Particle size distribution of captured sediments in stormwater treatment systems

Répartition granulométrique des sédiments capturés dans les systèmes de traitement des eaux pluviales

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RÉSUMÉ

Le ruissellement pluvial mobilise et transporte des matières particulaires issues des surfaces urbaines, générant des sédiments présentant des distributions granulométriques (PSD) variables, tandis que les analyses comparatives de PSD entre différents composants de traitement restent limitées. En contribution, cette étude évalue la PSD des sédiments collectés dans les eaux pluviales, l'écoulement de base, les entrées et sorties de bassins de sédimentation, les unités de décantation des systèmes compacts de traitement des eaux pluviales (CSTS) / chambres de traitement, les avant-bassins de biorétention et les avaloirs. Les résultats montrent que l'écoulement de base (D_{50}=30.7µm) et les eaux pluviales (D_{50}=22.7µm) contiennent les sédiments les plus fins parmi les systèmes échantillonnés, tandis que les sédiments des entrées de bassin (D_{50}=77.04µm) et des sorties (D_{50}=31.08µm) restent dominés par des particules fines. Les unités de décantation des CSTS retiennent des fractions relativement plus fines que celles observées à l'entrée des bassins, mais plus grossières que celles présentes à la sortie (D_{50}=58.4µm). Les avant-bassins de biorétention (D_{50}=614.1µm) et les avaloirs (D_{50} =585,5µm) accumulent quant à eux les fractions les plus grossières. Collectivement, ces résultats montrent comment les sédiments transportés par les eaux pluviales sont retenus à des degrés différents au sein des divers composants de traitement, clarifiant quels dispositifs captent préférentiellement les fractions fines, intermédiaires ou grossières.

ABSTRACT

Stormwater mobilizes and transports particulate matter from urban surfaces, producing sediments with variable particle size distributions (PSD), yet comparative analysis of PSD across different treatment components remains limited. As a contribution, this study evaluates PSD of sediments collected from stormwater, baseflow, sediment pond's inlet/outlet, compact stormwater treatment system (CSTS) sedimentation units/stormwater vaults, bioretention forebays, and gully pots. Results showed that baseflow (D_{50}=30.7µm) and stormwater (D_{50}=22.7µm) contained the finest sediments of the treatment systems sampled, pond inlet (D_{50}=77.04µm) and outlet (D_{50}=31.08µm) sediments remained dominated by fine particles. The CSTS sedimentation units captured relatively finer fractions than pond inlet but larger than pond outlet (D_{50}=58.4µm). Bioretention forebays (D_{50}=614.1µm) and gully pots (D_{50}=585.5µm) accumulated relatively the coarsest fractions. Collectively, these findings show how stormwater-transported sediments are retained to different degrees across the various treatment components, clarifying which units predominantly capture fine, intermediate, or coarse fractions.

KEYWORDS

particle size distribution, sediment, stormwater quality, stormwater treatment, urban drainage

1 INTRODUCTION

Urban stormwater transports suspended sediment particles, and the nature of these particles influence both pollutant behaviour and the performance of drainage and treatment systems (Fugate et al., 2021). Particle size distribution (PSD) provides a quantitative description of these materials, informing understanding of how sediments settle, move, and interact within different treatment systems (Mrowiec, 2020; Wang et al., 2018). Although *gully pots, bioretention forebays, ponds, and compact stormwater treatment systems (CSTS)* are widely used to manage particulate loads, their sediment characteristics have either been examined in isolation or, in some cases, not characterised fully. This gap restricts the ability to compare system components and to anticipate how sediments behave as they pass through multiple stages of storage, conveyance, and treatment. The present study contributes to addressing this need by examining PSD-based sediment characteristics across multiple sites including *pond* inlet and outlet zones, *CSTS sedimentation units, bioretention forebays, and gully pots.*

2 MATERIALS AND METHOD

The dataset analysed in this study compiles PSD measurements from multiple investigations conducted in several studies in Sweden. *Stormwater and baseflow* (134 and 12 samples, respectively) were collected in 2016–2017 from three urban catchments in Umeå, two industrial parks and a parking lot (75-95% impervious). All *stormwater* and *baseflow* samples were analysed using laser diffraction in liquid-dispersion mode (ISO/TS 5973:2024) (Lindfors et al., 2020). *Pond* sediment data was available for 42 inlet/outlet locations: 25 samples collected in 2013 using wet sieving > 63 µm followed by statistical extension for finer fractions (Al-Rubaei et al., 2017), and 17 samples collected in 2019 and analysed by wet sieving to 2 mm combined with laser diffraction in liquid mode (Flanagan et al., 2021). 22 sediment samples were collected from *stormwater vaults and sediment traps* (Ullared, Norrköping, Sundsvall, Östersund, Boden) in 2024 and 83 *gully pot* samples from Luleå and Stockholm in 2022 (Wei et al., 2023a, b). All were wet sieved to 63 µm and analysed by laser diffraction (liquid mode). Finally, *bioretention forebay sediments* (19 samples from Michigan and Ohio, USA) were processed using two-step approach: dry sieving for >63 µm and laser diffraction for <63 µm fractions (Furén et al., 2022). PSDs and particle size parameters for the different system types and were compared with each other. D_{10}, D_{50}, and D_{90} denote the particle diameters at which 10%, 50%, and 90% of the sample mass is finer, respectively, providing key percentile-based descriptors of the distribution, while the uniformity coefficient (C_u) quantifies the overall spread of particle sizes and the curvature coefficient (C_c) characterizes the gradation and shape of the PSD curve. Higher C_u values indicate a wide and poorly sorted particle-size distribution, whereas lower C_u reflects a narrower and more uniform grading; similarly, C_c values close to 1 suggest a well-graded distribution, while very low or very high C_c indicates irregular or gap-graded PSD shapes.

3 RESULTS AND DISCUSSION

Figure 1 summarizes the cumulative PSD for all investigated sediment sources. The PSD parameters (D_{10}, D_{50}, D_{90}, C_u, C_c) provide a quantitative basis for comparing how different treatment components retain different particle size fractions. The PSD metrics showed clear differences across the monitored components as illustrated in Figure1. *Baseflow* and *stormwater* samples contained the finest fractions, with the lowest D_{50} values and D_{90} values. *Stormwater* PSD characteristics are consistent with reported previously (Wang et al., 2018; Mrowiec, 2020). *Pond* inlet sediments displayed larger D_{50} and D_{90} coarse values, while *pond* outlet samples showed a reduced D_{50} but still in high D_{90} values indicating the presence of large particles in both inlet and outlet sediments. *CSTS sedimentation units* contained relatively intermediate D50 and D90 values, retaining particle fractions that are finer than those at the *pond* inlet but coarser than those observed at the pond outlet. *Bioretention forebay* and *gully pot* sediments contained the largest particles fractions across all components with highest D50 and D90 values, confirming that these units offer detention capacity for the coarsest materials.

Sorting indices varied considerably across the system (Figure 1). *Baseflow*, *pond* inlet, and *pond* outlet sediments exhibited high C_u values, reflecting very low D_{10} values in combination with relatively large D_{50}-D_{90} ranges, indicating well graded mixtures that include both fine and coarse fractions. *Bioretention forebays* also showed high C_u; however, this results from highly variable PSDs dominated by coarse material, rather than substantial retention of fine particles. *Stormwater, CSTS, and gully pot* sediments presented relatively lower C_u ranges indicating distributions with a narrow range size. Curvature coefficients (C_c) were generally low across all components except *bioretention forebays*, indicating that most units exhibited PSD curves that deviate from well-graded conditions, while the C_c observed in *bioretention forebays* reflects an irregular distribution of mid-sized particles relative to finer and coarser fractions.

Importantly, total suspended solids (TSS) removal percentages can be misleading, as standard gravimetric TSS methods quantify only particles larger than 1.2-1.6 µm (SS-EN 872:2005; ISO 11923) and therefore do not capture the finest particle size fractions retained by different stormwater control measures. Moreover, because TSS analyses measure only particles that remain suspended during sampling and filtration, they also exclude larger particles that settle rapidly and therefore are not represented in the measured suspended fraction. This underscores the need for routine PSD analysis in future stormwater studies to more accurately evaluate treatment performance and the functional role of individual system components.

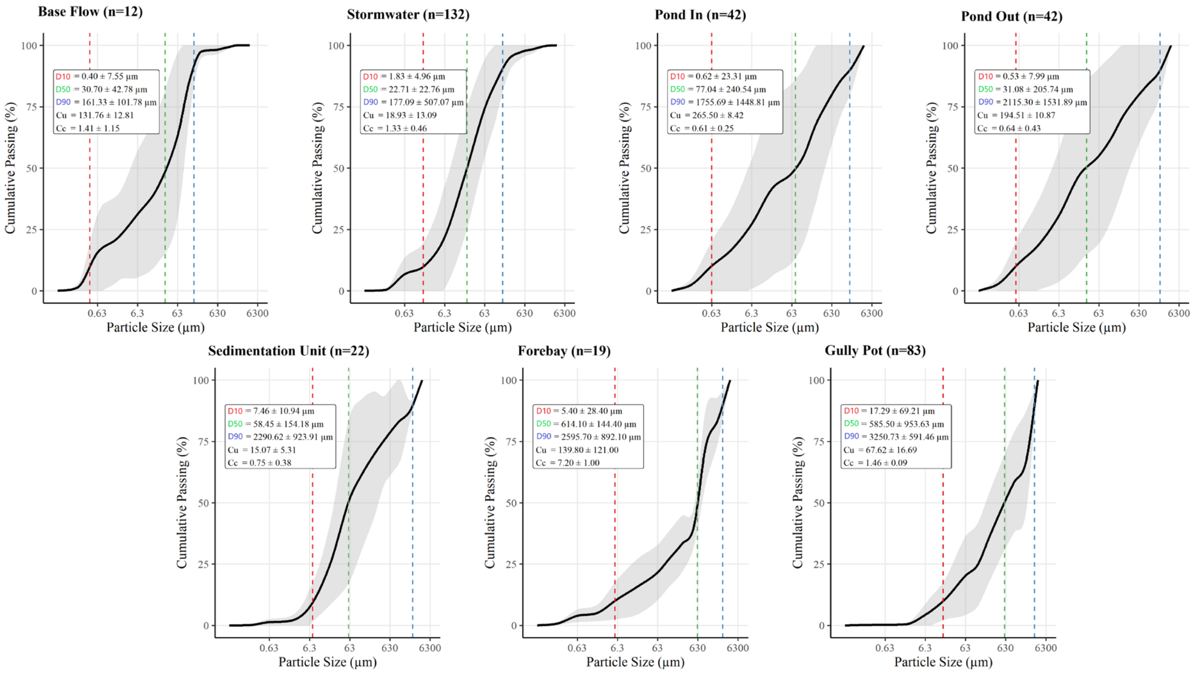

Figure 1. Particle size distributions for (i) Base Flow, (ii) Stormwater, (iii) Pond Inlet, (iv) Pond Outlet, (v) CSTS Sedimentation Unit, (vi) Bioretention Forebay, and (vii) Gully Pot

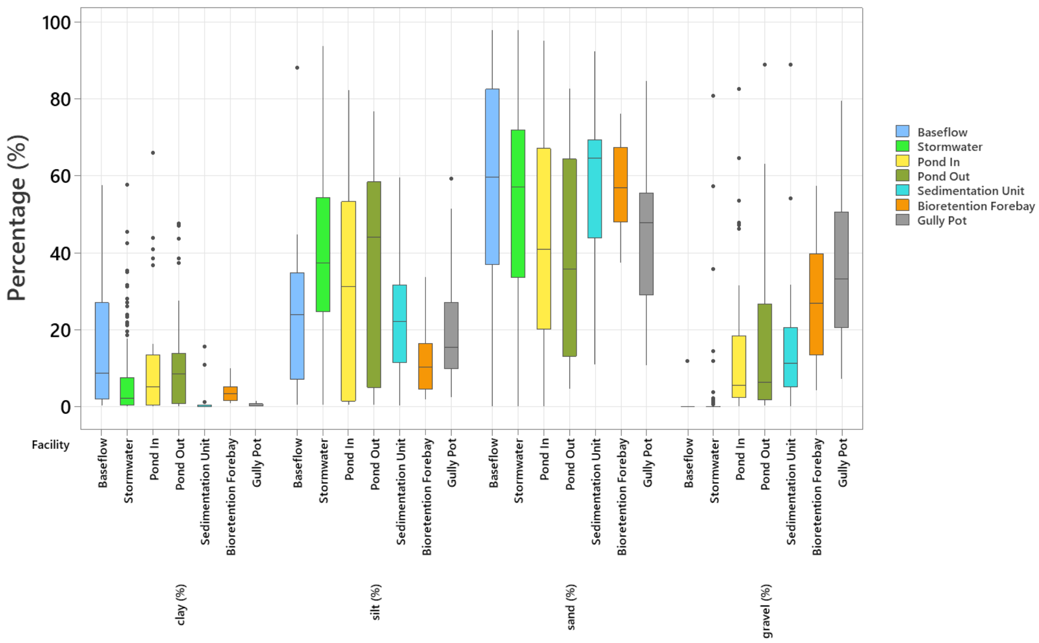

Figure 2. Clay, silt, sand, gravel distribution across baseflow, stormwater and treatment systems

Figure 2 compares the grain-size classes carried by *stormwater* and *baseflow* with those retained in the treatment units. Using the standard sediment classification (clay (<2 µm), silt (2–63 µm), sand (63 µm–2 mm), and gravel (>2 mm)), *ponds* were the only components in which clay sized particles constitute a considerable fraction of the deposited material, with median clay proportions of 5.2% (inlet) and 8.5% (outlet). *CSTS sedimentation units* retained sediments within the silt fraction (median 22.1%), whereas *bioretention forebays* (10.2%) and *gully pots* (15.3%) exhibited limited silt accumulation and show their primary retention capacity in the sand fraction (medians 56.9% and 47.8%, respectively).

4 CONCLUSION

This study shows that sediments transported by *stormwater* and *baseflow* accumulate with different PSD characteristics across treatment components i.e. system type is more important than location in terms of estimating PSD. *Pond* inlet and outlet samples contain fine to intermediate fractions, demonstrating that *ponds* are capable of retaining a broad range of particle sizes through settling. *CSTS sedimentation units* capture intermediate fractions, indicating they do not fully retain the finest fractions. *Bioretention forebays and gully pots* accumulate the coarsest materials. Overall, PSD metrics distinguish the sediment retention behaviour of each component and quantify how *stormwater* sediments are partitioned across the treatment systems, supporting treatment system design and maintenance optimisation.

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