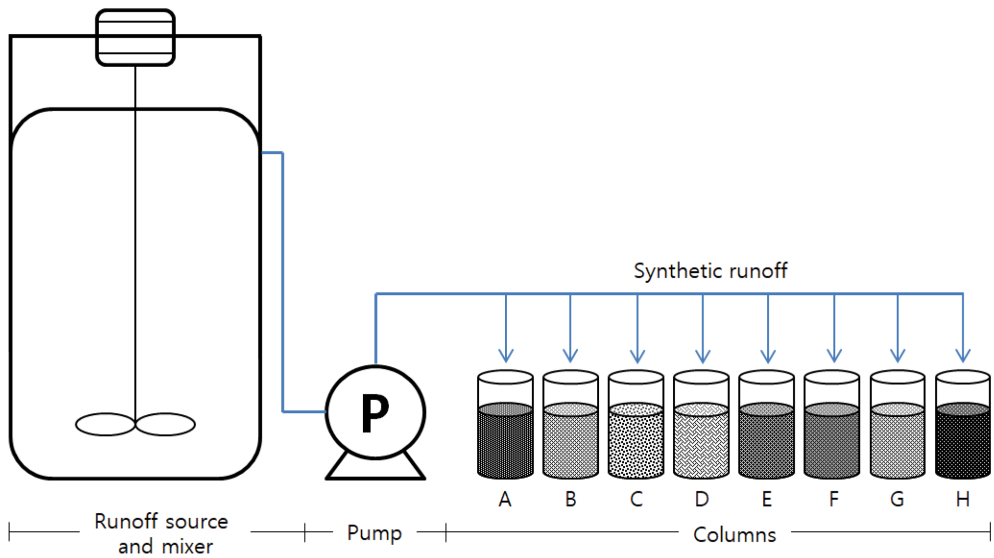

Fig. 1. Experimental set up and test column design.

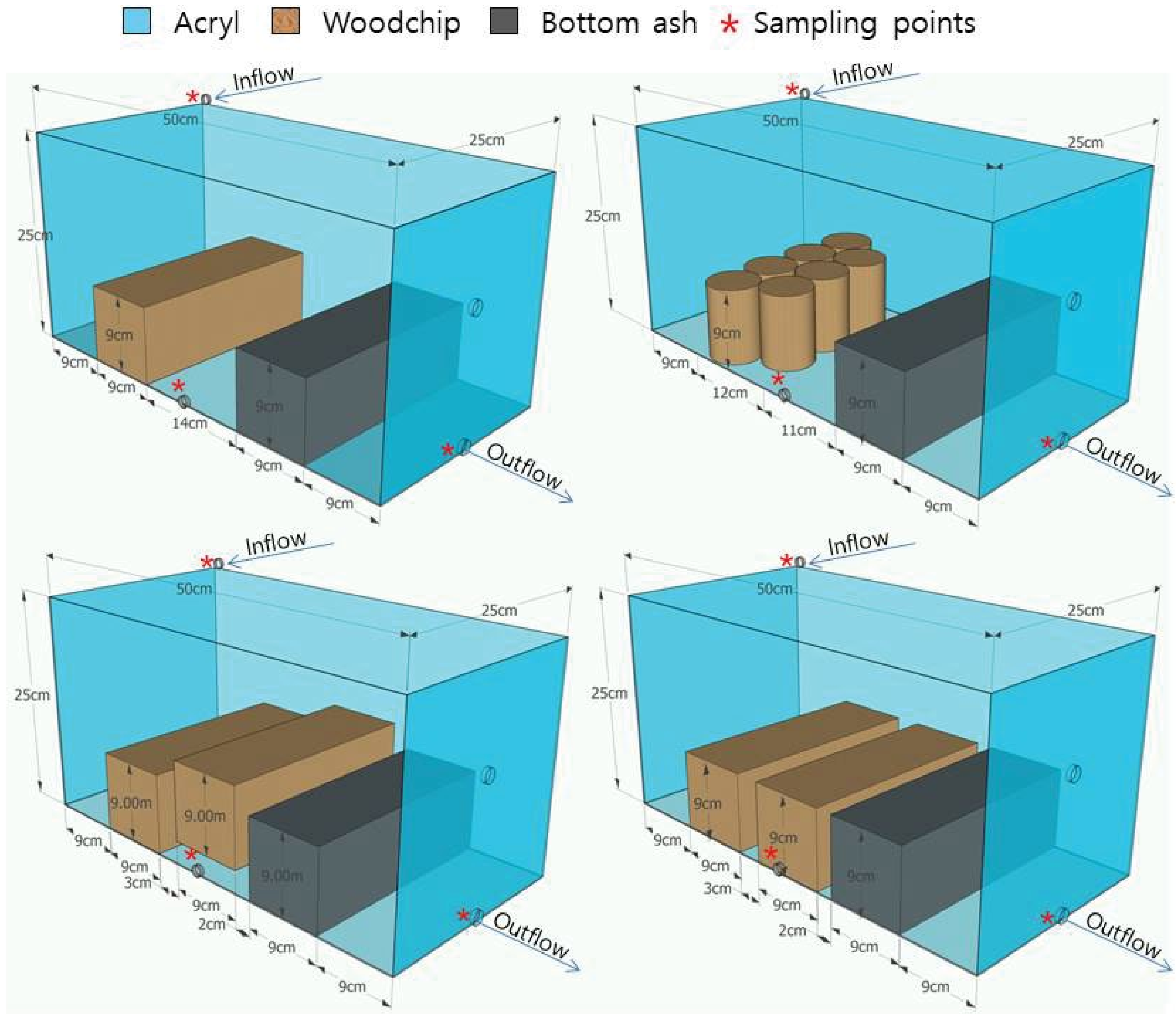

Fig. 2. Design configurations of pilot-scale facilities.

tend to vary greatly as a result of climate change. Water samples were tested for turbidity and total suspended solids based on the standard methods for the examination of water and wastewater [7]. To further analyze the results of the pilot-scale experiments, water samples were tested for particle size distribution.

2.4. Statistical analyses

Event mean concentrations (EMC) were used to quantify the pollutant concentrations and measure of treatment facilities' efficiency. The EMC represents a flow weighted average concentration computed by dividing the total pollutant mass by the total runoff volume for the event duration. The flow weighted average and the pollutant removal efficiencies of the system were calculated using Eqs. (1) and (2), respectively. Results were statistically analyzed using SYSTAT 12 and OriginPro 8 package software including correlation analysis, normality test, and analysis of variance (ANOVA). Pearson correlation coefficient (r) was used to determine the interdependence among the water quality parameters. Moreover, one-way ANOVA was used to analyze the difference between the variance of each water quality parameter. Significant correlations and differences between parameters were accepted at a 95% confidence level, signifying that the probability (p) value was less than 0.05.

$$\text{EMC} = \frac{\int_0^T C(t)\cdot Q(t)dt}{\int_0^T Q(t)dt} \quad (1)$$

where $C(t)$ = pollutant concentration and $Q(t)$ = runoff flow rate discharged at time t.

$$\text{EMC Removal Efficiency (\%)} = \frac{\text{Average inflow EMC} - \text{Average outflow EMC}}{\text{Average inflow EMC}} \quad (2)$$

3. Results and discussion

3.1. Column experiments

3.1.1. Hydraulic performance of test columns

The hydraulic performance of test columns was evaluated to determine the flowrate reduction capabilities and clogging potential of each filter media when subjected to synthetic construction site runoff. Except for cases B, F, and G, the outflow rates of all columns were found to be negatively correlated with hydraulic retention time (HRT), having r-values ranging from –0.88 to –0.99. This implied that an increase in HRT corresponded to decreased outflow rates. Introducing filter media into the system disrupted the flow, thereby causing a period of delay in the outflow time and reduction in outflow rates. Some columns did not exhibit a significant relationship between HRT and outflow rates due to the factor of compaction. Apart from porosity, the compaction of filter media in the test columns during the construction phase can greatly influence the hydraulic performance of the facility [8]. Among the test columns, case C was found to have the greatest reduction of inflow rate, with a mean value of 24.7%. On the other hand, the lowest flow reduction was obtained by case F and case H, with a corresponding mean value of 2.7%. Sawdust has particle sizes that are relatively finer as compared with the other filter media used, thus resulting in a lower hydraulic conductivity [9]. While excellent flow reduction was observed in the case C column, it was also found that sawdust media was prone to clogging in the middle layer of the column. Since construction site runoff tends to contain a high amount of sediments, sawdust may not be an appropriate filter media due to its high clogging potential. The hydraulic performance of each test column is summarized in Table 2.

3.1.2. Pollutant removal efficiency with respect to inflow rates and filter media sizes

The variation of mean pollutant reduction with respect to different inflow rates of the column experiments are provided in Fig. 3. The majority of the columns exhibited a negative correlation between total dissolved solids (TSS) removal efficiency and inflow rate (r-value: –0.6 to –0.99), implying that an increase in inflow rate corresponded to decreased TSS removal efficiency. This finding was similar to the study conducted by Geronimo et al., wherein hydraulic loading rates were identified as key factors affecting the pollutant removal performance of filtration systems [10]. Generally, columns with woodchip and sawdust filter

Table 2
Hydraulic performance of test columns

Column case	Test run	Average inflow rate	Average outflow rate	Hydraulic retention time (HRT)
		$1 \times 10^{-5}\,m^3/s$	$1 \times 10^{-5}\,m^3/s$	s
	1	1.02	0.96	3.25
A	2	0.45	0.40	22.75
	3	0.62	0.60	17.23
	1	1.02	0.96	15
B	2	0.45	0.42	11.27
	3	0.62	0.58	3
	1	1.02	0.48	23.63
C	2	0.45	0.38	44.7
	3	0.62	0.58	7.22
	1	1.02	1.00	15.59
D	2	0.45	0.41	17.69
	3	0.62	0.52	16.51
	1	1.02	0.98	5.36
E	2	0.45	0.43	16.7
	3	0.62	0.60	9.84
	1	1.02	1.00	6.43
F	2	0.45	0.43	6.96
	3	0.62	0.60	5.03
	1	1.02	0.93	6
G	2	0.45	0.43	5.38
	3	0.62	0.60	8.18
	1	1.02	1.00	5.38
H	2	0.45	0.43	10.65
	3	0.62	0.60	6.78

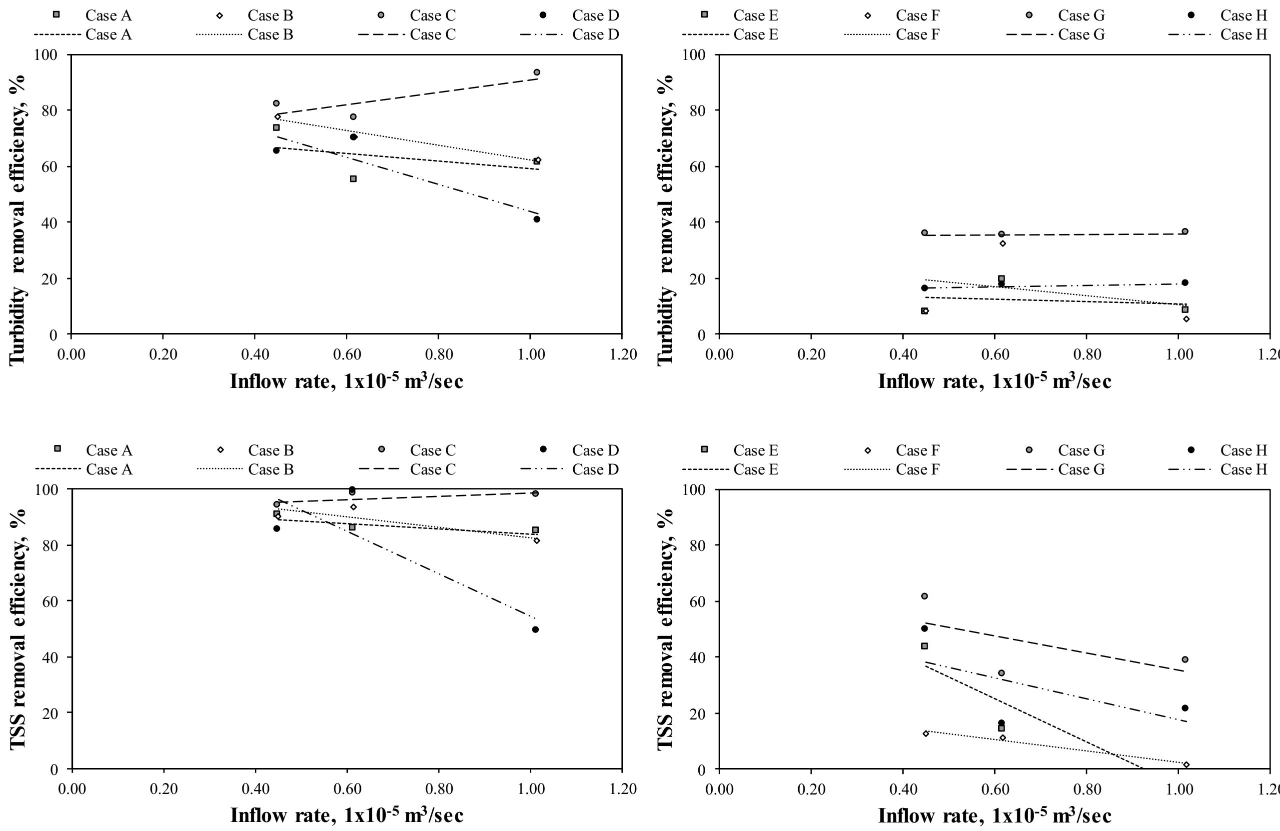

Fig. 3. Mean pollutant concentrations at varying inflow rates.

media showed higher turbidity and TSS pollutant removal as compared to column experiment cases with bottom ash and Roche volcanic. Specifically, cases A, B, and C exhibited significantly greater turbidity and TSS removal as compared to cases E, F, G, and H with p-values less than 0.01. Woodchips are excellent adsorbents, thereby efficiently reducing the number of suspended solids and sediments in the synthetic runoff [11].

Media sizing is an important factor to consider in filtration systems. As illustrated in Fig. 4, increasing the filter media sizes resulted in consequent decrease in turbidity and TSS removal efficiency. For woodchip, 2.4, 4.75, and 19 times increase in media size corresponded to 8%, 10%, and 19% decrease in TSS removal efficiency, respectively. Moreover, the treatment efficiency for turbidity was decreased by 14%, 21%, and 26% along with the 2.4, 4.75, and 19 times increase in the size of woodchip filter media. Using coarse media in filtration systems is disadvantageous due to the reduction of surface area for particle capture [12]. No significant differences were observed between the pollutant removal performance at varying sizes of woodchip and bottom ash filter media ($p > 0.05$).

3.1.3. Selection of appropriate filter media

The rating of each column according to factors to be considered in selecting appropriate media and media sizes are exhibited in Table 3. While case C exhibited the highest pollutant removal performance, considerable clogging potential was also observed in the column. Since the sawdust can trap fine particles, the formation of a clogging layer can be detrimental to the treatment efficiency and runoff reduction of the system in the long run. There was no significant difference found between the pollutant removal efficiencies of cases A, B, C, and case D ($p < 0.05$). For this reason, a 4.75 mm woodchip was selected as the first layer of a berm for the pilot-scale testing since it has the highest pollutant removal efficiency next to case C. Moreover, the clogging potential in case B is lower based on visual observation. Considering the bottom ash and Roche volcanic, no significant difference was noted in the pollutant removal performance ($p > 0.05$). The 4.75 mm bottom ash was chosen to be used as a secondary berm layer for the pilot-scale testing since fine-grained bottom ash was also prone to clogging.

3.2. Pilot-scale berm experiments

3.2.1. Hydraulic conditions and changes in pollutant concentrations

The berms applied in the pilot-scale facility successfully reduced the outflow rates. Mean flowrate reduction ranging from 16% to 31% was observed for the different media configurations. Case 2 had the greatest reduction of inflow rate, whereas the lowest flowrate reduction was noted in case 4. In accordance with the measured average outflow rate reduction, the longest and shortest HRT was also observed in case 2 (38 s) and case 4 (26 s), respectively.

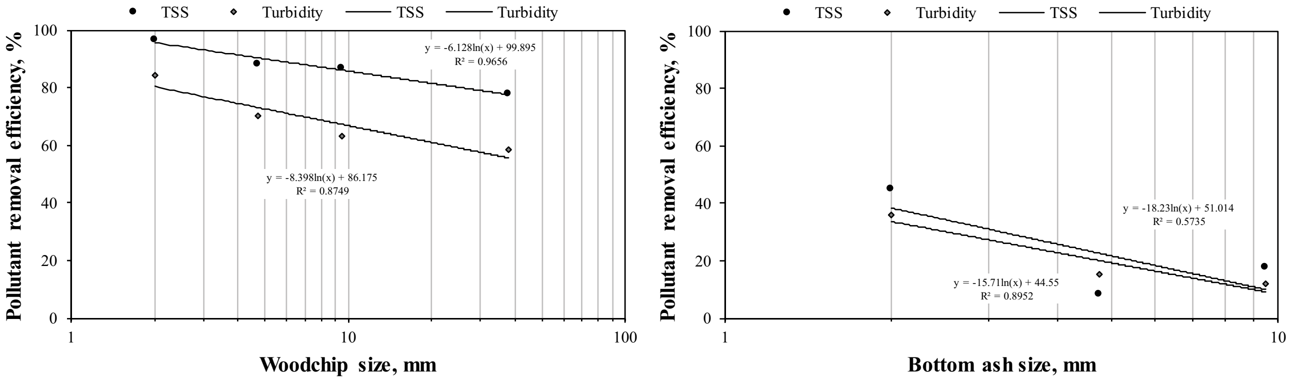

Fig. 4. Changes in pollutant removal efficiency at varying filter media sizes.

Table 3
Rating of each column case according to factors to be considered in selecting appropriate media size

Factors	Column cases							
	A	B	C	D	E	F	G	H
Pollutant reduction	●	●	☑	●	▪	▪	▪	▪
Flow reduction	▪	▪	●	▪	▪	▪	▪	▪
Effluent concentration stability	●	●	▪	●	☑	☑	☑	☑
Clogging	▪	▪	☑	▪	▪	▪	▪	▪

☑ = high; ● = moderate; ▪ = low

The configuration of berms in case 4 provided limited space for ponding due to the small spacing in between berms, thereby resulting in a reduced HRT and faster flowrate. On the other hand, the arrangement and shape of berms in case 2 yielded a better hydraulic performance as a result of adequate ponding volume in the facility and longer horizontal media layers.

Apart from the effective outflow rate reduction, the four pilot-scale facilities were able to improve the overall water quality of the influent. As depicted in Fig. 5, the mean turbidity of influent was reduced by 29% to 58% after passing through the first layer of berms in the facility. Outflow samples collected at the port midway of the facility length also indicated an efficient TSS removal amounting to 6% to 65%, except for case 3 which showed a negative removal efficiency (–53%) due to the trapped sediments in the intermediate berm near the outflow port. Considering the entire facility length, case 4 reduced turbidity most efficiently (78%). The small spacing between the berms of case 4 provided intensive filtering mechanisms and sediment trapping, which resulted in the efficient removal of pollutants. The mean TSS removal for all four configurations was comparable at 91% to 94%, signifying the effectiveness of berms.

3.2.2. Removal of varying sediment particle sizes

The actual construction site runoff may contain sediments with a wide range of particle sizes. Particle size analyses also play an important role in establishing new technologies for sediment control, since the function of filtration devices are directly influenced by sediment properties. Additionally, grain size can also be associated with pollutant mobility and concentration [13]. The removal efficiencies of varying particle sizes for each experimental set up were shown in Fig. 6. Accumulation of sediments with particle diameters <50 μm was observed in the middle section of case 3, as depicted by the negative removal efficiency noted in the system. However, further, examination revealed that case 3 had the highest overall reduction of particles less than 10 μm after passing through the third berm. Case 4 demonstrated the most stable removal of various particle sizes along with the system, corresponding to 52%–58% in the middle section of the facility and 86%–93% for the entire facility length. The stability and increased removal of different particle sizes in cases 3 and 4 can be attributed to the three berm layers which resulted to flow stabilization, proper settling, and filtration and adsorption mechanisms of the filter media.

3.2.3. Selection of the most effective pilot-scale configuration

The overall assessment revealed that the four pilot-scale configurations were effective in reducing turbidity and TSS in the synthetic runoff. Considering the pollutant reduction in the middle portion of the facility, only case 4 exhibited satisfactory performance. The greatest removal of particles less than 10 μm was also achieved in case 4. However, among the four configurations, case 4 exhibited the lowest HRT and flow reduction efficiency. Considering cost implications for construction, cases 3 and 4 may incur the highest construction cost since three layers of berms were

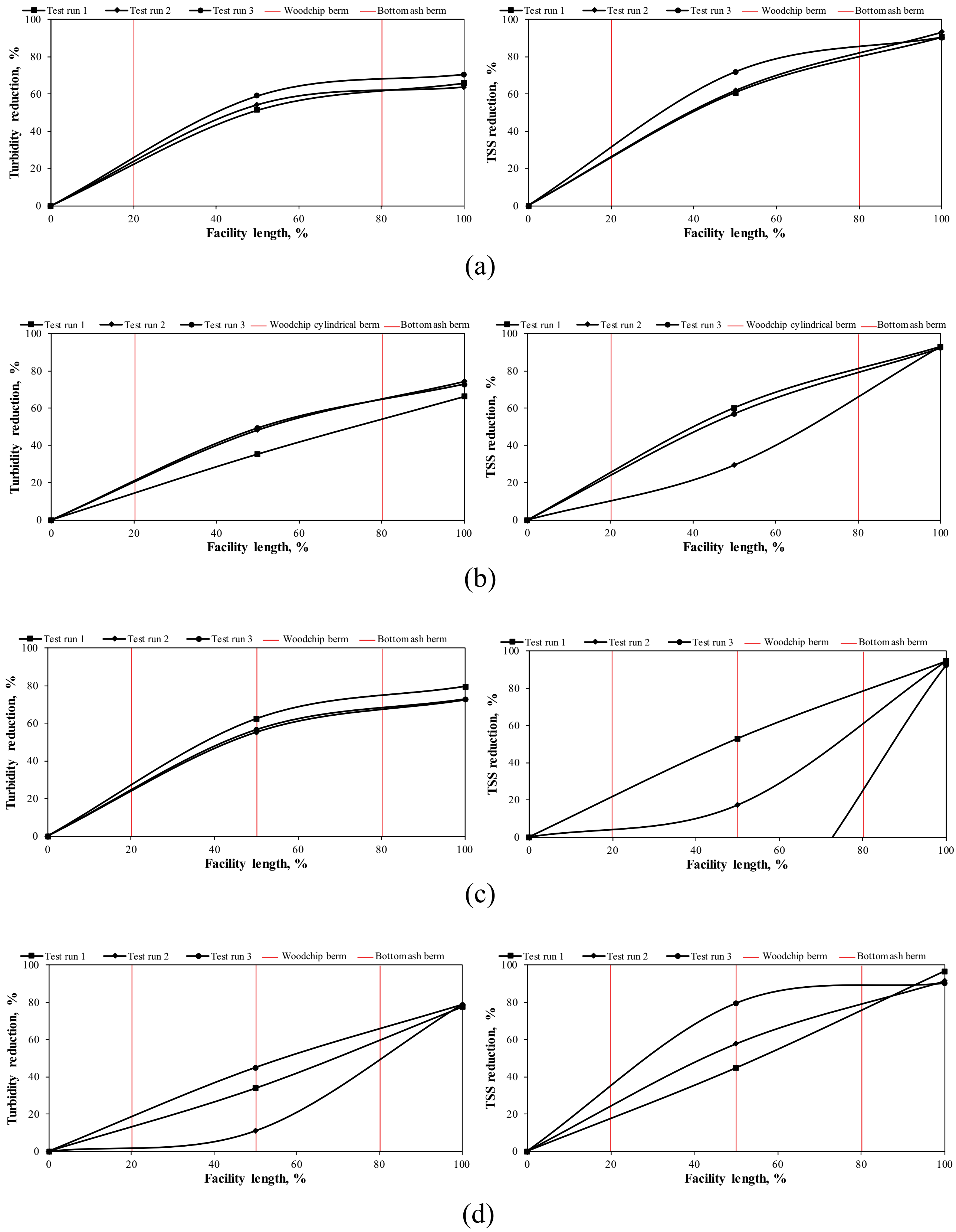

Fig. 5. Changes in pollutant concentration with respect to facility length (a) case 1, (b) case 2, (c) case 3, and (d) case 4.

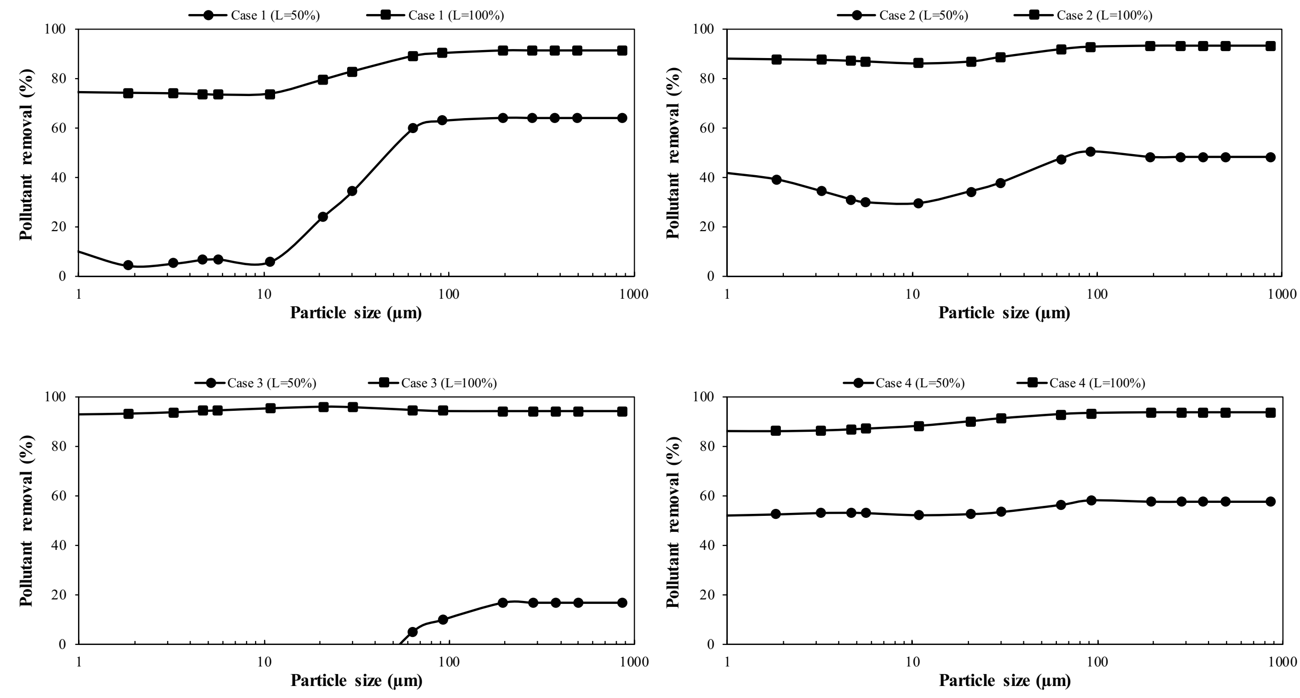

Fig. 6. Removal of varying particle sizes with respect to facility length.

Table 4
Summary of pilot-scale berm performances based on different factors

Factors	Pilot scale berm			
	Case 1	Case 2	Case 3	Case 4
Overall pollutant reduction	☑	☑	☑	☑
Pollutant reduction at 50% of length	▪	▪	▪	●
Removal of particles less than 10 μm	▪	●	▪	☑
Flow reduction	●	●	●	▪
Cost implication	●	●	☑	☑
Ease of maintenance	▪	●	▪	▪

☑ = high; ● = moderate; ▪ = low

utilized in the design of these pilot-scale berm cases. Ease of maintenance may be moderate for case 2 since the cylindrical design of the berm package in the first layer after the inflow can be easily disassembled in cases of maintenance needs. The performance of the four pilot-scale berm types according to different factors is summarized in Table 4.

4. Conclusions

Alteration or modification of the natural landscape can lead to soil erosion and massive deposition of sediments on streams. In order to prevent the adverse impacts of construction activities in the environment, it is important to consider some measures to treat construction site runoff. In this study, test columns containing various filter media were utilized to develop pilot-scale berms. The properties of filter media and configurations of the pilot-scale facilities were analyzed to formulate design criteria for optimized berm performance. Based on the results of this study, woodchips were more efficient, as compared with bottom ash and Roche volcanic, in terms of pollutant removal. 4.75 mm woodchips (case B) were selected as the first layer of a berm for the pilot-scale testing, due to its high pollutant removal efficiency and low clogging potential. Considering the bottom ash and Roche volcanic, there was no significant difference in the pollutant removal performance. The 4.75 mm bottom ash medium was chosen to be used as a secondary berm layer for the pilot-scale testing since finer grades were more prone to clogging.

Overall, the pollutant reduction efficiencies of the four pilot-scale berms developed were high. Depending on the consideration, a specific design of berm may be applicable. For designs considering satisfactory removal of particles less than 10 μm, case 4 may be applicable. Considering cost implications for construction, cases 1 and 2 may be advantageous, since only two layers of berms will be installed. Maintenance may be executed with ease for case 2 since the cylindrical design of the berm package in the first layer after the inflow can be easily disassembled in cases of maintenance needs. This study provided insights regarding the utilization of berms as a mechanism for sediment control in construction site runoff. The guidelines developed in this inquiry can serve as a baseline for developing facilities of the same type.

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